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Activation and Perception of Native-Language Phonotactics in Bilinguals

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ABSTRACT

Activation and Perception of Native-Language Phonotactics in Bilinguals

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As monolinguals and bilinguals hear words unfold over time, they experience competition from words that share sounds within the same language (e.g., *st-* activates *strict* and *stamp*). Unique to bilinguals is that they are also prone to competition from similar sounding-words between their two languages (e.g., *st-* activates Spanish *estrés* (“stress”)). In the present dissertation, we examine how experience with multiple languages transforms the way in which speech sounds are activated and perceived. Specifically, we investigated how and if bilinguals activated and perceived native-language (L1) structures when processing words in their second language (L2) across three experiments. We used phonotactic constraints, which are rules for combining speech sounds, to examine activation and perceptual processes. A Spanish phonotactic constraint is that s+consonant clusters are not permitted at word onsets, and a vowel must precede the cluster (prothesis; e.g., English: *strict*, Spanish: *estricto*). In Experiment 1, we investigated whether bilinguals activated L1 phonotactic constraints when processing L2 words. We found that L1 Spanish-L2 English bilinguals accessed the L1 Spanish constraint. Bilinguals were faster to make lexical decisions on English-like words containing the activated ‘e’ onset rule (e.g., *estomb*) when primed with Spanish-conflicting words (e.g., *strict*), relative to non-conflicting stimuli (e.g., *kneeling*, prime: *workers*). In Experiment 2, the extent to which bilinguals perceived, or perceptually repaired, L2 words and L2-like non-words to sound more like L1 words was investigated. Response time results across vowel detection and AX discrimination tasks revealed mixed effects for L1 perception during L2 processing. Bilinguals perceived the ‘e’ onset in English s+consonant words (e.g., *strict*) when the beginning sound of the word was the focus of the task (vowel detection), but not when making low-level perceptual judgments on whether conflicting (e.g., *strict* and *egg*) versus non-conflicting (e.g., *work* and *egg*) word pairs were the same (AX discrimination). Experiment 2's results suggest that when the beginning sound of the word is the explicit focus of the task, perceptual repair to the 'e' onset occurs. In Experiment 3, eye-tracking methodology was employed across a word recognition task and a combined word recognition and AX discrimination task. The goal was to examine the relation between activation and perception of L1 sounds during L2 processing. On the visual display, when a Spanish-conflicting English target word was present (e.g., *strict*), along with the potentially activated 'e' onset competitor word (e.g., *egg*) and two unrelated filler items (e.g., *work, can*), Spanish-English bilinguals with lower L2 (English) proficiency looked more at the 'e' onset competitor than the filler items. This pattern was observed on the two measures of word recognition. Moreover, in the combined word recognition and AX discrimination task, bilinguals did not perceive L1 phonotactics during L2 processing. Together, in Experiment 3, lower English proficiency bilinguals activated, but did not perceive, Spanish phonotactic constraints during English processing. Overall, the findings in this dissertation provide insight into the structure of acoustic space within the bilingual mind. L1 representations for sounds and words influence how L2 input is perceived. Speech perception and language activation are susceptible to interference from the L1. These results highlight the importance of accurately identifying differences versus disorders in bilingual populations. An L1 Spanish speaker learning an L2 (English) might not be able to identify and differentiate between *strict* and *estrict* due to the L1 Spanish phonotactic rule. However, the L1 Spanish speaker's behavior is due to a rule difference across languages and is not indicative of a disorder. Implications and future directions for the current research are discussed.

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CHAPTER 1

INTRODUCTION

Summary. The present dissertation examines language processing and speech perception in bilinguals. Previous investigations have demonstrated that bilinguals access their languages in parallel during auditory and visual word comprehension and perceive native-like sounds in line with the rules of their native language. This dissertation establishes that bilinguals activate native-language phonotactic constraints (i.e., rules for combining speech sounds) when processing their second language and these native-language constraints also affect how second language input is perceived. The introduction provides an overview of the main objectives and hypotheses for the dissertation, as well as the methodology employed. The introduction also presents relevant literature to these dissertation studies, including theoretical and empirical investigations on language activation and speech perception in monolinguals and bilinguals.

In the natural flow of speech, we hear sound sequences that allow us to understand a word and overall message with minimal effort. Languages differ on how sounds can be combined to form words. What if we hear a sequence that conflicts with how sounds are typically coupled together within our language? For example, a rule for combining speech sounds in Spanish is that a vowel must precede word-initial s+consonant clusters (s+c), as in *estudio* (English: “study”). In English, however, s+c onsets with and without an initial vowel are acceptable and plentiful. For a native Spanish speaker learning English, s/he may experience competition from the Spanish vowel+s+consonant cluster (v+s+c) rule when speaking English. This explains why native Spanish speakers often produce English s+c words with a vowel at the onset, such as *estudy* and *espring* (Yavas & Someillan, 2005). This phenomenon is so apparent that no matter which Spanish-speaking country the native Spanish speaker grew up in, s/he will likely produce English s+c words with a vowel onset. And, while prothesis (i.e., the addition of a vowel at a word's onset) is commonly observed in Spanish-English bilinguals' accented English speech, we have yet to uncover whether bilinguals implement rules of their native language (L1) when *perceiving* their second language (L2). One way to imagine this scenario is as an accent in comprehension (i.e., perceive *study* as *e̲study*), as opposed to an accent during production (i.e., produce *study* as *e̲study*). Do non-native speakers thus perceive speech differently than L1 speakers of a given language?

To address the question, bilingualism provides a unique tool with which perception of non-native sounds that conflict with L1 rules can be examined. Interestingly, when monolinguals heard nonsense sounds that contrasted with the rules of their language, they repaired the sound sequences to conform to the rules (Cuetos, Hallé, Domínguez, & Seguí, 2011; Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999; Flege, 2003; Hallé, Dominguez, Cuetos, & Segui, 2008). Altering sound sequences to align with the constraints of a language is known as perceptual repair. Spanish monolinguals repaired the Spanish-like non-word *special* (/spesjal/) to *especial*, the latter conforming to Spanish's v+s+c rule (Cuetos et al., 2011; Hallé et al., 2008). Spanish-dominant bilinguals also perceptually repaired sounds that did not align with their L1 when they were in an L1 testing environment (Carlson, 2018; Carlson, Goldrick, & Blasingame, Fink, 2016). What this dissertation examines is whether bilinguals also perceptually repair *L2* sound sequences that conflict with L1 rules. The idea that bilinguals might perceive L2 sounds according to L1 constraints contributes directly to existing knowledge on bilingual language comprehension, specifically parallel processing. Bilinguals have demonstrated parallel *activation* of the L1 when comprehending in the L2, across phonotactic-constraint (Freeman, Blumenfeld,

& Marian, 2016, Chapter 2), phonological-word (Marian & Spivey, 2003a, b; Blumenfeld & Marian, 2007, 2013; Darcy, Park, & Yang, 2015), lexical (Linck, Hoshino, & Kroll, 2008; Bartolotti & Marian, 2012), semantic (Martín, Macizo, & Bajo, 2010), and syntactic levels (Linck et al., 2008; Kootstra, Van Hell, & Dijkstra, 2012). This dissertation finds further evidence for parallel processing in bilinguals, with parallel activation and co-perception of L1 phonotactics during L2 processing. Moreover, the dissertation provides insight into the structure of acoustic space and the phonological system within the bilingual mind by characterizing new cross-linguistic interactions at the sub-lexical level. If bilinguals repair L2 input (e.g., English s+c word or non-word: *strict*/*spelg*) to conform to L1 phonotactic constraints (e.g., Spanish-like v+s+c word or non-word: *estrict*/*espelg*), then this would suggest that bilinguals perceive an illusory vowel onset due to L1 constraints on how phonetic categories are represented.

There are three goals within the present dissertation. The first is to examine activation of L1 phonotactic constraints during L2 comprehension. When examining between-language co-activation in bilinguals, previous studies have identified that bilinguals process auditory and visual input in a bottom-up way (e.g., *plum* activates Spanish *pluma* ("pen"); Blumenfeld & Marian, 2007; 2013; Marian & Spivey 2003b). As speech unfolds through time, for example, hearing the word *strict*, neighbors that share phonology become activated in a bottom-up manner (e.g., within-language neighbor: *string*, between-language Spanish neighbor *estudio*). The second goal of this dissertation is to investigate the extent to which bilinguals perceive L1 phonotactic constraints during L2 processing. In speech perception, a top-down process dictates that rules influence how sound sequences are perceived (e.g., Best, 1994; Carlson, 2018; Carlson et al., 2016; Dupoux, Pallier, Kakehi, & Mehler, 2001; Hallé, Dominguez, Cuetos, & Segui, 2008; McClelland & Elman, 1986). For example, a Spanish-English bilingual hearing *strict* may process the input in a top-down way, repairing *strict* to *e̲strict*, since their L1 (Spanish) contains the v+s+c rule. The third goal is to characterize and explain the flow of bottom-up and top-down processes as bilinguals activate and perceive L1 phonotactics within L2 single-word comprehension (see Figure 1). Across the three ways of processing input, cross-linguistic interactions take place. However, are the bottom-up and top-down mechanisms dissociable or do they occur simultaneously during bilingual language processing?

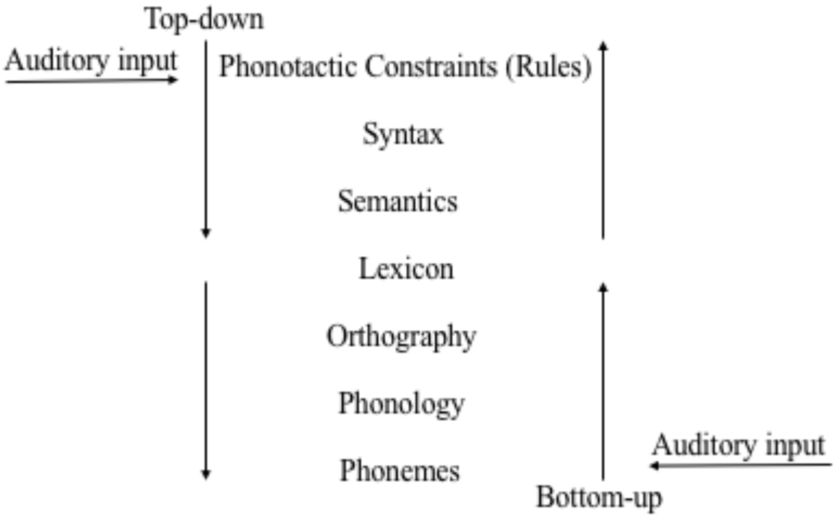

Figure 1: Top-down and bottom-up processing of auditory input

1.1 Dissertation Objectives and Hypotheses

Bilinguals activate their languages in parallel when listening to and producing words (Blumenfeld & Marian, 2007; 2013; Freeman, Blumenfeld, & Marian, 2016; Hartsuiker, Pickering, & Veltkamp, 2004; Linck, Hoshino, & Kroll, 2008; Marian & Spivey, 2003a, b; Martín, Macizo, & Bajo, 2010; but see Costa & Caramazza, 1999 for language-specific access). Do bilinguals also access L1 phonotactic constraints during L2 comprehension? Phonotactic constraints are rules imposed by a language in the production and perception of sounds and words and may serve as stumbling blocks for L2 learners. These obstacles are commonly observed when non-native speakers and L2 learners produce speech in the L2. For example, native Spanish speakers often overtly produce words such as *estudy*, adding an ‘e’ to the onset of an English word (Yavas & Someillan, 2005). The processes, or mechanisms, underlying phonotactic knowledge are less apparent. Specifically, and in addition to the question of parallel *activation* of phonotactic constraints, are L2 words that conflict with L1 phonotactic constraints *perceived* conforming to L1 rules (i.e., *study* = *estudy*)? Research has demonstrated that monolinguals fix nonsense words that conflict with phonotactic constraints within their language to conform to L1 rules (Côté, 2000; Davidson, 2003; Dupoux, Peperkamp, & Sebastián-Gallés, 2010; Dupoux, Sebastián-Gallés, Navarrete, & Peperkamp, 2008; Parlato-Oliveira, Christophe, Hirose, & Dupoux, 2010). The process underlying this top-down way of assimilating sounds to L1 phonotactic constraints is perceptual repair (Carlson et al., 2016; Hallé et al., 2008). Perceptual repair occurs when sounds or sound sequences which are phonotactically impermissible in the L1, are perceived as though they had been altered to conform to the relevant language system (Carlson et al., 2016; Hallé et al., 2008). This dissertation, and the existing literature on parallel activation and perceptual repair in bilinguals, provide support for the hypothesis that bilinguals activate and perceive L1 phonotactic constraints during L2 comprehension.

Understanding how bilinguals activate and perceive L2 sound sequences that conflict with L1 phonotactic constraints has important implications for identifying the underlying mechanisms associated with bilingual language processing. Bilinguals may recruit similar or different mechanisms during language activation (e.g., English *strict* may activate Spanish neighbor: *estudio* (“study”)) and speech perception (e.g., English *strict* may be perceived as *estrict*). For example, bilinguals may rely on bottom-up processes when experiencing parallel language activation. According to the Activation Threshold Hypothesis (Paradis, 2004), activation of a particular word and its neighbors occurs as a threshold is approached. Selection of a target word requires that its activation exceeds that of its alternatives. When perceiving sounds, bilinguals may rely on top-down processes. The Perceptual Assimilation Model (Best, 1994) states that if the phonetic characteristics of the sound are close to those of an existing phoneme category in the L1, the sound will be assimilated to that L1 category. Therefore, during perception of auditory input, bilinguals may apply top-down perceptual knowledge from the L1 to the L2. It is also clear from the Perceptual Assimilation Model that, to access a sound's or word's perceptual representation, one relies on auditory input. On the other hand, language activation occurs with and without auditory input, as visual input activates phonological competitors within and between languages in bilinguals (Chabal & Marian, 2015). Yet, *the relation between these mechanisms underlying language activation and speech perception in bilinguals remain unclear*. Since perception relies on auditory input, then it is likely that a combination of bottom-up and top-down processes influence how a sound sequence within a word is perceived. Moreover, if language co-activation can occur independently of auditory input (i.e., through reading/orthography), then bottom-up mechanisms and not top-down mechanisms provide activation of competitor or neighboring words between languages.

The objectives of the present dissertation are to identify whether bilinguals activate (Objective 1) and perceive (Objective 2) L1 phonotactic constraints during L2 comprehension. Furthermore, this dissertation examines how bilinguals process auditory and visual input in bottom-up and top-down ways, thus elucidating the mechanisms during bilingual language processing (Objective 3). The three objectives are presented next, along with their corresponding hypotheses.

Dissertation Objective 1: To identify whether bilinguals activate L1 phonotactic constraints while listening to L2 words. *Experiment 1* examined cross-linguistic influences of the L1 in the presence of L2 words. Spanish (L1) activation was indexed by the English (L2) cross-modal Phonological Priming Lexical Decision (PPLD) task. L2 auditory primes that conflicted with the L1 v+s+c rule were presented prior to L2-like visual non-word targets that conformed to the L1 v+s+c rule. Participants made lexical decisions on visual targets. Reaction times and accuracy rates indexed L1 activation during L2 comprehension within the PPLD task.

Hypothesis 1: Bilinguals experience L1 cross-linguistic influences during L2 processing at other linguistic levels (e.g., phonological, lexical, semantic), and activate, L1 phonotactic constraints during L2 processing as well.

Dissertation Objective 2: To investigate whether bilinguals are influenced by L1 phonotactic constraints when processing L2 words. *Experiments 2a* and *2b* included tasks that exploited speech perception. The tasks were employed for the first time to examine whether bilinguals explicitly (2a: vowel detection) and implicitly (2b: AX discrimination) perceived L2 sounds according to L1 rules. Participants heard English words and English-like non-words in the vowel detection task and reported if they heard a vowel at the onset of the stimulus. Participants in the AX discrimination task heard two consecutive English words and decided if the stimuli were the same or different. Spanish-conflicting stimuli were present in both tasks, as well as control stimuli that did not conflict with L1 constraints. Reaction times and accuracy rates indexed L1 perception during L2 comprehension.

Hypothesis 2: Bilinguals rely on perceptual repair to perceive foreign sounds as L1-like, and therefore assimilate L2 sounds to L1 phonotactic categories. This hypothesis stems from previous work examining perception of s+c in Spanish-English bilinguals in a Spanish testing environment (Carlson, 2018; Carlson et al., 2016), while this dissertation provides a novel contribution by investigating Spanish (L1) perception within English (L2) processing.

Dissertation Objective 3: To examine relation between activation and perception of L1 phonotactic constraints during L2 comprehension. Specifically, what are the mechanisms that underlie the relation between linguistic activation and perceptual processes in bilinguals and are they dissociable in any way? *Experiment 3a* examined co-activation of phonotactic constraints independently from auditory input through word recognition and eye-tracking. Eye fixations to target and competitor items measured cross-linguistic activation of phonotactic constraints while participants identified the target word by hearing its onset sound. *Experiment 3b* combined eye-tracking (word recognition) and AX discrimination to investigate the interplay between activation and perception of L1 phonotactics within the L2. English s+c onset words were present as targets and 'e' onset words were present as competitors in *Experiments 3a* and *3b*. Proportions of eye fixations to target, competitor, and filler items (*Experiments 3a* and *3b*), as well as response times to same/different judgments on two consecutive auditory stimuli (*Experiment 3b*), indexed the relation between activation and perception.

Hypothesis 3: A) Activation can occur independently of perception, as bilinguals activate L1 phonotactic constraints given minimal auditory input (target word's onset sound). B) Perception relies on auditory input, thus a combination of bottom-up and top-down mechanisms influence perception of L2 sounds to align with L1 rules. This two-part hypothesis is based on the evidence that language co-activation occurs with auditory and/or visual input (Blumenfeld &

Marian, 2007; 2013; Chabal & Marian, 2015; Marian & Spivey, 2003a, b). However, perception does not occur independently of activation because in order to perceive the acoustic properties of a sound, one relies on auditory input (Best, 1994). Moreover, previous studies have identified that bilinguals process acoustic and visual input in a bottom-up manner (e.g., Marian & Spivey, 2003b), and phonotactic constraints influence how acoustic input is perceived in a top-down way (e.g., Carlson et al., 2016).

In summary, the present dissertation examines activation and perception of phonotactic constraints, uses phonotactic constraints as a tool to dissociate activation from perception, and investigates the underlying mechanisms associated with sound and word processing in bilinguals. It is predicted that activation is dissociable from perception when there is no auditory input. Moreover, it is expected that activation and perception rely on similar processes and occur in tandem when auditory input is present. Alternatively, since bottom-up activation and top-down perceptual knowledge are distinct processes, they may not interact during auditory input. In the following sections, previous literature will be discussed on language activation and perception in monolinguals (*1.2*) and bilinguals (*1.3*), on the models of language processing (*1.4*), followed by a detailed overview of the methodology included in this dissertation (*1.5*), a preview of the clinical implications of this dissertation research (*1.6*), and a map for the dissertation (*1.7*).

1.2 Language Activation and Perception in Monolinguals

During auditory input, monolinguals have been shown to activate neighboring words that have phonologically-similar onsets. For example, in the visual world paradigm, English monolinguals look at the picture of a *candle* when hearing the target item *candy*, as these two items are within-language phonological neighbors (e.g., Blumenfeld & Marian, 2011; Blumenfeld, Schroeder, Bobb, Freeman, & Marian, 2016; Marian & Spivey, 2003a; Spivey-

Knowlton, Tanenhaus, Eberhard, & Sedivy, 1998). In Marian and Spivey (2003a), English monolinguals and Russian-English bilinguals were tested in the visual world paradigm. Participants were presented with within-English (e.g., *plug/plum*) and between-Russian-English phonological competitors (*marker/marka* ("stamp")). Monolinguals experienced within-language competition only, as evidenced by eye fixations to *plug/plum* versus filler pictures. Furthermore, Blumenfeld and Marian (2011) examined the role of inhibitory control during within-language competition in monolinguals and bilinguals. Participants viewed four pictures in the visual world paradigm and identified the target while eye movements were tracked. Target pictures included *plug* or *cab*, while within-language phonological competitor items included *plum* or *cat*, respectively, along with two filler pictures. Following the eye-tracking trial, a priming probe examined residual activation and inhibition of target and competitor words. Monolinguals demonstrated a delayed response on the priming probe when there was within-language competition from the previous eye-tracking display (e.g., *plug* and *plum*), indicating residual inhibition of the previous linguistic competitor item. The studies by Marian and colleagues suggest that monolinguals experience linguistic competition from words with similar phonological onsets within the same language.

The language activation literature demonstrates that when monolinguals process a word, interference occurs with neighbors that share phonological overlap with the given word. What happens when monolinguals hear foreign or nonsense words that conflict with their phonology? In other words, how do monolinguals *perceive* unfamiliar sound combinations? To illustrate this phenomenon, when an individual travels to a foreign country and communicates in his/her native language with non-native speakers, is this speaker able to understand these speakers? Does the individual assimilate these foreign/accented sounds into native-language categories? Previous research on speech perception in monolinguals has examined repair of foreign speech sounds to align with the phonotactics of their language (Cuetos et al., 2011; Dupoux, Parlato, Frota, Hirose, & Peperkamp, 2011; Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999; Hallé et al., 2008). In Japanese, for example, a phonotactic constraint is that syllable sequences, such as VCCV (e.g., *okru*), are illicit and a vowel is required within the cluster, such as VCVC (e.g., *okoru* ("occur")), to render the sequence legal. The process of adding a vowel within a syllable sequence is known as epenthesis. Other languages, such as English and French, allow VCCV syllable sequences (e.g., *estimate*). In Dupoux et al. (1999), Japanese and French monolinguals heard non-word stimuli that included VCCV (*ebzo*) and VCVC (*ebuzo*) clusters. Participants were asked if one of the two consecutive stimuli they heard was the same as the third stimulus. Japanese monolinguals had difficulty distinguishing between VCCV (*ebzo*) and VCVC (*ebuzo*) stimuli, suggesting that the VCCV input was perceptually repaired with epenthesis (*ebzo* was repaired to *ebuzo*).

As alluded to earlier in this Introduction, another example of a phonotactic constraint occurs with the v+s+c prothesis rule in Spanish. While English contains words with onsets such as e+s+c (*estimate*) and s+c (*stress*), words such as *stress* require a vowel at the onset in Spanish (Spanish: *estrés*). Hallé, Dominguez, Cuetos, and Segui (2008) visually primed Spanish monolinguals with pseudo-Spanish words that had the vowel spliced from the onset (e.g., *special* (/spesjal/) for *especial*). Immediately following the prime, participants viewed a Spanish word that conformed to the v+s+c Spanish constraint (*especial*) on which they made a lexical decision. With a longer delay (stimulus onset asynchrony) between prime and target (100ms as opposed to 44ms), the s+c primes were perceptually repaired to v+s+c, as phonological code had been accessed for v+s+c during the delay. (However, see sections *1.5.4* and *4.10* for an alternative explanation of these results.) Conclusively, in audio and visual studies on perceptual repair, monolinguals perceive native-like illicit non-words in line with the rules of their language. In addition, when the input conforms to L1 phonology, monolinguals activate neighboring words within their language that share phonology. Section 1.3 examines the activation and perception literature in bilinguals, discussing the cross-linguistic influences during language processing.

1.3 Language Activation and Perception in Bilinguals

While monolinguals and bilinguals access within-language phonological competitors, bilinguals also activate between-language neighbors (e.g., Blumenfeld & Marian, 2007; 2013; Marian & Spivey 2003a, b; Linck, Hoshino, & Kroll, 2008). For example, *plug* activates *plum* in English monolinguals, while *plug* also activates *pluma* ("pen") for Spanish-English bilinguals. This cross-linguistic competition scenario has been demonstrated across several studies by Marian and colleagues (Blumenfeld & Marian, 2007; 2013; Marian & Spivey 2003a, b; Mercier, Pivneva, & Titone, 2014; Spivey & Marian, 1999), and even without any linguistic input (Chabal & Marian, 2015). Chabal and Marian (2015) examined English monolinguals' and Spanish-English bilinguals' eye fixations to picture displays containing items that overlapped within English and within Spanish. Critically, participants were provided with no auditory input. When the target item was *clock*, English monolinguals and English-Spanish bilinguals also looked at a picture of *cloud*. Moreover, with the same target, bilinguals looked at *gift* (Spanish: "regalo") because *gift's* Spanish translation equivalent phonologically overlapped with the translation of *clock* (Spanish: "reloj"). Results from Chabal and Marian provide evidence that bilinguals process words that overlap in sound simultaneously within their languages with no auditory input. Moreover, since language activation can occur without auditory input, it may be possible to dissociate language activation from speech perception, given that auditory input is required to access a word's (or sound's) perceptual template (Best, 1994). The current dissertation further examines the relation between activation and perception in bilinguals.

Research on parallel language activation in bilinguals has also identified a link with executive functions. Blumenfeld and Marian (2013) found that the amount of parallel activation of both languages was related to cognitive control abilities in bilinguals. In the visual world paradigm, Spanish-English bilinguals and English monolinguals saw target (*comb*), competitor (*rabbit*, Spanish: "conejo"), and two filler items. Bilinguals activated the Spanish competitor item, as evidenced by looks to competitors over the filler items. In addition, greater parallel activation between 300-500ms after the onset of the target item followed by reduced parallel activation 633-767ms after the target onset, as indicated by looks to competitor versus filler items, was associated with smaller non-linguistic Stroop effects (i.e., more efficient inhibitory control abilities). The results from Blumenfeld and Marian, along with others (e.g., Freeman, Blumenfeld, & Marian, 2017; Mercier, Pivneva, & Titone, 2014) emphasize the role of cognitive control during bilingual language processing. There is a domain-general link between linguistic and non-linguistic cognitive control in bilinguals. This interdependent relation likely exists since bilinguals must manage simultaneous activation of two languages and then deploy inhibitory control to suppress activation of the irrelevant language (Freeman, Shook, & Marian, 2016). Bilinguals can be considered "mental jugglers" of two languages (Kroll, 2008), which increases cognitive control efficiency.

The literature on language co-activation in bilinguals suggests that bilinguals activate the native language (L1) in a non-native context (L2), and vice versa. In speech perception, however, the cross-linguistic influences involved are less clear, specifically, how bilinguals perceive L2 sound sequences that conflict with L1 rules. While listening to pseudowords that conflicted with

L1 phonotactic constraints, bilinguals repaired these sound sequences to make them more L1-like (Carlson, 2018; Carlson, Goldrick, Blasingame, & Fink, 2016; Parlato-Oliveira, Christophe, Hirose, & Dupoux, 2010; Weber & Cutler, 2006). Carlson, Goldrick, Blasingame, and Fink (2016) asked native-Spanish speakers of English whether they detected a vowel at the onset of Spanish-like non-words (vowel detection; e.g., *snid*). Participants also decided if two consecutive non-words they heard were the same or different (AX discrimination). Critically, in both tasks, the 'e' or 'a' onset was removed, or mostly removed, from e/as+consonant onset non-words, therefore conflicting with the Spanish phonotactic constraint of a vowel preceding an s+c. Results demonstrated that Spanish-dominant bilinguals, but not English-dominant bilinguals, perceived the 'e' onset when it was not present in the Spanish-conflicting stimuli. This misperception, or auditory illusion, was likely an effect of perceptually repairing the input to conform to the Spanish v+s+c constraint.

Furthermore, Parlato-Oliveira, Christophe, Hirose, and Dupoux (2010) found that bilinguals learned and adopted perceptual repair strategies in their L2. Parlato-Oliveira et al. (2010) exploited the Japanese and Portuguese phonotactic VCVC constraint in Japanese-Portuguese bilinguals across explicit (vowel detection) and implicit (forced-choice recall) measures of perceptual repair. Japanese requires repair of illicit VCCV clusters (e.g., *ebna*) with an epenthetic /u/ (e.g., *ebuna*), while Portuguese requires repair with an epenthetic /i/ (e.g., *ebina*). Perceptual repair with Japanese-Portuguese bilinguals to the Japanese (L1) or Portuguese (L2) vowel epenthesis depended on age of acquisition and task demands. Early Japanese-Portuguese bilinguals resolved the conflicting input to be Portuguese-like (e.g., *ebina*), while late Japanese-Portuguese bilinguals resolved the input to be L1- (Japanese) like (e.g., *ebuna*). Moreover, on the explicit measure of vowel perception (vowel detection), both participant groups demonstrated some evidence of Japanese perceptual repair as well, but this effect was absent in the forced-choice recall task. In the recall task, participants were not directly cued into the presence of a vowel as they were in the vowel detection task. Thus, it appeared that age of acquisition and metalinguistic demands of the task modulated the extent to which perceptual repair occurred.

In addition to how ambiguous vowels are resolved across languages, previous research has observed the extent to which perceptual repair occurs differentially across the L1 and L2. Weber and Cutler (2006) tested L1 German speakers of English, as well as English monolinguals in an English (L2) word detection task. English-like nonsense sequences were presented and participants had to indicate when they heard an English word within the sequence. Some of the sequences contained syllable boundaries that conformed to German phonotactic constraints, and others that conformed to English phonotactic constraints. Critically, the German-English bilinguals performed the task in their L2, as they were attending to English sequences. Therefore, the extent to which L1 phonotactic constraints affected L2 processing could be tested. While German-English bilinguals and English monolinguals were almost equally sensitive to English-like boundaries that aligned with English phonotactic constraints, only German-English bilinguals were sensitive to the English-like boundaries that followed German constraints. The results suggest that bilinguals become sensitive to L2 phonotactic constraints, however, they are still affected and influenced by L1 phonotactic constraints during L2 processing. We provide further support for perception of L1 phonotactic constraints during L2 comprehension, with real words, as well as non-words, and attempt to elucidate the mechanisms that underlie cross-linguistic activation and perception in bilinguals.

1.4 Models of Language Processing: Activation and Perception

This dissertation is built upon several theoretical accounts of language processing in monolinguals and bilinguals. An important distinction arises between bottom-up processing that accounts for language co-activation and top-down processing that entails language co-perception. Specifically, bottom-up mechanisms bolster activation of within- (monolinguals and bilinguals) and between-language phonological neighbors (bilinguals only), or competitors from the phonological level up to the lexical and conceptual levels (TRACE, McClelland & Elman, 1986; Bilingual Interactive Activation+, Dijkstra & van Heuven, 2002; Bilingual Language Interaction Network of Comprehension of Speech, Shook & Marian, 2013; Activation Threshold Hypothesis, Paradis, 2004). Top-down mechanisms support perception of sounds based on the phonotactic constraints within that language (Perceptual Assimilation Model, Best, 1994; Carlson et al., 2016; Dupoux et al., 1999; Dupoux, Pallier, Kakehi, & Mehler, 2001).

Two models specifically draw attention to the role of phonotactic constraints during language processing. The Activation Threshold Hypothesis (Paradis, 2004) states that as words unfold through the acoustic stream, constraints become activated based on the combination of sounds the bilingual is hearing. Activation of a particular word and its neighbors occurs as a threshold is approached. Selection of a target word requires that its activation exceeds that of its alternatives. Therefore, similarly to co-activation of phonological neighbors, bottom-up processes support co-activation of phonotactic constraints in bilinguals. The Perceptual Assimilation Model (Best, 1994) explains that the rule-based system influences how bilinguals perceive language input. Conflict arises when a bilingual hears a non-native (or L2) speech sequence that does not exist in the L1. Therefore, if the phonetic characteristics of the sound are close to those of an existing phoneme category in the L1, the sound will be assimilated to the L1 category. Based on the Perceptual Assimilation Model, during auditory input, bilinguals apply perceptual and phonemic category knowledge of the L1 to L2 representations. Thus, top-down mechanisms based on phonotactic constraints may impact bilingual phonological processing.

While the Perceptual Assimilation Model focuses mainly on individual phonemic categories, aspects of the model can be applied to phonotactic constraints as well. The s+c and v+s+c contrast is a prime example. When native Spanish speakers of English encounter an s+c or v+s+c word in English, there are two scenarios within the model that predict how bilinguals would perceive the input. The first is the Single Category (SC) type, which states that the L2 sounds (s+c and v+s+c) may be assimilated equally well to a single L1 category. The second scenario is the Category Goodness (CG) type. When a pair of sounds contrast in the L2, like the SC type, they may be assimilated to a single category in the L1, but one of the contrasting L2 sounds may be more similar than the other to the L1 phoneme. While this dissertation does not aim to dissociate between SC and CG, the Perceptual Assimilation Model is worth noting in order to provide a theoretical backdrop for what bilingual listeners experience when processing sounds that conflict with L1 rules. In any case, the s+c and v+s+c contrast in English likely applies to the CG scenario because v+s+c is a rule in Spanish.

One of the goals of this dissertation was to identify the relation between language co-activation and co-perception in bilinguals. To do so, certain aspects of the Activation Threshold Hypothesis and the Perceptual Assimilation Model can be combined. To illustrate the theoretical relation between activation and perception, as between-language neighbors are activated in a bottom-up way in the acoustic stream, the Spanish v+s+c phonotactic constraint is also activated because s+c onset words do not exist in Spanish. Before the activation threshold is reached where the target word's representation is processed in the intended language (i.e., English), and since the between-language words and the Spanish L1 v+s+c phonotactic constraint itself are accessed, the L2 words may be influenced by L1 phonotactics in a top-down manner because the constraint dictates how the input is perceived. See Figure 2 for an example of L2 word processing with non-cognates.

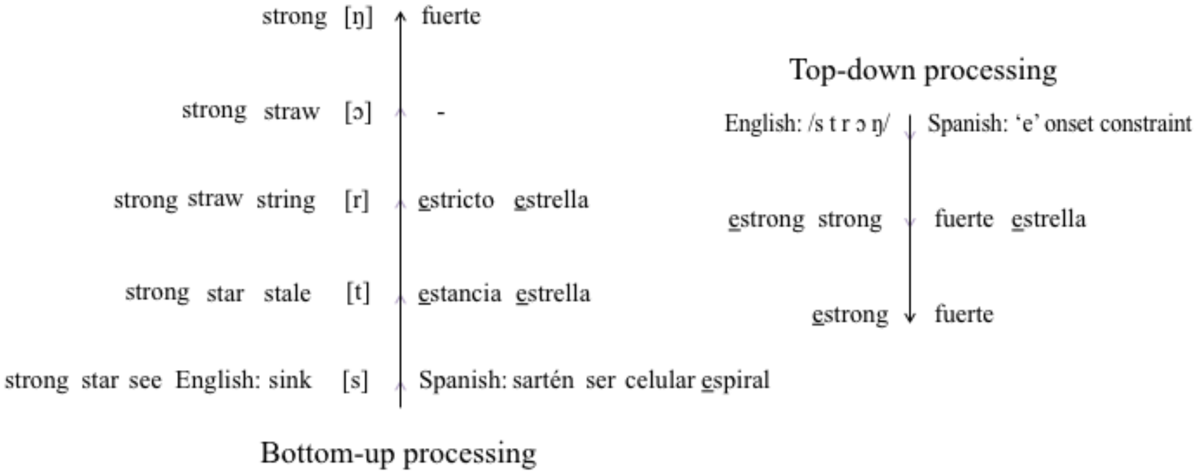

Figure 2: Bottom-up and top-down processing of the English word, *strong*, which conflicts with the Spanish 'e' onset constraint.

However, *the way in which bottom-up and top-down mechanisms interact during language activation and perception in bilinguals remains unclear*. The fourth chapter of this dissertation aims to identify and characterize the mechanisms associated with language activation and perception in bilinguals.

1.5 Dissertation Overview

The main objective of the present dissertation was to examine language co-activation and co-perception in bilinguals, as well as the mechanisms that underlie the two processes. The primary research questions included: 1) do bilinguals activate and perceive native-language (L1) phonotactic constraints during second language (L2) comprehension, and 2) what are the underlying mechanisms that support bilingual language processing, specifically the relation between co-activation and co-perception, and are these mechanisms dissociable. In *Experiment 1,* monolinguals and bilinguals completed an English cross-modal Phonological Priming Lexical Decision (PPLD) task that indexed activation of L1 phonotactic constraints during L2 single-word comprehension. In *Experiment 2a*, monolinguals and bilinguals completed an English vowel detection task that explicitly measured perceptual repair of s+c to v+s+c. Perceptual repair was also indexed in *Experiment 2b* implicitly, with an English AX discrimination task. In *Experiment 3a*, participants completed an English word recognition task with minimal auditory input to identify the target (i.e., the target word's onset sound). This paradigm used eye-tracking to measure bottom-up co-activation of L1 phonotactic constraints during L2 processing. Last, in *Experiment 3b*, participants performed an English combined word recognition (eye-tracking) and AX discrimination task to index bottom-up activation and top-down perceptual processes within the same task. Together, the three dissertation experiments allowed for the examination of L1 influences on bilinguals' processing of non-native sound sequences, as well as the identification of the mechanisms that are common and distinct to language co-activation and co-perception in bilinguals. In the following sections, the different methodologies used to address the research questions are discussed in detail.

1.5.1 Activation of Phonotactics: Phonological Priming Lexical Decision (PPLD) Task

The second chapter of this dissertation integrates previous research on parallel language activation, examining whether bilinguals activate phonotactic constraints of the irrelevant, or native language (L1) during auditory and visual second language (L2) processing. Auditory input may activate multiple competing words as it unfolds through time (Aitchison, 2003; Clahsen & Felser, 2006; Swinney, 1979). For example, *pl-* activates several word possibilities, such as *plug, plum, plan*. As the input is heard, competitors are excluded until the acoustic stream matches the target word for selection. The process of lexical selection requires inhibition of alternative words, narrowing down options to select the target. This scenario is typical for monolinguals, while inhibition of neighboring words may be more taxing for bilinguals. Bilinguals experience within-language competition (e.g., *plug, plum, plan*), and between-language competition (e.g., *pluma, plano, playa*) (Blumenfeld & Marian, 2013; Costa & Santesteban, 2004; Marian & Spivey, 2003a, b; Mercier, Pivneva, & Titone, 2014). Thus, the nature of competition for bilinguals is more demanding, yet there are no obvious costs in single-language comprehension or production; bilinguals need to suppress simultaneous activation of competing words within the target language, and the irrelevant language not in use (Kroll, 2008; Levy, McVeigh, Marful, & Anderson, 2007; Linck, Kroll, & Sunderman, 2009; Meuter, 1994).

Indeed, there is evidence to suggest that while bilinguals comprehend one language, the other, irrelevant language may be simultaneously accessed through parallel activation (e.g., Blumenfeld & Marian, 2007, 2013; Hartsuiker, Pickering, & Veltkamp, 2004; Linck et al., 2009; Marian & Spivey, 2003a, b; Martín, Macizo, & Bajo, 2010; Mercier et al., 2014; but see Costa & Caramazza, 1999 for language-specific access). Whereas evidence is consistent for parallel activation at the lexical level, little evidence exists for parallel activation at the sub-lexical level (Freeman, Blumenfeld, & Marian, 2016, Chapter 2; Lentz & Kager, 2015). Therefore, the objective of *Experiment 1* is to identify whether bilinguals co-activate L1 sub-lexical phonotactic constraints within an L2 context. The cross-modal PPLD task has been previously used to measure how L1 phonotactic constraints influence L2 word processing. Lentz and Kager (2015) presented Dutch monolinguals, L1 Japanese speakers of Dutch, and L1 Spanish speakers of Dutch with auditory v+s+c primes (legal in Dutch, Japanese, and Spanish), and visual s+c targets (legal in Dutch, illegal in Japanese and Spanish), on which participants performed a lexical decision. Results suggested that only the native-Spanish group accessed the vowel onset rule with illicit s+cs, as they were faster when primed with the prothesis clusters (i.e., the addition of a vowel at a word's onset). The native-Spanish group applied an L1 filter when processing the L2 sounds. In *Experiment 1*, a modified version of the task from Lentz and Kager was used (PPLD task, see Figure 3). The auditory primes included s+c onset words and the visual targets included v+s+c onset non-words. *Experiment 1* differed from Lentz and Kager in that the s+c and v+s+c stimuli presentation was switched to examine how s+c cognate status influenced activation of the constraint.

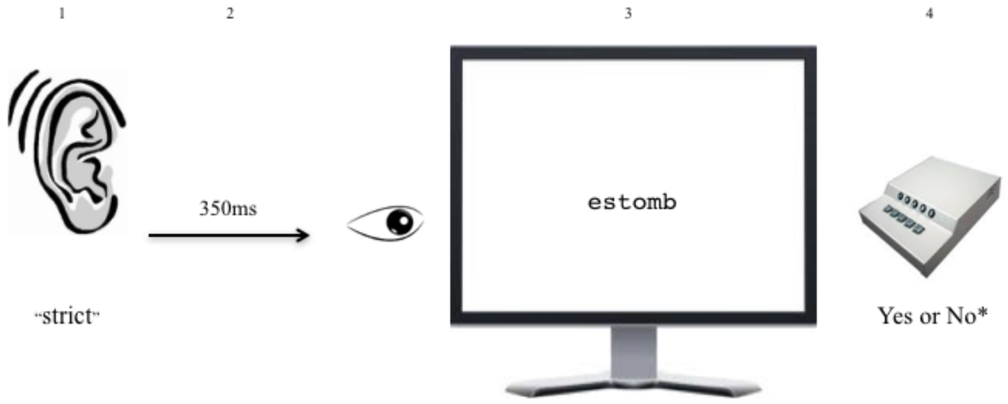

Figure 3: Example trial from cross-modal phonological priming lexical decision task. In this example, participants hear the English-Spanish cognate auditory prime *strict* and 350ms after the offset of the prime, view the phonotactic-constraint-and-form overlap non-word visual target *estomb*, on which they perform a lexical decision (*Yes response = English real word, No response = non-word).

1.5.2 Perception of Native-language Phonotactics in an L2 Context: Vowel Detection and AX Discrimination Tasks

The third chapter of this dissertation builds upon the previous chapter on phonotactic-constraint activation and examines whether bilinguals *perceive* non-native sounds according to

L1 phonotactic constraints. Past research suggests perceptual effects from the L1 persist into the L2 (Dupoux, Peperkamp, & Sebastián-Gallés, 2010; Dupoux, Sebastián-Gallés, Navarrete, & Peperkamp, 2008; Lentz & Kager, 2015; Pallier, Bosch, & Sebastián-Gallés, 1997; Weber & Cutler, 2006). For example, French-Spanish bilinguals demonstrated difficulty processing contrasting stress patterns in Spanish if French was their L1 (Dupoux et al., 2010; Dupoux et al., 2008). In addition, Spanish-Catalan bilinguals discriminated between /e/ and /ɛ/, a vowel contrast that occurs only in Catalan, if they learned Catalan first (Pallier, Bosch, & Sebastián-Gallés, 1997). Moreover, L2-dominant listeners immersed in an L2 environment acquired native-like perceptual patterns in their L2, and L1 influence was restricted to explicit metalinguistic tasks (Parlato-Oliveira, Christophe, Hirose, & Dupoux, 2010). Directly relevant to this dissertation is the previous research on L1 perceptual repair and phonotactic constraints, which has demonstrated that monolinguals, and even bilinguals, perceive nonsense speech sounds in line with L1 rules (Carlson, 2018; Carlson, Goldrick, Blasingame, & Fink, 2016; Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999; Flege, 2003; Hallé, Dominguez, Cuetos, & Segui, 2008; Lentz & Kager, 2015; Weber & Cutler, 2006). For example, Carlson, Goldrick, Blasingame, and Fink (2016) found that Spanish-dominant bilinguals of English reported hearing an 'e' onset when it was not present in Spanish-like non-words that conflicted with the Spanish v+s+c phonotactic constraint in vowel detection and AX discrimination tasks. Participants in Carlson et al. were tested in their L1; however, Chapter Three examined perceptual effects of L1 phonotactic constraints in the L2. Two tasks were used that differed in demands on metalinguistic awareness. An English vowel detection task (*Experiment 2a*) was employed in which metalinguistic demands were high, since the participants paid attention to the onset of the word/non-word and needed to know what a vowel was (see Figure 4).

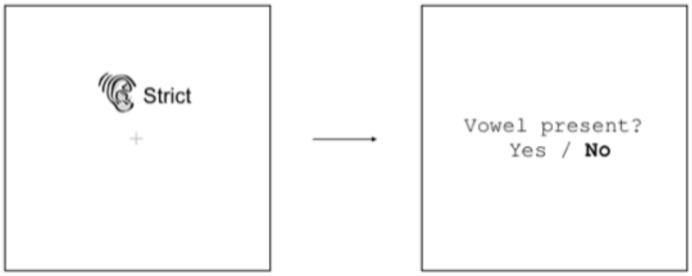

Figure 4: Example trial from the vowel detection task. In this example, participants heard *strict* and had to decide if a vowel was present at the word's onset (Yes response = vowel present, No response = no vowel present).

An English AX discrimination task (*Experiment 2b*) was used in which participants decided whether two consecutive words they heard were the same or different (see Figure 5). Therefore, metalinguistic demands were reduced in comparison to the vowel detection task, since the AX discrimination task tapped into lower-level perceptual processes (i.e., same/different judgments) during speech perception.

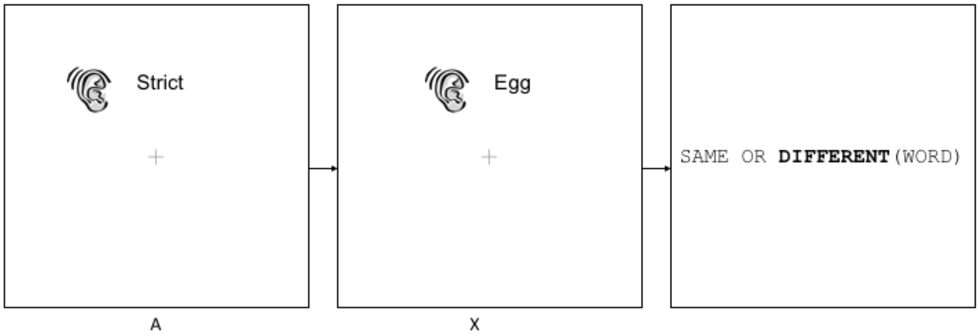

Figure 5: Example trial from the vowel discrimination task. In this example, participants heard *strict* followed by *egg* and had to decide if the two words they heard were the same or different.

Thus, bilinguals' perceptual repair was measured explicitly (*Experiment 2a*, vowel detection) and implicitly (*Experiment 2b*, AX discrimination). Critically, the stimuli in these experiments included words (*Experiments 2a* and *2b*) and non-words (*Experiment 2a*) that conflicted with the Spanish phonotactic constraint of v+s+c (e.g., *strict*). The word/non-word manipulation was used to determine whether lexicality of the stimuli affected perceptual repair. If bilinguals perceptually repaired the input that conflicted with the L1 Spanish phonotactic constraint, they may have perceived *strict* as *estrict* during auditory word processing. However, given the findings from Parlato-Oliveira et al. (2010) in which perceptual influences were limited to explicit (metalinguistically-demanding) measures of speech perception, differential effects of L1 perceptual repair during L2 processing may arise across Experiments 2a and 2b.

1.5.3 Activation without Perception: Eye-tracking Word Recognition Paradigm

In Chapter Four, activation and perception of L1 phonotactic constraints during L2 comprehension was further examined. The Activation Threshold Hypothesis (Paradis, 1994), along with other models of bilingual language activation (e.g., BIA+, Dijsktra & van Heven, 2002; BLINCS, Shook & Marian 2013), state that bilinguals activate their language systems concurrently. Empirical evidence has demonstrated parallel processing in bilinguals as well (e.g., Blumenfeld & Marian, 2007, 2013; Freeman, Blumenfeld, & Marian, 2016; Linck, Hoshino, & Kroll, 2008; Marian & Spivey 2003a, b; Martín, Macizo, & Bajo, 2010). It was predicted that activation could occur independently from perception because when reading (orthography), phonology is accessed. If a bilingual does not hear a word through the auditory modality that conflicts with the 'e' onset (v+s+c) rule for Spanish, then there is no opportunity for him/her to perceptually repair it. *Experiment 3a* examined strictly activation of phonotactic constraints with minimal auditory input. The main contribution of this experiment was that it dissociated activation from perception, since bilinguals were not hearing the target item's sound sequence that could be perceptually repaired. The participants identified the target word after hearing only its onset (e.g., "Click on /s/" for *strict*). Eye movements were tracked to four words presented on the screen: target *strict*, competitor *egg*, two filler items *work*, *can* (see Figure 6).

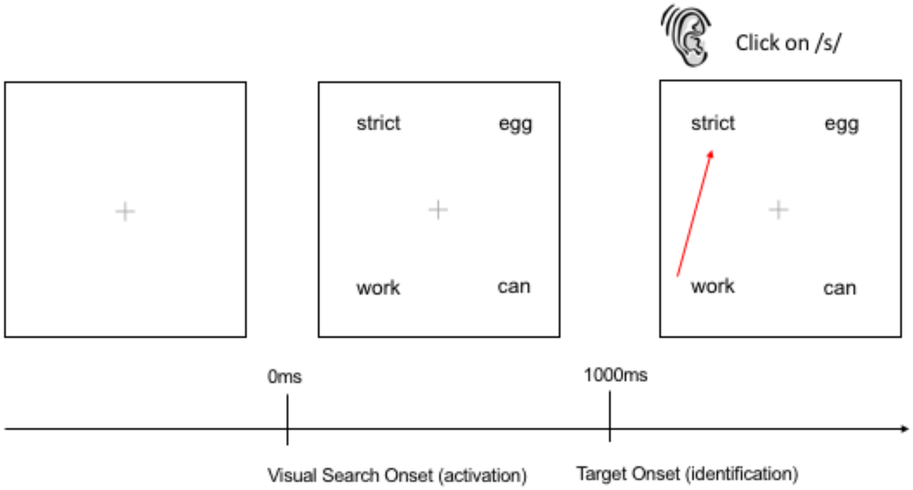

Figure 6: Example trial from the word recognition task. In this example, participants viewed four words on the screen while eye movements were tracked. The words included a target that conflicted with the Spanish 'e' onset constraint (*strict*), a competitor that contained an 'e' onset (*egg*), and two filler items (*work*, *can*). Participants then heard, "Click on /s/", where /s/ was the onset of the target item (*strict*).

The target and competitor words should have invoked between-language competition of Spanish phonotactic constraints during English processing. The visual world paradigm has been traditionally used to examine within- and between-language activation (Blumenfeld & Marian, 2007, 2011, 2013; Marian & Spivey, 2003a, b; Mercier, Pivneva, & Titone, 2014). Therefore, *Experiment 3a* did the same, however, instead of the participant identifying the target word with whole-word auditory input, the participant heard only the onset sound of the target (e.g., /s/). This design reduced the recruitment of top-down perceptual knowledge. The focus of *Experiment 3a* was to identify whether language co-activation of phonotactic constraints was possible based on a purely bottom-up mechanism, following the hierarchy from orthographic, phonological, lexical, to phonotactic constraints, when reading words.

1.5.4 Simultaneous Activation and Perception: Combined Eye-tracking Word Recognition and AX Discrimination Paradigm

Perception cannot occur independently of activation since perception relies on auditory input (Best, 1994). When an individual hears a word or combination of sounds, s/he perceives it a certain way based on top-down influences (Carlson et al., 2016; Dupoux et al., 1999), but s/he accesses neighbors and translation equivalents through bottom-up processing (Marian & Spivey, 2003b; Paradis, 2004; Shook & Marian, 2013; van Heuven & Dijkstra, 2002). It is therefore not possible to dissociate perception from activation during spoken language comprehension, but it can be said that these processes might be occurring in tandem. This is the first investigation to simultaneously examine bottom-up activation and top-down perception in bilinguals, uniting these distinct processes and identifying the commonalities among them. Specifically, this dissertation identifies if these mechanisms work together during activation and perception of the L1 when listening to and viewing L2 words.

To investigate how bottom-up and top-down mechanisms interact, *Experiment 3b* indexed activation and perception of L1 Spanish phonotactic constraints during L2 English single-word comprehension. Methodology was combined from *Experiment 3a* (word recognition) and *Experiment 2b* (AX discrimination). Specifically, bottom-up activation in word recognition was measured where the participant saw four words on the screen (target, competitor, 2 filler items). As in *Experiment 3a*, the target and competitor items were an s+c word and an ‘e’-onset word, respectively. If bilinguals processed visual-word input in a bottom-up way (activation), then they would have fixated on the target (*strict*) and competitor (*egg*) words more than the filler items (*work*, *can*) when hearing the target word during word recognition. It was likely that top-down perceptual processes also affected bilinguals' perception of the auditory input, which was examined in the second part of *Experiment 3b*. After hearing and identifying the target word, another word was heard. The participant then decided if the two words s/he heard were the same or different, as in *Experiment 2b* (AX discrimination) (See Figure 7).

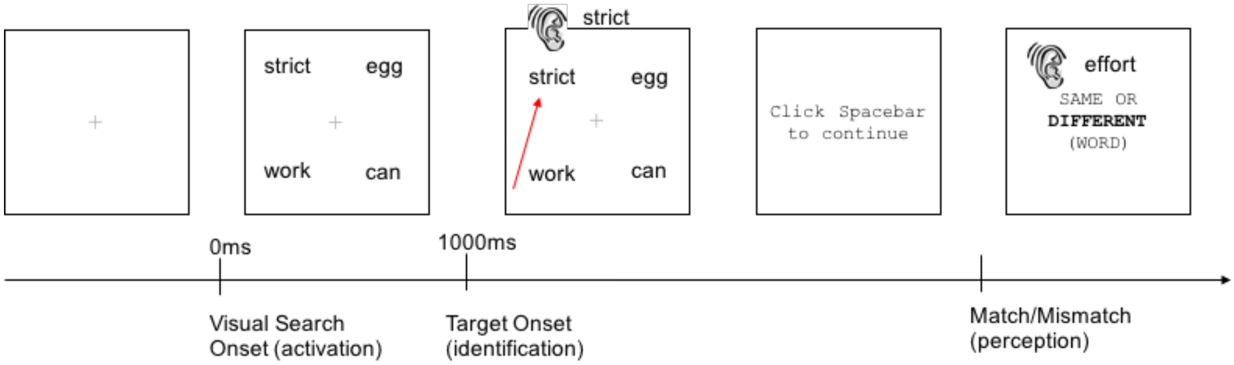

Figure 7: Example trial from the combined word recognition and AX discrimination task. In this example, participants viewed four words on the screen while eye movements were tracked. The words included a target that conflicted with the Spanish 'e' onset constraint (*strict*), a competitor that contained an 'e' onset (*egg*), and two filler items (*work*, *can*). Participants then heard the target word (*strict*). After identifying the target, participants heard a second word (*effort*) and had to decide if the two words they heard were the same or different.

Here, top-down perceptual mechanisms may have been exploited as this same/different judgment was an indirect measure of perceptual repair. Thus, it was predicted that bottom-up action and top-down perception influenced parallel processing in bilinguals. However, given the mixed findings of perceptual effects on implicit measures of vowel perception (e.g., Parlato-Oliveira et al., 2010), the same/different judgment may not be sufficiently sensitive to capture L1 perception during L2 processing.

In any case, if activation and perception mechanisms co-occur during bilingual language processing, the existing body of evidence on parallel processing and on perceptual repair in bilinguals would have to account for the possibility that bottom-up and top-down processes are not mutually exclusive. For example, work by Marian and colleagues has demonstrated that bilinguals activate both of their languages in parallel during auditory and visual processing, as evidenced by between-language competition from phonological neighbors (Blumenfeld & Marian, 2007; 2013; Chabal & Marian, 2015; Marian & Spivey, 2003a, b). Investigations examining auditory cross-linguistic competition in the context of whole-word phonological processing (i.e., lexical items) would need consider top-down perceptual mechanisms as well, including phonotactic constraints, since the entire word was heard. Similarly, previous investigations examining top-down perception (e.g., Dupoux and colleagues, Carlson et al., 2016) would need to integrate bottom-up phonological neighbor competition as well.

A limitation and assumption of *Experiments 3a* and *3b* is that bilinguals are not accessing stored representations for sound sequences in their minds. For example, when visually presented with an English word that conflicts with the Spanish v+s+c rule (e.g., *strict*), it is unclear whether the native Spanish speaker's phonological representation for English *strict* is *strict* or *estrict*. Based on the Perceptual Assimilation Model, auditory input is required to access a sound's or word's perceptual representation (Best, 1994). In a previous study examining perceptual repair in monolinguals without auditory input, Hallé et al. (2008) visually presented Spanish monolinguals with Spanish-like s+c onset non-words that conflicted with the Spanish v+s+c rule. The Spanish monolinguals appeared to perceptually repair the visual input to conform to the v+s+c rule. However, it is unclear whether *perceptual* repair was the process occurring or if the observed effects for Spanish monolinguals were due to processing the visual input through *activation* of the Spanish v+s+c phonotactic constraint. An alternative explanation for the results from Hallé et al. could be that when reading the words that conflicted with the Spanish phonotactic constraint, Spanish monolinguals activated the constraint in a bottom-up, but not top-down way, from orthography, to phonology, to the lexicon, to the v+s+c phonotactic constraint.

1.6 Clinical Implications

In addition to theoretical implications, this dissertation has important clinical significance. When a child or an adult is producing sounds and words in their L2 according to the rules of their L1, these individuals might be misidentified as having an articulation difficulty. What if these individuals are perceiving the sounds and words of their L2 in line with their L1? It is important to identify whether L2 sounds are assimilated to the L1 in order to know when and whether to treat bilingual children and adults with speech perception and phonemic awareness interventions. If bilinguals are perceiving L2 sounds in line with their L1, this is indicative of a speech sound/inventory difference. If bilinguals are perceiving sounds and phonemes incorrectly that are shared across both languages, this is indicative of a phonological processing disorder, or speech sound disorder.

1.7 Summary and Dissertation Outline

The three dissertation experiments aim to further investigate and characterize activation and perception within the context of parallel processing in bilinguals. Specifically, activation and perception of L1 phonotactic constraints during L2 comprehension is examined. Chapter Two (*Experiment 1*) addresses Dissertation Objective 1, which is to identify whether bilinguals activate L1 phonotactics in during L2 processing. Chapter Three (*Experiments 2a* and *2b*) addresses Dissertation Objective 2, which investigates perception of sounds according to L1 phonotactics when bilinguals are in an L2 environment. The two experiments provide an in-depth view, with direct and indirect measures of perception of phonotactic constraints. Chapter Four (*Experiments 3a* and *3b*) first attempts to dissociate activation from perception of L1 phonotactics during L2 processing (*Experiment 3a*) and then identifies the role of bottom-up and top-down mechanisms that influence parallel processing in bilinguals (*Experiment 3b*), thereby addressing Dissertation Objective 3. Chapter Five summarizes the key findings of this dissertation, provides scientific and clinical implications for the results, and discusses future directions for this research.

CHAPTER 2

PHONOTACTIC CONSTRAINTS ARE ACTIVATED ACROSS LANGUAGES IN BILINGUALS[1]

2.1 Abstract

During spoken language comprehension, auditory input activates a bilingual's two languages in parallel based on phonological representations that are shared across languages. However, it is unclear whether bilinguals access phonotactic constraints from the non-target language during target language processing. For example, in Spanish, words with s+ consonant onsets cannot exist, and phonotactic constraints call for epenthesis (addition of a vowel, e.g., stable/*estable*). Native Spanish speakers may produce English words such as *estudy* ("study") with epenthesis, suggesting that these bilinguals apply Spanish phonotactic constraints when speaking English. The present study is the first to examine whether bilinguals access Spanish phonotactic constraints during English *comprehension*. In an English cross-modal priming lexical decision task, Spanish-English bilinguals and English monolinguals heard English cognate and non-cognate primes containing s+consonant onsets or controls without s+onsets, followed by a lexical decision on visual targets with the /e/ phonotactic constraint or controls without /e/. Results revealed that bilinguals were faster to respond to /es/ non-word targets preceded by s+ cognate primes and /es/ and /e/ non-word targets preceded by s+ non-cognate primes, confirming that English primes containing s+ onsets activated Spanish phonotactic

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constraints. These findings are discussed within current accounts of parallel activation of two languages during bilingual spoken language comprehension, which may be expanded to include activation of phonotactic constraints from the irrelevant language.

2.2 Introduction

Across many contexts and discourse situations, bilinguals activate both languages simultaneously, even when only one language is used overtly, a phenomenon known as parallel activation (e.g., Blumenfeld & Marian, 2007; Dijkstra & van Heuven, 2002; Kroll, Bobb, Misra, & Guo, 2008; Green, 1998; Shook & Marian, 2013). Bilinguals have previously demonstrated parallel activation of phonological (Blumenfeld & Marian, 2007; 2013; Darcy, Park, & Yang, 2015; Marian & Spivey, 2003), lexical (Bartolotti & Marian, 2012; Linck, Hoshino, & Kroll, 2008), semantic (Martín, Macizo, & Bajo, 2010), and syntactic (Kootstra, van Hell, & Dijkstra, 2012; Linck et al., 2008) information across their two languages. In the current study, we explore whether cross-linguistic activation of phonological structures extends to phonotactic constraints (i.e., legal ways for combining speech sounds) of the non-target language during spoken word comprehension in bilinguals. Specifically, we address the question: *Do Spanish-English bilinguals access Spanish phonotactic constraints during English comprehension?*

Phonotactic constraints can differ across languages, which may become a stumbling block for second language (L2) speakers during initial stages of L2 acquisition and use (e.g., Flege & Davidson, 1984). Specifically, language production studies suggest that when the phonology of the L2 does not align with or is not present in the native language (L1), L2 learners and bilinguals may experience interference from the non-target language (e.g., Yavas & Someillan, 2005). For example, while word-initial s+ consonant clusters are legal in English, a phonotactic constraint for Spanish is that s+ consonant clusters cannot exist at word onsets and an epenthetic /e/ (i.e., the addition of a vowel) must be added to render the word acceptable in Spanish. This incongruence between phonotactic constraints in the L1 and L2 might result in Spanish-like pronunciations and perceptions of English words during spoken word production and comprehension (e.g., *stable*, Spanish: *estable*).

Comprehension. During receptive language processing, Spanish-only speakers have been shown to activate the epenthetic /e/ when viewing real Spanish words, even when the /e/ is removed from the word onset. Spanish speakers who performed a visual lexical decision task on words containing /as/+ and /es/+ consonant onsets showed facilitation of the epenthetic /e/ when primed with a Spanish word that had the /e/ onset removed (e.g., Spanish *stable*/"*estable*") (Hallé, Dominguez, Cuetos, & Segui, 2008). The Spanish monolinguals in Hallé et al.'s study likely activated the epenthesis onset because Spanish was *overtly* presented and participants were judging lexicality in Spanish (not English).

Within-language activation of phonotactic constraints has been observed with monolinguals in other consonant-vowel contexts. For example, Japanese monolinguals applied an epenthesis constraint by adding a vowel (e.g., /u/) to an illegal consonant cluster in the coda of syllables when hearing Japanese-like non-words (e.g., they heard 'mikdo', but perceived it as 'mikudo') (Dupoux, Pallier, Kakehi, & Mehler, 2001). Hallé et al. (2008) discuss the process of epenthesis within consonant clusters as phonological repair, (i.e., modifying auditory input that is phonologically illegal to conform to native language rules). Moreover, Parlato-Oliveira, Christophe, Hirose, and Dupoux (2010) examined how bilingual experience influenced the way the epenthesis constraint was repaired. Native Japanese-speaking adults who had been exposed to Portuguese (L2) when entering school demonstrated similar epenthesis patterns as native Portuguese listeners when processing illegal consonant clusters. Moreover, simultaneous

Japanese-Portuguese bilinguals who were exposed to both languages from birth also demonstrated epenthesis repair similar to that observed in native Portuguese speakers (adding an /i/). Thus, previous results suggest that monolinguals and bilinguals potentially access and repair auditory input to align with their native or more proficient language.

While cross-linguistic activation of phonotactic constraints has yet to be established in comprehension, parallel language activation has been identified in other areas of phonology. Studies suggest that non-native listeners may rely on phonological categories from the non-target L1 during L2 auditory comprehension. For example, the two distinct vowels /ɛ/ and /æ/ are contrastive phonemes in English, but are non-contrastive allophones in Dutch. Consequently, Dutch learners of English, but not English monolinguals, erroneously activated '*deaf*' when primed with '*daf*' (Broersma & Cutler, 2011). If the highly proficient Dutch-English bilinguals tested in this study had mastered the /ɛ/ and /æ/ phonological category distinction of their L2 (English), then the findings would suggest access of L1 phonological categories during L2 processing. Alternatively, it is possible that even proficient L2 learners routinely rely on L1 categories during phonological processing in L2. Thus, previous research indicates that individuals are attuned to the phonotactic constraints of their L1 during native-language listening tasks (Hallé et al., 2008), and that bilinguals may potentially activate L1 phonological categories during L2 comprehension (e.g., Broersma & Cutler, 2011; Darcy, Park, & Yang, 2015). In the current study, we ask if bilinguals are also attuned to the phonotactic epenthesis constraint of the L1 (Spanish) during L2 (English) comprehension.

Production. Evidence from word production also suggests that bilinguals are susceptible to cross-linguistic activation of phonological structures. Fabra and Romero (2012) found that L1 Catalan speakers of English produced English words with vowels (/i/, /ɛ/, /a/, /Λ/) that were less peripheral (i.e., sounded more like Catalan vowel phonology), than native English monolinguals. The less peripheral vowel effect disappeared as proficiency in English increased. Notably, all of the vowels except /Λ/ are shared across English and Catalan, thus the results suggest access of L1 phonological categories. As in comprehension (Broersma & Cutler, 2011), spillover effects of L1 phonological *categories* into L2 productions have been identified; but would there also be a similar effect with bilinguals accessing *phonotactic constraints* from the non-target language? Native Spanish speakers speaking English may at times produce words such as *estrict* in English ("strict"), adding an additional /e/ to the onset of words (Yavas & Someillan, 2005; see Roelofs & Verhoef, 2006, for review of bilingual cross-linguistic phonological access during production). While we have seen evidence for irrelevant-language phonological category and phonotactic constraint access during *production*, it is not clear whether bilinguals also access cross-linguistic phonotactic constraints during comprehension.

Previous investigations have explored the contexts in which cross-linguistic phonological activation could be facilitated. For example, cognates, which are words that overlap in form and meaning across languages (e.g., English: *stable/*Spanish: *estable*), have been used to test phonological co-activation during production (e.g., Amengual, 2012) and comprehension (e.g., Blumenfeld & Marian, 2007). It has been hypothesized that joint activation of similar-sounding translation equivalents enhances activation of phonological representations across languages. Amengual (2012) examined voice onset times (VOTs) of cognates and non-cognates produced by Spanish-English bilinguals. The results suggest that bilinguals produced longer (more English-like) VOTs on Spanish voiceless stops when producing cognates (e.g., English/Spanish *tumor*). In the presence of cognates, bilinguals may thus be more likely to experience activation of the non-target language. In an eye tracking study, English-German bilinguals' looks to pictures representing cognate targets and cross-linguistic competitors suggested that cognates increased phonological co-activation of a less proficient non-target L2 during auditory word comprehension (Blumenfeld & Marian, 2007). It is possible that activation of cross-linguistic phonotactic constraints may become enhanced when phonological representations of the other language are co-activated. Including cognates in the current study provides a condition in which phonological co-activation of languages is most likely to occur.

The large body of research on parallel language activation in bilinguals, including phonological co-activation, has been captured by current models of bilingual language comprehension and production (e.g., Dijkstra & van Heuven, 2002; Shook & Marian, 2013). While current models of bilingual language *comprehension* do not specifically account for phonotactic constraints, one model of bilingual language *production*, the WEAVER++ model, does indeed propose that bilinguals access non-target language phonology (Roelofs & Verhoef, 2006). During bilingual production, activation of non-target language phonotactic constraints is thought to occur between encoding of the phonological word form for production and its phonetic realization. WEAVER++ posits that non-target language phonological representations and/or phonotactic constraints may intrude during encoding of words for production, and may combine with the phonological representations or phonotactic constraints of the target language to affect phonetic realization (e.g., applying the Spanish epenthetic /e/ to an English s+consonant cluster, *estudy*).

In summary, while current experimental and theoretical work on bilingual language comprehension suggests that bilinguals co-activate phonological representations of the non-target language, it remains unclear whether they access cross-linguistic phonotactic constraints during language comprehension. The current study has the potential to expand upon the existing knowledge base for the types of cross-linguistic phonological interactions that occur during bilingual language comprehension.

2.3 Experiment 1: Activation of L1 Phonotactic Constraints in Bilinguals

In the current study, we explore for the first time whether bilinguals co-activate phonotactic constraints from the non-target language during comprehension. Furthermore, while phonotactic constraint activation has been observed empirically during production (e.g., Yavas & Someillan, 2005), we test whether bilinguals also access phonotactic constraints during comprehension. Thus, the current study attempts to provide evidence for the extent to which cross-linguistic structures are accessed during language comprehension in bilinguals.

In order to measure if bilinguals activated phonotactic constraints in the non-target language (Spanish), we employed a cross-modal phonological priming lexical decision (PPLD) task. We used cognates and non-cognates to index availability of phonotactic constraints in different contexts of cross-linguistic phonological activation (e.g., Blumenfeld & Marian, 2007; van Hell & Dijkstra, 2002). For example, when Spanish-English bilinguals hear the cognate *stable* unfold through the acoustic stream, they may initially activate phonological cohorts from both languages (e.g., *stand, stain*, *sink/sárten*, e.g., Blumenfeld & Marian, 2007; 2013) and the Spanish translation equivalent (i.e., *estable*) (e.g., Linck, Kroll, & Sunderman, 2009). Critically, when hearing '*stable*,' they may also activate phonological cohorts that overlap with Spanish through phonotactic constraints and phonological form (e.g., *estándar*/standard) and potentially even cohorts that overlap with Spanish through phonotactic constraints only (e.g., *edad*/age). As an alternative to activation of phonological and phonotactic cohorts upon hearing 'stable' in English, native Spanish speakers may perceptually repair 'stable' to "e-stable," ([/esteɪbəl/]) and therefore may not hear 'stable' (Hallé et al., 2008). Whether bilinguals access neighbors containing phonotactic constraints through spreading activation and mediated priming (English ‘stable’ activates Spanish “e” onset words) or repair the auditory input to have the epenthesis onset, both scenarios suggest that bilinguals may access the phonotactic constraint of “e” onsets from their L1 and apply it during L2 processing.

Here, we examine both phonotactic-constraint-*and*-form access as well as phonotactic-constraint-*only* access across English and Spanish in order to dissociate constraint from form overlap (e.g., *edad* and *estándar,* respectively, see Figure 8). We will henceforth refer to the phonotactic-constraint-*and*-form manipulation as the PCF condition, and to the phonotactic-constraint-*only* manipulation as the PC condition. We focused on the Spanish epenthesis constraint (/e/ onset, e.g., English ‘*estudy*’) because it is a commonly observed phenomenon that occurs in production with native Spanish speakers speaking English, and thus presents a good starting point in exploring a phonotactic constraint during comprehension. The Spanish epenthesis constraint is particularly suitable to the current experimental manipulation because of its potential to be primed with English words that violate the Spanish phonotactic constraint.

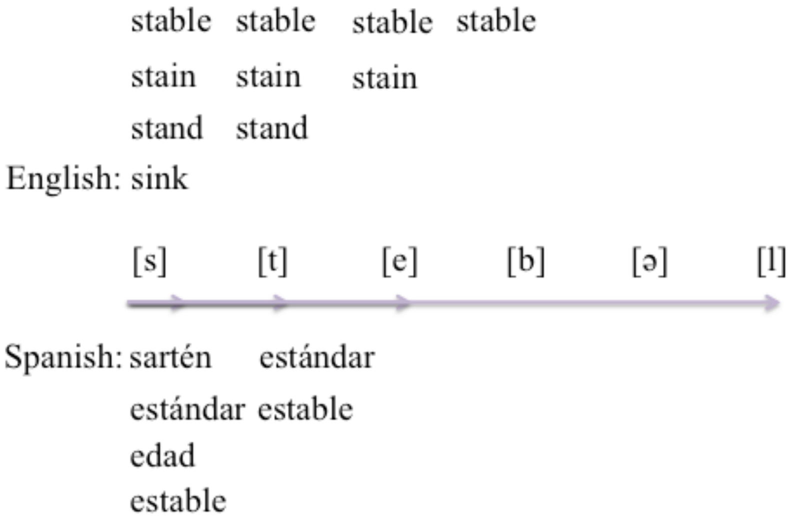

Figure 8: Example of competitor activation with an English-Spanish cognate (*stable*) for bilinguals. As the word unfolds through time, bilinguals may access multiple phonological cohorts across languages until the acoustic stream matches the target word representation. In the present study, words like *stable* will serve as auditory primes. Words such as *especie* represent phonological-form as well as phonotactic-constraint overlap between English and Spanish, while words such as *edad* represent phonotactic-constraint-only overlap between English and Spanish.

We hypothesized that Spanish-English bilinguals would access Spanish (L1) phonotactic constraints during English (L2) comprehension. The goal was to examine the presence or absence of non-target language phonotactic constraint activation when phonological and lexico-semantic (cognate) or no (non-cognate) overlap was present between auditory primes and their translation equivalents. Moreover, we predicted that when bilinguals were primed with an /st/ or /sp/ word, they would access shared phonological (e.g., ‘strong’/*stand/estándar*), lexical (e.g., ‘strong’/*fuerte*), and potentially phonotactic constraint (e.g., ‘strong’/*edad*) neighbors across languages. Presentation of visual /est/, /esp/, or /e/ non-word targets (e.g., *esteriors*) would then limit cross-linguistic activation to strictly phonological forms (/es/ onset) and/or phonotactic constraints (/e/ onset) that had been previously activated by the prime (e.g., Dijkstra & van

Heuven, 2002; Shook & Marian, 2013). Restricted activation of phonological representations (/e/ and /es/ onsets) across primes and targets would in turn facilitate lexical selection, and thus yield faster reaction times when making a lexical decision. Given that the phonology of critical targets (e.g., *esteriors*) was expected to activate partial phonological form and phonotactic constraints of Spanish, but no specific Spanish lexical items, we predicted that there would be no lexical interference from Spanish. These predictions are supported by previous research using a lexical decision task and manipulating the amount of word-initial phoneme overlap across languages (e.g., no-overlap, 1-phoneme overlap, 2 phoneme-overlap and 3-phoneme overlap). When Russian-English bilinguals processed words in the non-native language (English), cross-linguistic phonological overlap of word onsets was associated with faster reaction times as compared to no phonological overlap (Marian, Blumenfeld, & Boukrina, 2008). In the current study, we expected that s+consonant priming would restrict activation to words with /e/ and /es/ onsets. Therefore, Spanish-English bilinguals would be able to quickly search through a constrained space within the lexicon of s+consonant, es+consonant, and e+consonant onset words to make a lexical decision. In contrast, for control non-words that did not conform to the epenthesis constraint, phonological representations would need to be activated for the first time, delaying the subsequent lexical search, and resulting in slower reaction times.

Including the cognate and non-cognate priming conditions, as well as the target conditions with PCF and PC overlap, ensured that bilingual participants would experience local (i.e., intermittent) co-activation of Spanish throughout the task. We predicted that cognates (e.g., *stable* [/steɪbəl/]/*estable* [/estaβle/]) would facilitate activation of Spanish translation equivalents more strongly than non-cognates (e.g., *strong/fuerte*) based on phonological form overlap (e.g., *stable* [/steɪbəl/]/*estable* [/estaβle/]). Following the /sp/ and /st/ primes, PCF non-word targets that overlapped with Spanish /esp/ or /est/ onsets would potentially activate Spanish phonological form in addition to the constraint. The PC targets shared just the Spanish /e/ onset (epenthesis constraint), therefore activating Spanish to a lesser degree. We expected that, if bilingual participants would locally co-activate Spanish, effects on /e/ and /es/ non-word targets would be present only when directly preceded by /sp/ or /st/ primes, but not when preceded by control primes (e.g., workers).

We specifically predicted, across conditions on the PPLD task, that if cognate auditory primes (e.g., *stable*) facilitated non-target language phonotactic constraint and phonological form access, then bilinguals would demonstrate faster reaction times to visual letter strings that contained the previously-activated phonological cohorts (e.g., PCF non-words: *esteriors*), as compared to conditions in which less or no phonological overlap was present (e.g., controls: *stable/hereander* or *workers/hainsail*). In addition, we expected that if the non-cognate auditory primes (e.g., *strong*) facilitated phonotactic constraint access, then the bilingual group would demonstrate faster reaction times to non-word targets with PCF overlap (e.g., *estimagle*), relative to control trials (e.g., *strong/atongside*). However, this facilitation effect was predicted to be less strong than the cognate prime/PCF trials because of the absence of overlap between translation equivalents in the non-cognate prime. If bilinguals routinely activated phonotactic constraints across their two languages, then we would also expect to see similar reaction time facilitation effects for non-word targets that overlapped only with the phonotactic constraint when paired with cognate and non-cognate primes (e.g., /e/-only onset: *stable/elopevent* and *strong/encimpass*, respectively). We expected that this facilitation effect would be less robust in comparison to the PCF overlap condition, since phonological form overlap was not present. We included a control-prime condition, which was not expected to activate Spanish due to either phonotactic constraint or lexico-semantic overlap, as no overt overlap between English and Spanish was present in the control stimuli.

2.4 Materials and Methods

Participants

Participants included 22 Spanish-English bilinguals and 23 English monolinguals, ages 18-33. Monolinguals and bilinguals were recruited via word-of-mouth, e-mails to local student and community organizations, flyers posted around campus and the community, as well as through existing participant databases. This study was carried out in accordance with the recommendations of Northwestern University's Institutional Review Board with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. Any of the monolingual English participants who had a self-reported Spanish speaking proficiency of greater than 3 (1-10 scale) on the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007) did not participate in the experiment. Bilinguals were native Spanish speakers, were exposed to Spanish at least 30% of the time daily, and acquired English at age 5 or later. See Table 1 for additional participant information. Monolinguals and bilinguals differed on English age of acquisition ($p < .001$), current exposure to English ($p < .001$), and foreign accent in English ($p < .01$). Participants were matched on age, non-verbal cognitive reasoning (WASI; PsychCorp, 1999), and working memory (backward digit span; Woodcock, McGrew, & Mather, 2001; 2007).

*Table 1: Linguistic and cognitive background of Spanish-English bilingual (n = 22) and English monolingual (n = 23) participants. **p < .001; *p < .01*

	Bilinguals Mean (SE)	Monolinguals Mean (SE)
Age	24.09 (0.84)	22.95 (0.74)
Age of Spanish acquisition	0.45 (0.12)	--
Age of English acquisition**	6.05 (0.49)	0.18 (0.08)
Current exposure to Spanish	36.77% (6.40)	--
Current exposure to English**	62.50% (6.80)	98.65% (0.69)
Foreign accent in Spanish (1-10 scale)	2.10 (0.44)	--
Foreign accent in English (1-10 scale)*	2.82 (0.56)	0.73 (0.56)
Spanish receptive vocabulary (NIH Toolbox)	116.77 (2.84)	--
English receptive vocabulary (NIH Toolbox)	110.14 (3.55)	118.86 (3.39)
Self-reported Spanish proficiency (1-10 scale)	9.03 (0.14)	--
Self-reported English proficiency (1-10 scale)	8.95 (1.10)	9.83 (0.05)
WASI, matrix reasoning	29.27 (0.53)	28.78 (0.61)
Backward digit span	7.33 (1.20)	10.14 (1.10)

Materials

The English cross-modal Phonological Priming Lexical Decision (PPLD) task was designed to measure cross-linguistic activation of the Spanish phonotactic constraint (the epenthetic /e/) in the presence of phonological and lexico-semantic overlap between languages (cognate auditory primes) or in the absence of phonological overlap between languages (non-cognate auditory primes) through accuracy and reaction time to target identification. The within-subjects independent variables included prime type (cognate, non-cognate, control) and target type (PCF overlap non-word, PC non-word, non-word control, word control). The /st/ and /sp/ consonant clusters were chosen because they are illegal consonant clusters in Spanish without the obligatory epenthetic /e/ at the word onset. In addition, the two consonant clusters are present in a sufficient number of English cognates and non-cognates to generate stimuli for the current study.

The cross-modal PPLD task was programmed in MatLab (Psychtoolbox add-on) (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). The auditory primes were recorded in a soundproof room (44,100 Hz, 16 bits) by a native female speaker of English. The audio recording was split into individual audio files and all files were normalized (via audio compression) in Praat (Boersma and Weenink, 2013) and exported into MatLab (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Each prime type was paired with each target type (3x4), resulting in 12 different pairing combinations and the repetition of each prime four times and each target three times throughout the duration of the experiment. Table 2 depicts examples of stimulus pairings for each prime and target type.

Table 2: Example stimulus pairings and total number of each item type.

Auditory prime	Phon. constraint + phon. form target	Phon. constraint only target	Non-word control target	Word control target
30 Cognates *(stable)*	30 *(esteriors)*	30 *(elopevent)*	30 *(hereander)*	30 *(flattened)*
30 Non-cognates *(strong)*	30 *(estimagle)*	30 *(encimpass)*	30 *(atongside)*	30 *(daughters)*
30 Controls *(workers)*	30 *(esported)*	30 *(ebvision)*	30 *(hainsail)*	30 *(kneeling)*

A total of 360 critical trial pairs were created, comprised of cognate primes (30 items), non-cognate primes (30 items), and control primes (30 items). Each of the auditory primes was paired with a visual target that included non-words that overlapped with Spanish via phonotactic constraint and phonological form (/es/ onset, 30 items), via phonotactic constraint only (/e/ onset, 30 items), non-words that did not overlap with Spanish via phonotactic constraint or form (non-word control, 30 items), or a real word in English that did not overlap with Spanish (word control, 30 items). The PCF (/es/ onset) non-word targets were controlled in such a way that they overlapped cross-linguistically with only the first three letters of the Spanish translation of the cognate prime [e.g., cognate prime *stable* (***est***_able_) was paired with /es/ non-word target (***est***_eriors_)]. Controlling the targets in this manner would avoid any priming effects due to additional phonological and orthographic overlap. The PC non-word targets overlapped with the cognate prime's translation equivalent only at the /e/ onset [e.g., cognate prime *stable* (***e***_stable_) was paired with /e/ non-word target ***e***_lopevent_)]. To a) balance the proportion of word (50%) versus non-word (50%) trials, and b) prevent the participants from noticing any patterns concerning the critical stimulus pairs, 45 auditory prime fillers and 45 visual target fillers (180 total trial pairs) were also generated. Twelve additional pairs were created as practice trials. The experiment was divided into four blocks and the items were pseudo-randomized such that no two consecutive trials contained cognate primes. Consistent with cross-linguistic priming studies employing lexical decision tasks, cognate and non-cognate trials were presented in an intermixed order (Davis et al., 2010; Dijkstra, Miwa, Brummelhuis, Sappelli, & Bayeen, 2010; Duyck, Van Assche, Drieghe, & Hartsuiker, 2007; Siyambalapitiya, Chenery, & Copland, 2009). Finally, trial order was counterbalanced (reversed) across participants.

All stimuli were controlled for various lexical characteristics. The three types of auditory primes did not differ on any of the lexical characteristics listed in Appendix A (all *p*s > .05). The four types of lexical decision targets also did not differ on any of the lexical characteristics (*p*s > .05), with the exception of lexical decision reaction time (LDT RT) and lexical decision z-score (LDT Zscore) in which non-words had slower lexical decision response times than words in the normed sample, *p*s < .05 (Balota et al., 2007). See Appendix B for means and standard deviations. Similar to previous studies (e.g., Martín, Macizo, & Bajo, 2010), we did not control for part of speech (auditory primes) due to the number of lexical characteristics on which the stimuli needed to be matched.

Procedure

Tasks were administered in the following order:

1) the LEAP-Q (Marian, Blumenfeld, & Kaushanskaya, 2007) to obtain linguistic background information and current language exposure, and to ensure that each participant met the criteria for the study;

2) the cross-modal PPLD task (auditory prime, visual target) to examine cross-linguistic phonotactic constraint access;

3) a non-linguistic Stroop task to index competition resolution abilities (adapted from Blumenfeld & Marian, 2014);

4) a backward digit span task (numbers reversed, Woodcock, McGrew, & Mather, 2001; 2007) to index working memory;

5) the Wechsler Abbreviated Scale of Intelligence (WASI; PsychCorp, 1999) to index non-verbal cognitive reasoning; and

6) the NIH Cognition Toolbox Battery (NIH Toolbox CB, 2013) picture vocabulary test, as a measure of English (bilinguals and monolinguals) and Spanish (bilinguals only) proficiency.

Participants were seated in a quiet room with a single iMac computer and were asked to pay attention to the word they heard and then respond by indicating whether what they saw on the screen was a word or non-word in English as quickly and as accurately as possible. After the instructions and 12 practice trials, participants performed the experimental task in which they first heard an auditory prime (cognate, non-cognate, control, filler) and then saw a visual written target (PCF overlap non-word, PC non-word, non-word control, word control, filler) on the screen after a 350ms inter-stimulus interval (ISI). During presentation of the auditory prime through the 350ms ISI, participants viewed a central fixation crosshair on the computer screen. Previous studies using similar priming techniques have shown effects of parallel activation 350-500ms post-stimulus onset (e.g., Blumenfeld & Marian, 2013; Martín, Macizo, & Bajo, 2010). The visual targets were presented in the center of a white screen in black, size 16 font, Courier, and the left/right shift keys represent yes/no responses. Presentation of written words lasted until the participant made a response or for 3,000ms after the onset of the display (see Figure 9/Figure 3).

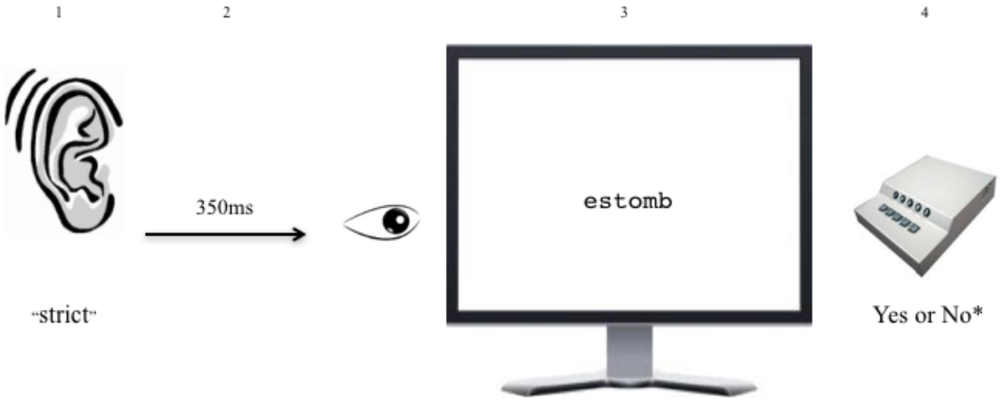

Figure 9: Example trial from cross-modal phonological priming lexical decision task. In this example, participants hear the English-Spanish cognate auditory prime *strict* and 350ms after the offset of the prime, view the phonotactic-constraint-and-form overlap non-word visual target *estomb*, on which they perform a lexical decision (*Yes response = English real word, No response = non-word).

Participants were given three short, but untimed, breaks in between each of the four blocks. The total time to complete this task was approximately 30 minutes. Participants performed the remaining tasks, then were debriefed about the study and compensated. The total study duration was approximately two hours.

Coding and Analysis

For the PPLD task, reaction times and accuracy rates were analyzed. Reaction times were measured from the onset of the visual lexical decision target (PPLD task). Filler trials were not analyzed, as they only served to balance the word/non-word ratio. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time were disregarded for both tasks. Means and standard deviations for each condition (12 critical conditions) were then calculated.

2.5 Results

Overall accuracy effects on the PPLD task. We examined lexical decision accuracy, expecting that decisions on non-words would be less accurate than on real words based on previous research (de Groot, Delmar, & Lupker, 2000). A 3 (auditory prime: cognate, non-cognate, control) x 4 (visual target: PCF overlap non-word, PC non-word, non-word control, word control) x 2 (language group: monolingual, bilingual) repeated measures ANOVA was conducted on the lexical decision targets. There was a main effect of target, $F(3,129) = 4.26$, $p < .01$, $\eta_p^2 = .09$, with Bonferroni-corrected pairwise post-hoc comparisons revealing that participants were more accurate on PCF overlap non-word trials (e.g., *esteriors*) ($M = 96.89\%$, $SE = .47$) than on word control trials (e.g., *flattened*) ($M = 94.87\%$, $SE = .90$), $p = .045$. While we did not anticipate higher accuracy for non-words, we reason that this accuracy effect may have been due to participants using more time to make a decision on non-words than on words, as evidenced by increased reaction times for non-words (see below).

Overall reaction time effects on the PPLD task. We next examined whether monolinguals would be faster overall in their lexical decision response rates than bilinguals, as bilinguals were performing a lexical decision in their L2 (Dijkstra, Grainger, & van Heuven, 1999). Further, we tested whether participants were slower to respond to non-words than words, a pattern demonstrated in previous research (Dijkstra, Grainger, & van Heuven, 1999). There was a main effect of language group, $F(1,43) = 11.70$, $p < .01$, $\eta_p^2 = .21$, indicating that monolinguals ($M = 655$ms, $SE = 46.10$) indeed responded to targets more quickly than bilinguals ($M = 881$ms, $SE = 47.10$), $p < .01$. A main effect of visual target condition was also identified, $F(3,129) = 16.02$, $p < .001$, $\eta_p^2 = .27$, with Bonferroni-corrected pairwise post-hoc comparisons indicating the following patterns: participants were faster to respond to PCF overlap non-word trials (e.g., *esteriors*) ($M = 759$ms, $SE = 31.49$) than to non-word controls (e.g., *hereander*) ($M = 800$ms, *SE*

= 37.11), $p < .001$; faster to respond to PC non-word trials (e.g., *elopevent*) (*M* = 770ms, *SE* = 32.54) than to non-word controls (e.g., *hereander*) (*M* = 800ms, *SE* = 37.11), $p < .01$; faster to respond to word-control trials (e.g., *flattened*) (*M* = 744ms, *SE* = 31.90) than to PC non-word trials (e.g., *elopevent*) (*M* = 770ms, *SE* = 32.54), $p < .05$; and faster to respond to word-control trials (e.g., *flattened*) (*M* = 744ms, *SE* = 31.90) than to non-word-control trials with other word onsets (e.g., *hereander*) (*M* = 800ms, *SE* = 37.11), $p < .001$. Thus, reaction time differences across target conditions confirmed faster overall responses in monolinguals than bilinguals and faster responses to words over non-words. Effects of target condition warranted further follow-up analyses across monolinguals and bilinguals.

Monolingual versus bilingual reaction time performance. Next, related to our prediction of greater cross-linguistic activation effects in bilinguals than monolinguals, we examined whether differences in performance across target conditions would be greater for bilinguals than monolinguals. Indeed, an interaction emerged for reaction times between target type and language group, $F(3,129) = 4.18$, $p < .01$, $\eta_p^2 = .09$. Bonferroni-corrected pairwise comparisons revealed that, relative to monolinguals, bilinguals showed additional reaction time effects across target conditions, with faster reaction times to PCF overlap non-words (*M* = 866ms, *SE* = 59.16) than to non-word control trials (*M* = 928ms, *SE* = 68.28), $p < .01$, and a marginal effect of faster reaction times to PC non-word trials (*M* = 885ms, *SE* = 60.30) than to non-word control trials (*M* = 928ms, *SE* = 68.28), $p = .058$. Monolinguals did not demonstrate such effects, *p*s > .05.

Phonotactic constraint activation between cognate and non-cognate primes and target conditions. Finally, we tested our key prediction following the hypothesis of bilinguals' activation of irrelevant-language phonotactic constraints during comprehension. We conducted planned follow-up t-test comparisons within monolingual and bilingual groups to probe for reaction time effects across prime and target conditions of interest. It was expected that some priming effects would occur for monolinguals, as there was /st/ or /sp/ overlap between the prime and target. Indeed, a significant difference was observed for monolinguals, with faster reaction times to PCF overlap targets (e.g., *estimagle*) preceded by non-cognate primes (e.g., *strong*) (M = 662ms, SE = 27.10) than to non-word controls (e.g., *atongside*) preceded by non-cognate primes (M = 677ms, SE = 32.10), $t(22) = -2.51$, $p = .02$. However, bilinguals demonstrated several significant reaction time differences across prime and target conditions in line with non-target language phonotactic constraint activation. Bilinguals were faster to respond to PCF overlap non-word trials (e.g., *esteriors*) preceded by cognate primes (e.g., *stable*) (M = 848ms, SE = 57.70) than to non-word controls (e.g., *hereander*) preceded by cognate primes (M = 922ms, SE = 66.42), $t(21) = -3.94$, $p = .001$. Bilinguals were also marginally faster to respond to PC non-word trials (e.g., *elopevent*) preceded by cognate primes (M = 883ms, SE = 56.68) than to non-word control trials preceded by cognate primes (M = 922ms, SE = 66.42), $t(21) = -1.83$, p = 0.082. Finally, bilinguals were faster to respond to PCF overlap non-word targets (e.g., *estimagle*) *and* PC non-word targets (e.g., *encimpass*) preceded by non-cognate primes (e.g., *strong*) (M = 876ms, SE = 61.85; M = 881ms, SE = 62.67, respectively) than to non-word controls preceded by non-cognate primes, $t(21) = -4.63$, $p < .001$; $t(21) = -3.56$, $p < .01$, respectively. (See Figure 10A/10B for the bilingual versus monolingual reaction time by condition comparison.)

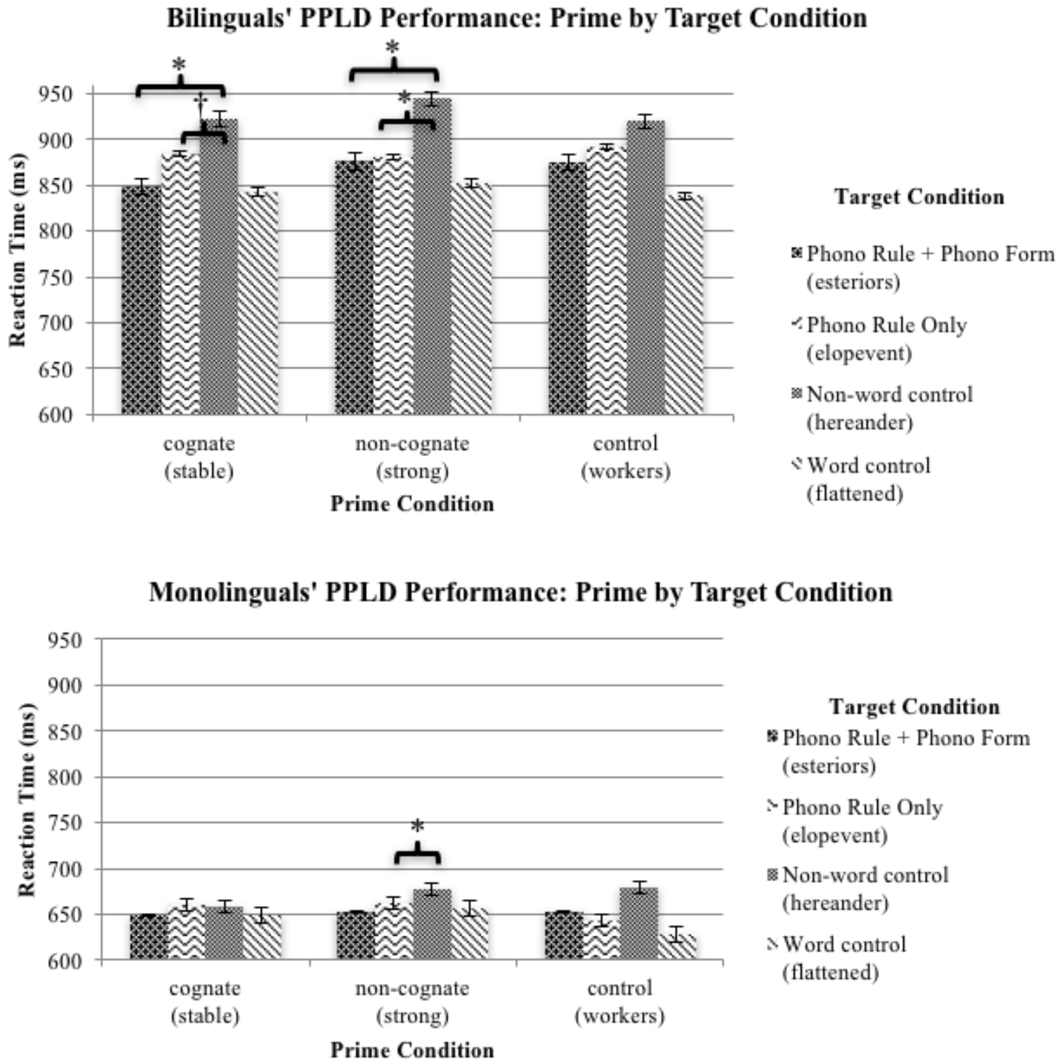

Figure 10A/10B: Reaction times (RT) on the cross-modal PPLD task for bilinguals (10A) and monolinguals (10B) by condition. Error bars = standard error. Differences marked for primary conditions of interest: $*p < .05$, $\dagger p = .082$.

The results within the bilingual group demonstrate significant effects of Spanish phonotactic constraint activation during English comprehension. Bilinguals demonstrated faster reaction times, relative to control conditions, to PCF overlap non-words when primed with cognates, as well as faster reaction times to PCF overlap non-words and PC overlap non-words when primed with non-cognates.

2.6 Discussion

Our goal was to explore whether bilinguals accessed phonotactic constraints from the irrelevant language (Spanish) during English-only receptive language processing. Participants heard English words that were chosen to enhance cross-linguistic phonological activation (cognates: *stable*), that did not provide cross-linguistic phonological activation beyond the shared word onset (non-cognates: *strong*), or that were non-facilitatory of Spanish /es/ or /e/ words (controls: *workers*). Immediately after hearing the auditory prime, participants performed a lexical decision on either (1) an English-like non-word that corresponded to Spanish via phonotactic constraint (epenthesis, /e/) and form (/s/) overlap (/es/ non-words: *esteriors*), (2) PC overlap (/e/ non-words: *elopevent*), (3) on an English-like non-word that did not correspond to Spanish phonotactic constraints or form (non-word controls: *hereander*), (4) or on a real-word control (*flattened*). Both monolinguals' and bilinguals' performance patterns were consistent with co-activation of phonologically-similar representations. That is, both monolinguals and bilinguals showed facilitated responses to constraint-and-form overlap non-words. However, bilinguals displayed patterns of parallel language activation based on phonological form and/or constraint overlap, as demonstrated by significant reaction time differences to PCF overlap non-words when primed by both cognates and non-cognates and PC overlap non-words when primed with non-cognates compared to control conditions. See Table 3 for a summary of results.

Table 3: Summary of results for bilinguals and monolinguals. Conditions of interest compared to the non-word control condition. † = Marginally significant difference, ✓ = Significant difference.

	Cognate prime Phon. constraint + form target: *stable/esteriors*	Cognate prime Phon. constraint only target: *stable/elopevent*	Non-cognate prime Phon. constraint + form target: *strong/estimagle*	Non-cognate prime Phon. constraint only target: *strong/encimpass*
Bilinguals	✓	†	✓	✓
Monolinguals	-	-	✓	-

Non-target language phonotactic constraint access via non-cognates. We aimed to tease apart PCF access in the presence (cognate primes) and absence (non-cognate primes) of previous cross-linguistic activation. With monolinguals, we expected to see a small amount of priming, as there was English phonological overlap between the prime and target conditions of interest. Critically, bilinguals but not monolinguals were found to activate the Spanish epenthesis constraint with PCF and PC overlap non-word targets when primed with English non-cognate words that had s+ phonology onsets. This finding suggests that proficient Spanish-English bilinguals may activate phonotactic constraints from their L1 when listening to English words.

Non-target language phonotactic constraint access via cognates. There were no significant differences across the cognate prime and non-word target conditions for monolinguals. Bilinguals, however, appeared to have accessed the Spanish phonotactic constraint when primed with cognates, but that access was limited to PCF overlap non-word trials; the effect for PC overlap non-word trials was only marginally significant. This finding is consistent with previous results of bilingual parallel language activation in the presence of cognate words (e.g., Blumenfeld & Marian, 2007; Shook & Marian, 2013). Yet contrary to previous findings and expectations (e.g., Blumenfeld & Marian, 2007; Shook & Marian, 2013), cognates were found to facilitate cross-linguistic access to phonotactic constraints to a lesser extent than did non-cognates. The finding that non-cognates independently activated bilinguals' Spanish via phonotactic constraint and phonological form overlap suggests that lexico-semantic activation of the non-target language (via cognate primes) is not needed to facilitate Spanish phonotactic constraints. Instead, phonological form overlap alone (via non-cognate primes) may consistently activate Spanish phonotactic constraints.

Taken together, the current findings suggest that Spanish-English bilinguals may activate a phonological epenthesis constraint in the non-target language (e.g., the constraint of adding an /e/ to the onset of an s+ consonant cluster) during comprehension when primed by *non-cognates*, with smaller but similar effects for *cognates*. This finding is at odds with initial predictions that a phonotactic constraint activation effect would be stronger with cognate primes, as cognate processing yields broader activation of the lexico-semantic and phonological system across both languages (Dijkstra & van Heuven, 2002; Shook & Marian, 2013). However, preliminary conclusions can be drawn from the current findings based on the cognate and non-cognate differences we observed. While it is believed that cognates, compared to non-cognates, increase co-activation of the two languages, bilinguals may need to work harder to protect from cross-linguistic competition resulting from cognates. In the current study, enhanced parallel language activation may result in an increased likelihood of intrusion from non-target language phonotactic constraints. For example, when a bilingual makes a decision on whether a string of letters forms a word, or when s/he produces a word when cross-linguistic competition (i.e., cognates) is present, s/he may emphasize language-specific plans in her response to help resolve competition. Consistently, Nip and Blumenfeld (2015) found that production of cognate sentences was associated with a greater range of speech articulator movements than non-cognate sentences in the L1 of L2 learners. Greater ranges of movement have been associated with more detailed phonological specification (Lindblom, 1990), suggesting more care in the precise articulation of the target language. Thus, across both comprehension and production, the presence of cognates may necessitate muting of phonotactic constraints from the non-target language so that bilinguals can use language-specific plans. With non-cognates, such muting is not necessary, likely due to decreased amounts of cross-linguistic competition. This preliminary conclusion is in line with the prediction that more cognitive resources may be required to inhibit the non-target language during cognate word processing (Green, 1998).

Implications for current accounts of parallel activation. The findings from this study suggest parallel activation of phonotactic constraints across two languages and are thus consistent with previous research demonstrating parallel activation of phonological (Blumenfeld & Marian, 2007; 2013; Marian & Spivey, 2003; Mercier, Pivneva, & Titone, 2014) and lexico-semantic (e.g., Martín, Macizo, & Bajo, 2010) cohorts in bilinguals during auditory and visual word processing. The current study adds to the existing bilingual language comprehension literature an additional level within cross-linguistic phonological access, the phonotactic constraint. As such, this study complements bilingual language production research that suggests bilinguals access phonotactic constraints from the non-target language (e.g., Yavas & Someillan, 2005). Furthermore, these results highlight the additional linguistic competition that bilinguals manage, relative to monolinguals, during language processing: while monolinguals demonstrated minimal interference between the primes and targets across conditions, suggesting activation of phonological representations within-language, bilinguals experienced activation from the non-target language, at the levels of both phonotactic constraint and phonological form competition.

Moreover, using the existing framework from models of bilingual language comprehension, we can extend current explanations of parallel language activation in bilinguals to incorporate the findings of the current project. Two models of bilingual language comprehension, the Bilingual Language Interaction Network for Comprehension of Speech model (BLINCS) (Shook & Marian, 2013) and the Bilingual Interactive Activation + model (BIA+) (Dijkstra & van Heuven, 2002), suggest that bilinguals activate both languages in parallel during single language comprehension. While both of these comprehension models do posit language co-activation based on phonology (e.g., English: *plug*, Spanish competitor: *pluma*, or *pen*), no specific claims are made about phonotactic constraint access of the non-target language.

Within the BLINCS model, bilinguals are thought to access both of their languages across various interconnected levels of processing, including phonological, phono-lexical, ortho-lexical, and semantic representations. The levels rely on a network of self-organizing maps, which provide an algorithm for learning. With activation of cross-linguistic phonological representations during comprehension, as auditory input unfolds through time, the input is first mapped onto the closest node that best matches the target (e.g., language co-activation of translation equivalents, English: *strong*/Spanish: *fuerte*), and the node is altered to become more similar to the input. Based on current findings, we can extend the BLINCS model by suggesting that nearby nodes, which include words that activate words consistent with non-target language phonotactic constraints (e.g., English: *strong*/Spanish: *edad*), might then be adapted to become more similar to the input. The space around the input, containing words following similar phonological patterns, becomes more uniform as the target word is selected. The BLINCS model also has the potential to explain the differences in processing observed across cognate and non-cognate prime conditions and non-target language phonotactic constraint access. It is possible that when bilinguals process cognates, neighboring words following the "e" epenthesis constraint are more quickly activated than when processing non-cognates. Over time, the cognate neighbors are suppressed as the target word is reached for selection. When processing non-cognates that activate the "e" epenthesis constraint, neighbors also become activated, however, target word selection may take longer due to the lack of lexico-semantic overlap. Thus, stronger effects of non-target language phonotactic constraint activation may emerge when processing non-cognates.

Like the BLINCS model, the BIA+ model of bilingual written word recognition (Dijkstra & van Heuven, 2002) supports language non-selectivity (integrated bilingual lexicon) and spreading activation of cross-linguistic phonological neighbors during bilingual language comprehension. The BIA+ model states that when orthographic representations become active, associated within- and between-language phonological representations start to become activated as well. However, the model does not account for how and if phonotactic constraints from the irrelevant language are accessed, which is what was observed in the current study. As non-target language phonotactic constraints become active, so too phonological neighbors may become active that include cohorts of both languages (e.g., English and Spanish). For example, English *strong* may activate an intermediate form where the epenthesis constraint is applied, *estrong,* which may in turn co-activate Spanish words that overlap in phonological form (e.g., *estar*/*edad*, English: to be/age). It is thus possible that phonotactic constraint cohort members from the irrelevant language may be activated during visual word processing in addition to non-target language orthographic, and phonological cohorts. Both the BIA+ and BLINCS models can be minimally extended to provide a theoretical framework to account for parallel activation of phonotactic constraints across languages in bilinguals.

Limitations and future directions. The PCF overlap ("es") non-words used in the current study could have facilitated global activation of Spanish throughout the entire task, as the non-words were Spanish-like in form. However, this was likely not the case since we provided an additional condition in which irrelevant-language phonotactic constraint access was possible, the PC overlap ("e" non-words) condition. Including the two conditions allowed us to dissociate between phonotactic constraint and phonological form overlap with Spanish. Indeed, we found that when primed with non-cognates, bilinguals accessed the "e" onset phonotactic constraint when making a lexical decision on the PC overlap targets. This effect was also marginally significant with cognate primes. Therefore, we can rule out that Spanish was activated only in the PCF condition, based on the evidence from the PC overlap condition. Relatedly, the finding that effects on "e" and "es" non-word targets were present only when directly preceded by an "sp" and "st" prime (and not control primes) suggests that there was no global activation of "e" and "es" phonology across the entire task. Finally, bilinguals, but not monolinguals, showed a significant effect for the PC condition when primed with non-cognates.

Future research is needed to further explore the possibility that Spanish-English bilinguals perceptually repair L2 auditory input (i.e., primes such as stable) to have an "e" onset, as has been shown on a Spanish-language task in Spanish monolinguals (Hallé et al., 2008). If bilinguals experienced a perceptual illusion of repairing the auditory prime to "e-stable" ([/esteɪbəl/]), this would also be suggestive of access to the phonotactic epenthesis constraint in the L1. While perceptual repair remains an alternative explanation to the current results, this alternative explanation is also consistent with the hypothesis of cross-linguistic activation. Thus, while the present study provides evidence that bilinguals access phonotactic rules from the non-target language during comprehension, whether the underlying mechanism(s) is constraint activation or perceptual repair remains an open question.

The contrast identified here between non-cognate and cognate words suggests that language selection mechanisms during phonotactic constraint competition also warrant further examination. For example, research might identify the time course of non-target language phonotactic constraint access (i.e., duration of L1 interference in an L2 context) during language comprehension, which will shed light on mechanisms involved with activation and suppression of non-target language phonotactic constraints. In addition, our findings showed effects of non-target language phonotactic constraint access with /es/ or /e/ onset non-word targets, not across actual English and Spanish words. We believe our results have clear implications for theoretical models of bilingual language comprehension, though stronger evidence for cross-linguistic activation of phonotactic constraints would be provided by a replication study using actual English and Spanish word targets. Moreover, varying the age of acquisition of the L2 (e.g., earlier than 5) will elucidate whether simultaneous versus sequential bilinguals experience phonotactic constraint access to a similar degree.

Finally, future studies may test different sets of language-specific phonotactic constraints to examine whether such constraints are generally accessible across languages. For example, Spanish does not permit consonant clusters at the end of words, and oftentimes native Spanish speakers reduce final consonant clusters when speaking English (e.g., *soun* for *sound*). As is the case in cross-linguistic co-activation of phonological representations (e.g., Blumenfeld &

Marian, 2007; 2013; Marian & Spivey, 2003), it is possible that phonotactic constraints are especially likely to become co-activated across languages when they are specific to the dominant language. Furthermore, such constraints may become active cross-linguistically in contexts where the less dominant language violates a phonotactic constraint in the native language.

2.7 Conclusion

To conclude, results from the current study demonstrate that Spanish-English bilinguals access Spanish phonotactic constraints during English *comprehension*. Moreover, bilinguals' access to structures across both languages during spoken word comprehension is not limited specifically to phonology, but also applies to phonotactic constraints. Finally, the degree of phonological and semantic overlap across languages, as manipulated in cognate vs. non-cognate words, may modulate the extent to which cross-linguistic constraints are available, thus providing further support that the bilingual language system is highly interactive and dynamic.

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CHAPTER 3

BILINGUALS' SECOND LANGUAGE SPEECH PERCEPTION IS INFLUENCED BY NATIVE-LANGUAGE RULES.

3.1 Abstract

We examined speech perception in bilinguals. When monolinguals listen to non-words that conflict with rules for combining speech sounds (i.e., phonotactic constraints), they repair, or alter the input to conform to the correct representation in their language. Bilinguals also perceptually repair *native-sounding* non-words that conflict with the rules of their mother tongue. The current studies examine the extent to which *second-language* sounds are perceived according to native-language constraints. The present investigation relied on the Spanish phonotactic constraint that vowels must precede s+consonant clusters (e.g., Spanish: *e̲stricto* (“strict”)). Experiment 2a used an explicit measure of vowel perception, vowel detection, in which English monolinguals and Spanish-English bilinguals were asked whether they heard a vowel at the onset of English stimuli that conflicted with the Spanish vowel-onset constraint (e.g., *strict*). Experiment 2b employed an implicit measure of vowel perception, AX discrimination, in which participants heard two consecutive words (e.g., *strict*, *egg*) on which same/different judgments were made. Response time results demonstrated that bilinguals perceived hearing an ‘e’ onset when it was not present in s+consonant words, as indicated by differences in reaction times to Spanish-conflicting words relative to control words. However, the illusory effect was only observed on the vowel detection task, suggesting that perceptual repair was modulated by the task’s metalinguistic demands (i.e., knowledge of a vowel, paying attention to onset). Bilinguals therefore repaired L2 lexical input to conform to L1 rules in an explicit measure of vowel perception, suggesting parallel processing in perception at the sub-

lexical level. These findings are consistent with previous research on language co-activation, whereby bilinguals also co-perceive their languages during comprehension.

3.2 Introduction

When hearing non-native sounds, listeners may alter the input they hear to be similar to the native language (L1), a process known as perceptual repair (Carlson, Goldrick, Blasingame, & Fink, 2016; Dupoux, Parlato, Frota, Hirose, & Peperkamp, 2011; Hallé, Dominguez, Segui, & Cuetos, 2008; Weber & Cutler, 2006). Perceptual repair is especially apparent when the sound sequence is not present in the L1. For example, English permits s+consonant cluster (s+c) word onsets, as in *strict,* as well as vowel+s+c (v+s+c) word onsets, as in *estimate*. However, Spanish requires the insertion of a segment, a vowel at the beginning of all s+cs, as in *estricto*, a process known as prothesis. Prothesis of the s+c is a Spanish phonotactic constraint, or rule for combining speech sounds. L1 Spanish speakers encounter conflict when producing and listening to English words such as *strict*, as the syllable structure for s+c onset words does not exist in Spanish. Therefore, the question arises, how do bilinguals perceive second-language (L2) words that conflict with L1 phonotactic constraints?

Perceptual repair in monolinguals and bilinguals. Previous investigations have identified that perceptual repair occurs on-line when monolinguals process non-native sound sequences. Dupoux, Hirose, Kakehi, Pallier, and Mehler (1999) presented Japanese speakers with VCCV non-words (e.g., *ebzo*) and VCVC non-words (e.g., *ebuzo*) in an ABX discrimination task. The VCVC non-words conformed to Japanese phonotactics, while the VCCV non-words did not. Findings revealed that Japanese speakers had difficulty distinguishing between *ebzo* and *ebuzo*, suggesting that *ebzo* was perceptually repaired to *ebuzo* using epenthesis (addition of a vowel). Similarly, Hallé, Dominguez, Segui, and Cuetos (2008) presented Spanish speakers with written

Spanish-like non-words that conflicted with Spanish phonotactic constraints, such as *special* (/spesjal/, "especial*"*) in a visual-masked priming lexical decision task and found that participants *perceived* the prothetic 'e' when it was not present. The participants in Hallé et al. were living in a country in which the L1 was the official language and were likely monolingual. While perceptual repair occurs with monolinguals, how does knowing a second language affect perceptual repair? Carlson, Goldrick, Blasingame, and Fink (2016) tested native Spanish speakers of English on vowel detection and AX discrimination tasks using Spanish-like s+c non-word stimuli (e.g., *spid*). Findings suggest that Spanish-English bilinguals, who were dominant in Spanish, perceptually repaired the s+c non-words to have a vowel at the onset, favoring 'e'. In addition, perceptual repair was weaker for the Spanish-dominant bilinguals, relative to Spanish monolinguals that were tested on a similar vowel detection task in Cuetos, Hallé, Domínguez, and Segui (2011). The repair effect was almost nonexistent for the English-dominant bilinguals. The results from Carlson et al. suggest that knowledge of English, or a language in which the constraint does not exist, modulates the extent to which bilinguals perceptually repair L1-like conflicting sounds to conform to the L1. In this case, dominance or knowledge of English weakened bilinguals' Spanish perceptual repair.

Aside from language dominance, metalinguistic demands induced by a task, as well as age of L2 acquisition, modulate the presence of perceptual repair in bilinguals. Parlato-Oliveira, Christophe, Hirose, and Dupoux (2010) tested early and late Japanese-Portuguese bilinguals across explicit (vowel detection) and implicit (forced-choice recall) measures of perceptual repair, exploiting the Japanese and Portuguese phonotactic VCVC constraint. Both participant groups demonstrated some evidence of Japanese vowel perceptual repair in vowel detection, but this effect was absent in the forced-choice recall task. In the recall task, participants were not directly cued into the presence of a vowel as they were in the vowel detection task. Moreover, perceptual repair to the Japanese (L1) or Portuguese (L2) vowel epenthesis depended on age of acquisition. Early Japanese-Portuguese bilinguals resolved the conflicting input to be Portuguese-like (e.g., *ebina*), while late Japanese-Portuguese bilinguals resolved the input to be L1- (Japanese) like (e.g., *ebuna*). Thus, the metalinguistic demands of the task and age of acquisition modulated the extent to which perceptual repair occurred.

Perceptual repair during L2 processing. With respect to the Spanish prosthesis (v+s+c) constraint, weakened L1 perceptual repair due to knowledge of an L2 (English) that does *not* contain the L1 phonotactic constraint might suggest that bilinguals do not apply L1 phonotactic constraints when immersed in an L2 environment. However, L1 Spanish speakers often add a vowel to the onset of English s+c words, as in *e̲strict* when speaking (Yavas & Someillan, 2005), which is known as prothesis. During comprehension, is it likely that L1 Spanish speakers also *hear* the vowel onset in English s+c words? If perceptual repair of English s+c onsets occurs during spoken word comprehension, then L1 Spanish speakers would perceive *strict* as *e̲strict*. The prediction that L1 Spanish speakers align non-native or L2 auditory input to conform to L1 rules fits within the Perceptual Assimilation Model (Best, 1994). The model states that infants build an auditory template for speech input they receive that becomes a paired association, or rule. Phonotactic constraints are thus learned early on in language development. Best further describes an ecological approach to speech development. An infant learns L1 phonology based on environmental cues from speakers around him/her. There is a strong perception-production link since the infant must recognize the same L1 sounds and words across various productions and different speakers. The infant then approximates (produces) these sounds and words. The model supports that perceptual repair occurs with speech input that does not align with L1 rules.

The input is assimilated to the closest phoneme category, or the category that shares the greatest similarity within the L1. Therefore, when perceiving non-native speech sounds, bilinguals likely assimilate these sounds into L1 categories. Furthermore, empirical evidence supports this assimilation, with bilinguals repairing syllable sequences to conform to L1 phonotactics (e.g., Dupoux, Hirose, Kakehi, Pallier, & Mehler, 1999). Relevant to the current study, Spanish-English bilinguals might repair the L2 (English) s+c onset word with a prothesis (vowel onset; e+s+c). This perceptual repair reflects processing L2 input with an L1 (Spanish) e+s+c filter.

Empirical evidence indeed suggests that bilinguals process L2-specific speech sounds using an L1 filter (Lentz & Kager, 2015; Weber & Cutler, 2006). Weber and Cutler (2006) gave L1 German speakers of English, as well as English monolinguals, English nonsense sequences in which participants detected when they heard an English word. Some of the syllable boundaries within the sequences, however, conformed to L1 German phonotactics and other boundaries conformed to L2 English phonotactics. While German-English bilinguals and English monolinguals were almost equally sensitive to English boundaries following English constraints, only German-English bilinguals were sensitive to the English boundaries that conformed to German constraints. The results suggest that bilinguals were able to learn and become sensitive to L2 phonotactics, however, they were still influenced by L1 phonotactic constraints during L2 processing. During foreign language or L2 listening, intrusion from the L1 can interfere with how the sounds are perceived. If a mismatch exists between L1 and L2 phonotactic constraints, the L1 may influence bilinguals' representation of an L2 sound or sound sequence (Best, 1994; Strange, 1999, Weber & Cutler, 2006). L1 perceptual influence may be so pervasive that even L1 vocabulary may be accessed during L2 word recognition (Spivey & Marian, 1999; Weber & Cutler, 2006). While Weber and Cutler used nonsense sequences, the current study additionally employed single words to examine real-world generalizability, and to investigate the extent to which stimulus lexicality affected perceptual repair. Moreover, the testing environment was strictly in the bilinguals’ L2, whereas in Weber and Cutler, the word detection task contained sequences conforming to L1 and L2 phonotactics. Maintaining an L2-only testing environment with bilinguals ensures that any perceptual effects observed in the present study are due to L1 perception and not induced by tasks or stimuli that contain L1 items.

Further evidence for influence of L1 phonotactic constraints during L2 processing comes from Lentz and Kager (2015). Dutch monolinguals, L1 Japanese speakers of Dutch, and L1 Spanish speakers of Dutch performed a cross-modal lexical decision task, similar to Freeman, Blumenfeld, and Marian (2016, Chapter 2). Participants were first presented with auditory v+s+c primes that were legal across Dutch, Japanese, and Spanish. After the auditory primes, visual s+c targets were presented, which were legal in Dutch but illegal in Japanese and Spanish, on which participants performed a lexical decision. Results suggest that the native-Spanish group perceived the illicit s+c to have a vowel (‘e’) onset, as their response times were faster when primed with the prothesis clusters. These findings demonstrate that the native-Spanish group used an L1 filter when processing L2 sounds, suggesting parallel processing of the L1 during L2 comprehension. In Weber and Cutler, as well as Lentz and Kager, implicit measures of vowel perception were used. In the current study, as in Carlson et al. (2016), we employed implicit and explicit measures of perception.

Parallel processing in bilinguals. The literature on parallel processing in bilinguals supports that the L1 may be accessed, or activated in an L2 context. Work by Marian and colleagues has demonstrated that words which contain phonological overlap *between* languages are activated in the visual world paradigm. For example, in Marian and Spivey (2003b), Russian-

English bilinguals viewed four pictures on a visual display. Two of the pictures overlapped phonologically across Russian and English (e.g., a picture of a *marker* and a *stamp* (Russian: “marka”)), while two filler items contained no phonological overlap with the target and competitor. The bilinguals fixated more on the target *marker* and between-language phonological competitor *stamp* than the filler items, suggesting that the L1 (Russian) was activated during L2 (English) processing. In addition to phonological neighbors, bilinguals also activate L1 phonotactic constraints during L2 processing. Freeman, Blumenfeld, and Marian (2016, Chapter 2) tested Spanish-English bilinguals and English monolinguals on a cross-modal lexical decision task. Participants were primed with English auditory input that conflicted with L1 phonotactics (e.g., *stable*) and then made a visual lexical decision on English-like non-words that conformed to the Spanish v+s+c phonotactic constraint (e.g., *esteriors*). Results suggested that bilinguals activated the Spanish phonotactic constraint during English auditory and visual processing, as evidenced by differences in reaction times to experimental (e.g., auditory prime: *stable*/lexical decision target: *esteriors*) versus control pairings (e.g., prime: *workers*/lexical decision target: *hainsail*). Conclusively, evidence demonstrates that bilinguals *activate* L1 phonology and phonotactic constraints during L2 comprehension. The present studies examined if bilinguals *perceived* L1 phonotactics when listening to L2 speech.

The present study. The current investigation builds upon previous research testing the extent to which perceptual repair occurs during speech perception. As a follow-up to Carlson et al. (2016), Freeman et al. (2016; Chapter 2), Lentz and Kager (2015), and Weber and Cutler (2006), we examined whether bilinguals used L1 perceptual repair during L2 comprehension. Therefore, across two tasks which differed in metalinguistic demands, our objective was to determine whether bilinguals *perceived* L1 phonotactics when hearing L2 sound sequences.

Understanding whether L1 perception occurs during L2 processing would provide insight into the extent to which cross-linguistic influences impact bilingual speech and language processing. Specifically, if bilinguals perceive Spanish when listening to English, existing evidence and theory on maintaining multiple languages can be extended by providing insight into the structure of the acoustic space within bilinguals. Previous evidence demonstrates that bilinguals perceptually repair L2 syllable sequences that are illegal in the L1 to conform to the L1 (e.g., Weber & Cutler, 2006). Therefore, the hypothesis is that Spanish-English bilinguals rely on perceptual repair to perceive English and English-like sounds as Spanish-like, assimilating L2 sound sequences to L1 phonotactic constraints. This hypothesis stems from previous work examining perception of s+c in Spanish-English bilinguals in a Spanish context (Carlson et al., 2016), while a novel contribution is provided here by investigating Spanish (L1) perception within during English (L2) comprehension.

We tested our hypothesis across two tasks. First (Experiment 2a, vowel detection), participants were explicitly asked if they perceived a vowel at the onset of English s+c words (e.g., *strict*) and English-like s+c non-words (e.g., *spelg*). The s+c words and non-words were expected to be perceived according to Spanish rules. As such, participants may have “false alarmed” or experienced a perceptual illusion during these trials, perceiving a vowel, ‘e’, at the word onset, when it was not present. The use of non-words and words in the same experiment was an additional novel contribution, as previous studies have only used non-words to examine phonotactic-constraint perception (e.g., Carlson et al., 2016; Cuetos et al., 2011; Weber & Cutler, 2006). Since words exist within the lexicon, it was likely that participants recruited top-down lexical information as opposed to only top-down phonotactic information associated with non-words. The use of words and non-words thus allowed for the examination of whether perceptual repair was modulated by lexicality of the stimuli. Second (Experiment 2b, vowel discrimination), implicit perception of English sounds that conflicted with Spanish phonotactic constraints was examined. Participants were asked to decide whether two consecutive words they heard were the same or different. This discrimination task tapped into low-level perceptual processes as only same/different judgments were made. The task demands were lower in comparison to, for example, a vowel detection task, which required explicit knowledge of a vowel. The use of two tasks that differ in metalinguistic demands would test the extent to which metalinguistic awareness modulates any potential perceptual repair effect.

3.3 Experiment 2a: Perception of L1 Phonotactic Constraints in Bilinguals: Vowel Detection

In Experiment 2a, we examined whether bilinguals perceived a non-native speech sequence in line with L1 rules, specifically the English s+c onset in a vowel detection task. Previous studies have used the task as an index of perceptual repair of illegal sound sequences (e.g., Carlson et al., 2016; Cuetos et al., 2011). Participants listened to English words and English-like non-words that either conflicted with the Spanish v+s+c constraint (e.g., *strict*) or that did not conflict with the constraint (e.g., control: *issue*) and were asked to indicate if they heard a vowel sound at the onset of the stimulus. Unlike Carlson et al. and Cuetos et al., Experiment 2a did not use a gating technique (e.g., degraded ‘e’ onset in *strict*) in order to avoid any further possibility of perceiving the L1. It was important to maintain a strictly-English testing environment to make claims about L1 perception during L2 processing. English words and English-like non-words that conflicted with the Spanish v+s+c constraint were included to examine whether lexicality of the stimuli affected perceptual repair. If bilinguals perceived the Spanish vowel during English auditory comprehension, then they would respond more slowly to and be less accurate with Spanish-conflicting stimuli (words and non-words) relative to control stimuli (words and non-words). This prediction is based on previous evidence that L1 Spanish speakers of English respond more slowly (Carlson, 2018) and less accurately (Carlson et al., 2016) to Spanish-conflicting stimuli than to controls. Furthermore, if differential effects are found for Spanish-conflicting words relative to non-words, this would suggest that stimulus lexicality could modulate perceptual repair. Moreover, if the task's metalinguistic demands modulate perceptual repair effects, then differences in perceptual repair may arise across vowel detection and AX discrimination.

3.4 Experiment 2a Methods

Participants

Participants were healthy adults from Evanston and northern Chicago, Illinois, as well as San Diego, California, aged 18-35. Monolinguals and bilinguals were recruited through word-of-mouth, existing participant databases, contact with local student and community organizations, and flyers posted around university campuses. A total of 25 English monolinguals (5 males) and 26 Spanish-English bilinguals (9 males) were tested. All participants had normal or corrected-to-normal vision and no history of a neurological impairment. Bilinguals were native Spanish speakers. English monolinguals who reported Spanish speaking proficiency of greater than 3 (1-10 scale) or another foreign language speaking proficiency of greater than 4 on the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007) were not tested. Bilinguals' daily exposure to Spanish was around 30%. Bilinguals acquired English upon entering primary school (around age 5). See Table 4 for additional participant information. Monolinguals and bilinguals differed on English age of acquisition ($p < .001$), current English exposure ($p < .001$), foreign accent in English ($p < .01$), and self-reported English proficiency ($p < .001$). Monolinguals and bilinguals were matched on age, non-verbal cognitive reasoning (WASI; PsychCorp, 1999), and working memory (backward digit span; Woodcock, McGrew, & Mather, 2001; 2007). The Language Experience and Proficiency Questionnaire (LEAP-Q, Marian et al., 2007) served as an index of history and dominance for the monolinguals and bilinguals. See Table 4 for participant information.

Table 4: Linguistic and cognitive background of Spanish-English bilingual (n = 26) and English monolingual (n = 25) participants.

	Bilinguals Mean (SE)	Monolinguals Mean (SE)	P-value
Age	22.42 (0.84)	22.08 (0.34)	0.78
Age of Spanish acquisition	0	--	--
Age of English acquisition**	5.42 (0.54)	0	< 0.01
Current exposure to Spanish	34.88% (4.10)	--	
Current exposure to English**	60.81% (4.56)	98.65 (0.69)	< 0.01
Foreign accent in Spanish (1-10 scale)	1.69 (0.35)	--	
Foreign accent in English (1-10 scale)	3.15 (0.59)	1.56 (0.64)	0.07
Spanish receptive vocabulary (TVIP)	112.35 (1.79)	--	
English receptive vocabulary (PPVT)	111.23 (3.89)	108.04 (2.44)	0.49
Self-reported Spanish proficiency (1-10 scale)	9.09 (0.71)	--	

Self-reported English proficiency (1-10 scale)**	9.01 (0.11)	9.61 (0.08)	< 0.01
WASI, matrix reasoning	28.50 (0.99)	28.89 (0.61)	0.88
Backward digit span	8.46 (0.95)	11.39 (0.81)	0.11

Materials

The vowel detection task measured perception of the Spanish ‘e’ onset constraint in English words and English-like non-words with s+c onsets. The within-subjects independent variables included onset type (s+c onset, control) and lexical status (word, non-word), and the between-subjects independent variable was language group (monolingual, bilingual). The dependent variables were reaction time and accuracy of vowel detection. The ‘st’ and ‘sp’ consonant clusters were used in Experiment 2a since these are illegal consonant clusters in Spanish without the obligatory prothesis ‘e’ at the word onset. In addition, the two consonant clusters were used in Freeman et al. (2016, Chapter 2), which demonstrated significant effects of parallel processing of L1 phonotactic constraints during L2 processing.

The vowel detection task was programmed in MatLab (Psychtoolbox add-on) (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Button presses to the keyboard allowed for the collection of accuracy and reaction time data. The task was controlled by an iMac 3.3 GHz Intel Core i5 running MatLab 2011a, and the display included a 27-inch monitor with a screen resolution of 5120x2880. The stimuli were recorded in a sound attenuated room (44,100 Hz, 16 bits) by a male native speaker of English. The audio recording was split into individual audio files and all files were normalized (via audio compression) in Praat (Boersma and Weenink, 2013) and exported into MatLab (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997).

Stimuli for Experiment 2a contained two types of words (s+c, control), and were controlled for the following lexical characteristics (*p*s > .05): number of letters in English and in Spanish (translation), English and Spanish (translation) lexical frequency, English and Spanish orthographic neighborhood density (CLEARPOND: Marian, Bartolotti, Chabal, & Shook, 2012). Stimuli also included two types of non-words (s+c, control) which were controlled for the following lexical characteristics (*p*s > .05): number of letters and neighborhood density (CLEARPOND: Marian et al., 2012). See Table 5 for example stimuli and Appendix C for all stimuli and controlled lexical characteristics.

Table 5: Example stimuli for Experiment 2a.

Experiment 2a: Vowel Detection Task	s+consonant word	s+consonant non-word	control word	control non-word
	strict	*spift*	*can*	*nulse*

A total of 192 stimuli were created, consisting of 24 s+c words, 24 s+c non-words, 72 control onset words (24 consonant, 48 vowel onset), and 72 control onset non-words (24 consonant, 48 vowel onset). The ratio of words to non-words was 1:1 The ratio of stimuli with vowel to consonant onsets was 1:1 The experiment was divided into two intermixed blocks and the items were pseudo-randomized such that no more than two consecutive trials contained s+c-onset stimuli. Trial order was counterbalanced across participants by reversing the order of presentation.

Procedure

Participants were administered the following tasks in the order as listed:

1) the LEAP-Q (Marian et al., 2007) to obtain linguistic background information and current language exposure, and to ensure that each participant met the criteria for the study

2) the AX discrimination task to investigate implicit L1 phonotactic constraint perception in an L2 context (see Experiment 2b)

3) the vowel detection task to examine explicit L1 phonotactic constraint perception in an L2 context

4) a lexical decision task to examine lexicality effects of perceptual repair task (See Chapter 5 for results)

4) a non-linguistic Stroop task to index competition resolution abilities (adapted from Freeman, Blumenfeld, & Marian, 2017)

5) the Wechsler Abbreviated Scale of Intelligence (WASI; PsychCorp, 1999) to index non-verbal cognitive reasoning

6) a backward digit span task (numbers reversed, Woodcock, McGrew, & Mather, 2001; 2007) to index working memory

7) the Peabody Picture Vocabulary Test-3 (PPVT-3) (Dunn & Dunn, 1997) for monolinguals and bilinguals, and the Vocabulario en Imágenes Peabody (TVIP) (Dunn, Lugo, & Dunn, 1997) for the bilinguals only

Monolinguals were tested by a male proficient in English. Bilinguals were tested by a male speaker proficient in English and Spanish. Participants were seated in a quiet room in front of an iMac computer and were instructed to pay attention to the beginning sound of the word or non-word they heard. Participants were asked to respond to the stimulus they heard as quickly and as accurately as possible. A ‘yes’ response indicated that the participant detected a vowel at the stimulus onset, while a ‘no’ response signified that a consonant was present at the onset. After the instructions and 12 practice trials, participants performed the experimental task in which they heard a word (s+c onset, control onset) or non-word (s+c onset, control onset). During presentation of the stimulus, participants viewed a central fixation crosshair on the computer screen. Following the stimulus, participants then viewed a prompt on the visual display, asking if a vowel was heard. The crosshair and proceeding prompt were presented in the center of a white screen in black, size 16 font, Courier, and the left/right shift keys represent yes/no responses. Presentation of the prompt lasted until the participant made a response. Accuracy and reaction times to identifying whether or not a vowel was present was measured. See Figure 11 for task procedure.

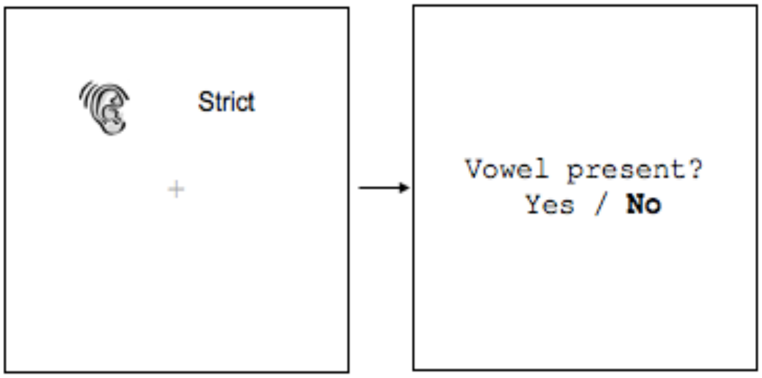

Figure 11: Example trial from vowel detection task. In this example, participants heard *strict* and decided if a vowel was present at the word onset (Yes response = vowel present, No response = no vowel present).

Participants were given one short, but untimed, break halfway through the experiment. The total time to complete this task was approximately 10 minutes. Participants performed the remaining tasks, then were debriefed about the study and compensated. The total study duration (Experiments 2a and 2b, individual difference measures) was approximately two hours.

Coding and Analysis

To examine perception of irrelevant-language phonotactic constraints in the vowel detection task, separate ANOVAs within words and non-words for accuracy and reaction times were used, followed by planned follow-up t-tests. Reaction times were measured from the onset of the auditory stimulus. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time were excluded from the analyses. Means and standard deviations for each of the four conditions were then calculated (s+c word, control word, s+c non-word, control non-word). Reaction time difference scores were also calculated across Spanish-conflicting and control conditions. The difference scores allowed for a fair comparison of reaction times between monolinguals and bilinguals across target and control conditions, as bilinguals are slower and less accurate in tasks involving their L2. Moreover, reaction-time difference scores indexed the amount of interference, or slowing, induced by the s+c illicit onset. Reaction times to control words were subtracted from Spanish-conflicting words. The same calculations were performed for the non-word conditions.

3.5 Experiment 2a Results

Accuracy on the vowel detection task: Words. We examined vowel detection accuracy, expecting that decisions to s+c words and non-words would be overall less accurate within bilinguals if they perceived an ‘e’ onset. A 2 (onset type: s+c, control) x 2 (language group: bilingual, monolingual) repeated-measures ANOVA was conducted on accuracy rates for identifying vowels at the onsets of the stimuli. There were no main effects or significant interactions for words (*p*s > .05).

Accuracy for non-words. Within non-words, there was a main effect of onset type $F(1,49) = 7.145$, $p = .010$, $ŋ_p^2 = .127$, with both participant groups responding more accurately to s+c non-words ($M = 98.22\%$, $SE = .60$) than to control non-words ($M = 95.97\%$, $SE = .56$), $t(50) = 2.632$, $p = .011$. In a followed-up t-test, monolinguals responded more accurately to s+c non-words ($M = 99.33\%$, $SE = .39$) than to control non-words ($M = 95.99\%$, $SE = .79$), $t(24) = 3.489$, $p = .002$. Bilinguals did not show this difference ($p > .05$). Additional follow-up t-tests revealed no significant differences in accuracy rates across Spanish-conflicting words relative to control words for monolinguals and bilinguals (*p*s >.1). The absence of accuracy difference can be explained by the fact that all participants performed at or close to ceiling on the vowel detection task (*M*s > 95%).

Reaction time effects on the vowel detection task: Words[2]. The next step was to examine overall reaction times for bilinguals and monolinguals. A 2 (onset type: s+c, control) x 2 (language group: bilingual, monolingual) repeated-measures ANOVA was conducted for word reaction times on the vowel detection task. The ANOVA revealed a main effect of onset, $F(1,49) = 9.584$, $p = .003$, $ŋ_p^2 = .164$; a main effect of language, $F(1,49) = 13.373$, $p = .001$, $ŋ_p^2 = .214$; and a marginal interaction between onset and language, $F(1,49) = 3.302$, $p = .075$, $ŋ_p^2 = .063$. Participants were slower to respond to s+c words ($M = 1036.26$, $SE = 18.01$) than to control words ($M = 996.08$, $SE = 19.70$), $t(50) = 4.939$, $p < .001$. Bilinguals responded more slowly to s+c words ($M = 1112.86$, $SE = 30.29$) than monolinguals ($M = 959.65$, $SE = 18.86$), $t(49) = -4.524$ $p < .001$, suggesting greater interference to Spanish-conflicting words. Bilinguals also

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[2] Bilinguals responded more slowly to *both* conflicting cognates (M = 1118.89, SE = 31.38) and conflicting non-cognates (M = 1102.67, SE = 33.86) relative to controls (M = 1049.09, SE = 33.95). Neither difference was significant for monolinguals. Importantly, there was no significant difference in bilinguals' responses to cognates or non-cognates (mean difference ~16 ms), suggesting that cognate status did not affect perceptual repair in vowel detection.

responded more slowly to control words ($M = 1049.09$, $SE = 33.95$) than monolinguals ($M = 943.06$, $SE = 19.14$), $t(49) = -4.004$, $p < .001$.

Planned follow-up paired t-tests revealed that bilinguals showed a significant difference in response times to s+c words ($M = 1112.85$, $SE = 30.29$) than to control words ($M = 1049.09$, $SE = 33.95$), $t(25) = 2.712$, $p = .012$. Monolinguals did not show a difference in response times to s+c words ($M = 959.65$, $SE = 18.86$) relative to control words $M = 943.06$, $SE = 19.14$), $t(24) = 1.638$, $p = .114$.

Reaction time effects for non-words. Within non-words, there was a main effect of language only, $F(1,49) = 16.667$, $p < .001$, $\eta_p^2 = .254$. Bilinguals responded more slowly to s+c non-words ($M = 1136.03$, $SE = 35.45$) than monolinguals ($M = 970.22$, $SE = 18.79$), $t(49) = -4.459$ $p < .001$. Bilinguals also responded more slowly to control words ($M = 1130.02$, $SE = 44.61$) than monolinguals ($M = 970.22$, $SE = 18.78$), $t(49) = -3.225$, $p = .002$.

Paired T-tests revealed that bilinguals and monolinguals showed no differences across s+c non-words relative to control non-words. Unlike with words, bilinguals were not significantly slower to respond to s+c non-words ($M = 1136.04$, $SE = 35.45$) than to control non-words ($M = 1130.02$, $SE = 44.62$), $t(25) = .186$, $p = .854$. Monolinguals did not show a significant difference in response times across s+c non-words ($M = 958.61$, $SE = 16.93$) and control non-words ($M = 970.21$, $SE = 18.79$), $t(24) = -1.288$, $p = .210$.

Difference score analyses[3]*:* Difference scores were employed to examine relative amounts of slowing caused by the Spanish-conflicting onset. One-way ANOVAs were employed for response-time difference scores across words and non-words and language groups. One-

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[3] There were no effects of age of acquisition, proficiency, or language dominance.

sample follow-up t-tests were performed on reaction time difference scores across conditions within each group, with the test value set to 0. *Words:* The one-way ANOVA revealed a marginal main effect of language group, *F*(1,49) = 3.864, *p* = .055. One-sample t-tests revealed that bilinguals showed a greater reaction time difference between s+c words and controls (*M* = 63.77, *SE* = 14.64), *t*(25) = 2.712, *p* = .012. Monolinguals did not show such a difference (*M* = 16.59, *SE* = 15.61), *t*(24) = 1.638, *p* = .114. See Figure 12 for bilingual/monolingual differences across word conditions on the vowel detection task.

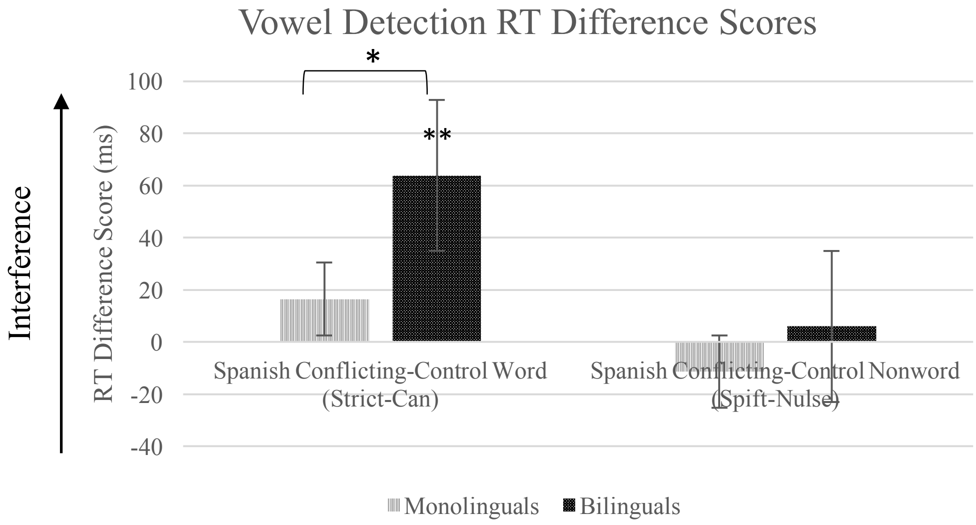

Figure 12: Monolingual and bilingual reaction-time (RT) difference scores across word and non-word conditions on the vowel detection task. Error bars represent standard error. Bilinguals demonstrated marginally greater interference from Spanish-conflicting words than monolinguals, **p* = .055. Within bilinguals, Spanish-conflicting words resulted in increased interference relative to controls, as indicated by a significant RT difference score, ***p* = .012.

Non-words: The one-way ANOVA did not demonstrate a significant language group effect, *F*(1,49) = .921, *p* = .342. Bilinguals did not show a significant difference between s+c and control non-words (*M* = 6.01, *SE* = 29.96), *t*(25) = .186, *p* = .854; nor did monolinguals (*M* = -11.60, *SE* = 13.06), *t*(24) = -1.288, *p* = .210. See Figure 12 for bilingual/monolingual reaction-time difference scores across non-word conditions on the vowel detection task. See Table 6 for bilingual/monolingual differences across word conditions on the vowel detection task.

Table 6: Reaction time difference scores on the vowel detection task for bilinguals and monolinguals. SE = standard error.

	Bilinguals Mean (SE)	*p*	Monolinguals Mean (SE)	*p*
Spanish-conflicting words minus control words	63.77 (14.64)	0.012*	16.59 (15.61)	0.114
Spanish-conflicting non-words minus control non-words	6.01 (29.96)	0.854	-11.60 (13.06)	0.210

Thus, reaction time results revealed that 1) monolinguals responded more quickly overall in the vowel detection task; 2) onset type and lexical status affected participants' responses such that Spanish-conflicting stimuli, specifically words, resulted in slower response times; 3) This effect was driven by bilinguals' slower response times to Spanish-conflicting words relative to control words, suggesting perceptual repair of s+c words.[4]

3.6 Discussion

The results from the vowel detection task partially confirm our hypothesis that bilinguals perceptually repaired English s+c onset words with an 'e' onset (prothesis). Although bilinguals and monolinguals demonstrated similar accuracy rates across all conditions, only bilinguals exhibited significant reaction time differences across Spanish-conflicting words relative to

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[4] See Chapter 5 of this dissertation for a follow-up lexical decision task using the same stimuli from the vowel detection task, which further examined the effect of stimulus lexicality.

control words. Based on previous findings of perceptual repair when processing the L1, we expected to observe more false alarms in bilinguals, erroneously indicating that a vowel was present in s+c (Carlson et al., 2016). The Spanish-dominant bilinguals in Carlson et al. (2016) reported hearing an initial ‘e’ 22% of the time in s+cs and the monolinguals in Cuetos et al. (2011) reported 56%. The bilinguals in the present study heard a vowel in 2-4% of occasions in the Spanish-conflicting stimuli. For Spanish-English bilinguals who are tested in their L2, the representation of an s+c onset is acceptable, which is not the case for bilinguals who are tested in their L1 or for Spanish monolinguals. Since Spanish-dominant bilinguals, relative to English-dominant bilinguals, experience less L2 interference during L1 processing, they were more likely to report an illusory vowel (Carlson et al., 2016). Furthermore, Spanish monolinguals have not been exposed to the s+c sequence in their language, and thus, more frequently reported a vowel onset when it was not present. Given that bilinguals in the current study were tested in their L2 in which s+cs were permissible, reaction times, rather than accuracy, were more sensitive to the observed effects of perceptual repair (Carlson, 2018; see General Discussion for further discussion on the use of reaction times as an indicator of perceptual repair).

Current findings align with previous work on perceptual repair in bilinguals (Carlson, 2018; Carlson et al., 2016; Dupoux et al., 1999; Dupoux, et al., 2011; Lentz & Kager, 2015; Parlato-Oliveira et al., 2010; Weber & Cutler, 2006). However, the present results elucidate the *extent* to which bilinguals perceive the L1 when listening to the L2. Instead of using only L2-like non-words that conflicted with L1 phonotactic constraints, the current study incorporated L2 words and L2-like non-words. Also, we used an explicit measure of perceptual repair by directly asking participants if they heard a vowel at the onset of the word/non-word. In this design, we examined the cross-linguistic influences and interactions that occur during speech perception.

Interestingly, Spanish perceptual repair was observed differentially across s+c-onset English words and non-words. Bilinguals showed greater reaction-time differences than monolinguals to Spanish-conflicting words relative to control words. This latter finding suggests that lexicality of the stimuli modulated perceptual repair; perceptual repair occurred only when the Spanish-conflicting stimulus was a word. More on the dissociation between perceptual effects with words versus non-words is discussed in the General Discussion section (3.10).

The vowel detection task used in Experiment 2a required explicit awareness of 1) a vowel, 2) the initial sound of the word/non-word. This scenario taxed metalinguistic awareness, as the stimulus onset was the explicit focus of the task. As a follow-up, Experiment 2b employed a task that reduced metalinguistic demands, the AX discrimination task. Same/different judgments were made about two words presented consecutively, tapping into lower level perceptual processes. Vowel onsets were not the explicit focus of the task. These tasks differences may result in differential effects of perceptual repair in bilinguals, as observed in Parlato-Oliveira et al. (2010).

3.7 Experiment 2b: Perception of L1 Phonotactic Constraints in Bilinguals: AX Discrimination

Experiment 2b served as the second step in understanding the extent to which bilinguals perceived L1 phonotactic constraints during L2 comprehension. Relative to Experiment 2a, a more implicit task of perceptual repair was used, the AX discrimination task, to gain further insight into perceptual processing. Previous studies have used the AX discrimination task as a measure of perceptual repair of illicit sound sequences (e.g., Carlson, 2018; Carlson et al., 2016; Dupoux, Hirose, Kakehi, Pallier, & Mehler, 1999). Experiment 2b did not tax metalinguistic awareness abilities, as participants were not required to detect the presence of a vowel at the onset of the word. Only word stimuli (s+c onset words, control words) were used in Experiment 2b in the first (A) trial. The same stimuli were used in an immediately-following (X) trial. An additional control condition was included in which the A and X trials contained different words with 'e' onsets. Participants first heard the A trial, then the X trial, and last, decided if the two words they heard were the same or different with a button click on the keyboard. If bilinguals perceived the Spanish v+s+c constraint in an English context, then they would show differences in reaction times and accuracy rates to s+c onset words followed by 'e' onset words, relative to control AX conditions. On the other hand, since the task required less metalinguistic awareness than vowel detection or lexical decision tasks (see Chapter 5), it could also be predicted that perceptual repair would be modulated by the nature of the task (Parlato-Oliveira et al., 2010). Specifically, the extent to which L1 perceptual repair occurred during L2 processing may be limited to tasks where the stimulus onset was the explicit focus of the task, or that require lexical access (lexical decision, See Chapter 5).

3.8 Experiment 2b Materials and Methods

Participants

The same participants were tested in Experiment 2b as in Experiment 2a, and included 25 English monolinguals and 26 Spanish-English bilinguals, aged 18-35, with normal or corrected-to-normal vision.

Materials

The AX discrimination task examined perception of the Spanish 'e' onset in English s+c onset words implicitly. Whereas the vowel detection task in Experiment 2a explicitly asked participants if they heard a vowel at the onset of the word or non-word, the AX discrimination task implicitly measured vowel perception (Carlson, 2018; Carlson et al., 2016; Dupoux et al., 1999; Dupoux et al., 2011). Experiment 2b did not rely on metalinguistic awareness, as knowledge of vowels and needing to detect the presence of a vowel onset were unnecessary. The word stimuli (s+c onset words, control words) from Experiment 2a were used in Experiment 2b in the first (A) word. The same stimulus set was used in an immediately-following (X) word as the A word. An additional control condition was included in which the A and the X trials were mismatched 'e' onset words. The within-subjects independent variables included AX trial type (Spanish-conflicting, control, and second control) and the between-subjects independent variable was language status (monolingual, bilingual), resulting in a 3x2 mixed factorial design. The AX discrimination task included three conditions of interest:

1) Spanish conflicting: s+c word followed by e-onset word (e.g., *strict* → *egg*) (S→E); 2) Control: control onset followed by e-onset (e.g., *work* → *egg*) (C→E);

3) 'E' onset control: e-onset followed by e-onset (e.g., *effort* → *egg*) (E→E).

The dependent variables were reaction time and accuracy to identifying whether the word pair was the same or different.

The AX discrimination task was programmed in MatLab (Psychtoolbox add-on) (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Accuracy and reaction time data were collected with keyboard button presses. Experiment 2b was administered on the same computer as in Experiment 2a, using the same process for recording and splitting the audio files.

Stimuli for Experiment 2b contained only the word stimuli from Experiment 2a, with the addition of an 'e' onset condition. The three types of words (s+c onset, e onset, control word) were controlled for the following lexical characteristics (*p*s > .05): number of letters in English and in Spanish (translation), English and Spanish (translation) lexical frequency, English and Spanish orthographic neighborhood density (CLEARPOND: Marian, Bartolotti, Chabal, &

Shook, 2012). See Table 7 for example stimuli from Experiment 2b and Appendix D for all stimuli and controlled lexical characteristics.

Table 7: Example stimuli for Experiment 2b: AX discrimination.

Experiment 2b: AX Discrimination Task	s+consonant word	e onset word	control word
	strict	*egg*	*work*

A total of 120 stimuli were created, comprising of 24 s+c words, 24 ‘e’ onset words, and 72 control words. Match responses consisted of 44% of trials, while mismatch responses consisted of 56%. The percentage was originally set to 50%, however, an additional control condition (‘e’ onset mismatch) was added. The number of match/mismatch trials was not central to the experiment. Experiment 2b consisted of a total of 228 trials (12 practice, 216 experimental) and the experiment was divided into two blocks. The trials were pseudo-randomized such that no more than two consecutive trials contained s+c onsets. Trial order was counterbalanced across participants by reversing the order of presentation.

Procedure

Participants were seated in a quiet room with a single iMac computer. Participants were instructed to listen to two consecutive English words and then indicate if the two words were the same or different. After the instructions and 12 practice trials, participants performed the experimental task in which they first heard the A stimulus (s+c, e onset, control) followed by the X stimulus (s+c, e onset, control). There was a 250ms inter-stimulus interval between the two words. During presentation of the A stimulus and the X stimulus, participants viewed a central fixation crosshair on the computer screen. Participants were then asked if the two words they heard were the same or different. Presentation of the question about whether the words were the same or different lasted until the participant made a response. The left/right Shift keys represented same/different responses. See Figure 13 for task procedure.

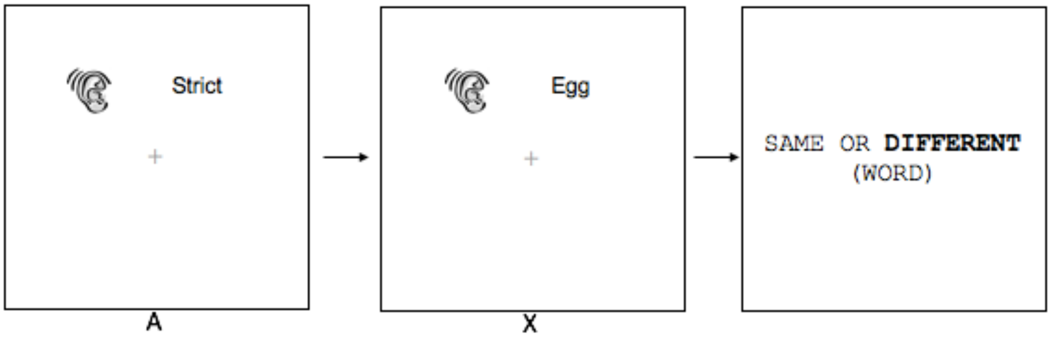

Figure 13: Example trial from the vowel discrimination task. In this example, participants heard *strict* followed by *egg* and had to decide if the two words they heard were the same or different.

Participants were given one short, but untimed, break halfway through the experiment. The total time to complete this task was approximately 12 minutes. Participants performed the remaining tasks, then were debriefed about the study and compensated.

Coding and Analysis

For the AX discrimination task, reaction times and accuracy rates were analyzed. Reaction times were measured from the onset of the visual display in which participants made a response. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time by participant were disregarded. Means and standard deviations for each condition were then calculated and repeated-measures ANOVAs were performed for accuracy and reaction times. Conditions for comparison included, Spanish-conflicting condition: s+c followed by e-onset (e.g., *strict* → *egg*) (S→E), control condition: control followed by e-onset (e.g., *work* → *egg*) (C→E), and 'E' onset control: e-onset followed by e-onset (e.g., *effort* → *egg*) (E→E).

3.9 Experiment 2b Results

Accuracy effects on the AX discrimination task. First, accuracy rates were analyzed. A 3 (condition: S→E, C→E, E→E) x 2 (language group: bilingual, monolingual) repeated measures ANOVA was conducted on accuracy rates for identifying if AX pairs were the same or different. There were no significant main effects or interactions for accuracy, likely because participants performed at ceiling on this task (*Ms* > 98%, *p*s > .30).

Reaction time effects on the AX discrimination task[5]. Next, overall reaction times for bilinguals and monolinguals were analyzed. A 3 (condition: S→E, C→E, E→E) x 2 (language group: bilingual, monolingual) repeated-measures ANOVA revealed only a significant main effect of language, $F(1,44) = 5.004$, $p = .030$, ŋ$_{p}^{2}$ = .102. Bilinguals (*M* = 1084.72, *SE* = 43.57) responded more slowly than monolinguals (*M* = 980.77, *SE* = 21.67) with S→E trials, $t(44) = -2.136$, $p = .038$. Bilinguals (*M* = 1108.29, *SE* = 39.29) were also slower than monolinguals (*M* = 997.71, *SE* = 18.92) with E→E trials, $t(44) = -2.536$, $p = .015$. In addition to the lack of a main effect of condition or interaction between condition and language, planned follow-up paired t-tests between S→E and C→E, and S→E and E→E conditions revealed no significant differences for either monolinguals or bilinguals (*p*s > .05). Overall, these results suggest that there are no low-level effects of perceptual repair in bilinguals, with the only significant main effect being language group. See Figure 14 for monolingual/bilingual differences on the AX discrimination task.

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[5] There were no effects of age of acquisition, dominance, or proficiency on bilinguals' response times (*p*s > .15).

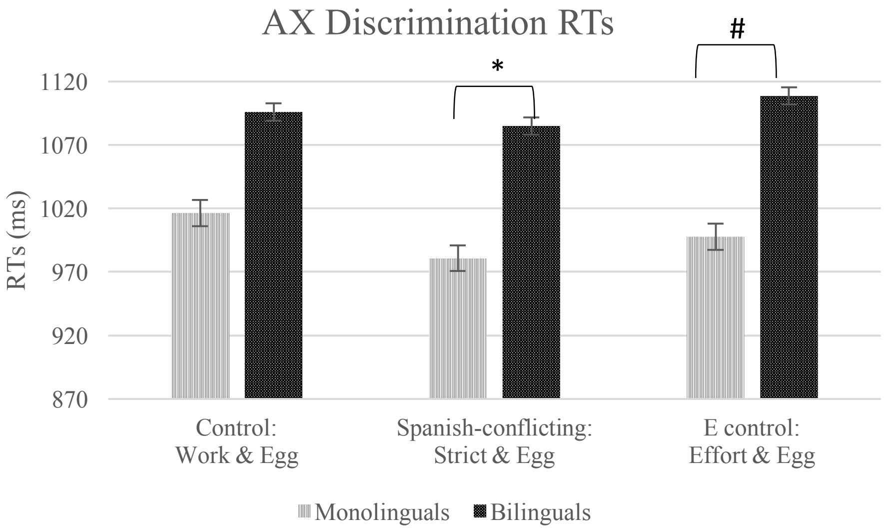

Figure 14: Monolingual/bilingual reaction times (RTs) on the AX discrimination task. Group effects indicated that bilinguals were slower than monolinguals in the Spanish-conflicting and 'E' control conditions, **p* = .038, #*p* = .015, respectively. There were no between-condition differences within bilinguals and monolinguals

3.10 Discussion

The results from AX discrimination contrast with the findings from vowel detection. Specifically, the prediction was that bilinguals would be slower to respond to Spanish-conflicting trials (e.g., *strict* followed by *egg*) relative to control trials (e.g., *work* followed by *egg*). Reaction-time and accuracy rates were similar across all conditions in monolinguals and bilinguals, suggesting that perceptual repair was not present in AX discrimination. A tentative explanation for this pattern of results is found in the low-level perceptual nature of this task. Participants paid attention only to the combination of sounds within the A and X stimuli, without the need to focus on a specific aspect of the stimuli (vowel detection) or to access the lexicon (lexical decision). Inherent to the increased metalinguistic demands of vowel detection and lexical decision may come the need to perceptually repair the L2 input such that it aligns with L1 acoustic categories.

The current results test the extent to which bilinguals apply an L1 filter when processing L2 words. Specifically, we examined perceptual repair of non-native, L2 sound sequences within bilinguals. The findings suggest that when metalinguistic demands are lower in a task (see Parlato-Oliveira et al., 2010 for further discussion), such that same/different judgments are being made on two stimuli, perceptual repair, applying the ‘e’-onset rule, is not present. Generally speaking, in an implicit measure of vowel perception, L1 rules are not applied to L2 sounds that conflict with L1 constraints during L2 processing. Examining L1 perceptual repair during L2 processing further elucidates the extent of cross-linguistic influences, such as parallel processing, that bilinguals experience in daily interactions in everyday environments. These findings also have important implications for the structure of acoustic space within the bilingual mind.

3.11 General Discussion

Summary of findings. We examined the extent to which bilinguals perceptually repaired second language (L2) words to conform to native language (L1) rules. We exploited the L1 Spanish vowel+s+consonant cluster (v+s+c) rule (e.g., *estricto*) by aurally presenting English monolinguals and Spanish-English bilinguals with English words (e.g., *strict*; Experiment 2a, vowel detection; 2b, AX discrimination) and non-words (e.g., *spelg*; Experiment 2a, vowel detection) that conflicted with the Spanish rule. In vowel detection, an explicit measure of vowel perception, Spanish-English bilinguals perceived an illusory ‘e’ onset when listening to L2 words that conflicted with the L1 v+s+c rule. However, perceptual repair was not observed in bilinguals when the vowel onset was not an explicit focus of the task (AX discrimination). The current investigation partially extends previous findings that individuals perceptually repair sound sequences that conflict with their native language (L1) to sound similar to the L1. The results also support the initial hypothesis that bilinguals rely on perceptual repair when listening to L2 sound sequences, exploiting L1 phonotactic constraints to make L2 sounds more L1-like.

In order to obtain a comprehensive account of L1 perceptual repair during L2 processing in bilinguals, we used vowel detection and AX discrimination tasks. Previous studies have used these tasks to index perceptual repair with monolinguals (vowel detection: Cuetos et al., 2011, AX discrimination: Dupoux et al., 1999) and bilinguals (Carlson et al., 2016), but participants were tested in their L1. A key difference between vowel detection and AX discrimination is that in vowel detection, the presence of a vowel onset is the primary focus of the task, which is not the case in AX discrimination. In AX discrimination, participants make lower-level perceptual judgments on whether two stimuli they hear are identical or not. Therefore, perceptual representations may not be accessed to the same extent as they are in vowel detection or lexical decision, and perceptual repair may not occur.

Accounting for differential perceptual outcomes across experiments and previous studies. The current investigation was novel with respect to 1) using real words, and 2) testing L1 perceptual repair during L2 auditory input. In vowel detection, perceptual repair was observed in bilinguals with only Spanish-conflicting words and not non-words. In previous studies (e.g., Carlson et al., 2016), L1 perceptual repair was found with non-words, however, the bilinguals were tested in their L1. In the current dissertation, bilinguals' L1 perceptual repair during L2 processing was influenced by task difficulty and lexicality of the stimulus. When metalinguistic demands were high (i.e., vowel detection), and the stimulus onset is the explicit focus of the task, L2 words are subject to perceptual effects from the L1. This argument is supported by the lack of perceptual repair effects observed on the AX discrimination task, in which metalinguistic demands were lower (see Parlato-Oliveira et al., 2010 for further support of this argument). In addition, vowel detection did not require participants to access the lexicon, but lexical status modulated perceptual repair. A potential explanation as to why there were differential effects for words versus non-words on vowel detection is that with words, bilinguals recruited top-down perceptual knowledge of phonotactic constraints, as well as top-down lexical knowledge. It thus appears that when the onset sound of a stimulus is the explicit focus, a stronger perceptual representation exists for words than with non-words, likely due to differential recruitment of top-down processes. The current results extend previous empirical investigations and theoretical models on speech perception in bilinguals and monolinguals. These findings also shed light on the mechanisms involved during bilingual language processing.

Within the context of the literature on speech perception, the current findings are in line with previous investigations examining perceptual repair effects. Carlson et al. (2016) examined perception of the Spanish v+s+c constraint in Spanish-English bilinguals, however, in their L1 (Spanish). Results suggested that only Spanish-dominant bilinguals were likely to repair illicit s+c sound sequences to have a prothetic ‘e’, in vowel detection and AX discrimination tasks. In both tasks, a gating procedure was used in which the s+c had a degraded ‘e’ onset present, therefore making the sound sequences more L1-like. In the current investigation, gating was not used, as the intention was to uncover the cross-linguistic influences involved during speech perception. We thus aimed to keep the testing environment and stimuli as L2-like as possible. Similarly, Cuetos et al. (2011) used the vowel detection task, but with Spanish monolinguals, and found that Spanish monolinguals perceptually repaired the s+c onset sequences with a prothetic ‘e’. Another difference between Carlson et al., Cuetos et al., and the current investigation was that accuracy rates, or “false alarms”, were more indicative of perceptual repair than reaction times, as accuracy was an explicit measure of whether or not the participant heard an illicit vowel. In the present study, it was less likely that L1 Spanish speakers would report explicitly hearing a vowel, as they were tested in their L2. S+cs are permissible in the L2 (English). Thus, reaction times were a more sensitive measure of vowel perception. Carlson (2018) similarly found that reaction times were a more sensitive measure of perceptual repair from a representational standpoint. Carlson claimed that the representation of the s+c onsets was inherently different between Spanish monolinguals and Spanish-English bilinguals, since Spanish monolinguals have not been exposed to s+c, while Spanish-English bilinguals have been exposed through their L2 knowledge and experience. Therefore, to account for the discrepancy between reaction times and accuracy rates, bilinguals perceive the ‘e’ onset in Spanish-conflicting stimuli, and show differences in response rates due to accessing this ‘e’ onset representation, but are able to provide accurate responses due to their knowledge of English.

Empirical and theoretical implications. The current study builds upon previous investigations examining perceptual repair in bilinguals in that we used real words. Previous studies have used non-words (Carlson et al., 2016) and nonsense sound sequences (Weber & Cutler, 2006), which limits real-world generalizability to non-lexical processing. Moreover, we examined L1 influences during L2 processing. Lentz and Kager (2015), and Weber and Cutler (2006) similarly tested bilinguals in their L2 and obtained patterns suggestive of L1 access to phonotactic constraints. The participants in Carlson et al. (2016) were tested in their L1, but had 40-70% daily exposure to their L2. The authors further mentioned that even though the testing context was in the L1, psychology studies involving these bilinguals were typically conducted in English, therefore setting an expectation for English in the testing environment. If the testing environment was more L1-like, or if there was no expectation for the L2, perceptual repair effects may have been more robust in Carlson et al. However, the results obtained here, in Lentz and Kager, and in Weber and Cutler generally support that bilinguals perceptually repair L2 input to sound more L1-like.

Overall, when hearing English words, L1 Spanish speakers perceived the auditory input according to Spanish constraints, especially when part of or the entire stimulus was the explicit focus of the task. This perceptual repair likely occurred because the English s+c onset stimuli conflicted with the Spanish 'e' onset rule. These results provide insight into the structure of acoustic space within bilinguals. For example, L1 speakers of a given language build an auditory template based on the sound combinations they hear as children (Best, 1994). The Perceptual Assimilation Model explains that these templates are how phonotactic constraints become stored within individuals. When speech input is processed that does not match the auditory template, the individual will likely repair this input so that it is assimilated to the closest phoneme category (sound) in the L1. Within the Perceptual Assimilation Model, the Category Goodness (CG) type states that when two sounds contrast in the L2 (e.g., *strict*, *estrict*) that do not normally contrast in the L1, the two sounds are assimilated into a single L1 category. Given that Spanish does not permit s+c at word onsets, the English s+c ad e+s+c are assimilated into the Spanish e+s+c. Moreover, one of the contrasting L2 sounds (e.g., English e+s+c) may be more similar to the L1 phoneme (Spanish e+s+c) than the other sound (English s+c). In the current study, the English e+s+c (*estrict*) sequence is most similar to the Spanish e+s+c (*estricto*) sequence relative to the English s+c (*strict*). The way sounds are assimilated into L1 categories within the context of the Perceptual Assimilation Model supports the obtained results, that L1 Spanish speakers are likely to perceive the prothetic 'e' in English s+c words and non-words during speech perception. In addition, current findings further support the literature on parallel activation (e.g., Marian &

Spivey, 2003), that L1 influence during L2 processing is robust and pervasive, even influencing speech perception.

Future directions. Aside from the important theoretical and empirical implications for perceptual repair, the current study provides the foundation to investigate the mechanisms involved in speech perception in bilinguals. During phonotactic-constraint perception and perceptual repair, monolinguals and bilinguals may process speech input in a top-down way. For example, when an individual hears a word or a sound sequence that conflicts with the rules of their language, a top-down process is likely initiated where the constraint comes on-line, and dictates how the input should be perceived, and therefore repaired. To illustrate, if an L1 Spanish speaker hears L1-like input, such as *stricto* (/strikto/), s/he will be influenced in a top-down manner to repair the input so that it is *estricto* ("strict"). This top-down, rule-based approach is supported in previous investigations on perceptual repair (e.g., Carlson et al., 2016; Dupoux et al., 1999; Lentz & Kager, 2015; Parlato-Oliveira et al., 2010; Weber & Cutler, 2006) and within the Perceptual Assimilation Model (Best, 1994). In the current study, we found that L1 perceptual repair extends to processing the L2 such that an L2 word that conflicted with L1 constraints (e.g., *strict*) was repaired to conform to the L1 (e.g., *estrict*)

In addition to the top-down rules that dictate how the input is perceived, it is important to consider bottom-up influences from phonology, the lexicon, and rules as well. Within the current and previous studies, the individual is receiving auditory or visual input, therefore phonology is accessed immediately. Through phonological overlap, within- and between-language neighbors are accessed (see Shook & Marian, 2013). For example, *strict* activates English *stamp*, its Spanish translation equivalent *estricto*, and neighbor *estudio* ("study"). Future work should further examine the role of bottom-up and top-down processes as the mechanisms involved during speech perception in bilinguals. See Freeman et al. (in prep, Chapter 4) for this work.

3.12 Conclusion

While participating in conversations in their L2, bilinguals may perceptually repair L2 input to be perceived as L1-like. For native Spanish speakers, English words such as *strict* may be heard as *estrict* due to the Spanish phonotactic constraint of adding an ‘e’ to the onset of s+consonant cluster onset words. The current investigation employed two measures that differed in metalinguistic demands to examine perceptual repair in bilinguals. Findings extend evidence that bilinguals process their languages in parallel when the task is an explicit measure of perceptual repair, or when metalinguistic demands are higher. Moreover, the results are supported by previous studies on perceptual repair in monolinguals and bilinguals, as well as theoretical models on how bilinguals perceive language input. Future work should identify and characterize the mechanisms associated with bilingual speech perception. Specifically, the role of top-down and bottom-up processes should be further examined within the context of perceptual repair.

CHAPTER 4

THE ROLE OF AUDITORY INPUT IN LANGUAGE ACTIVATION AND SPEECH PERCEPTION IN BILINGUALS

4.1 Abstract

With and without auditory input, bilinguals activate words that share sounds across languages. In addition, bilinguals perceive sounds from their native language (L1) when hearing words in their second language (L2), further highlighting the cross-linguistic interactions during bilingual language processing. Across two experiments, we examined 1) whether bilinguals activated L1 phonotactic constraints (i.e., rules for combining speech sounds) when viewing L2 words, and 2) the relation between activation and perception of L1 phonotactic constraints when viewing and listening to L2 words. In Experiment 3a, English monolinguals and Spanish-English bilinguals saw four words on a visual display while eye movements were tracked. Participants identified the target word by hearing its onset (e.g., "Click on /s/", target = strict). On critical trials, items included a target word that conflicted with the Spanish phonotactic constraint of a vowel onset at the beginning of s+consonant clusters (e.g., strict) and a competitor word which contained the activated 'e' onset (e.g., egg). Two filler words were also present that did not conflict or overlap with the Spanish constraint (e.g., work, can). Lower English proficiency bilinguals looked more at competitor versus filler items, suggesting cross-linguistic activation of the Spanish phonotactic constraint during English processing. In Experiment 3b, the same participants viewed words on a visual display as in Experiment 3a, identified the target word by hearing it (e.g., strict) (word recognition), and then heard a second word (e.g., effort), at which point they decided if the two words they heard were the same or different (AX discrimination).

Once again, lower English proficiency bilinguals looked at the competitor items more than the filler items, suggesting activation of the Spanish phonotactic constraint. Bilinguals were not slower overall to respond to the Spanish-conflicting trials than to the non-conflicting trials in AX discrimination, indicating an absence of Spanish perceptual repair of English input. However, bilinguals who may have perceptually repaired during AX discrimination, as indicated by slower responses to Spanish-conflicting than non-conflicting pairs, did not also activate the Spanish phonotactic constraint in word recognition. Together, Experiments 3a and 3b demonstrate that L2 proficiency modulates the extent to which L1 phonotactics are accessed on-line during L2 comprehension. Bilinguals with lower English proficiency experienced increased Spanish interference. Furthermore, the lack of a perceptual effect suggests that AX discrimination may not be sensitive enough to uncover the relation between L1 perception and activation during L2 processing.

4.2 Introduction

Bilinguals inadvertently access their two languages when just one is being processed (Blumenfeld & Marian 2007; 2013; Freeman, Blumenfeld, & Marian, 2016; Giezen, Blumenfeld, Shook, & Marian, 2015; Kroll, Bobb, Misra, Guo, 2008; Marian & Spivey, 2003a, b; Sunderman & Kroll, 2006). This cross-language interactivity within bilinguals is surprising given that individuals can only speak and comprehend in one language at a time. Taking this finding a step further, if bilinguals access their languages simultaneously, does this joint activation change how auditory input, specifically in the second language (L2), is perceived? In the realm of speech perception, foreign speech sounds may be repaired, or adapted, to conform to the rules of the L1 (Carlson, 2018; Carlson, Goldrick, Blasingame, & Fink, 2016; Hallé, Dominguez, Cuetos, & Segui, 2008; Lentz & Kager, 2015; Weber & Cutler, 2006). In addition, bilinguals process their

L2 consistently with the rules or constraints ascribed by the native language (L1) not only in the initial stages of L2 acquisition, but also even when proficiency in the L2 is reached (Freeman et al., in prep, Chapter 3; Lentz & Kager, 2015; Weber & Cutler, 2006). Therefore, phonotactic constraints, or rules for combining speech sounds, may influence how bilinguals perceive L2 auditory input. The current investigation examines 1) cross-linguistic activation independently from speech perception, as well as 2) the relation between activation and perception in bilinguals.

Language co-activation in bilinguals. The literature on bilingual language activation suggests that during single-language comprehension, bilinguals access phonological neighbors within and between languages (Blumenfeld & Marian, 2007; 2011; 2013; Marian & Spivey, 2003a, b; Shook & Marian, 2013; Spivey-Knowlton, Tanenhaus, Eberhard, & Sedivy, 1998). For example, when hearing the word *comb*, a Spanish-English bilingual will activate the English neighbor *cone* and the Spanish neighbor *conejo* (rabbit). A connectionist computational model that accounts for within- and between-language co-activation in bilinguals is the Bilingual Language Interaction Network for Comprehension of Speech (BLINCS; Shook & Marian, 2013). The model supports that bilinguals access phonological neighbors during spoken word comprehension; for example, the word *tenedor* (English: “fork”) activates *tiburón* (English: “shark”), *tunnel*, and *tent*. Further support for neighbor activation in bilinguals, including access to phonotactic constraints, comes from the Activation Threshold Hypothesis (Paradis, 2004). The hypothesis supports that activation of a particular word and its neighbors occurs as a threshold is approached. Selection of a target word requires that its activation exceeds the threshold of its alternatives. Thus, activation of neighbors within the Activation Threshold Hypothesis occurs during initial stages of auditory word comprehension.

Aside from theoretical models, empirical evidence on bilingual language activation suggests that bilinguals also access L1 phonotactic constraints during L2 processing (e.g., Freeman, Blumenfeld, & Marian, 2016, Chapter 2). Broadly speaking, evidence for co-activation has been observed in spoken and visual modalities during language comprehension (e.g., Blumenfeld & Marian, 2013; Chabal & Marian, 2015; Giezen, Blumenfeld, Shook, Marian, & Emmorey, 2015; Hoshino & Kroll, 2008; Marian & Spivey, 2003a, b; Shook & Marian, in press; Sunderman & Kroll, 2006). Parallel language activation also occurs with varying degrees of proficiency in the L2 (Blumenfeld & Marian, 2007; van Hell & Dijkstra, 2002; van Hell & Tanner, 2012). It has been noted across linguistic levels, including phonological (Ju & Luce, 2004; Marian & Spivey, 2003a, b), orthographic (Kaushanskaya & Marian, 2007; Thierry & Wu, 2007), lexical (Finkbeiner, Forster, Nicol & Nakamura, 2004; Schoonbaert, Duyck, Brysbaert & Hartsuiker, 2009; Sunderman & Kroll, 2006), semantic (Fitzpatrick & Indefrey, 2010; Martín, Macizo, & Bajo, 2010), syntactic processing (Hartsuiker, Pickering & Veltkamp, 2004; Loebell & Bock, 2003), and phonotactic constraints (Freeman, Blumenfeld, & Marian, 2016; Lentz & Kager, 2015; Weber & Cutler, 2006).

In addition to the various linguistic levels at which parallel activation has been observed, there is recent evidence to suggest that bilinguals co-activate their languages covertly. Previous studies investigating cross-linguistic activation at the phonological level have demonstrated that auditory input maps onto potential lexical candidates across languages in bilinguals (e.g., Blumenfeld & Marian, 2007; 2013; Marian & Spivey, 2003a, b). Shook and Marian (in press) examined how bilinguals accessed the irrelevant language when the input did not directly map onto both languages. For example, English-Spanish bilinguals were presented with a picture of a *duck* (Spanish: *pato*), a *shovel* (Spanish: *pala*), and an unrelated distractor. Critically, *duck* and *shovel* overlapped phonologically in the non-target language, Spanish. Bilinguals were found to look at the *shovel* more than to the unrelated distractor when *duck* was the target. This finding suggests that translation equivalents from the non-target language become activated during auditory comprehension, and activation spreads to neighbors of the non-target language. Relating these findings to the BLINCS model, when hearing *duck*, the translation equivalent *pato* is accessed, and phonological neighbors across languages are also activated (e.g., *pala*). Activation of the between-language neighbor *pala* is due to covert phonological overlap and a lateral, excitatory connection mechanism within the lexicon. Parallel language processing in bilinguals is robust and pervasive, as it has been demonstrated overtly and covertly during language input. Less clear is how a bilingual's two languages interact when perceiving speech input.

Speech perception in bilinguals. Interestingly, an infant-based speech perception model provides an explanation for how bilingual adults perceive auditory input. The Perceptual Assimilation Model (Best, 1994) explains that rules specific to each language influence how individuals process speech. Conflict occurs when a bilingual hears a non-native (L2) speech sound that does not exist in the L1 inventory. The model further explains that if the phonetic characteristics of the sound resemble those of an existing phoneme in the L1, the sound will be assimilated, or adapted to the L1 category. Thus, bilinguals may apply L1 perceptual knowledge when processing L2 auditory input. This top-down manner of processing speech sounds provides a potential explanation as to why a rule, such as a phonotactic constraint, may impact bilingual speech processing. The current investigation relies on a Spanish phonotactic constraint where s+consonant clusters (s+c) are illicit at word onsets. A vowel, such as 'e', is added before the s+c onset (prothesis). When an L1 Spanish speaker of English encounters an s+c or vowel+s+c (v+s+c) word in English (e.g., *strict* and *estimate*, respectively), the model predicts two scenarios for speech perception. The Single Category (SC) type states that the L2 sounds, such as the s+c and v+s+c contrast, may be assimilated equally well to a single L1 category, v+s+c (e.g., *estrict* and *estimate*). The Category Goodness (CG) type explains that when two sounds contrast in the L2, as in the SC type, the sounds may be assimilated to a single category in the L1. However, one of the contrasting L2 sounds may be more similar than the other to the L1 phoneme. It is likely for the s+c and v+s+c contrast in English, the CG scenario applies because the v+s+c rule exists in Spanish (see Freeman et al., in prep, Chapter 3 for discussion). The Perceptual Assimilation Model thus provides a theoretical backdrop for the current study, specifically shedding light on what bilingual listeners experience when processing sounds that conflict with L1 rules.

Previous studies have investigated perceptual processes within a single language (Carlson, 2018; Carlson et al., 2016; Dupoux et al., 2010; Dupoux et al., 2008; Hallé et al., 2008; Parlato-Oliveira et al., 2010). For example, when listening to pseudowords that conflict with L1 phonotactic constraints, bilinguals repair these sound sequences to make them more L1-like (Carlson, 2018; Carlson et al., 2016; Parlato-Oliveira, Christophe, Hirose, & Dupoux, 2010). Weber and Cutler (2006) examined influence from L1 constraints when listening to sound sequences that contained L1-like and L2-like syllable boundaries. Weber and Cutler tested L1 German speakers of English, as well as English monolinguals, in an English word detection task in which nonsense sequences were presented. While both German-English bilinguals and English monolinguals were almost equally sensitive to English boundaries that conformed to English phonotactic constraints, only German-English bilinguals were sensitive to English boundaries that conformed to German constraints during English processing. The results suggest that even though bilinguals become sensitive to L2 phonotactic constraints, they are still influenced by L1 constraints as well.

Related to the v+s+c phonotactic-constraint difference in the current investigation, Carlson, Goldrick, Blasingame, and Fink (2016) asked L1 Spanish participants whether they detected a vowel at the onset of Spanish-like non-words (vowel detection). Participants also decided if two consecutive non-words they heard were the same or different (AX discrimination). In both vowel detection and AX discrimination, the vowel onset was spliced from e/a+s+consonant onset non-words. Therefore, these Spanish-like non-words conflicted with the Spanish v+s+c constraint. Findings demonstrated that only Spanish-dominant, but not English dominant, bilinguals were more likely to perceive the 'e' onset when it was not present. The authors ascribe this auditory illusion to the Spanish-dominant bilinguals' perceptual repair of the input, conforming to the Spanish v+s+c constraint. The participants in this study were bilingual, but were tested in their L1. Do bilinguals also misperceive, or experience an auditory illusion of, L2 sound combinations to align with L1 phonotactic constraints? The current investigation aimed to provide further support for perception of L1 phonotactic constraints when listening to the L2, as well as attempted to elucidate the mechanisms that underlie cross-linguistic activation and perception in bilinguals.

The relation between language co-activation and speech perception. Moreover, no single study has attempted to examine co-activation and co-perception within one task (Experiment 3b: combined word recognition and AX discrimination). Understanding how bilinguals perceive sounds and sound sequences in the L2 that conflict with L1 phonotactic constraints has important implications for identifying the underlying mechanisms associated with bilingual language processing. Bilinguals may recruit similar or different mechanisms during language activation (e.g., English *strong* activates the 'e' onset rule in Spanish: *estrong* (Freeman et al., 2016)) and perception (e.g., English *strict* may be perceived as *estrict* due top-down knowledge of the Spanish v+s+c constraint (Freeman et al., in prep, Chapter 3)). For example, during single-word comprehension, bilinguals process auditory input in a bottom-up way (Activation Threshold Hypothesis; Paradis, 2004). With bottom-up activation, Spanish-English bilinguals access the Spanish 'e' onset rule while listening to English words (*strong* activates Spanish *estricto* ("strict") through between-language phonological neighborhood activation; Freeman, Blumenfeld, & Marian, 2016, Chapter 2). Another potential mechanism is top-down feedback (Perceptual Assimilation Model; Best, 1994; see also Dupoux, Pallier, Kakehi, & Mehler, 2001) from Spanish phonotactic constraints to phonology, with perceptual repair dictating that the English input is perceived conforming to Spanish phonotactics (*strong* is perceived as *e̲strong*).

Alternatively, top-down perceptual influences from the L1 may be limited to tasks that tax metalinguistic awareness. Parlato-Oliveira et al. (2010) found that L1 and L2 perceptual repair was present in bilinguals only in an explicit measure of vowel perception (vowel detection) and not in an implicit measure (forced-choice recall), where only L2 repair was present. Critically, the vowel detection task requires knowledge of vowels versus consonants and attention to stimuli onsets. Forced-choice recall and AX discrimination tasks tap into lower-level perceptual representations, and are easier for participants since vowel knowledge is not required. Moreover, the results from the current dissertation (see Freeman et al., in prep, Chapter 3) are in line with this prediction. Freeman et al., in prep, Chapter 3, found that L1 perceptual repair during L2 processing was present in vowel detection, and not in AX discrimination tasks.

The present investigation. Within the current study, we intended to uncover the extent to which bottom-up and top-down processes interacted during language comprehension.

Specifically, the mission was to identify if these mechanisms worked in tandem during activation and perception of the L1 (Spanish) in an L2 (English) context. The research questions included:

1) Is language co-activation dissociable from speech co-perception (Experiment 3a)?

2) What is the relation between activation and perception in bilinguals (Experiment 3b)?

We hypothesized that 1) activation could occur independently of perception; however, perception could not occur without activation. This hypothesis is based on the evidence that language co-activation may occur with auditory and/or visual input (Blumenfeld & Marian, 2007; 2013; Chabal & Marian, 2015; Marian & Spivey 2003a, b), while perception does not occur independently of activation because in order to perceive the acoustic properties of a sound, one relies on auditory input. We also hypothesized that 2) bilinguals process auditory input (i.e., a word) in bottom-up and top-down ways. Within- and between-language neighbors and eventually phonotactic constraints are accessed bottom-up. Bilinguals may adjust the input to conform to the phonotactic constraints of the unintended language in a top-down manner (see studies on perceptual repair: e.g., Carlson et al., 2016; Hallé et al., 2008; Parlato-Oliveira et al., 2010). See Figure 15 for an illustration of bottom-up and top-down processing.

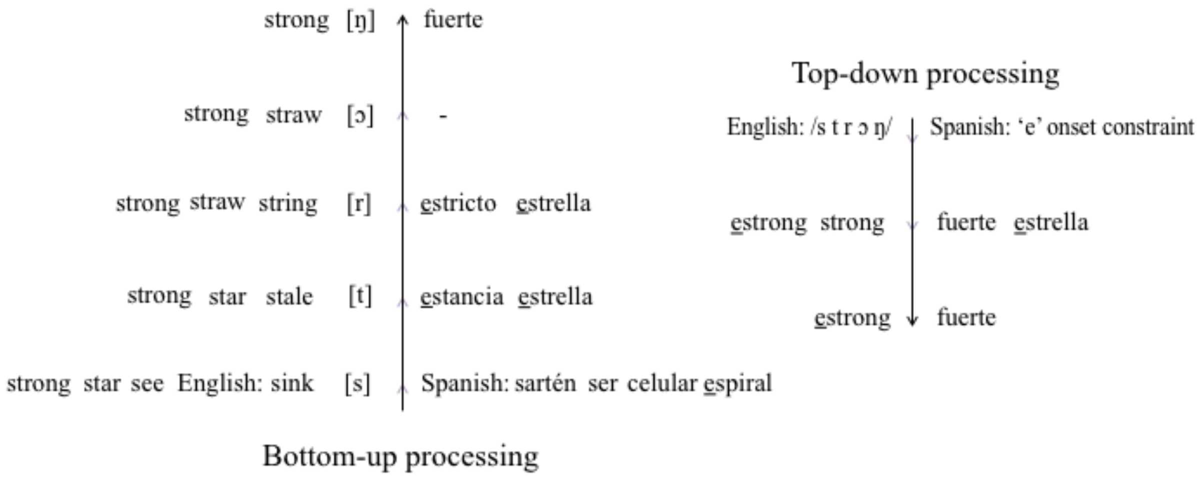

Figure 15: Bottom-up and top-down processing of English *strong,* which conflicts with the Spanish ‘e’ onset constraint.

4.3 Experiment 3a: Activation Without Perception of L1 Phonotactic Constraints in Bilinguals: Word Recognition

Experiment 3a addressed the first research question, examining whether activation and perception were dissociable processes. In Experiment 3a, participants viewed four words on the screen while eye movements were tracked. An advantage of using eye tracking is that participants’ behavior could be examined before the decision level is reached. Spanish-conflicting s+c onset words (e.g., *strict*) as well as ‘e’-onset competitor words (e.g., *egg*) were presented, along with two filler items that did not conform to or conflict with the Spanish ‘e’ constraint (e.g., *work*, *can*). Participants were asked to identify the target item (e.g., *strict*) by clicking on the word that started with the sound (e.g., “click on /s/”). If bilinguals activated Spanish phonotactic constraints during English comprehension, then more looks to ‘e’ onset competitors (e.g., *egg*) than fillers (e.g., *work*/*can*) were expected when presented with s+c onset targets. This prediction is in line with Freeman et al. (2016), which demonstrated phonotactic-constraint activation of the Spanish v+s+c rule during English s+c single-word comprehension. The prediction is also supported by the Activation Threshold Hypothesis (Paradis, 2004), which suggests that a target word and its neighbors become activated based on the combination of sounds and sound sequences from the input (bottom-up process). It was expected that activation of Spanish phonotactic constraints could occur independently of auditory input, as activation does not rely on hearing sounds and words in the same way that perception does. Specifically, it was predicted that as bilinguals read the words with which they were presented, phonological encoding would occur, which would activate phonological neighbors, translation equivalents, and phonotactic constraints of the irrelevant language (Freeman et al., 2016, Chapter 2). Therefore, the task examined purely bottom-up processing.

4.4 Experiment 3a Methods

Participants

In Experiment 3a, 28 English monolinguals (8 males) and 27 Spanish-English bilinguals (5 males) were tested. Participants were recruited from the areas of Evanston and northern Chicago, Illinois, aged 18-35, had normal or corrected-to-normal vision, and no history of a neurological impairment. Bilinguals were native Spanish speakers. The same recruitment procedures were implemented from Experiments 2a and 2b (Chapter Three) with a new set of participants. Monolingual participants were not included in Experiment 3a if they had a reported Spanish or another foreign language speaking proficiency of greater than 3 (1-10 scale) on the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007). Bilinguals were exposed to Spanish around 30% daily, and acquired English at age 5 (entry into primary school) or later. See Table 8 for additional participant information.

*Table 8: Linguistic and cognitive background of Spanish-English bilingual (n = 27) and English monolingual (n = 28) participants. **p < .001; *p < .01*

	Bilinguals Mean (SE)	Monolinguals Mean (SE)
Age	23.14 (1.03)	22.10 (0.62)
Age of Spanish acquisition	0	--
Age of English acquisition**	6.15 (0.59)	0
Current exposure to Spanish	31.96% (2.92)	--

Current exposure to English**	66.88% (2.80)	99.57% (0.21)
Foreign accent in Spanish (1-10 scale)	1.59 (0.34)	--
Foreign accent in English (1-10 scale)*	2.00 (0.44)	0.73 (0.39)
Spanish receptive vocabulary (TVIP)	116.77 (2.84)	--
English receptive vocabulary (PPVT)	110.14 (3.55)	118.86 (3.39)
Self-reported Spanish proficiency (1-10 scale)	8.98 (0.12)	--
Self-reported English proficiency (1-10 scale)**	8.95 (0.17)	9.67 (0.08)
WASI, matrix reasoning	27.59 (0.82)	29.17 (0.5)
Backward digit span	10.25 (0.82)	10.57 (0.78)

Monolinguals and bilinguals differed on English age of acquisition ($p < .001$), current exposure to English ($p < .001$), foreign accent in English ($p = .02$), and self-reported English proficiency ($p < .001$). Monolinguals and bilinguals were matched on age, non-verbal cognitive reasoning (WASI; PsychCorp, 1999), and working memory (backward digit span; Woodcock, McGrew, & Mather, 2001; 2007). The Language Experience and Proficiency Questionnaire (LEAP-Q, Marian, Blumenfeld, & Kaushanskaya, 2007) served as an index of language history and dominance for the monolinguals and bilinguals.

Materials

The word recognition task indexed activation of ‘e’ onset competitor words when s+c onset target words were present in the visual world paradigm. Activation of the Spanish v+s+c phonotactic constraint was examined with minimal auditory input. The participant was told to click on the target word when only the target’s onset was played. It was predicted that when the target (e.g., *strict*) and competitor items (e.g., *egg*) were present along with two filler items (e.g., *work*, *can*), participants would fixate more on the competitor item than the filler items when hearing the target onset of the word. The within-subjects independent variable was fixations on cross-linguistic phonotactic competitors relative to unrelated filler items. The between-subjects variable was language status (monolingual, bilingual), resulting in a 2x2 design. The dependent variables included accuracy and reaction times to identifying the target, as well as proportions of fixations to competitor and filler items, using growth curve analyses.

Experiment 3a was controlled by an iMac 3.3 GHz Intel Core i5 running MatLab 2011a, and stimuli were displayed on a 27-inch monitor with a screen resolution of 5120x2880. Eye movements were recorded using a desk-mounted eye-tracker (EyeLink 1000 Version 1.5.2, SR Research Ltd.) at a sampling rate of 1000 Hz. Mouse clicks to identify the target allowed for the collection of accuracy and reaction time data. The stimuli (initial sounds of each word) were recorded in a sound attenuated room (44,100 Hz, 16 bits) by a male native English speaker. The audio recording was normalized using audio compression, split into individual audio files in Praat (Boersma and Weenink, 2013), and exported into MatLab (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997).

Stimuli for Experiment 3a contained 1) s+c onset, 2) ‘e’ onset, or 3) control onset, and 4) two filler items. The four words were displayed in the visual world paradigm. The three types of words (s+c onset, ‘e’ onset, control word) were matched on the following lexical characteristics, with all *p*s > .05: number of letters in English and in Spanish (translation), English and Spanish (translation) log lexical frequency, and English and Spanish orthographic neighborhood density (CLEARPOND: Marian, Bartolotti, Chabal, & Shook, 2012) (*p*s > .05). Experiment 3a contained a total of 156 trials (12 practice, 144 experimental). See Appendix D for stimuli and lexical characteristics. The task consisted of 48 trials in which cross-linguistic phonotactic competitors were present (e.g., s+c *strict* and ‘e’ onset *egg*), as well as 96 control trials were no such competitor competition was present. The items were pseudo-randomized such that no more than two consecutive trials contained s+c onsets. Trial order was counterbalanced across participants by reversing the order of presentation.

Procedure

Participants were administered the following tasks in the order listed in Table 9:

Table 9: Order of tasks for Experiments 3a and 3b.

Task	Purpose
LEAP-Q (Marian, Blumenfeld, & Kaushanskaya, 2007)	To obtain linguistic background information and current language exposure, and to ensure that each participant met the criteria for the study
Word recognition task	To investigate activation of the L1 phonotactic constraint in an L2 context without perception
Combined word recognition and AX discrimination task	To examine the mechanisms underlying activation and perception of L1 phonotactics (see Experiment 3b)
Non-linguistic Stroop task (adapted from Blumenfeld & Marian, 2014)	To index competition resolution abilities
the Wechsler Abbreviated Scale of Intelligence (WASI; PsychCorp, 1999)	To index non-verbal cognitive reasoning
Backward digit span task (numbers reversed, Woodcock, McGrew, & Mather, 2001; 2007)	To index working memory
• Peabody Picture Vocabulary Test-3 (PPVT-3) (Dunn & Dunn, 1997) for monolinguals and bilinguals	To index English and Spanish vocabulary

- Vocabulario en Imágenes Peabody (TVIP) (Dunn, Lugo, & Dunn, 1997) for bilinguals only

Participants were seated in a quiet room and the eye-tracker was calibrated. Instructions were to select the target item (e.g., *strict*) by clicking on the word, when the word's onset was played (e.g., /s/). In Experiment 3a, the screen with four words appeared, a 1000ms delay occurred before the participant heard the carrier phrase, "Click on…," which lasted 830ms, with the onset sound immediately following. This design allowed for the investigation of activation processes via eye fixations. It would thus be possible to elucidate the time course of cross-linguistic activation of phonotactic constraints within this design. After the instructions and 12 practice trials, participants completed the experimental trials. Presentation of the visual display contained the target, a phonotactic-constraint competitor in critical trials, and two filler items, as well as a central fixation crosshair. The four word stimuli were presented in four quadrants (top-left, bottom-left, top-right, bottom-right), on a white screen in black, size 16 font. Presentation of the display lasted until the participant made a mouse click on a quadrant. See Figure 16 for task procedure.

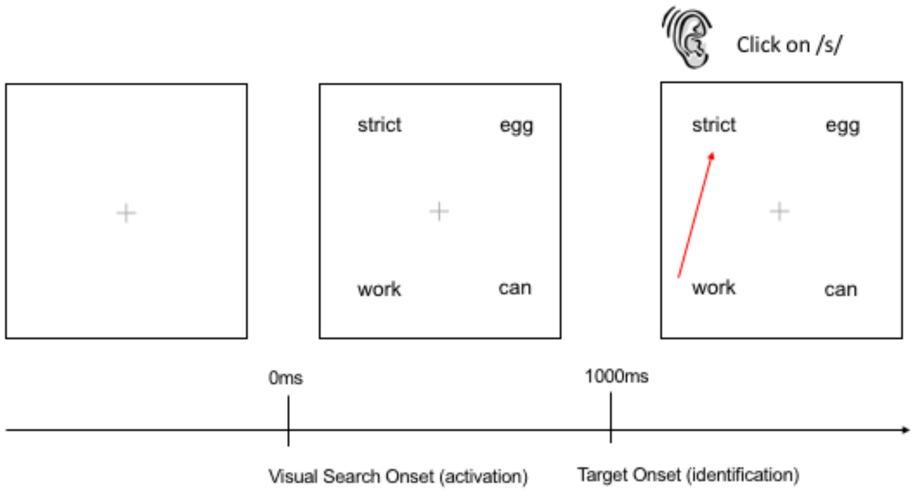

Figure 16: Example trial from the word recognition task. In this example, participants viewed four words on the screen while eye movements were tracked. The words included a target that conflicted with the Spanish 'e' onset constraint (*strict*), a competitor that contained an 'e' onset (*egg*), and two filler items (*work*, *can*). Participants then heard, "Click on /s/", where /s/ was the onset of the target item (*strict*).

The total time to complete this task was approximately 10 minutes. Participants performed the remaining tasks, then were debriefed about the study and compensated. The total study duration (Experiment 3a and 3b) was approximately two hours.

Coding and Analysis

For Experiment 3a, repeated-measures ANOVAs were used to analyze accuracy and reaction times to identify the target via mouse click. Response times were measured at the start of the visual display, until the participant responded. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time were disregarded, approximately 0.5% of the data. Means and standard deviations for each condition were then calculated. Growth curve analysis (GCA; Mirman, Dixon, & Magnuson, 2008) of eye-tracking data was employed to examine activation of irrelevant-language phonotactic constraints during word processing.

Time-course of fixations. Eye-fixations were counted when participants maintained a consistent gaze duration on one of the four quadrants within the visual display for greater than 70ms; fixations below this duration were not included. Fixation interest areas were constructed within each quadrant, measuring 350 x 350 pixels surrounding the center of each word. Only looks within the quadrants were considered for analysis. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time were discarded prior to analysis. The time-course analyses included fixations that were collapsed into 10ms bins, and participants' average fixation duration to each item at the 10ms bin was recorded. Visual fixations were analyzed from the auditory sound onset (of the target word) until the point at which fixations to the target peaked, indicating final target selection, which was around 800ms post-initial sound onset. This calculation also includes 200ms to account for the time required to plan and execute an eye movement (Viviani, 1990). The fixation analyses included comparisons of fixations to the /e/ onset item (competitor) relative to the unrelated filler items (averaged together) on the visual display. Time-courses included fixed effects of item type (competitors, fillers), language group (bilinguals, monolinguals), and the polynomial time terms. Random effects of participant and polynomial time terms were also included. Within this window, a base fourth-order orthogonal polynomial was implemented to capture the rise and fall of visual fixations to the visual competitor and the average of both filler objects in the display. Orthogonal time terms were also treated as random slopes in the model. The best-fitting orthogonal polynomial time terms were determined by constructing models including linear, quadratic, cubic, and quartic time terms, and comparing the models using chi-square model comparisons. The maximally-converging model included random slopes of the linear, quadratic, cubic, and quartic orthogonal time terms on the random-effects structure of participant, and random slopes of the four time terms on the item type-by-language group structure ($\chi^2(9)=194.75$, $p<0.001$). *P*-values from all GCA models were calculated by assuming that the *t*-values converged to a normal distribution given the large number of observations present in time course data (Mirman, 2014).

4.5 Experiment 3a Results

The results of Experiment 3a were organized in the following manner. First, accuracy rates and reaction times to identifying the target word (e.g., *strict*) on the visual display were analyzed across bilinguals and monolinguals. Accuracy and reaction time effects were examined using repeated measures ANOVAs. Next, to uncover whether bilinguals activated L1 phonotactic constraints during L2 processing, eye movements, specifically fixation proportions over time to the competing words (e.g., *egg*) relative to filler words (e.g., *work* and *can*) on the visual display were analyzed across language groups. Last, within the bilingual group, an analysis was performed on eye-movement data for competitors and fillers based on L2 proficiency. All time course data were analyzed using growth curve analyses.

Accuracy and Reaction Time[6]. Bilingual and monolingual participants performed near ceiling with accuracy, around 99.46% (*SD* = 1.67). Bilinguals' mean reaction time was 3385.83ms (*SD* = 369.13) and monolinguals' was 3228.87ms (*SD* = 403.12), $p < 0.001$.

Accuracy effects on the Word Recognition task. Participants' accuracy was based on whether they correctly identified the target word on the visual display when hearing the onset sound (e.g., /s/ for *strict*). The conditions for analysis included target (s+c target *strict* and 'e' onset competitor) and control (control target and 'e' onset on the visual display). A 2 (trial type: target, control) x 2 (language group: bilingual, monolingual) repeated measures ANOVA was conducted on accuracy rates for identifying the target. There were no main effects of language group, $F(1,53) = .005$, $p = .945$, $\eta_p^2 = .000$, or condition $F(1,53) = .002$, $p = .969$, $\eta_p^2 = .000$. Bilinguals and monolinguals were equally accurate in their responses to identifying English words.

Reaction time effects on the Word Recognition task. Next, reaction times to identifying the target word for bilinguals and monolinguals were analyzed. A 2 (trial type: target, control) x 2 (language group: bilingual, monolingual) repeated measures ANOVA was conducted on

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[6] Note: response times were overall longer for the word recognition task than the combined word recognition and AX task because in the word recognition task, there was a carrier phrase ("click on") that preceded the onset sound (e.g., /s/) indicating the target on the visual display. Response times were measured from the onset of the visual display.

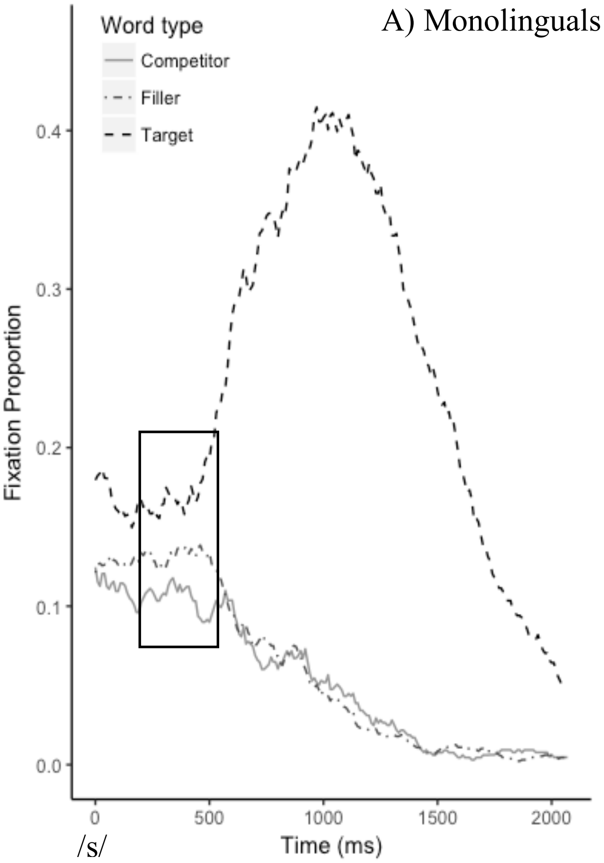
reaction times for identifying the target when hearing its onset. There were no main effects of language, $F(1,53) = 1.822$, $p = .183$, $\eta_p^2 = .034$, or condition, $F(1,53) = .445$, $p = .508$, $\eta_p^2 = .009$, or an interaction, $F(1,53) = .427$, $p = .517$, $\eta_p^2 = .008$. Reaction-time findings confirm that bilinguals and monolinguals responded at a similar speed when identifying English words on a visual display.

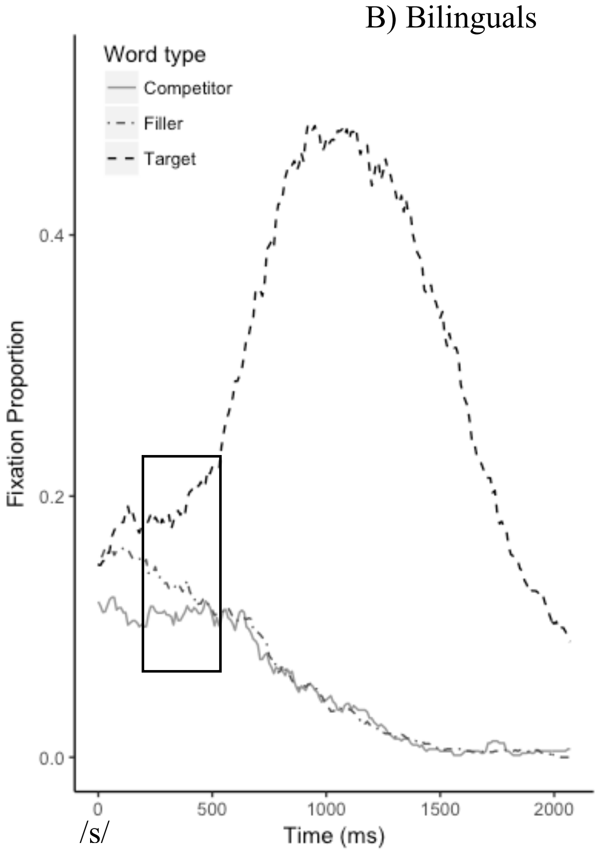
Time course analyses in monolinguals and bilinguals. Growth-curve analysis (GCA) was used to examine the time course of phonotactic-constraint activation in bilinguals. A time window was selected up to 800ms post-initial sound onset, including 200ms for fixation planning and execution. This time window was used in order uncover the effects of cross-linguistic activation of phonotactic constraints when there was no auditory input of the target word's representation, besides the onset sound. Bilinguals and monolinguals did not differ in fixation proportions to competitor versus filler items, as the model revealed no effect of language group on the intercept, linear, quadratic, cubic, or quartic terms (ps > .2). Participants produced a greater proportion of fixations to filler than competitor items, as there was a main effect of item type (competitor and averaged filler) on the intercept term, $\beta = 0.120$, $SE = 0.009$, $t = 12.128$, $p < .001$, and on the linear term, $\beta = -0.837$, $SE = 0.087$, $t = -9.595$, $p < .001$. There was, however, a significant interaction between item type and language group on the quadratic, $\beta = 0.622$, $SE = 0.0174$, $t = 3.565$, $p < .001$, and cubic terms, $\beta = -0.436$, $SE = 0.174$, $t = -2.501$, $p = .012$, suggesting that monolinguals produced a larger difference in fixation proportions between filler and competitor items (more fixations to fillers) than did bilinguals. No additional main effects or interactions emerged on any time terms. Time course data suggest that monolinguals looked at filler items more than competitor items. In addition, bilinguals looked at competitor items more than monolinguals did. However, within the bilingual group, fixation proportions to fillers were greater than to competitors in the 0-800ms time window post-initial sound onset, suggesting a lack of activation of the Spanish vowel onset when processing English words in bilinguals. See Table 10 for a summary of fixed effects in the GCAs.

Table 10: Summary of parameter estimates for fixations by item type (competitor, filler) and language (bilingual, monolingual) in the Growth Curve Analysis.

	β	Standard Error	*t*	*p*
Language: Intercept	0.023	0.078	0.296	0.76
Language: Linear	-0.156	0.599	-0.261	0.79
Language: Quadratic	-0.295	0.257	-1.148	0.25
Language: Cubic	-0.386	0.280	-1.378	0.17
Language: Quartic	0.298	0.207	1.435	0.15
Item Type: Intercept	0.120	0.009	12.128	< 0.001
Item Type: Linear	-0.837	0.087	-9.595	< 0.001
Item Type: Quadratic	0.108	0.087	1.244	0.21
Item Type: Cubic	-0.026	0.087	-0.306	0.75
Item Type: Quartic	-0.042	0.087	-0.486	0.62
Language*Item Type: Intercept	-0.037	0.019	-1.863	0.06
Language*Item Type: Linear	0.076	0.174	0.436	0.66
Language*Item Type: Quadratic	0.622	0.174	3.565	< 0.001
Language*Item Type: Cubic	-0.436	0.174	-2.501	0.01
Language*Item Type: Quartic	0.060	0.174	0.348	0.72

See Figure 17 for monolingual/bilingual differences in the time course of fixations to ‘e’ onset competitor items, relative to filler items.


A) Monolinguals
Word type
Competitor
Filler
Target
Fixation Proportion
0.0
0.1
0.2
0.3
0.4
0
500
1000
1500
2000
Time (ms)
/s/


B) Bilinguals
Word type
Competitor
Filler
Target
Fixation Proportion
0.0
0.2
0.4
0
500
1000
1500
2000
Time (ms)
/s/

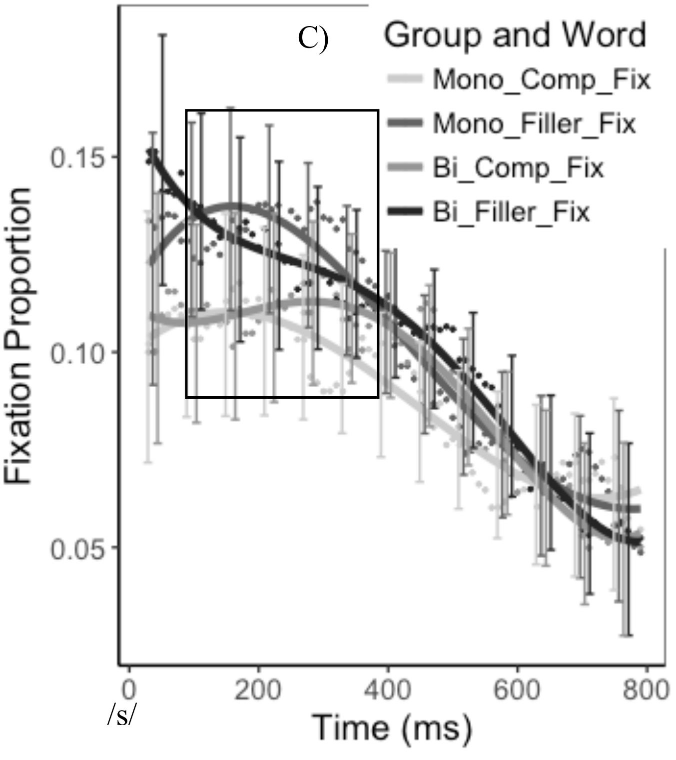

C)
Group and Word
Mono_Comp_Fix
Mono_Filler_Fix
Bi_Comp_Fix
Bi_Filler_Fix
Fixation Proportion
0.05
0.10
0.15
0
200
400
600
800
Time (ms)
/s/

Figure 17: Time course analyses for A) monolinguals and B) bilinguals. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler items (*work*, *can*). X axis represents the time course starting at the onset sound of the target (*strict*). C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions to competitor and filler items for monolinguals and bilinguals. Error bars represent 95% confidence interval of GCA model fits. Overall, there were no observed differences in fixations to competitor versus filler items across monolinguals and bilinguals in the 200-500ms time window post-initial sound onset.

Differences in L2 proficiency within bilinguals[7]. To uncover whether the lack of phonotactic-constraint activation during word recognition was pervasive throughout bilinguals, a follow-up analysis was conducted to examine whether L2 (English) proficiency affected bilinguals' performance. A composite score comprising of objective (PPVT percentile rank) and subjective measures (LEAP-Q averaged speaking, understanding, and reading proficiency ratings) was calculated. Within the bilingual group, 11 bilinguals were rated as having lower proficiency in English, and 16 were rated as having higher proficiency in English. Within the 0-800ms post-sound onset time window (including 200ms for fixation planning), there was a main effect of proficiency on the intercept term, $\beta = -0.218$, $SE = 0.099$, $t = -2.188$, $p = 0.037$ and on the quadratic term, $\beta = -0.860$, $SE = 0.357$, $t = 2.409$, $p = 0.023$. There were also significant interactions of item type x proficiency on the intercept term, $\beta = 0.149$, $SE = 0.030$, $t = 4.898$, p

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[7] There were no bilingual differences in proportions of fixations to competitor versus filler items with respect to dominance and age of acquisition. Furthermore, follow-up GCA analyses for bilingual/monolingual and proficiency time-course data were conducted to examine whether there were any competitor versus filler effects in the absence of the Spanish-conflicting target (e.g., *strict*), which was replaced by a non-conflicting word (target-absent condition: e.g., *demand*). For bilinguals and monolinguals, there were no main effects of language group on any of the time terms, *p*s > 0.2, and fixation patterns did not diverge from the target-present condition. Within the bilingual group, the main effects of proficiency on the time terms disappeared in the target-absent condition, *p*s > 0.1, suggesting that in the target-present condition, greater fixation proportions to competitors (e.g., *egg*) versus fillers (e.g., *work/can*) occurred because of the presence of a Spanish-conflicting target.

< 0.001, quadratic term, $\beta = -0.984$, $SE = 0.030$, $t = -3.795$, $p < 0.001$, and on the cubic term, $\beta = 0.153$, $SE = 0.030$, $t = 5.919$, $p < 0.001$. The model revealed that bilinguals who had a lower L2 (English) proficiency produced a greater proportion of fixations to the 'e' onset word relative to filler items. A follow-up t-test within the 170-420ms post-sound onset window confirmed this result, with the lower proficiency bilinguals demonstrating a greater proportion of fixations to competitor versus filler items, $t = 2.868$, SE=0.39, $p = 0.004$. No additional main effects or interactions emerged on any time terms. Time course data within the bilingual group suggest that those bilinguals with lower proficiency in their L2 are more likely to activate the Spanish (L1) phonotactic constraint when processing English (L2) words. Therefore, decreased L2 proficiency results in increased L1 interference. See Table 11 for a summary of fixed effects in the GCAs.

Table 11: Summary of parameter estimates for fixations by item type (competitor, filler) and English proficiency (lower, higher) in the Growth Curve Analysis.

	β	Standard Error	*t*	*p*
Proficiency: Intercept	-0.218	0.099	-2.188	0.03
Proficiency: Linear	0.516	0.819	0.630	0.53
Proficiency: Quadratic	-0.860	0.357	2.409	0.02
Proficiency: Cubic	-0.230	0.477	-0.484	0.63
Proficiency: Quartic	0.133	0.256	0.520	0.60
Item Type: Intercept	0.108	0.015	7.219	< 0.01
Item Type: Linear	-0.778	0.127	-6.104	< 0.01
Item Type: Quadratic	0.419	0.127	3.287	< 0.01
Item Type: Cubic	-0.230	0.127	-1.812	0.07

Item Type: Quartic	-0.070	0.127	-0.550	0.58
Proficiency*Item Type: Intercept	0.149	0.030	4.898	< 0.01
Proficiency*Item Type: Linear	0.134	0.259	0.517	0.60
Proficiency*Item Type: Quadratic	-0.984	0.259	-3.795	< 0.01
Proficiency*Item Type: Cubic	0.153	0.259	5.919	< 0.01
Proficiency*Item Type: Quartic	-0.414	0.259	-1.559	0.10

See Figure 18 for differences among lower and higher proficiency bilinguals in the time course of fixations to ‘e’ onset competitor items, relative to filler items.

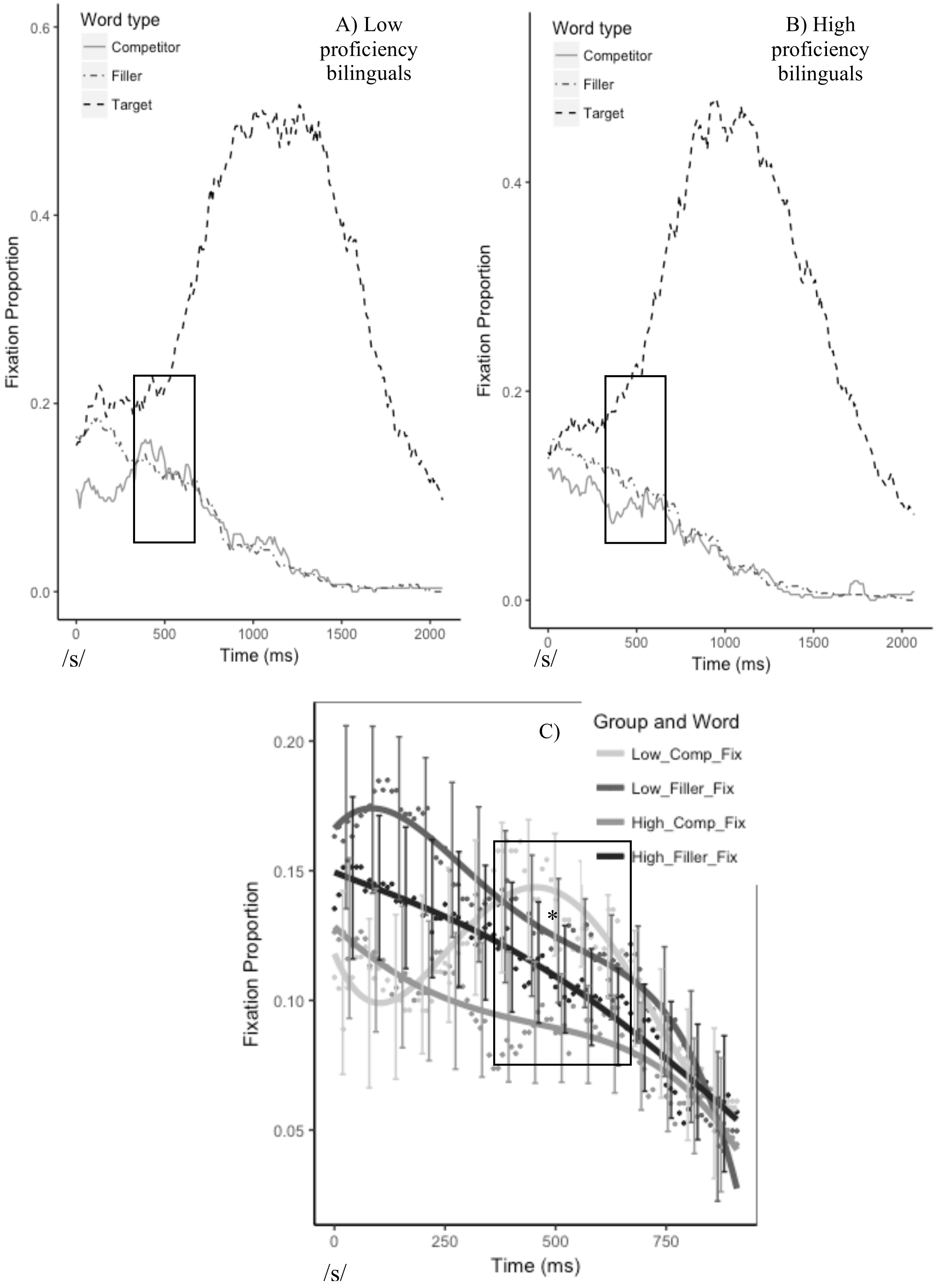
A) Low proficiency bilinguals
Word type
Competitor
Filler
Target
Fixation Proportion
0.0
0.2
0.4
0.6
Time (ms)
0
500
1000
1500
2000
/s/
B) High proficiency bilinguals
Word type
Competitor
Filler
Target
Fixation Proportion
0.0
0.2
0.4
Time (ms)
0
500
1000
1500
2000
/s/
C)
Group and Word
Low_Comp_Fix
Low_Filler_Fix
High_Comp_Fix
High_Filler_Fix
*
Fixation Proportion
0.05
0.10
0.15
0.20
Time (ms)
0
250
500
750
/s/

Figure 18: Time course analyses for A) lower proficiency in English bilinguals and B) higher proficiency in English bilinguals. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler items (*work*, *can*). X axis represents the time course starting at the onset sound of the target (*strict*). C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions to competitor and filler items for lower and higher proficiency bilinguals. Error bars represent 95% confidence interval of GCA model fits. Lower proficiency bilinguals looked more at the competitor than filler items in the 400-700ms post-initial sound onset time window, *$p = 0.004$.

4.6 Discussion

The purpose of Experiment 3a was to identify whether activation could occur independently and be dissociated from perception. When reading (orthography), phonology could be accessed. It was predicted that bilinguals experienced language co-activation of phonotactic constraints in a purely bottom-up manner, following the hierarchy from phonological, lexical, to phonotactic constraints, when reading words. The rationale for this prediction was that if a bilingual was not hearing a word through the auditory modality that conflicted with the Spanish 'e' onset rule, there was no opportunity for him/her to perceptually repair it. There was minimal auditory input for the participant, where s/he identified the target word amongst four options when only hearing the onset of target (i.e., "Click on /s/"). Although fixation patterns across bilinguals and monolinguals did not differ, we found differences within the bilingual group with respect to L2 (English) proficiency. Results from Experiment 3a suggest that bilinguals with lower English proficiency activated the Spanish v+s+c phonotactic constraint with English s+c words. These bilinguals looked more frequently at the 'e' onset competitor than the filler items, when the target had an s+c onset.

The main contribution of this experiment was that it dissociated activation from perception. Hearing the target word's onset sound resulted in bottom-up processing, since the auditory representation of the target word could not be accessed, and top-down perceptual influences were limited. The current findings replicate and extend previous studies examining parallel processing of phonotactic constraints in bilinguals (e.g., Freeman et al., 2016, Chapter 2; Lentz & Kager, 2015; Weber & Cutler, 2006). In the next section, we combined the word recognition task employed in Experiment 3a with the AX discrimination task from (Freeman et al., in prep, Chapter 3, Experiment 2b) in order to examine the interplay between bottom-up activation and top-down perception during parallel processing in bilinguals.

4.7 Experiment 3b: Activation and Perception of L1 Phonotactic Constraints in Bilinguals: Word Recognition and AX Discrimination

Experiment 3b addressed the second research question in this investigation, which was to examine the interplay between language co-activation and co-perception in bilinguals. The eye-tracking word recognition and AX discrimination (WRAX) task served as an index of activation *and* perception during visual and auditory language comprehension. Participants viewed four words on the screen while eye movements were tracked. During critical trials, an s+c onset word (e.g., *strict*) was presented along with an 'e' onset word competitor (e.g., *egg*), as well as two filler items (e.g., *work*, *can*). Participants were told to identify the target item (e.g., *strict*) after 1000ms. As in Experiment 3a, the time course of cross-linguistic activation of phonotactic constraints was examined within this design. Following identification of the target, participants heard another word (e.g., *effort*) and decided if the two consecutive words they heard were the same or different. During control trials, s+c and 'e' onset words were not present together on the visual display. In this combined design, activation and perception were examined within a single task.

Similar results as Experiment 3a, activation of the L1 constraint during L2 processing, were expected for the first part of Experiment 3b (word recognition). Moreover, performance on the first part of the task (word recognition) was compared to the second part (AX discrimination) in order to examine the relation between activation and perceptual processes across participants. It was predicted that if bilinguals demonstrated residual effects of *perceptual repair* when presented with an s+c- or ‘e’-onset word during the AX discrimination part of the task, then they would also show cross-linguistic activation of the Spanish phonotactic constraint during English comprehension (i.e., looks to competitor *egg* when target *strict* is present). This pattern was expected due to the dependence of perception on auditory input, *which may have also generated activation mechanisms*. The Perceptual Assimilation Model (Best, 1994) suggests that L1 rules influence how sounds and sound sequences are perceived during auditory input in a top-down manner. Perceptual assimilation, or repair, would occur in this top-down way, with bilinguals initially accessing knowledge of the L1 (Spanish) phonotactic constraint and then repairing the input to conform to the constraint (e.g., *strict/estrict*). It was anticipated that auditory input would also be processed in a bottom-up way since within- and between-language phonological neighbors would be accessed, and eventually phonotactic constraints. Activation and perception may thus rely on top-down and bottom-up processes when auditory input is present. Alternatively, and given the results from Freeman et al. (in prep, Chapter 3, Experiment 2b) and Parlato-Oliveira et al. (2010), the low-level nature of the AX discrimination task may not be sensitive enough to tap into L1 perceptual influences during L2 processing. Therefore, a relation may not arise between activation and perception on the WRAX task. However, the results from Experiment 3b might discern the relative contributions of co-activation and co-perception, and how bottom-up and top-down processes influence bilingual language comprehension.

Monolinguals were not expected to demonstrate activation or perception patterns similar to bilinguals, as the stimuli lacked within-language (English) phonological overlap.

4.8 Experiment 3b Methods

Participants

Participants from Experiment 3b were the same from Experiment 3a, consisting of 26 English monolinguals and 25 Spanish-English bilinguals, aged 18-35, with normal or corrected-to-normal vision. Four participants (2 monolinguals, 2 bilinguals) were discarded in Experiment 3b due to eye-tracking equipment failure. Participants' overall linguistic and cognitive background measures did not change in significance from what was reported in Table 8.

Materials

The combined word recognition and AX discrimination (WRAX) task examined cross-linguistic activation from 'e' onset words when s+c onset words were present with eye-tracking, as well as perception of the 'e' onset in the AX discrimination portion of the task. Participants were instructed to 1) click on the target word they heard, after which they 2) heard a second word, and 3) decided if the two words they heard were the same or different. It was predicted that if bilingual participants activated the 'e' onset during the word recognition part of the trial (e.g., target *strict*, competitor *egg*), they would also perceive the 'e' onset during the AX part of the trial (e.g., *strict*). On the word recognition portion of the task, the within-subjects independent variable was fixations on cross-linguistic phonotactic competitors relative to unrelated filler items. On the AX discrimination portion of the task, the within-subjects independent variable was perception trial type (target: s+c onset followed by 'e' onset, control: 'e' onset followed by 'e' onset). Across both portions of the task, the between-subjects variable was language status (monolingual, bilingual). The dependent variables included eye fixation proportions to target and competitor items (word recognition), as well as accuracy and reaction times to identifying the target (word recognition) and to making the same/different judgment (AX).

The WRAX task was controlled by an iMac 3.3 GHz Intel Core i5 running MatLab 2011a, and stimuli were displayed on a 27-inch monitor with a screen resolution of 5120x2880. Eye movements were recorded using a desk-mounted eye-tracker (EyeLink 1000 Version 1.5.2, SR Research Ltd.) at a sampling rate of 1000 Hz. Mouse clicks to identify the target and keyboard button presses for the same/different judgment allowed for the collection of accuracy and reaction time data. The stimuli were recorded in a soundproof room (44,100 Hz, 16 bits) by a native male speaker of English. The audio recording was split into individual audio files. All files were normalized (via audio compression) in Praat (Boersma and Weenink, 2013) and exported into MatLab (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997).

Stimuli for the WRAX task included the same items from the word recognition task (Experiment 3a) and the AX discrimination task (Experiment 2b). Stimuli for Experiment 3b contained 1) s+c onset or control, 2) ‘e’ onset or control, and 3) two filler items. The four words were displayed in the visual world paradigm. The stimuli for the discrimination part of Experiment 3b included 1) s+c, 2) ‘e’ onset, and 3) control onset. See Sections 4.4 Materials (word recognition) and 3.7 Materials (AX discrimination) for lexical characteristics of the stimuli. Experiment 3b contained a total of 204 trials (12 practice, 192 experimental). The task included 48 trials in which phonotactic-constraint competition was present in the word recognition and AX discrimination portions, 48 trials in which cross-linguistic competition was not present, and 96 filler trials to balance the same/different judgments (AX discrimination part of the task) to a 1:1 ratio. The items were pseudo-randomized such that no more than two consecutive trials contained s+c onsets. Trial order was counterbalanced across participants by reversing the order of presentation.

Procedure

Participants were seated in a quiet room and the eye-tracker was calibrated. Instructions were to select the target item (e.g., *strict*) by clicking on the word they heard and then to decide if the second word (e.g., *effort*) heard was the same or different as the first (target item). Participants viewed four words on the screen while eye movements were tracked. During target trials, an s+c word was presented along with an ‘e’ onset competitor, as well as two filler items. Participants were told to identify the target item (e.g., *strict*) after 1000ms. As in Experiment 3a, the time course of cross-linguistic activation of phonotactic constraints could be examined within this design. The four word stimuli were presented in four quadrants (top-left, bottom-left, top-right, bottom-right), on a white screen in black, size 16 font. Presentation of the question lasted until the participant made a mouse click on a quadrant. Following target identification, the screen displayed “Press the spacebar to continue” in order to orient participants from the mouse to the keyboard. Participants then heard another word (e.g., *effort*) and decided if the two consecutive words they heard were the same or different. Presentation of the question about whether the words were the same or different lasted until the participant made a response. The left/right shift keys on the keyboard represented same/different responses. During control trials, s+c and ‘e’ onset words were not presented together. In this combined design, it was thus possible to examine both activation and perceptual processes. After the instructions and 12 practice trials, participants performed the experimental trials. See Figure 19 for task procedure.

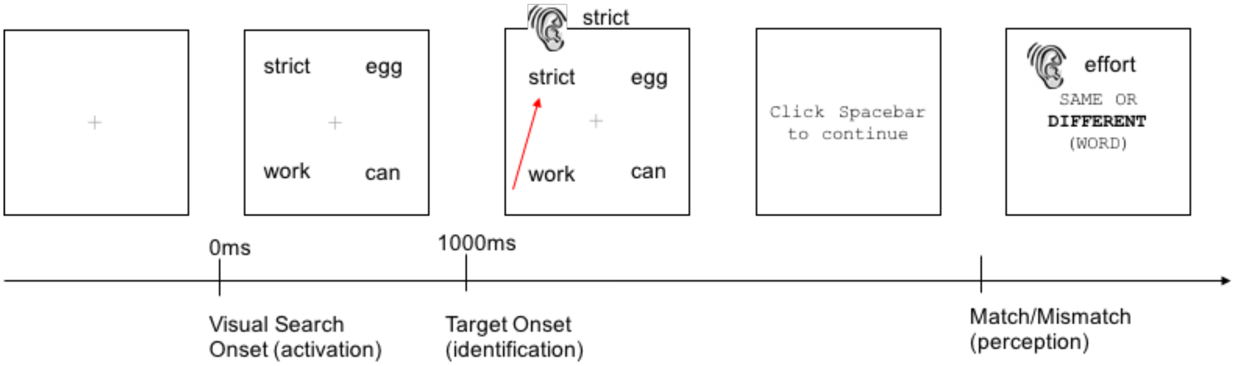

Figure 19: Example trial from the combined word recognition and AX discrimination task. In this example, participants viewed four words on the screen while eye movements were tracked. The words included a target that conflicted with the Spanish ‘e’ onset constraint (*strict*), a competitor that contained an ‘e’ onset (*egg*), and two filler items (*work*, *can*). Participants then heard the target word (*strict*). After identifying the target, participants heard a second word (*effort*) and had to decide if the two words they heard were the same or different.

The total time to complete this task was approximately 15 minutes. Participants performed the remaining tasks, then were debriefed about the study and compensated.

Coding and Analysis

For Experiment 3b, repeated-measures ANOVAs were employed to analyze accuracy and reaction times for activation and perception of phonotactic constraints. Reaction times and accuracy rates were collected from mouse clicks to identifying the target on the visual display (word recognition), as well as from keyboard clicks for same/different judgments (AX discrimination). Response times for the word recognition portion of the task were measured at the start of the visual display, until the participant responded. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time were not counted, approximately 1.5% of the data. Growth curve analysis (GCA; Mirman, Dixon, & Magnuson, 2008) of eye-tracking fixation proportions were employed to examine activation of irrelevant-language phonotactic constraints during auditory and visual word processing (word recognition).

Time-course of fixations. Eye-fixations were counted when participants maintained a consistent gaze duration on one of the four quadrants on the visual display for greater than 70ms; fixations below this time were not included. Fixation interest areas were built within each quadrant, measuring 350 x 350 pixels surrounding the center of each word. Only looks within the quadrants were considered. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time were discarded prior to analysis. The time-course analyses included fixations that were collapsed into 10ms bins, and participants' average fixation duration to each item at the 10ms bin was recorded. Time-courses included fixed effects of item type (competitors, fillers), language group (bilinguals, monolinguals), and the polynomial time terms. Visual fixations were analyzed from the auditory word onset until the point at which fixations to the target peaked, indicating final target selection, which was around 800ms post-word onset. This calculation also factors in 200ms to account for the time required to plan and execute an eye movement (Viviani, 1990). Within the 800ms time window post-word onset, a base fourth-order orthogonal polynomial was implemented to capture the rise and fall of visual fixations to the visual competitor and the average of both filler objects in the display. Orthogonal time terms were also treated as random slopes in the model. Random effects of participant and polynomial time term were also included. The best-fitting orthogonal polynomial time terms were determined by constructing models including linear, quadratic, cubic, and quartic time terms, and comparing the models using chi-square model comparisons. The maximally-converging model included random slopes of the linear, quadratic, cubic, and quartic orthogonal time terms on the random-effects structure of participant, and random slopes of the four time terms on the item type-by-language group structure ($\chi^2(9)=183.26, p<0.001$). The fixation analyses included comparisons of fixations to the /e/ onset item (competitor) relative to the unrelated filler items on the visual display. The average fixations to the two filler items were averaged together. *P*-values from all GCA models were calculated by assuming that the *t*-values converged to a normal distribution given the large number of observations present in time course data (Mirman, 2014).

For the AX discrimination portion of the WRAX task, reaction times and accuracy rates were analyzed. Reaction times were measured from the onset of the visual display upon hearing the second word, in which participants made a response. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time were disregarded. Means and standard deviations for each condition were then calculated and repeated-measures ANOVAs were performed for accuracy and reaction times. Condition comparisons of interest included, Spanish-conflicting: s+c (*strict*) followed by ‘e’ onset (*egg*) (S→E); and control: ‘e’ onset (*egg*), followed by ‘e’ onset (*effort*). Bilinguals who demonstrated a difference greater than the mean reaction time difference between these two conditions placed into greater difference (perceptual repair) group, *n* = 10, and bilinguals who had a smaller difference than the mean reaction time difference were placed into the smaller difference (no perceptual repair) group, *n* = 15. The AX perceptual repair effect was analyzed in a separate GCA.

4.9 Experiment 3b Results

The results of Experiment 3b were organized in a similar manner to word recognition in Experiment 3a, in addition to the AX discrimination task analyses. Accuracy rates and reaction times to identifying the target word (e.g., *strict*) on the visual display were first analyzed across bilinguals and monolinguals. Effects of accuracy and reaction time were examined using repeated measures ANOVAs. For word recognition, to uncover if bilinguals activated L1 phonotactics during L2 processing, eye movements, specifically fixation proportions over time to the competing words (e.g., *egg*) relative to filler words (e.g., *work* and *can*) on the visual display were analyzed across language groups. An analysis was performed based on L2 proficiency for eye-movement data for competitors and fillers. All time course data were analyzed using growth curve analyses (GCAs). Next, accuracy rates and reaction times to same/different judgments on AX discrimination were analyzed between bilinguals and monolinguals using repeated measures ANOVAs. Last, to examine the relation between performance on AX discrimination and word recognition within the bilingual group, an analysis was performed whereby bilinguals were divided into those who may have perceptually repaired the English words that conflicted with Spanish rules (e.g., *strict*) and those who did not perceptually repair. Performance between the repair and no-repair groups was examined on word recognition.

Accuracy and reaction time on Word Recognition. Bilingual and monolingual participants' accuracy was near ceiling, at 98.57% (*SD* = 3.22). Bilinguals' mean reaction time was 2437.07ms (*SD* = 246) and monolinguals' was 2243.77ms (*SD* = 271), $p < 0.01$.

Accuracy effects on Word Recognition. Accuracy rates were examined for the word recognition part of the task. Conditions of interest included target (s+c target *strict* and 'e' onset competitor) and control (control target and 'e' onset). A 2 (trial type: target, control) x 2 (language group: bilingual monolingual) repeated measures ANOVA was conducted on accuracy rates for identifying the target. There were no main effects of language group, $F(1,49) = 2.381$, $p = .129$, $\eta_p^2 = .043$, or condition $F(1,49) = 1.551$, $p = .218$, $\eta_p^2 = .028$. Bilinguals and monolinguals were equally accurate in their responses to identifying English words on the visual display.

Reaction time effects on Word Recognition. Reaction times to identifying the target word for bilinguals and monolinguals were analyzed next. A 2 (trial type: target, control) x 2 (language group: bilingual, monolingual) repeated measures ANOVA was conducted on reaction times for identifying the target when hearing its onset. There was a main effect of language, $F(1,49) = 8.578$, $p = .005$, $\eta_p^2 = .139$, with bilinguals ($M = 2449.17$ms, $SE = 33.12$) responding more slowly overall than monolinguals ($M = 2257.64$ms, $SE = 34.33$). There were no other main effects or interactions for reaction times (ps > .05). Bilinguals performing tasks in their L2 have been shown to demonstrate slower response times compared to monolinguals of the L2 (e.g., Dijkstra, Grainger, & van Heuven, 1999; Freeman et al., 2016).

Time course analyses on Word Recognition: monolinguals and bilinguals. The next step was to analyze whether bilinguals activated the Spanish phonotactic constraint during English processing through their looks to 'e' onset competitors items, relative to filler items with other onsets, when a Spanish-conflicting target word was present. Growth-curve analysis (GCA) was used to examine the time course of phonotactic-constraint activation in bilinguals. A time window was selected between 0 to 800ms post-word onset (including 200ms for fixation planning). This time window was used in order to uncover the effects of cross-linguistic activation of phonotactic constraints, with auditory presentation of the target word (e.g., *strict*). The model revealed a main effect of item type on the intercept, $\beta = 0.112$, $SE = 0.009$, $t = 11.879$, $p < 0.001$; linear, $\beta = 0.339$, $SE = 0.089$ $t = 3.779$, $p < 0.001$, cubic, $\beta = 0.219$, $SE = 0.089$, $t = 2.449$, $p = 0.014$; and quartic terms, $\beta = -0.420$, $SE = 0.089$, $t = -4.689$, $p < 0.001$, suggesting more fixations to filler versus competitor items for bilinguals and monolinguals. There were also significant interactions between item type and language group on the intercept, $\beta = 0.116$, $SE = 0.018$, $t = 6.172$, $p = 0.042$; linear, $\beta = -0.428$, $SE = 0.179$, $t = -2.386$, $p = 0.017$; quadratic, $\beta = -0.132$, $SE = 0.179$ $t = -7.353$, $p < 0.001$, and cubic terms, $\beta = 0.124$, $SE = 0.179$ $t = 6.938$, $p < 0.001$, demonstrating that bilinguals produced a larger difference in fixation proportions between filler and competitor items (more fixations to fillers) than did monolinguals.

Specifically, bilinguals looked at the filler items more than monolinguals, and less at the competitor items than monolinguals. No additional main effects or interactions emerged on any time terms. This pattern of results whereby bilinguals looked more to filler items than competitors during the time course is contradictory to our prediction, and indicative of no interference of L1 phonotactic constraints during L2 processing. However, the absence of a main effect of language suggests that there were no differences overall between bilinguals and monolinguals in fixation proportions to competitor versus filler items. See Table 12 for fixed effects on the word recognition portion of the WRAX task.

Table 12: Summary of parameter estimates for fixations by item type (competitor, filler) and language (bilingual, monolingual) in the Growth Curve Analysis for the word recognition portion of the WRAX task.

	β	Standard Error	*t*	*p*
Language: Intercept	0.013	0.075	0.182	0.85
Language: Linear	0.397	0.611	0.650	0.51
Language: Quadratic	-0.227	0.337	-0.674	0.50
Language: Cubic	-0.135	0.082	-1.647	0.11
Language: Quartic	-0.031	0.168	-0.185	0.85
Item Type: Intercept	0.112	0.009	11.879	< 0.001
Item Type: Linear	0.339	0.089	3.778	< 0.001
Item Type: Quadratic	-0.151	0.089	-1.689	0.09
Item Type: Cubic	0.219	0.089	2.449	0.01
Item Type: Quartic	-0.420	0.089	-4.689	< 0.001
Language*Item Type: Intercept	0.116	0.018	6.172	< 0.001
Language*Item Type: Linear	-0.428	0.179	-2.386	0.02

Language*Item Type: Quadratic	-0.132	0.179	-7.353	< 0.001
Language*Item Type: Cubic	1.246	0.179	6.938	< 0.001
Language*Item Type: Quartic	0.328	0.179	1.830	0.06

See Figure 20 for monolingual/bilingual differences in time course analyses.

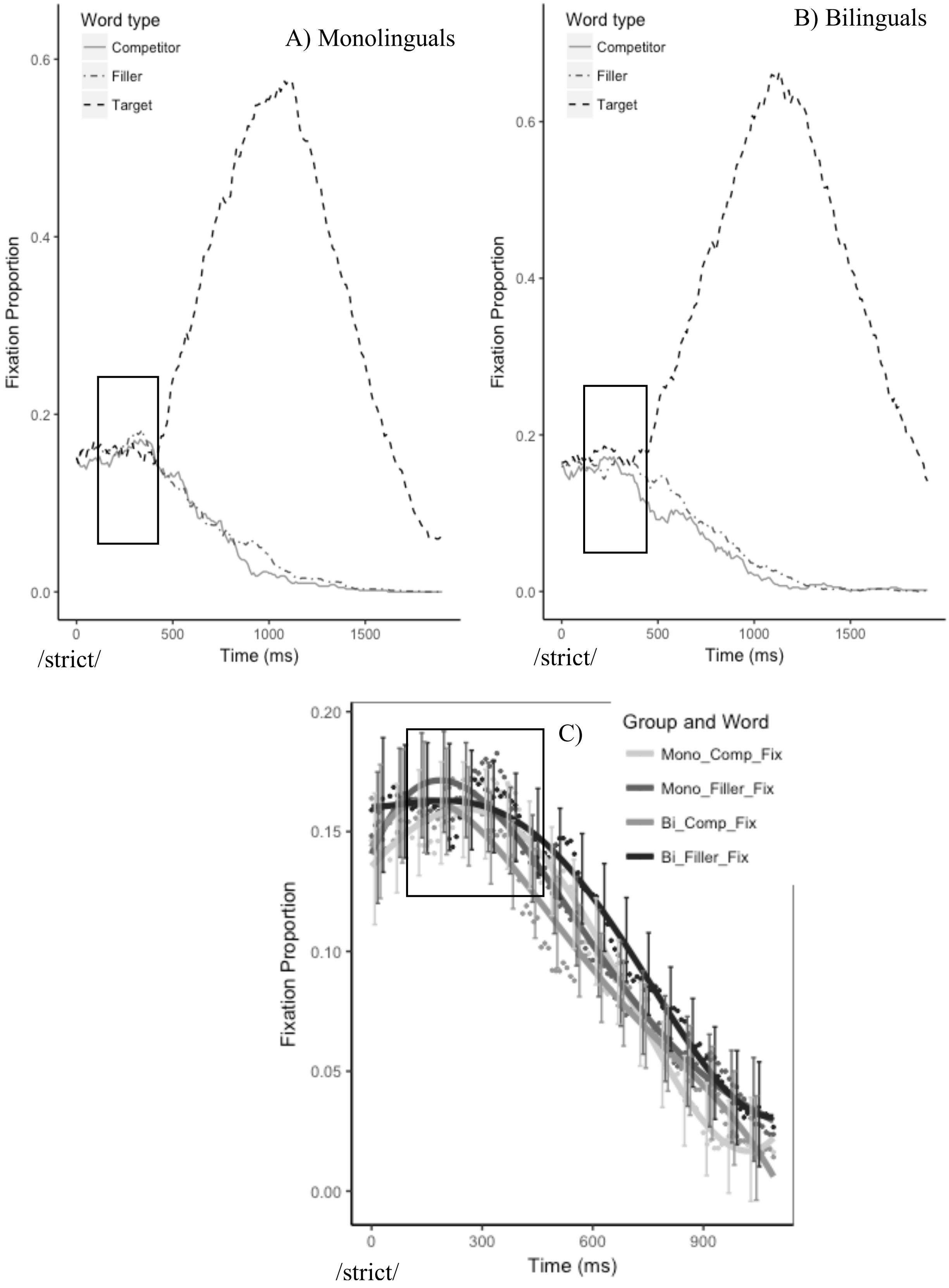
A) Monolinguals
Word type
Competitor
Filler
Target
Fixation Proportion
0.0
0.2
0.4
0.6
0
500
1000
1500
Time (ms)
/strict/
B) Bilinguals
Word type
Competitor
Filler
Target
Fixation Proportion
0.0
0.2
0.4
0.6
0
500
1000
1500
Time (ms)
/strict/
C)
Group and Word
Mono_Comp_Fix
Mono_Filler_Fix
Bi_Comp_Fix
Bi_Filler_Fix
Fixation Proportion
0.00
0.05
0.10
0.15
0.20
0
300
600
900
Time (ms)
/strict/

Figure 20: Time course analyses for A) monolinguals and B) bilinguals. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler items (*work*, *can*). X axis represents the time course starting at the onset of the target (*strict*). C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions to competitor and filler items for monolinguals and bilinguals. Error bars represent 95% confidence interval of GCA model fits. Overall, there were no observed differences in fixations to competitor versus filler items across monolinguals and bilinguals in the 200-400ms time window post-initial sound onset.

Differences in L2 proficiency within bilinguals[8]. We next examined whether the absence of phonotactic-constraint activation during word recognition was present throughout the entire bilingual group. As in Experiment 3a, a follow-up analysis was employed to examine whether L2 (English) proficiency affected bilinguals' performance on word recognition. A composite score comprising of objective (PPVT percentile rank) and subjective measures (LEAP-Q averaged speaking, understanding, and reading proficiency ratings) was calculated. Within the bilingual group, 10 bilinguals were rated as having lower proficiency in English, and 15 were rated as having higher proficiency in English. Within the 0-400ms time window post-word onset, there was a main effect of proficiency on the intercept term, $\beta = -0.389$, $SE = 0.172$, $t = -2.261$, $p = 0.032$. There was a main effect of item type on the intercept, $\beta = 0.534$, $SE = 0.028$, $t = 2.339$, $p = 0.019$; quadratic, $\beta = 0.463$, $SE = 0.144$, $t = 3.207$, $p = 0.001$; cubic $\beta = 0.300$, $SE = 0.144$, $t =$

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[8] Differences in age of acquisition and dominance did not modulate any of the observed effects within the bilingual group. As in Experiment 3a, follow-up GCA analyses for time course data across bilingual/monolingual groups and within the bilingual group (proficiency) were performed to verify if there were any competitor versus filler effects in the absence of the Spanish-conflicting target (e.g., *strict*), which was replaced by a non-conflicting word (target-absent condition: e.g., *demand*). Between bilinguals and monolinguals, there were no main effects of language group on any of the time terms, *p*s > 0.1, and fixation patterns did not differ from the target-present condition. Within the bilingual group, the main effects of proficiency on the time terms once again disappeared in the target-absent condition, *p*s > 0.1, suggesting that in the target-present condition, greater fixation proportions to targets versus competitors occurred because of the presence of a Spanish-conflicting target.

2.079, $p = 0.037$; and quartic terms, $\beta = -0.339$, $SE = 0.144$, $t = -2.344$, $p = 0.019$, with more looks to filler than competitor items. There were also significant interactions of item type x proficiency on the intercept, $\beta = 0.430$, $SE = 0.047$, $t = 9.038$, $p < 0.001$; and linear terms, $\beta = -0.663$, $SE = 0.30$, $t = -2.203$, $p = 0.027$. A follow-up t-test within 0-400ms post-word onset revealed that bilinguals who had a lower L2 (English) proficiency produced a greater proportion of fixations to the 'e' onset word relative to filler items, $t = 2.472$, SE=0.40, $p = 0.013$. Time course data within the bilingual group suggest that those bilinguals with lower proficiency in their L2 were more likely to activate the Spanish (L1) phonotactic constraint when processing English (L2) words. This finding is in line with our initial prediction that bilinguals experience L1 interference from phonotactic constraints during L2 processing. However, proficiency modulated phonotactic-constraint activation whereby those bilinguals with lower proficiency in the language of testing (L2) accessed the constraint. See Table 13 for a summary of fixed effects in the GCAs.

Table 13: Summary of parameter estimates for fixations by item type (competitor, filler) and proficiency (lower, higher) in the Growth Curve Analysis for the word recognition portion of the WRAX task.

	β	Standard Error	*t*	*p*
Proficiency: Intercept	-0.389	0.172	-2.261	0.03
Proficiency: Linear	0.264	0.357	0.738	0.46
Proficiency: Quadratic	-0.112	0.259	-0.434	0.66
Proficiency: Cubic	-0.757	0.171	-0.044	0.96
Proficiency: Quartic	0.002	0.161	0.002	0.99
Item Type: Intercept	0.534	0.022	2.339	0.02
Item Type: Linear	0.085	0.144	0.591	0.55

Item Type: Quadratic	0.463	0.144	3.207	< 0.01
Item Type: Cubic	0.300	0.144	2.079	0.03
Item Type: Quartic	-0.339	0.144	-2.344	0.01
Proficiency*Item Type: Intercept	0.430	0.047	9.038	< 0.01
Proficiency*Item Type: Linear	-0.663	0.301	-2.203	0.02
Proficiency*Item Type: Quadratic	-0.226	0.301	-0.750	0.45
Proficiency*Item Type: Cubic	-0.171	0.301	-0.568	0.56
Proficiency*Item Type: Quartic	0.087	0.301	0.291	0.77

See Figure 21 for monolingual/bilingual differences in the time course of fixations to ‘e’ onset competitor items, relative to filler items.

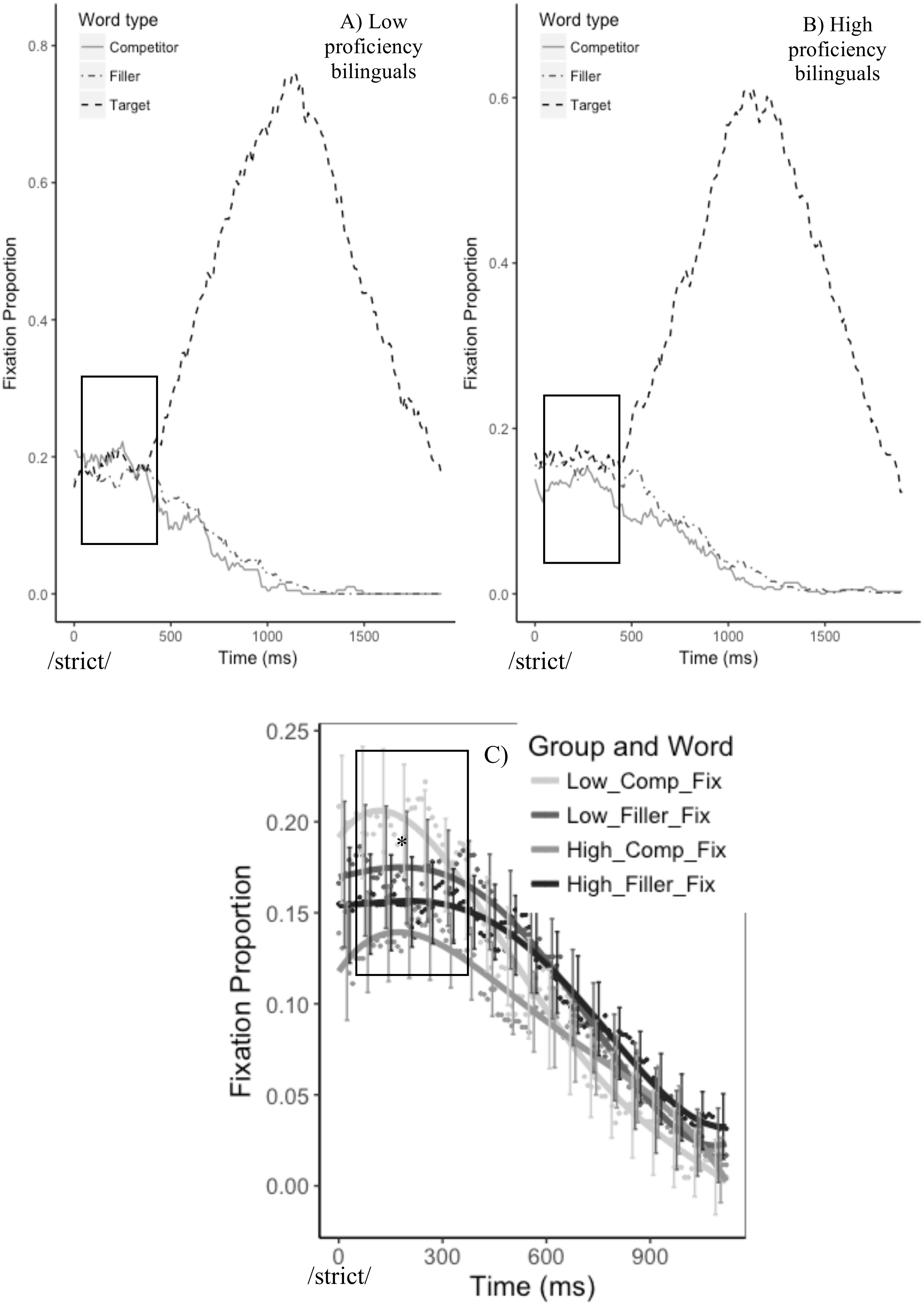
A) Low proficiency bilinguals
Word type
Competitor
Filler
Target
Fixation Proportion
0.0
0.2
0.4
0.6
0.8
0
500
1000
1500
Time (ms)
/strict/
B) High proficiency bilinguals
Word type
Competitor
Filler
Target
Fixation Proportion
0.0
0.2
0.4
0.6
0
500
1000
1500
Time (ms)
/strict/
C)
Group and Word
Low_Comp_Fix
Low_Filler_Fix
High_Comp_Fix
High_Filler_Fix
*
Fixation Proportion
0.00
0.05
0.10
0.15
0.20
0.25
0
300
600
900
Time (ms)
/strict/

Figure 21: Time course analyses for bilinguals with A) lower proficiency and B) higher proficiency in English. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler items (*work*, *can*). X axis represents the time course starting at the onset of the target (*strict*). C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions to competitor and filler items for lower proficiency and higher proficiency bilinguals. Error bars represent 95% confidence interval of GCA model fits. Bilinguals with lower English proficiency looked at the competitor more than the filler during the 100-300ms time window post-word onset, suggesting activation of the 'e' onset phonotactic constraint, *p = 0.013.

Word recognition findings from Experiment 3b are in line with the results from Experiment 3a. Across Experiments 3a and 3b, although bilinguals and monolinguals did not demonstrate any group differences in looks to competitor (e.g., *egg*) versus filler items (e.g., *work/can*) when the target word for identification conflicted with Spanish rules (e.g., *strict*), lower English (L2) proficiency bilinguals indeed demonstrated greater fixation proportions to competitor versus filler items. The subsequent results from Experiment 3b pertain to perceptual processes, specifically perceptual repair, when L2 words (e.g., *strict*) conflict with L1 rules (e.g., Spanish v+s+c onset rule), as well as the relation between activation and perception processes in bilinguals.

Accuracy effects on AX Discrimination. Next, accuracy rates were analyzed on the AX discrimination portion of the task. Condition comparisons of interest included, A: s+c (*strict*), followed by X: 'e' onset (*egg*) (S→E); and A: 'e' onset (*egg*), followed by X: 'e' onset (*effort*). A 2 (condition: S→E, E→E) x 2 (language group: bilingual, monolingual) repeated measures ANOVA was conducted on accuracy rates for identifying if AX pairs were the same or different. There were no significant main effects of language group, $F(1,49) = .057$, $p = .812$, $\eta_p^2 = .001$, or condition, $F(1,49) = 2.953$, $p = .092$, $\eta_p^2 = .053$, likely because participants performed at ceiling on this task (*Ms* > 98%, *p*s > .30). Therefore, bilinguals and monolinguals were equally accurate in their same/different judgments to English word pairs.

Reaction time effects on AX Discrimination[9]. Overall reaction times for bilinguals and monolinguals were analyzed, with the prediction that bilinguals would be slower to decide if the two words they heard were the same or different, as they were performing this task in their L2 (Dijkstra, Grainger, & van Heuven, 1999). A 2 (condition: S→E, E→E) x 2 (language group: bilingual, monolingual) repeated-measures ANOVA revealed no main effects of language, $F(1,49) = 1.119$, $p = .295$, $\eta_p^2 = .021$, or condition, $F(1,49) = .004$, $p = .952$, $\eta_p^2 = .000$. There was also no interaction between condition and language group, $F(1,49) = 2.816$, $p = .099$, $\eta_p^2 = .050$. Despite the lack of any observed language or condition effects, planned follow-up paired t-tests between S→E and E→E conditions revealed no significant differences for either monolinguals or bilinguals (*p*s > .2). Overall, the absence of bilingual/monolingual group differences, as well as the lack of between-condition differences within the bilingual group on AX discrimination suggest that L1 perceptual repair during L2 processing does not occur in a task that taps only into low-level perceptual representations. The current AX discrimination findings are also in line the AX discrimination results from Chapter 3 of this dissertation, whereby no effects of perceptual repair were detected.

Relation in performance across AX Discrimination and Word Recognition in bilinguals. To examine the relation between performance on the word recognition and AX discrimination portions of the task (activation and perception), an additional GCA was constructed. Bilinguals who demonstrated a difference greater than the mean reaction-time difference to the target

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[9] A follow-up ANOVA on proficiency, age of acquisition, and dominance and condition within the bilingual group revealed no main effects or interactions on the AX task (*p*s > .09)

(S→E) minus control (E→E) conditions were assigned to the greater difference group (*n* = 10). The greater difference in response time between the Spanish-conflicting and control conditions could indicate that perceptual repair was responsible. Bilinguals who showed a difference smaller than the mean reaction-time difference across the two conditions were assigned to the smaller difference group (*n* = 15). The bilinguals with a smaller difference in response time between Spanish-conflicting and control conditions may have not perceptual repaired the input, such that conflicting versus control trials were regarded as the same. Word recognition patterns were then compared between the greater difference and smaller difference AX groups. This is the first investigation to examine performance on a single task measuring both activation and perception of phonotactic constraints of the irrelevant language (Spanish). The GCA model included fixed effects of item type (competitors, fillers), AX group (greater difference, smaller difference), and the polynomial time terms. Random effects of participants were also included. Based on the prediction that language co-activation affects perception, it was expected that there would be a main effect of AX group and an interaction between item type and AX group. Alternatively, given the findings of Chapter 3 of this dissertation, AX discrimination, the low-level perceptual nature of task might not have been sensitive enough to tap into the perceptual repair effect. Results mostly supported the latter prediction. While there was no main effect of AX group on any of the terms (ps > 0.1), there were main effects of item type on the intercept, $\beta = 0.172$, $SE = 0.045$, $t = 13.499$, $p < 0.001$; quadratic, $\beta = -0.788$, $SE = 0.123$, $t = -6.386$, $p < 0.001$; cubic, $\beta = 0.901$, $SE = 0.045$, $t = 7.304$, $p < 0.001$; and quartic terms, $\beta = -0.285$, $SE = 0.123$, $t = -2.313$, $p = 0.020$, as well as interactions between AX group and item type on the linear, $\beta = 0.068$, $SE = 0.261$, $t = 2.615$, $p = 0.008$; quadratic, $\beta = -1.189$, $SE = 0.252$, $t = -4.718$, $p < 0.001$; cubic, $\beta = 1.595$, $SE = 0.252$, $t = 6.330$, $p < 0.001$; and quartic terms, $\beta = 0.987$, $SE =$

0.252, $t = 3.917$, $p < 0.001$. This interaction suggests that the bilinguals in the greater difference AX group showed a greater difference in fixation proportions between competitors (e.g., *egg*) and fillers (e.g., *work/can*) throughout the 0-800ms post-word onset time window[10]. See Table 14 for a summary of fixed effects in the GCAs. Initially, it appeared that the greater AX group looked more to the competitor versus filler items in the 120-300ms time window post-word onset, followed by the inverse pattern after 500ms post-word onset. However, given the lack of an overall group effect, the greater and smaller AX difference groups performed similarly on word recognition. Thus, we saw an absence of a relation between activation and perception on the WRAX task. Those bilinguals who may have perceptually repaired Spanish-conflicting input did not also activate the Spanish constraint. This lack of a relation may be found in the AX discrimination portion of the task, where an overall perceptual repair effect was absent within the bilingual group.

Table 14: Summary of parameter estimates for fixations by item type (competitor, filler) and AX group (greater difference in reaction times between target and control conditions, smaller difference in reaction times between target and control conditions) in the Growth Curve Analysis for the word recognition portion of the WRAX task.

	β	Standard Error	*t*	*p*
AX Group: Intercept	-0.095	0.097	-0.981	0.33
AX Group: Linear	1.215	0.755	1.609	0.12
AX Group: Quadratic	0.368	0.517	0.712	0.48

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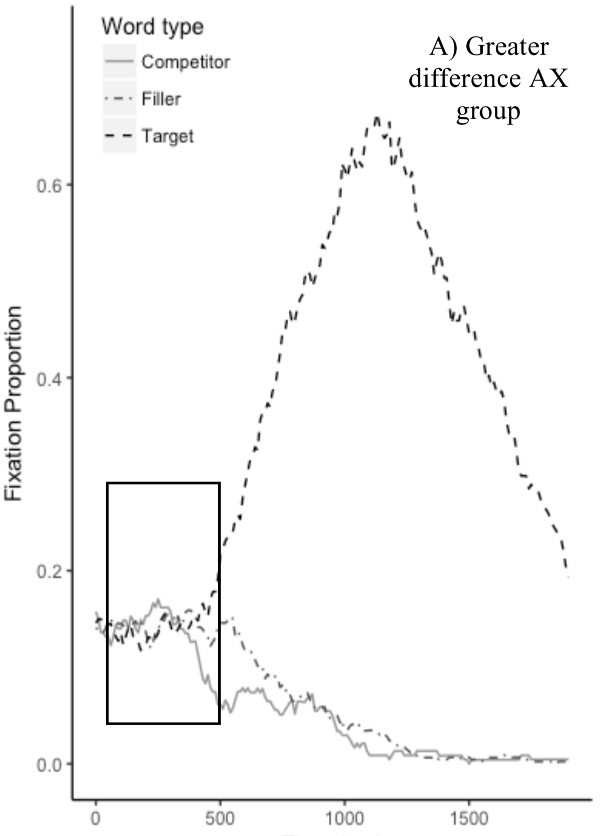
[10] Following up on this interaction in which the greater difference AX group looked more at the competitor than filler items during the 120-300ms time window post-word onset, an additional GCA was performed within this time window, however there were no significant main effects of AX group or AX-group by item-type interactions in the model (*p*s > 0.1). Moreover, a proficiency*AX group analysis was conducted resulting in no significant effects (*p*s > 0.1). This latter analysis has limited viability due to the small number of participants assigned to each group leading to low effect sizes.

AX Group: Cubic	-0.359	0.353	-1.015	0.31
AX Group: Quartic	0.220	0.173	1.270	0.21
Item Type: Intercept	0.172	0.012	13.499	< 0.001
Item Type: Linear	0.108	0.123	0.875	0.38
Item Type: Quadratic	-0.788	0.123	-6.386	< 0.001
Item Type: Cubic	0.901	0.123	7.304	< 0.001
Item Type: Quartic	-0.285	0.123	-2.313	0.02
AX Group*Item Type: Intercept	0.068	0.261	2.615	0.01
AX Group*Item Type: Linear	-0.210	0.252	-0.834	0.40
AX Group*Item Type: Quadratic	-1.189	0.252	-4.718	< 0.001
AX Group*Item Type: Cubic	1.595	0.252	6.330	< 0.001
AX Group*Item Type: Quartic	0.987	0.252	3.917	< 0.001

See Figure 20 for the bilingual graphs. This finding preliminarily suggests that activation in the word recognition portion of the WRAX task did not affect perception in the AX portion of the WRAX task. However, these results should be interpreted with caution, as the AX task might not be sensitive enough to tap into L1 perception during L2 processing (see Chapter 3 for discussion).



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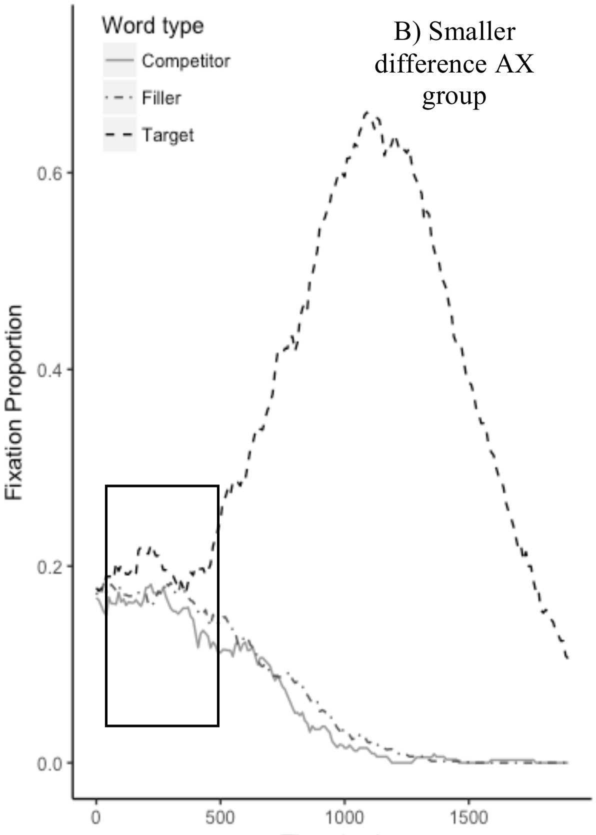

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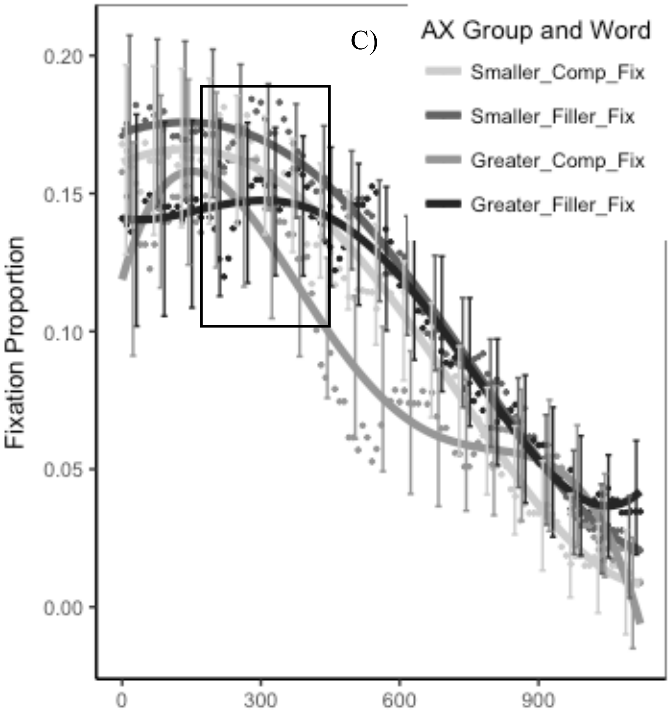

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Figure 22: Time course analyses for A) bilinguals who demonstrated a difference greater and B) less than the mean difference between target (S→E) and control (E→E) conditions on the AX task. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler items (*work*, *can*). X axis represents the time course starting at the onset of the target (*strict*). C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions to competitor and filler items for greater and smaller difference bilinguals. Error bars represent 95% confidence interval of GCA model fits. Bilinguals who may have perceptually repaired to the 'e' vowel onset (greater AX difference group) did not look at the 'e' onset competitor more than the filler items when there was a Spanish-conflicting target (e.g., *strict*).

4.10 Discussion

The focus of Experiment 3b was to examine the interplay between bottom-up and top-down processes in activation and perception during bilingual language comprehension. Experiment 3b included measures of activation and perception of L1 Spanish phonotactic constraints during L2 English visual and spoken word comprehension. Methodology was combined from Experiment 3a (word recognition) and Freeman et al. (in prep, Chapter 3) (AX discrimination). Specifically, bottom-up activation in word recognition was measured where the participant saw four words on the screen (target, competitor, 2 filler items). As in Experiment 3a, the target and competitor items were s+c- and 'e'-onset words, respectively. With respect to bottom-up activation, we predicted that L1 Spanish speakers would look more at the phonotactic competitor items (e.g., *egg*) than the filler items (e.g., *work*, *can*) when hearing the target during the time course of word recognition. In the second part of Experiment 3b, the participant heard another word after the target and decided if the two words s/he heard were the same or different. Here, we predicted that top-down processing affected bilinguals' perception of the auditory input due to knowledge of the Spanish v+s+c constraint.

Results demonstrated no differences across bilinguals and monolinguals when looking at the 'e' onset competitor (e.g., *egg*) when an s+c target (e.g., *strict*) was present, relative to filler items (e.g., *work*, *can*). However, within the bilingual group, those with lower L2 (English) proficiency *did* demonstrate the predicted pattern, with more looks to competitor than filler items early on during the time-course of phonotactic-constraint activation. This pattern of results in lower proficiency bilinguals suggests that the Spanish phonotactic constraint was initially activated in a bottom-up way. Furthermore, for the AX discrimination part of the task, there were no differences in performance across monolinguals and bilinguals. Within bilinguals, there was no observed relation between activation and perception, as performance on AX discrimination did not predict performance on word recognition. Although not in line with our initial predictions, this finding should be interpreted along with the notion that AX discrimination in the bilinguals' L2 is not sensitive to capture perceptual effects from the L1, as supported by the results of AX discrimination in Experiment 2b of Freeman et al. (in prep, Chapter 3). Therefore, top-down perceptual influences were limited in the WRAX task.

4.11 General Discussion

Summary of findings. The focus of the current investigation was twofold: 1) to dissociate language activation from perception in bilinguals (Experiment 3a), and 2) to examine the interplay between the bottom-up and top-down processes employed during bilingual language co-activation and co-perception (Experiment 3b). In Experiment 3a, participants identified a target word amongst four words on a visual display, while receiving minimal auditory input (word onset: "Click on /s/"). This design allowed us to investigate if bilinguals accessed L1 phonotactic constraints during L2 processing in a bottom-up manner. Results demonstrated that bilinguals with lower proficiency in their L2 (English), looked at the 'e'-onset competitor (e.g., *egg*) in the visual display when the s+c-onset word (target; *strict*) was present more so than the filler items (e.g., *work*, *can*). These results suggest that native Spanish speakers with lower proficiency in English activated the Spanish phonotactic constraint when processing English words. These findings are similar to those of previous studies examining how L2 proficiency modulates parallel processing (Blumenfeld & Marian, 2013; Mercier, Pivneva, & Titone, 2014). Experiment 3a is unique in that, for the first time, evidence is found for phonotactic-constraint activation of the unintended language with minimal auditory input, as participants only heard the onset sound of the target word for identification.

In Experiment 3b, participants first viewed four words on the screen, heard the target word, and then heard a second word, at which point a same/different judgment was made. This combined word recognition (activation) and AX discrimination (perception) (WRAX) task allowed for the examination of the relation between activation and perception during bilingual language processing. Results suggested that when a Spanish-conflicting word (s+c onset) was present, only bilinguals with lower L2 proficiency looked more to the ‘e’-onset competitor than on the filler items. Interestingly, no differences in performance were observed between bilinguals and monolinguals on the AX discrimination portion of the task. Moreover, model analyses revealed no effects of activation during word recognition and repair of Spanish-conflicting input during perception. Therefore, although lower L2 proficiency bilinguals initially experienced bottom-up activation when identifying target words, top-down perceptual processes were not engaged when making low-level same/different judgments based on two consecutive auditory stimuli. The low-level nature of this task was not suitable to capture the perceptual effects that have been observed previously in explicit measures of L1 vowel perception during L2 processing, as in vowel detection (see Freeman et al., in prep, Chapter 3, Experiment 2a, as well as Parlato-Oliveira et al., 2010, for discussion). Current findings for Experiments 3a and 3b are discussed in more detail within the context of previous literature on bilingualism. Furthermore, we elucidate the mechanisms involved during bilingual language processing by relating the current findings to theoretical models on language activation and perception.

Language co-activation in bilinguals. Across Experiment 3a and 3b, we found further evidence that bilinguals activated both of their languages simultaneously when in a single-language context. In the current investigation, bilinguals with lower L2 proficiency accessed phonotactic constraints from the irrelevant language. Bilinguals face cross-linguistic conflict at the lexical (Finkbeiner, Forster, Nicol & Nakamura, 2004; Fitzpatrick & Indefrey, 2010; Hartsuiker, Pickering & Veltkamp, 2004; Ju & Luce, 2004; Kaushanskaya & Marian, 2007; Loebell & Bock, 2003; Marian & Spivey, 2003a, b; Martín, Macizo, & Bajo, 2010; Schoonbaert, Duyck, Brysbaert & Hartsuiker, 2009; Sunderman & Kroll, 2006; Thierry & Wu, 2007) and sub-lexical levels (Freeman et al., 2016, Chapter 2; Freeman et al., in prep, Chapter 3; Lentz & Kager, 2015; Weber & Cutler, 2006), and this type of language competition is greater than what monolinguals encounter in everyday conversations (see Kroll & Bialystok, 2013 for discussion). Evidence for phonological competition between languages in bilinguals of varying proficiencies has been widely supported and replicated in previous studies (e.g., Blumenfeld & Marian, 2007; 2013; Linck, Hoshino, & Kroll, 2008; Marian & Spivey 2003a, b; Mercier, Pivneva, & Titone, 2014). To illustrate, *plug* activates *plum* in English monolinguals, while *plug* also activates *pluma* ("pen") for Spanish-English bilinguals. In the current study, bilinguals were tested in their L2. Those participants with lower L2 proficiency experienced increased L1 activation. In parallel, participants in Blumenfeld and Marian (2013), as well as Mercier, Pivneva, and Titone (2014) were tested in their L1 and experienced increased L2 activation as L2 proficiency increased.

This cross-linguistic competition scenario has been demonstrated even without auditory input (Chabal & Marian, 2015). These experiments have traditionally employed the visual world paradigm to examine within- and between-language activation (Blumenfeld & Marian, 2007, 2011, 2013; Chabal & Marian, 2015; Marian & Spivey, 2003a, b; Mercier et al., 2014). Only one study has examined within- and between-language activation without auditory input. Chabal and Marian (2015) investigated English monolinguals' and Spanish-English bilinguals' eye movements to picture displays containing phonological target and competitor items within and between languages. Critically, a picture of the target item was visually presented in the center of the screen (no auditory input), and participants identified the target amongst the other four pictures. When the target item was *clock*, English monolinguals and Spanish-English bilinguals looked at a picture of *cloud*. However, bilinguals also looked at *gift* (Spanish "regalo") because it phonologically overlapped with the Spanish translation of *clock* ("reloj"). Results from Chabal and Marian provide further evidence that bilinguals experience parallel language processing, in this case, without auditory input. In Experiment 3a, we demonstrated that bilinguals accessed phonotactic constraints from the irrelevant language. First, bilinguals' looks to competitor and filler items suggested that bilinguals accessed the Spanish phonotactic constraint during English comprehension when only being cued into the target's onset sound. Similar results were found in Experiment 3b, however, the target word was presented aurally in its entirety. Findings from Experiment 3a, along with Chabal and Marian, suggest that bilinguals activate both languages in parallel when viewing words and pictures with no to minimal auditory input.

Speech perception in bilinguals. Aside from previous findings on simultaneous language activation in bilinguals, the current investigation sheds light on the extent to which bilinguals co-perceive languages. Previous studies have demonstrated that when listening to L1-like pseudowords, or made-up words, that conflicted with L1 phonotactic constraints, bilinguals repaired the sound sequences to make them in line with L1 rules (Carlson, Goldrick, Blasingame, & Fink, 2016; Parlato-Oliveira, Christophe, Hirose, & Dupoux, 2010; Weber & Cutler, 2006). Carlson, Goldrick, Blasingame, and Fink (2016) tested native Spanish speakers on tasks measuring vowel perception. Across perceptual measures, Spanish-conflicting nonsense words were used with the 'e' or 'a' onset spliced away from the onset at varying degrees. While Carlson et al. found that Spanish-dominant bilinguals perceived the vowel onset when it was not present during *L1* processing, the current investigation found an absence of L1 perceptual repair during L2 processing. There were no perceptual effects when participants were asked to distinguish between two competing stimuli (e.g., *strict* followed by *egg*), potentially since the task was not sensitive enough to tap into L1 perceptual repair. It may be that this L1-like perceptual vowel illusion during L2 processing only occurs on tasks that explicitly measure vowel perception and/or tax metalinguistic awareness (i.e., vowel detection, lexical decision, and not AX discrimination) (Parlato-Oliveira et al., 2010). This finding is also supported by the results from Freeman et al. (in prep, Chapter 3), which demonstrated that L1 perceptual repair during L2 speech comprehension was limited to when the participants were asked if they detected a vowel at the beginning of Spanish-conflicting words (vowel detection) or when lexical access was required (lexical decision, Chapter 5). Thus, findings from the current investigation test the extent to which L1 perceptual representations influence L2 processing.

On the relation between language activation and speech perception. We now turn towards a discussion on bilingual language modeling to garner support for the mechanisms on which bilinguals rely to process auditory input. In Experiment 3b, it was posited that two processes interacted: language co-activation in a bottom-up manner and language co-perception in a top-down way. Specifically, processing auditory and/or visual input in a bottom-up way as it unfolds, supports activation of within- (monolinguals and bilinguals) and between-language (bilinguals only) neighbors. This activation flows from orthography/phonology, the lexicon, and constraints. Top-down processing of auditory input, as predicted in AX discrimination in Experiment 3b, suggests that perception begins at the level of rules or constraints within the L1, flowing down to the phonological level. Constraints may dictate, for example, whether a sound sequence being heard needs to be repaired to conform to L1 rules. Although our findings confirm the former scenario with language co-activation, more evidence is needed for the top-down perceptual processes involved during speech comprehension. The lack of effects on AX discrimination demonstrate that low-level same/different judgments on consecutive stimuli are not sensitive to cross-linguistic perceptual repair. Perhaps in a more explicit measure combined with word recognition, such as asking whether a vowel was present at the target word's onset (Carlson et al., 2016; Cuetos et al., 2008; see Experiment 2a, vowel detection, Freeman et al., in prep, Chapter 3), bilinguals would demonstrate L1 perceptual effects during L2 processing. Thus, in an explicit measure of vowel perception combined with the current word recognition task, it is predicted that bottom-up and top-down processes would be responsible for language co-activation and co-perception in bilinguals.

In addition to empirical support, the current findings can be interpreted within the context of the Activation Threshold Hypothesis (Paradis, 2004). As sounds unfold during auditory input, constraints from the unintended language may become activated based on the combination of sounds the bilingual is hearing in a bottom-up manner. Activation of a word and its neighbors occurs as a threshold is approached. Target word selection requires that activation of the target exceeds that of its alternatives. The Activation Threshold Hypothesis thus suggests that co-activation of phonotactic constraints in bilinguals occurs in a bottom-up way.

Limitations and future directions. A potential limitation of Experiments 3a and 3b is the assumption that bilinguals are not accessing stored representations for sound sequences in their minds. For example, when visually presented with an English word that conflicts with the Spanish v+s+c rule (e.g., *strict*), it is unclear whether the L1 Spanish speaker's representation of English *strict* is *strict* or *estrict*. Hallé et al. (2008) showed Spanish monolinguals Spanish-like s+c non-words (orthography), which conflicted with the Spanish v+s+c rule. The Spanish monolinguals appeared to perceptually or phonotactically repair the visual input to conform to the v+s+c rule. However, an alternative explanation for the pattern of results for Spanish monolinguals in Hallé et al. is that they processed the visual input in a bottom-up manner, therefore *activating* the Spanish phonotactic constraint. The results from the current investigation suggest the latter interpretation given that in order to tap into speech perception processes (i.e., auditory templates for sounds in words), auditory input is required (Best, 1994).

The two experiments in this investigation set the stage to further examine the two mechanisms come on-line as bilinguals process auditory input. 1) Bilinguals hear a word unfold through time, and neighbors are accessed that conform to L1 phonotactics within and between languages in a bottom-up way. 2) Bilinguals perceive a word, specifically through the recruitment of L1 phonotactic constraints, in a top-down manner. Although in Experiment 3a we dissociated activation from perception by minimizing auditory input, in Experiment 3b, when auditory input was present, it was similarly processed in a bottom-up manner by bilinguals with lower L2 proficiency. As a Spanish-English bilingual views or hears the word *strict*, s/he accesses neighbors, such as *sink*, *sárten* (pan), *string*, *estudio* (study) through bottom-up activation. Future investigations should identify if the phonotactic constraint of adding an ‘e’ to the onset of a Spanish word influences how English *strict* is perceived, in a top-down manner (e.g., *estrict*), once auditory input is heard.

In Experiments 3a and 3b, we identified the mechanism recruited during bilingual language comprehension, specifically bottom-up activation, which accounted for cross-linguistic access of phonotactic constraints in bilinguals. Future investigations should further examine the role of top-down perceptual mechanisms and how they may vary depending on the perceptual nature of the task. Moreover, cognitive control in perception of phonotactic constraints should be explored. In a previous investigation, Freeman, Blumenfeld and Marian (2017) identified a link between activation of Spanish phonotactic constraints during English processing and non-linguistic Stroop task performance within Spanish-English bilinguals. Specifically, decreased phonotactic-constraint competition was associated with better, or more efficient Stroop performance. Moreover, Blumenfeld and Marian (2013) found that the amount of parallel activation of both languages was linked to cognitive control abilities in bilinguals. In the visual world paradigm, Spanish-English bilinguals and English monolinguals saw target (*comb*), competitor (*rabbit*, Spanish: “conejo”), and two filler items. Bilinguals activated the Spanish competitor item, as evidenced by looks to those items over the filler items. In addition, greater early parallel activation (between 300-500ms after the onset of the target item) followed by reduced later parallel activation (633-767ms after the target onset) was associated with smaller non-linguistic Stroop effects (i.e., more efficient performance). The results from Blumenfeld and Marian (2013), along with others (e.g., Mercier, Pivneva, & Titone, 2014), emphasize the role of cognitive control during bilingual language processing. This interdependent relation likely exists since bilinguals must manage simultaneous activation of two languages (Freeman, Shook, &

Marian, 2016). Bilinguals can be considered “mental jugglers” of two languages (Kroll, 2008), which therefore increases cognitive control efficiency. Future work should identify how bottom-up activation and top-down perception relate to cognitive control in bilinguals.

4.12 Conclusion

The current study found evidence that 1) activation is dissociable from perception within the context of parallel language processing in bilinguals, and 2) activation may not co-occur with perception if the task taps into implicit perceptual processes. Moreover, activation of L1 phonotactic constraints during L2 processing was limited to lower L2 proficiency bilinguals, suggesting that proficiency modulates the extent to which the L1 influences the L2 at the sub-lexical level. Future research should examine the relation between activation (bottom-up) and perception (top-down) processes in bilinguals. Language co-activation, specifically of L1 phonotactics during L2 processing, occurs at the sub-lexical level of phonotactic constraints. Furthermore, it is predicted that explicit measures of speech perception would be more sensitive to capture top-down processing effects, such as repairing L2 input to conform to L1 rules. The current investigation extends the existing body of evidence on parallel processing in bilinguals. For example, work by Marian and colleagues has demonstrated that bilinguals activate their languages in parallel in a bottom-up manner, as evidenced by between-language competition from phonological neighbors. Investigations examining this type of cross-linguistic activation in the context of whole-word phonological processing (i.e., lexical items) would need to consider sub-lexical phonotactics across languages as well.

CHAPTER 5: ADDENDUM TO CHAPTER 3

LEXICAL STATUS AND PERCEPTUAL REPAIR

Summary. Note: the present lexical decision task was not part of the dissertation prospectus and is an addendum chapter to Chapter 3. To further examine the effect of stimulus lexicality on perceptual repair, a lexical decision task was included with the same stimuli and participants as in Experiment 2a, vowel detection. Results suggest that bilinguals, and not monolinguals, were slower to respond to Spanish-conflicting words and non-words, relative to control words and non-words. These findings, along with the findings of Experiments 2a and 2b, demonstrate that as task difficulty, or metalinguistic demands within a task, increase, bilinguals are more likely to perceptually repair second-language sounds that conflict with native-language rules.

5.1 Introduction

See Chapter 3, Introduction and Discussion for a review of the relevant literature on perceptual repair in monolinguals and bilinguals. See Chapter 3, Experiment 2a for Methods, Participants Materials, and Procedure. The Procedure was identical to vowel detection, with the exception that participants decided if the auditory stimulus they heard was a word or a non-word in English.

5.2 Results

Accuracy for words. A 2 (onset type: s+c, control) x 2 (language group: bilingual, monolingual) repeated-measures ANOVA was conducted on accuracy rates for making word/non-word judgments on the stimuli. There was a main effect of onset type for words, $F(1,49) = 11.608$, $p = .001$, $\eta_p^2 = .192$, with bilinguals and monolinguals groups responding more accurately when making word/non-word judgments to control words such as *can* ($M = 95.85\%$, $SE = .80$) than to s+c words such as *strict* ($M = 93.16\%$, $SE = 1.30$), $t(50) = -3.385$, $p = .001$.

Accuracy for non-words. There was a main effect of language for non-words $F(1,49) = 19.173$, $p < .001$, $\eta_p^2 = .281$, with bilinguals ($M = 85.73\%$, $SE = 1.55$) responding less accurately to non-words such as *spelg* than monolinguals. ($M = 95.44\%$, $SE = 1.58$). No other main effects were observed for words or non-words. Bilinguals have been shown to be less accurate in making lexical decisions in their L2, especially with non-words (e.g., Dijkstra, Grainger, & van Heuven, 1999)

Reaction time effects for words[11]. Similar to the reaction time results on the vowel detection task, there was a main effect of language for words, $F(1,49) = 15.89$, $p < .001$, $\eta_p^2 = .245$, with bilinguals ($M = 1125.37$, $SE = 29.31$) responding more slowly than monolinguals ($M = 958.67$, $SE = 29.82$). There was also a main effect of onset, $F(1,49) = 8.19$, $p = .006$, $\eta_p^2 = .143$. There was an interaction of onset by language, $F(1,49) = 5.215$, $p = .027$, $\eta_p^2 = .096$. Paired T-tests revealed that bilinguals showed a difference in response times to s+c words ($M = 1153.09$, $SE = 36.45$) than to control words ($M = 1097.65$ $SE = 37.09$), $t(25) = 3.893$, $p = .001$. Monolinguals did not show a difference in response times to s+c words ($M = 961.58$, $SE = 17.87$) relative to control words $M = 955.35$, $SE = 25.33$), $t(24) = .384$, $p = .704$. Overall, bilinguals were slower to respond to Spanish-conflicting words (e.g., *strict*) than to control words

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[11] Bilinguals responded more slowly to conflicting cognates (M = 1141.25, SE = 40.39) and conflicting non-cognates (M = 1141.50, SE = 35.79) relative to controls (M = 1097.65, SE = 37.08). Neither difference was significant for monolinguals. Once again, there was no significant difference between bilinguals' responses to conflicting cognates or non-cognates (~0.25 ms). Overall results across vowel detection and and lexical decision suggest that cognate status did not affect the extent to which bilinguals perceptually repaired the Spanish-conflicting input. Bilinguals perceive the 'e' onset both when form overlap between translation equivalents is present (e.g., *strict*, *estricto*) and is not present (e.g., *strong*, *fuerte*), due to conflicting phonotactics across languages.

(e.g., *can*) suggesting interference from the L1 due to violation of the L1 Spanish-constraint, while monolinguals did not show this pattern of slowing.

Reaction time effects for non-words. The same main effects and interaction for words were observed for non-words. There was a main effect of language, $F(1,49) = 23.390$, $p < .000$, $\eta_p^2 = .323$; main effect of onset, $F(1,49) = 13.298$, $p = .001$, $\eta_p^2 = .213$; and an interaction between onset and language, $F(1,49) = 8.131$, $p = .006$, $\eta_p^2 = .142$. Paired T-tests revealed that bilinguals showed a difference in response times to s+c non-words ($M = 1242.61$, $SE = 36.04$) than to control non-words ($M = 1137.61$ $SE = 38.32$), $t(25) =5.288$, $p < .001$. Monolinguals did not show a difference in response times to s+c non-words ($M = 979.65$, $SE = 23.16$) relative to control non-words $M = 966.79$, $SE = 34.57$), $t(24) = .500$, $p = .621$. Response times across Spanish-conflicting relative to control conditions (words and non-words) indicate that bilinguals experienced increased L1 interference from Spanish-conflicting stimuli, than with control stimuli. The source of this interference was likely perceptual repair to a vowel onset that conforms to the L1 v+s+c rule.

Difference score analyses[12]. Difference scores were used to investigate the amount of slowing induced by the Spanish conflicting onset. One-way ANOVAs were employed for response-time difference scores across words and non-words and language groups. One-sample follow-up t-tests were performed on reaction time difference scores across conditions within each group, with the test value set to 0. *Words:* The one-way ANOVA revealed a marginal main

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[12] Follow-up analyses were conducted within the bilingual group based on proficiency, dominance, and age of acquisition. Bilinguals with lower L2 (English) proficiency ($n = 8$) demonstrated a greater reaction-time difference score ($M = 166.01$, $SE = 33.56$) with non-words than bilinguals with higher L2 proficiency ($n = 18$) ($M = 77.89$, $SE = 22.16$), $t(24) = 2.200$, $p = 0.38$. No other significant effects were observed for words and non-words for dominance and age of acquisition (*p*s > .1).

effect of language group for words, *F*(1,49) = 5.215, *p* = .027. The one-sample t-test demonstrated that bilinguals showed a greater reaction time difference between s+c and control words (*M* = 55.44, *SE* = 14.24), *t*(25) = 3.893, *p* = .001. Monolinguals did not show such a difference (*M* = 6.23, *SE* = 16.23), *t*(24) = .384, *p* = .704. *Non-words:* The one-way ANOVA revealed a marginal main effect of language group for non-words, *F*(1,49) = 8.131, *p* = .006. One-sample t-tests demonstrated that bilinguals showed an increased reaction time difference between s+c and control non-words (*M* = 105.00, *SE* = 19.86), *t*(25) = .5.288, *p* < .001. Monolinguals did not (*M* = 12.85, *SE* = 25.69), *t*(24) = .500, *p* = .621. See Table 15 for a summary of bilingual/monolingual reaction-time difference score data and Figure 23 for a graphical depiction of the data. Analyses of difference scores for response times support the by-condition analyses (Spanish-conflicting relative to control words anon-words) in bilinguals, such that Spanish-conflicting stimuli resulted in increased slowing, or interference, due to L1 phonotactic-constraint interference during L2 processing.

Table 15: Reaction time difference scores on the lexical decision task for bilinguals and monolinguals. SE = standard error.

	Bilinguals Mean (SE)	*p*	Monolinguals Mean (SE)	*p*
Spanish-conflicting words minus control words	55.44 (14.24)	0.001*	6.23 (16.23)	0.704
Spanish-conflicting non-words minus control non-words	105.00 (19.86)	< 0.001*	12.85 (25.69)	0.621

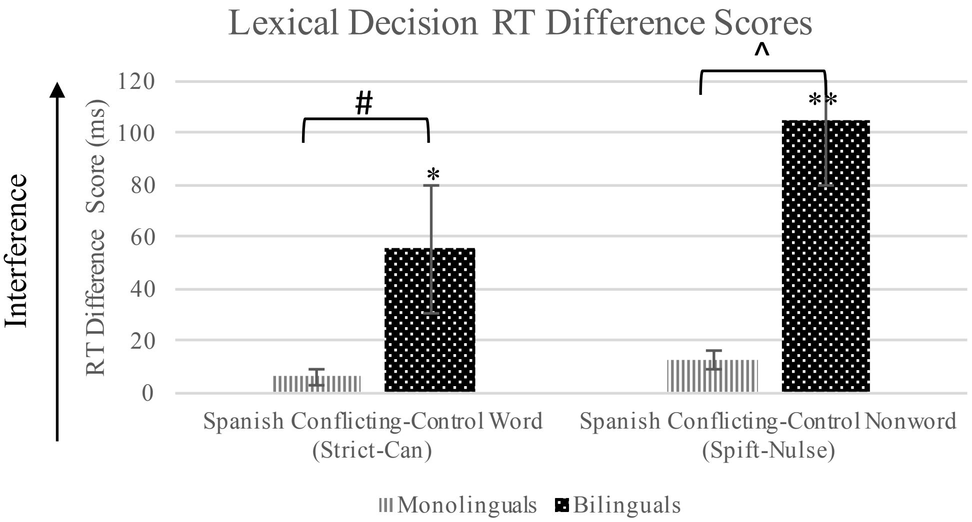

Figure 23: Monolingual and bilingual reaction-time (RT) difference scores across word and non-word conditions on the lexical detection task. Error bars represent standard error. Bilinguals demonstrated greater interference from Spanish-conflicting words ($p = 0.027$) and non-words ($p = 0.006$) than monolinguals. Within bilinguals, Spanish-conflicting words ($p = 0.001$) and non-words ($p < 0.001$) resulted in increased interference relative to controls, as indicated by significant RT difference scores.

Overall, results suggest that when presented with an s+c stimulus (word or non-word), bilinguals perceptually repair it to have an e-onset. This task was more difficult than the vowel detection and AX discrimination, as indicated by accuracy differences across bilinguals and monolinguals, especially with non-words. Increased task demands/metalinguistic demands, and explicit access to the lexicon modulate and enhance the word/non-word effect.

5.3 Discussion and Interpretation

The lexical decision task was included to examine the effect of lexical status on perceptual repair. Perceptual repair was observed for Spanish-conflicting words and non-words in lexical decision, whereas perceptual repair was observed only for Spanish-conflicting words in vowel detection. In vowel detection, top-down perceptual knowledge of phonotactic constraints, as well as top-down lexical knowledge influenced how the input was perceived, specifically whether the Spanish-conflicting input was perceptually repaired to conform to Spanish phonotactics. With lexical decision, top-down phonotactic and lexical knowledge influenced bilinguals' performance, however, the difficulty of deciding on stimulus lexicality in the L2 for bilinguals also influenced performance. Since both potential word and non-word representations (word: *strict* and *estrict*, non-word: *spelg* and *espelg*) are present and in conflict with each other through perceptual illusion (i.e., 'e' onset), conflicting words and non-words result in slower response times. There was an even greater slowing effect for non-words since not only were the representations competing, but also, non-words are more difficult to reject in the L2 (e.g., Dijkstra, Grainger, & van Heuven, 1999), as bilinguals are searching the lexicon to see if there is a match for these conflicting perceptual representations (e.g., *spelg* and *espelg*). Furthermore, the greater slowing effect for non-words relative to words was supported by lower accuracy rates for bilinguals and not monolinguals.

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSION

Summary. The present dissertation found evidence that bilinguals access and perceive their native language during second language comprehension. Native-language phonotactic constraints, or rules for combining speech sounds, influenced how bilinguals processed their second language. The last chapter of this dissertation summarizes the key findings and interprets them within the context of previous theoretical and empirical investigations. Clinical implications, as well as future directions for the current work, are also discussed.

6.1 Summary of Findings

This dissertation unifies two areas of research on bilingual language processing: parallel activation and speech perception. Several studies have demonstrated evidence that bilinguals access their languages simultaneously (e.g., Blumenfeld & Marian, 2007; 2013; Linck, Hoshino, & Kroll, 2008; Marian & Spivey, 2003a, b; Shook & Marian, in press). For example, Shook and Marian (in press) examined covert parallel activation where the input bilinguals heard did not explicitly map onto the irrelevant language. English-Spanish bilinguals looked more at a picture of *shovel* (Spanish: “pala”) when the target image was *duck* (Spanish: “pato”), as the pictures’ *translation equivalents* overlapped phonologically in the irrelevant language (Spanish). The literature on bilingual speech perception suggests that bilinguals perceive nonsense sounds in a way that coincides with the rules of their native language (L1; Carlson et al., 2016; Carlson, 2018; Lentz & Kager, 2015; Parlato-Oliveira, Christophe, Hirose, & Dupoux, 2010; Weber & Cutler, 2006). Carlson et al. (2016) demonstrated that Spanish-dominant bilinguals perceived L1-like speech as if it was the L1, even though the speech conflicted with L1 phonotactics.

Specifically, Spanish-English bilinguals heard Spanish-like non-words, such as *snid*, and perceived an illusory 'e' at the beginning. Therefore, bilinguals recruit perceptual repair when listening to sound sequences that conflict with L1 rules. The current dissertation examined co-activation and co-perception of cross-linguistic phonotactics within bilinguals.

More broadly, the purpose of the experiments was to further characterize and understand the involvement of the L1 during L2 comprehension. Previously, language co-activation of phonological competitors within- and between-languages has been identified to occur in bottom-up way, from the level of phonology to the lexicon and conceptual representations (e.g., Marian & Spivey, 2003a, b; Shook & Marian, in press). Perception of auditory input in line with L1 rules has been theorized to occur in a top-down manner, from the level of phonotactic constraints to phonology (e.g., Best, 1994; Carlson et al., 2016; Dupoux, Pallier, Kakehi, & Mehler, 2001). Although language co-activation can occur through audio (auditory input) or visual modalities (reading/orthography), perception of a word requires access to its representation through auditory input. Therefore, during speech perception, bottom-up and top-down mechanisms are engaged. To account for activation and perception of L1 phonotactic constraints when in an L2 environment, this dissertation found evidence that bilinguals relied on bottom-up and top-down ways of processing auditory input, depending on whether they received a stimulus's audio and/or visual input. Thus, the studies in this dissertation aimed to characterize *how* auditory and visual linguistic input was processed in bottom-up and top-down ways during bilingual language comprehension.

In Experiment 1, the *objective* was to identify whether bilinguals activated L1 phonotactic constraints during L2 processing. Participants were primed with L2 words that conflicted with L1 constraints (e.g., *strict* conflicts with Spanish vowel+s+consonant cluster (v+s+c) onset) and then immediately after, viewed L2-like non-words that conformed to L1 phonotactic constraints (e.g., *esteriors*) on which lexical decisions were made. Findings showed that Spanish-English bilinguals activated the L1 phonotactic constraint, v+s+c onset, during L2 comprehension. Moreover, this co-activation of phonotactic constraints was stronger with non-cognate than cognate primes. In order to make a decision about the lexicality of the non-word stimuli that conformed to the Spanish v+s+c constraint (e.g., *esteriors*) when primed with cognates that conflicted with the Spanish constraint (e.g., *strict*), bilinguals may have muted activation of the Spanish constraint (e.g., v+s+c rule) in the presence of cognate primes so that they could use language-specific plans (i.e., make a decision on English, and not Spanish, lexicality). Enhanced cross-linguistic competition is typical with cognates in comparison to non-cognates (e.g., Blumenfeld & Marian, 2007). With non-cognate primes, less muting of Spanish constraints was necessary due to a decreased, but still present, amount of cross-linguistic competition. Experiment 1 also elucidated the extent to which language co-activation occurred within bilinguals, at the sub-lexical level of phonotactic constraints. However, since there was visual *and* auditory input present in the task, the next step was to examine how top-down perceptual knowledge influenced bilinguals' processing.

In Experiment 2, the *objective* was to investigate whether bilinguals perceived L2 words in an L1-like manner. Findings showed that bilinguals repaired L2 words to conform to L1 phonotactics (e.g., *strict*/*estrict*, Spanish v+s+c rule). It has been identified that monolinguals and bilinguals perceptually repair nonsense, L1-like speech sounds to align with L1 phonotactic constraints (Carlson, 2018; Carlson et al., 2016; Cuetos et al, 2011; Halle et al., 2008; Parlato-Oliveira et al., 2010). Evidence from Experiment 2 suggests that bilinguals also employ perceptual repair when listening to L2 words that conflict with L1 phonotactic constraints. Prior studies have examined implicitly, or indirectly measured, L1 perception of phonotactic constraints during L2 processing through lexical decision or word detection tasks (Lentz & Kager, 2015; Weber & Cutler, 2006). In the current investigation, perceptual repair was examined in bilinguals explicitly (Experiment 2a, vowel detection) and implicitly (Experiment 2b, AX discrimination). In Experiment 2a, when participants were explicitly asked if they heard a vowel at the beginning of the English word or English-like non-word, only bilinguals demonstrated reaction-time differences across Spanish-conflicting words (e.g., *strict*) and controls (e.g., *can*). In a follow-up lexical decision task (see Chapter 5), reaction-time differences were observed with Spanish-conflicting non-words (e.g., *spift*) relative to controls (e.g., *nulse*), in addition to words. In Experiment 2b, when participants were implicitly asked to judge whether two consecutive English words they heard were the same or different, no differences emerged in bilinguals' and monolinguals' response patterns. Overall, Experiment 2 demonstrated that bilinguals repaired L2 words to conform to L1 rules when the task tapped into higher-level perceptual representations, providing further evidence for cross-linguistic interactions at the sub-lexical level.

Last, in Experiment 3, the *objective* was to examine the relation between activation and perception of L1 phonotactic constraints during L2 comprehension, therefore shedding light on the mechanisms involved during bilingual language processing. Findings showed that the mechanism responsible for language co-activation was bottom-up processing linguistic input. First, lower L2 proficiency bilinguals activated an L1 phonotactic constraint (Spanish v+s+c rule) in a bottom-up manner, with greater fixations to a competitor word that contained an onset ('e') conforming to the L1 rule than filler items when presented with the onset sound of and viewing an L2 word that conflicted with the constraint (Experiment 3a, word recognition).

Lower L2 proficiency bilinguals also activated an L1 phonotactic constraint in bottom-up was when viewing and listening to L2 words in a novel, combined word recognition and AX discrimination paradigm (Experiment 3b). Unlike in Experiment 3a, in Experiment 3b, perceptual processes were examined when bilinguals received lexical-level auditory input (target word) and had to make same/different judgments on the two words they heard. Bottom-up processes were initially engaged and permitted within- and between-language neighbors to come on-line during language processing. In Experiment 3a and 3b, when viewing a word that conflicted with the Spanish v+s+c constraint (e.g., *strong*), the English s+c onset cluster activated words in English that conformed to the Spanish rule in a bottom-up way (e.g., *egg*). However, we did not find evidence for top-down processing in the perceptual portion of Experiment 3b (AX discrimination), as participants did not demonstrate response-time differences to Spanish-conflicting input, relative to controls. It was predicted that, for example, s*trong*, a Spanish-conflicting word, would have forced the v+s+c rule to come on-line. After hearing a second word that contained the illusory vowel onset (e.g., *effort*), bilinguals should have been slower to make same/different judgments, relative to controls, since the input was being perceptually repaired. However, the predicted pattern did not emerge in bilinguals, not only in the AX discrimination portion of Experiment 3b, but also in AX discrimination in Experiment 2b. A potential explanation is that the AX discrimination task was not sensitive to capture the effects of top-down perceptual processing between the L1 and the L2. We found evidence for stronger perceptual effects when metalinguistic demands were high (see Experiment 2a vowel detection and Chapter 5, lexical decision), whereas the low-level perceptual nature of the AX discrimination task did not tax metalinguistic awareness.

Taken together, the three experiments across Chapters 2, 3, and 4 indicated that bilinguals activated and perceived speech input. In the realm of language co-activation, when reading words with minimal auditory input (i.e., target's onset sound), bottom-up mechanisms were engaged. When listening to auditory input, bottom-up and top-down processes were relied upon. Previous studies examining language co-activation have suggested that bilinguals process auditory input in a bottom-up way (e.g., Marian & Spivey, 2003b). In the current dissertation, we found evidence bilinguals processed auditory input also recruiting top-down information, as higher-level structures such as phonotactic constraints, or linguistic rules, influenced how the auditory input was perceived.

6.2 Theoretical Contributions

6.2.1 ***Theoretical Contributions: Implications for Activation and Perception in Bilinguals.*** During language processing, bilinguals activate their languages in parallel (e.g., Blumenfeld & Marian, 2013; Freeman, Shook, & Marian, 2016; Kroll & Bialystok, 2013; Kroll, Bobb, Misra, & Guo, 2008; Linck, Hoshino, & Kroll, 2008). For example, bilinguals access both within- *and* between-language competitor words during auditory comprehension and must inhibit these irrelevant words (e.g., *pl-* activates target *plug*, competitors *plum*, and Spanish *plancha* ("iron") for a Spanish-English bilingual; e.g., Blumenfeld & Marian, 2013). By contrast, monolinguals activate within-language competitors only (e.g., *pl-*, activates target *plug*, and phonological competitor *plum* for an English monolingual; e.g., Blumenfeld & Marian, 2011; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). The additional amount of between-language competition that bilinguals face over monolinguals is what makes the bilingual experience unique; what's more is that bilinguals maintain their two languages without any obvious costs (Kroll & Bialystok, 2013). Experiments 1, 3a, and 3b extend current findings on the extent to which bilinguals access both languages simultaneously. Evidence from this dissertation suggests, when listening to or viewing L2 words that conflict with L1 rules, bilinguals activate L1 (and L2) competitor words that conform to L1 rules. Moreover, through this spreading activation, the L1 phonotactic constraint itself is activated, the v+s+c rule.

Interestingly, in Experiment 1, evidence for L1 phonotactic-constraint activation was more robust when L2 stimuli were non-cognates that conflicted with the Spanish constraint (e.g., *strong*). Cognates have been found to increase language co-activation in bilinguals (e.g., Blumenfeld & Marian, 2007; Hoshino & Kroll, 2008; van Hell & Tanner, 2012). Increased cross-linguistic competition induced by cognates may require increased mental effort within bilinguals when processing such words. The increased cross-linguistic competition may take form of intrusion from L1 phonotactic constraints. Therefore, during cognate word processing, bilinguals may engage language-specific plans to manage increased competition within and between languages. This idea is consistent with Nip and Blumenfeld (2015), who found that when producing L1 sentences with cognates, bilinguals demonstrated a greater range of speech articulator movements than when producing L1 sentences with non-cognates. Greater movements have been associated with more detailed phonological specification (Lindblom, 1990), which suggests more care, or effort, is taken in the precise articulation of the intended language. Thus, when processing cognates either in L2 comprehension or production, bilinguals may need to mute L1 phonotactic constraints so that language-specific plans can be employed. Non-cognates do not create as much cross-linguistic conflict as do cognates due to a decreased amount of phonological overlap between translation equivalents; therefore, a smaller amount of irrelevant-language muting with non-cognates is necessary.

Another interpretation for the differential effects of phonotactic-constraint activation for cognates versus non-cognates can be found within BLINCS (Shook & Marian, 2013). Since lateral connections are formed with translation equivalents of a given word, L1 phonotactic-constraint activation during L2 processing may be suppressed more quickly with cognates than with non-cognates. For example, the cognate *strict* activates its translation equivalent that conforms to the Spanish v+s+c onset rule, *estricto*, while the non-cognate *strong* activates its translation equivalent *fuerte*. With the cognate, since the L1 phonotactic constraint is on-line almost immediately, bilinguals may be able to suppress it more quickly than with a non-cognate. With a non-cognate such as *strong*, an additional step is required to access L1 neighbors that conform to the L1 constraint (e.g., *estrés*), since the phonotactic constraint is not accessed directly through the translation equivalent. Thus, it may take longer to suppress L1 phonotactic-constraint activation during L2 processing with non-cognates, and L1 access with non-cognates is more pervasive.

Further evidence for language co-activation came from Experiment 3a. Participants did not hear the target word while viewing four words on a visual display in this experiment. Instead, participants heard the target word's onset (e.g., "Click on /s/"). This design was critical to examine whether bilinguals activated the unintended language without being directly cued into the auditory representation of the target (e.g., *strict*). Based on eye fixation patterns, lower L2 (English) proficiency bilinguals looked at the competitor (e.g., *egg*) before and after hearing the target's onset more than the filler items (e.g., *work*, *can*) on the visual display. This finding is supported by Chabal and Marian (2015), who found that bilinguals activated words within and between languages without any auditory input. The current findings elucidate how bilinguals process words in their environment. When viewing a word, other words that share orthography and phonology become activated within and between languages. In Experiment 3a, viewing a word such as *strict* would activate words such as *sink, sárten* (English: pan), *stamp*, *estricto*, *estudio* (English: study). While previous studies by Marian and colleagues have demonstrated cross-linguistic competition at the level of phonology, the current dissertation (Experiments 1, 3a, and 3b) extends existing work to competing representations at the sub-lexical level of phonotactic constraints.

Experiments 3a and 3b similarly found that lower L2 (English) proficiency resulted in increased L1 interference during L2 processing. Specifically, these bilinguals activated the Spanish L1 phonotactic constraint more strongly than the higher L2 proficiency bilinguals. This proficiency effect is not surprising, given that bilinguals of varying proficiencies experience parallel activation, especially at the phonological level (e.g., Blumenfeld & Marian 2013; Mercier, Pivneva, & Titone, 2014). For example, Blumenfeld and Marian (2013) tested bilinguals in their L1 (we tested bilinguals in their L2) and found that higher L2 proficiency bilinguals experienced increased parallel activation of, or interference from, their L2. English-Spanish bilinguals with high proficiency in Spanish looked more at a picture of *thumb* (Spanish: *pulgar*) than the filler items (e.g., *candle*/*vela*, *log*/*tronco*) when *pool* was the target word for identification. Therefore, the current findings of increased L1 activation during L2 processing for bilinguals with lower L2 proficiency fits well with previous studies examining between-language phonological competition.

Importantly, results from Experiments 1, 3a, and 3b demonstrate that bilinguals access rule-based structures (i.e., phonotactic constraints) across languages when processing speech and viewing words. Phonotactic constraints may additionally influence which competing words are activated. For the Spanish vowel-onset rule with s+c, the conflicting input (e.g., English: strict) activates the Spanish rule itself, and Spanish words that begin with this vowel onset (e.g., estricto, ensalada). English words that begin with this vowel onset (e.g., estimate, egg) are also activated through spreading language co-activation. This dissertation extends the existing body of research on how words across both languages are accessed during comprehension. In addition to words being activated based on phonological overlap, we find evidence that rule-based structures are also accessed, which in turn affect which words are activated.

Furthermore, this dissertation elucidates the cross-linguistic interactions in bilinguals within speech perception. Combined, the results from Experiments 2a and Chapter 5 (lexical decision) suggest that bilinguals perceptually repair L2 sounds to conform to L1 phonotactic constraints. Since it has been established that bilinguals access the L1 when processing the L2, the current findings extend knowledge on bilingual co-activation to speech perception. Results from Experiments 2a, vowel detection and lexical decision, suggest that bilinguals perceived an illusory ‘e’ onset when it was not present in L2 words (vowel detection and lexical decision) and non-words (lexical decision) that conflicted with the L1 ‘e’ onset phonotactic constraint (e.g., *strict* conflicts with the Spanish v+s+c rule, *estricto*). Previous studies examining perception of phonotactics in monolinguals and bilinguals have used the vowel detection, lexical decision, and AX discrimination tasks in Experiments 2a, 2b, and Chapter 5 of this dissertation (see also Carlson, 2018; Carlson et al., 2016; Cuetos et al., 2011). These studies have demonstrated that monolinguals and bilinguals perceptually repair input that conflicts with L1 rules (Carlson, 2018; Carlson et al., 2016; Cuetos et al., 2011; Dupoux et al., 1999; Dupoux, Parlato, Frota, Hirose, & Peperkamp, 2010; Dupoux, Sebastián-Gallés, Navarrete, Peperkamp, 2008; Parlato-Olivieria et al., 2010).

To illustrate perceptual repair in bilinguals, Carlson et al. (2016) tested L1 Spanish speakers on vowel detection and AX discrimination tasks, similar to the ones used in Experiments 2a and 2b. The participants were placed in an L1 testing environment, such that all the tasks were administered in Spanish. The non-words used in the tasks were L1-like and had varied on the extent to which the 'e' onset vowel was spliced (gating; from fully present to not present at all). Only Spanish-dominant bilinguals were found to detect a vowel onset when it was not present, and these bilinguals demonstrated a weaker perceptual repair effect than the Spanish monolinguals who were administered the vowel detection task in Cuetos et al. (2011). The dependent variable of interest was participants' accuracy across the two studies. Another method of observing differences across critical conditions (s+c) versus control conditions (other word onset) is by comparing reaction times. In the current dissertation, greater reaction time differences were observed across critical versus control conditions than with participants' accuracy rates. Carlson (2018) administered an AX discrimination (and lexical decision; Carlson, under review) task with s+c non-word stimuli in the L1 (Spanish), where the testing environment was either in the L1 or L2 (English) directly before the experimental tasks. Results demonstrated that reaction times, rather than accuracy rates, were more reliable indicators of the perceptual repair effect in bilinguals. The discrepancy in accuracy rates for Spanish-English bilinguals' versus Spanish monolinguals' perceptual repair may have been due to the cross-linguistic interaction within bilinguals. Monolinguals in Cuetos et al. (2011) perceived hearing an illusory 'e' onset when it was not present in L1-like s+c non-words through perceptual repair, since their phonotactic inventory did not contain an s+c-onset representation. S+cs are permissible in the bilinguals' L2 (English), therefore the bilinguals may have accessed this L2 representation during L1 (Spanish) processing (Carlson, 2018). Bilinguals were cued into this L2 representation and may have more accurately detected if a vowel was present, explicitly (vowel detection). However, reaction time rates to these stimuli may have been slower as compared to control stimuli due to this cross-linguistic interaction between the L1 and L2.

Two discrepancies were found in the current dissertation across Experiments 2a and 2b, including the differential perceptual effects observed 1) for Spanish-conflicting words and non-words, and 2) with tasks that vary on metalinguistic demands. In Experiment 2a, Spanish-conflicting words, not non-words, were susceptible to perceptual repair. Lexical status of the stimulus modulated perceptual repair, in a task that did not require lexical access, as the participant only paid attention to the onset sound of the stimulus. It appeared that top-down influence from knowledge of phonotactic constraints, also top-down lexical knowledge, impacted bilinguals' perceptual representations of the s+c versus v+s+c, where this Spanish phonotactic was accessed for true words only. In the follow-up lexical decision task, similar perceptual effects were observed across Spanish-conflicting words and non-words, with an even greater effect for non-words. A potential explanation for greater non-word perceptual effects is that non-words were harder to reject in the L2 as bilinguals were searching to find a match within the lexicon, as indicated by slower response times and lower accuracy rates (Dijkstra, Grainger, & van Heuven, 1999). When the metalinguistic demands of the task are higher (e.g., see Parlato-Oliveira et al. 2010 for the lack of perceptual effects on a task with lower metalinguistic demands), whether detecting a vowel onset or judging stimulus lexicality, it appears that bilinguals perceptually repair L2 input to conform to L1 phonotactic constraints. Moreover, access to the lexicon (lexical decision) appears to enhance perceptual repair. In AX discrimination, only words were present and metalinguistic demands were reduced in comparison to vowel detection and lexical decision, since only low-level, same/different perceptual judgments were made. In this scenario, bilinguals did not rely on perceptual repair, and influence from the L1 during L2 processing did not appear to be present.

Moreover, the lack of perceptual repair effects observed in Experiment 2b, supports the absence of a relation between a cross-linguistic activation and perception in Experiment 3b. It was predicted that those bilinguals who accessed the irrelevant language (L1) also perceived the L1. The novel combined word recognition and AX discrimination (WRAX) task allowed for the examination of language co-activation and co-perception in bilinguals within the same paradigm. Bilinguals' greater proportion of eye fixations towards the 'e' onset competitor items than filler items when s+c onset targets were present suggest that even in an L2 testing environment, L1 speakers of Spanish activate the L1 'e' onset rule. However, given that there were no significant effects of perceptual repair observed on the AX discrimination portion of the task (also in Experiment 2b), it was likely that no relation across activation and perception could be observed. Those bilinguals who showed a difference greater than the mean response time difference between the Spanish-conflicting condition relative to the control condition, suggesting conflict from L1 rules, did not produce an increased proportion of fixations to competitor items relative to filler items on the word recognition portion of the task. Importantly, the findings from Experiment 3b replicate the lack of perceptual repair/reaction time effect in the AX discrimination task from Experiment 2b. A task that is more demanding on metalinguistic awareness and sensitive to capture effects of perceptual repair, such as vowel detection or lexical decision, might better examine the relation between activation and perception in bilinguals. The next section (5.2.2) integrates the findings of the dissertation with a further explanation of the mechanisms involved during bilingual language comprehension.

6.2.2 ***Theoretical Contributions: A Mechanistic View of Bilingual Language Processing.*** Typically, as auditory input unfolds through the acoustic stream, bilinguals activate neighboring words within and between their languages (e.g., Shook & Marian 2013). As each phone is heard, neighboring words are eliminated that do not coincide with the input until the target representation is reached. This process of elimination explains how phonologically-competing words are activated and suppressed. However, the findings of the current dissertation suggest that when the L2 acoustic stream conflicts with L1 phonotactic constraints, or rules, then words that conform to this rule are activated as well. Previous studies, such as Marian and Spivey (2003b), claim that bilinguals activate within- and between-language phonological neighbors in a bottom-up way. When phonotactic constraints are violated, auditory input is processed in a top-down way as well, as the phonotactic constraint, a higher-level knowledge-based structure, dictates which neighbors become activated across a bilingual's languages (Experiment 2). The result is that bilinguals process speech with an integration of bottom-up and top-down processes.

Within speech perception, monolinguals and bilinguals apply L1 constraints when processing foreign or nonsense sounds (Carlson, 2018; Carlson et al., 2016; Dupoux et al., 1999; Lentz & Kager, 2015; Parlato-Oliveira et al., 2010; Weber & Cutler, 2006), therefore perceptually repairing the input in a top-down way. Top-down processing of auditory input constrains how a sound sequence is perceived. For example, if the Spanish-English bilingual hears the word *strict*, which conflicts with the Spanish 'e'-onset rule, evidence from the current dissertation (Experiment 2a: vowel detection and lexical decision) suggests that the input is processed and repaired in a top-down manner. Therefore, the Spanish-English bilingual's perception of *strict* is *estrict*. Common to the bottom-up and top-down ways of language processing is that auditory input occurs across both scenarios. Experiment 3a reduced the influence of top-down perceptual knowledge with the exclusion of whole-word auditory input. Findings demonstrated that bilinguals activated the Spanish v+s+c constraint, however, this activation occurred in a bottom-up way, from the levels of orthography and phonology, to the lexicon, and last, to the level of phonotactic constraints. Across Experiments 1, 2a, 2b, and 3b, auditory input was present. Therefore, across tasks indexing activation and perception, speech input was processed in both bottom-up and top-down ways, from phonology to rules, and from rules to phonology.

Based on the characterization of bottom-up and top-down processes established in the present dissertation, it is important to consider how previous studies have accounted for the ways in which bilinguals process language input (activation and perception). Activation, whether within or between languages, has been typically characterized in a bottom-up manner, from the level of phonology to the lexicon, as well as in a top-down manner, from the lexical and semantic levels down to phonology (Blumenfeld & Marian, 2007, 2011, 2013; Tanenhaus et al., 1995). Perception has been accounted for through a top-down way, from a language's rules, to the lexicon, and then to phonology, and in a bottom-up way from phonology, to the lexicon, and then to phonotactic constraints (Carlson et al., 2016). When processing sounds and words, an interplay occurs between bottom-up and top-down processing that influences 1) what words listeners activate within and between languages and 2) how listeners perceive the input. This dissertation invites a new perspective on bilingual language processing whereby language activation and speech perception engage similar bottom-up and top-down processes. While previous studies have examined language activation and speech perception separately, the current dissertation finds a commonality that these processes rely on the same mechanisms (i.e., bottom-up and top-down). Therefore, prior studies investigating language activation should account for speech perception, and previous studies exploring speech perception should account for language activation.

6.2.3 ***Theoretical Contributions: Implications for Bilingual Language Modeling.***

Current models on bilingual language processing have also accounted for how bilinguals 1) activate neighbors within and between languages, and 2) perceive auditory input. The models address activation and perception independently. First, in the current dissertation, the finding that bilinguals activate phonotactic constraints from the unintended language when receiving auditory and visual input (Experiment 1) and only visual input (Experiment 3a) suggests that models of bilingual language activation should include phonotactic constraints as further evidence for the extent to which cross-linguistic structures can be activated. Some of the prominent models that account for parallel language processing include the Bilingual Interactive Activation + (BIA+; Dijkstra & van Heuven, 2002) and Bilingual Language Interaction Network for Comprehension of Speech (BLINCS, Shook & Marian, 2013). These models should be expanded to include activation of neighbors at the sub-lexical level, specifically with phonotactic constraints. Second, the evidence that bilinguals perceive auditory input to conform to L1 constraints suggests that the speech sequence is repaired or assimilated due to L1 influence. When in an L2 testing environment and immersed in the L2, bilinguals still experience interference from the L1 (Carlson, 2018; Freeman, Blumenfeld, & Marian, 2016; Lentz & Kager, 2015). This suggests that the auditory templates formed in infancy and childhood based on speech input are robust and pervasive into adulthood, even with extensive L2 experience. The Perceptual Assimilation Model accounts for phonemic processing such that foreign sounds are assimilated to the best matched category within the L1 (Best, 1994). Here, findings could expand the Perceptual

Assimilation Model to include that influence from L1 phonotactic constraints on syllable sequences persists not only with foreign speech sounds for monolinguals and bilinguals, but also with L2 speech sounds for bilinguals.

6.3 Clinical Contributions

6.3.1 ***Implications for Accent Modification Services.*** In addition to the theoretical contributions this dissertation provides, there are also important clinical and educational implications for services offered to bilingual speakers. For many non-native speakers of English, their speech can be characterized as accented. Some speakers choose to receive accent modification services to sound more English-like, for professional or personal reasons. The Spanish phonotactic constraint of adding an ‘e’ to the onset of s+c is often applied when L1 Spanish speakers produce English s+c words (e.g., Yavas & Someillan, 2005). Aside from production, the findings from this dissertation suggest that when processing English s+c words, L1 Spanish speakers activate and perceive the illusory ‘e’ onset. To enhance accent modification services available to L1 Spanish speakers who wish to sound more English-like, this Spanish ‘e’ onset constraint could be targeted in a training program. Specifically, the clinician should first identify the perceptual aspect of the constraint. The client can be trained on the English/Spanish v+s+c and s+c onset contrast, since both onsets are permissible in English but not in Spanish. Once the client is made explicitly aware of the phonotactic-constraint difference across English and Spanish, the clinician can provide a hierarchy of s+cs for mastery, beginning at the syllabic level, extending to the word, phrase, sentence, and paragraph levels. By addressing both perception and production in accent modification, clients’ phonotactic representation and pronunciation outcomes would be enhanced.

6.3.2 ***Implications for Speech Perception and Bilingual Language Assessment.*** An important, yet obvious finding that can be gleaned from this dissertation is that bilinguals process sounds and words differently than monolinguals of a given language. Therefore, bilinguals' speech perception abilities should not be viewed upon as deficient, but different. This theme ties into the identification of speech sound differences versus speech sound disorders within bilingual children. For example, a child who is an L1 Spanish speaker and who is learning English might not be able to identify and differentiate between s+c and v+s+c syllabics, given that the v+s+c structure is an L1 phonotactic constraint. When assessing bilingual children, no matter the L1, the clinician must pay attention to the phonotactic-constraint differences across languages to ensure good clinical practice and optimal identification of disorders versus differences in speech perception. Phonemic category differences have been well established in the literature (Diaz, Baus, Escera, Costa, & Sebastián-Gallés, 2008; Sebastián-Gallés & Baus, 2005; Sebastián-Gallés et al., 2012), and observed in clinical practice with bilingual clients. Combined, the findings from this dissertation and previous literature on phonotactic-constraint and phonemic-level category distinctions across languages emphasize the importance of clinicians becoming educated on phonotactic differences. This knowledge would in turn ensure proper identification and treatment outcomes for bilingual children and adults.

6.3.3 ***Implications for English Language Learners.*** Last, this dissertation provides important contributions for educational practices with English Language Learners. Phonotactic-constraint differences across languages should be targeted in the classroom for both children and adults who are learning English as an L2. For example, by making L1 Spanish speakers explicitly aware that Spanish has the v+s+c constraint at word onsets, while English permits v+s+c and s+c, metalinguistic understanding about how language structures differ would be provided. This knowledge would in turn translate into increased awareness of the subtle differences across languages that could influence how the target language is perceived and produced, and therefore enhance L2 educational outcomes. For example, when language instruction uses contrastive analysis to highlight similarities and differences between the L1 and L2, learning outcomes are optimized (Laufer & Girsai, 2008; Lin, 2015). Generalization to other phontotactic differences is also possible.

6.4 Future Directions

This dissertation found further support that bilinguals activate the L1 when receiving L2 input, repair L2 sounds using an L1 filter, and identified that bilinguals process auditory input in bottom-up and top-down ways. There are several next steps to gaining a comprehensive understanding of how bilinguals process language input differently than monolinguals. Ideas for future directions include, the malleability of activation and perceptual processes throughout the lifespan, whether accented speech influences activation and perception, the potential influence of cognitive control during bilingual language processing, cognates versus non-cognate differences in processing, and the consideration of other language pairings and other phonotactic constraints.

6.4.1 ***Activation and Perception in Children.*** While work on language co-activation and co-perception in bilingual children is limited, one study found that bilingual children co-activated their languages in speech *production*, especially as L2 proficiency increased (Poarch & van Hell, 2012). The current dissertation's participants were mostly college-aged, and therefore the findings are generalizable to that age group (18-35 years old). Many bilingual children growing up in the United States learn their home language or L1 before attending school, at which point they begin to acquire English or L2, around the age of 5. It is known that monolinguals repair foreign sound sequences to be more L1-like (e.g., Cuetos et al., 2011; Hallé et al., 2008). Of particular interest would be to examine whether bilingual children in the initial stages of L2 acquisition possess the same L1 filter as monolingual or bilingual adults. An additional question with a child population would be at what stage during L2 learning does the L1 filter begin to weaken or look more like the one of bilingual adults?

Some of the existing methodology from this dissertation can be adapted for use with children. The AX discrimination task would be particularly suitable for children, as they can make same/different judgments at a very young age (around 4-5 years old). The vowel detection task requires greater metalinguistic awareness, and young children do not know the difference between a vowel or consonant, or what the “beginning” or “onset” of a word means. In addition, the auditory AX discrimination task does not require children to read words, thus decisions are made only based on auditory input. Marcel. Although perceptual effects on the AX discrimination task were absent in the current study with college-aged adults, it is predicted that during the initial stages of L2 acquisition in childhood, children apply the L1 filter more strongly than proficient bilinguals of both languages, but less strongly than monolinguals of the L1.

The eye-tracking tasks (Experiments 3a and 3b) could be used with slightly older children to understand activation and perception processes. Children who have literacy skills, around the age of 8-9, would be able to perform the tasks given that there are written words and children would have to match the aurally-presented target word to the written stimulus. By the age of 8- or 9-years-old, these children are becoming more proficient in their L2 due to increased exposure within the school context. However, the prediction would be that these children apply the L1 filter to a slightly lesser degree as younger children, and even less so than monolingual children of the L1, when processing L2 words. In any case, these results would highlight the malleability of language system at a younger age, during initial stages of L1 and L2 acquisition, an important next step in understanding how the bilingual experience is different from the monolingual experience.

6.4.2 ***Activation and Perception in Older Bilinguals.*** As with children, testing older adults on L1 activation and perception of phonotactic constraints during L2 processing would shed light on the changes within the language system over time. Specifically, results from older adults with a lifelong experience of being bilingual would allow insight into whether the effects observed in younger adults are as robust throughout the lifespan. While certain aspects of cognition decline with age, bilingualism may serve as a protective mechanism for brain plasticity, Alzheimers disease, and white matter (Alexander, et al., 1997; Bialystok, Craik, & Freedman, 2007; Craik, Bialystok, & Freedman, 2010; Schweizer, Ware, Fischer, Craik, & Bialystok, 2012). Does the L1 perceptual filter decline with age or is it maintained? In addition, it would be important to identify whether the bottom-up and top-down ways of processing auditory input during bilingual language activation and perception are similar at an older age. Experiments 1, 2, and 3 can be used with an aging population of bilinguals.

It is predicted that older bilinguals would not demonstrate the same pattern of results as younger (college-aged) bilinguals. Extended experience navigating multiple languages would yield older bilinguals as experts on the subtle differences across languages, such as phonotactic constraints. In production, increased proficiency, experience, and immersion in an L2 leads to a weakened L2 accent (e.g., Munro & Mann, 2005), thus older bilinguals who have lifelong experience with both languages may be less likely to use an L1 filter, or apply the Spanish v+s+c constraint to English words (e.g., *estrict*). However, it is important to recognize that this is not an all-or-nothing effect. Therefore, in perception, older bilinguals might apply the L1 filter to a lesser degree when processing L2 words due to more extensive L2 experience than younger bilingual adults.

6.4.3 ***The Influence of Accented Speech.*** Previous studies on processing of accented speech have found that adaptation comes with increased exposure, experience, and speaker variability (Bradlow & Bent, 2003; Cristia et al., 2012). This dissertation examined the effect of L1 intrusion during L2 processing. L2 stimuli and an L2 testing environment were used to minimize the intrusion of overt cross-linguistic interactions. However, future research should examine the role of L1-accented speech in the perception of L1 phonotactic constraints during L2 processing. For example, does Spanish accented speech in English modulate the extent to which bilinguals activate and perceive the 'e' onset in English s+cs (Experiments 1, 2a, and 3a)? Moreover, are native Spanish speakers of English able to perceive the difference between Spanish accented English s+c (e.g., *strict*) and Spanish accented English v+s+c (e.g., *estrict*) in AX discrimination (Experiments 2b and 3b)? It is predicted that when listening to L2 English speech spoken by an L1 Spanish speaker, Spanish-English bilinguals would be more likely to perceive an 'e' onset, conforming to the Spanish v+s+c rule, than when the speech input is spoken by an L1 English speaker. Thus, in L1-accented speech stimuli, bilinguals would not be able to distinguish between *strict* and *estrict*. This is predicted since L1 Spanish speakers of English often *produce* English s+c words with an 'e' onset (Yavas & Someillan, 2005; however, see Lagrou, Hartsuiker, & Duyck, 2011 for equivalent effects cross-linguistic interaction when stimuli were produced by a L1 or a L2 speaker).

6.4.4 ***Links Between Activation, Perception, and Cognitive Control.*** Parallel activation during single language processing may increase overall cognitive load as competition from the irrelevant language is suppressed (e.g., Blumenfeld & Marian, 2013; Freeman, Blumenfeld, &

Marian, 2017; Freeman, Shook, & Marian, 2016; Kroll & Bialystok, 2013; Kroll, Bobb, Misra, & Guo, 2008; Linck, Hoshino, & Kroll, 2008). Bilinguals access both within- and between-language competitor words when receiving auditory input and inhibit irrelevant words across languages (e.g., *plug* activates *plum* and *plancha*/iron for a Spanish-English bilingual; Blumenfeld & Marian, 2013). On the other hand, when monolinguals hear *plug*, they may activate multiple neighbors within the same language only (e.g., phonological competitor *plum*, e.g., Blumenfeld & Marian, 2011; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Therefore, bilinguals may rely on cognitive control during language processing to suppress not only within-, but also between-language interference to select the target word (e.g., Blumenfeld & Marian, 2011, 2013; Giezen, Blumenfeld, Shook, Marian, & Emmorey, 2015; Mercier, Pivneva, & Titone, 2014).

The involvement of inhibitory control skills during bilingual language processing has been identified in various tasks examining phonotactic (Freeman, Blumenfeld, & Marian, 2017), phonological (Blumenfeld & Marian, 2011, 2013; Blumenfeld, Schroeder, Bobb, Freeman, & Marian, 2016; Mercier, Pivneva, & Titone, 2014), lexical (Linck, Hoshino, & Kroll, 2008; Linck, Schwieter, & Sunderman, 2012; Prior & Gollan, 2011), semantic (Martín, Macizo, & Bajo, 2010), and syntactic co-activation (Linck, Hoshino, & Kroll, 2008; Teubner-Rhodes et al., 2016; see Freeman, Shook, & Marian, 2016, for review). For example, Freeman, Blumenfeld, and Marian (2017) found that competition resolution was recruited during L2 single-word comprehension to suppress activation of L1 phonotactic constraints. They used the non-linguistic Stroop task from Blumenfeld and Marian (2013, 2014) and the same cross-modal phonological priming lexical decision task in Chapter 2 of this dissertation. Results demonstrated that better performance on the Stroop task was related to decreased competition from the L1 Spanish v+s+c phonotactic constraint on the lexical decision task. Bilinguals may thus employ domain-general cognitive control mechanisms to manage lexical and sub-lexical competition. More efficient cognitive abilities are associated with decreased co-activation of the irrelevant language. Future work should identify if cognitive control is recruited in the same manner for speech perception as it is for cross-linguistic activation in bilinguals. Specifically, follow-up studies should examine whether bilinguals rely on competition resolution to suppress interference from L1 phonotactic constraints during L2 speech perception. If bilinguals engage competition resolution during perception in a similar way as during cross-linguistic activation, then their performance would suggest a relation between measures of L1 perception of phonotactic constraints during L2 processing and tasks of non-linguistic cognitive control.

6.4.5 ***Further Examining the Relation Between Activation and Perception.*** The lack of a relation between activation and perception of L1 phonotactics during L2 processing observed in the WRAX should be further examined using a different task that is more difficult, or metalinguistically demanding. Such tasks include vowel detection and lexical decision. Given that this dissertation provided evidence for L1 perceptual repair with L2 words across two (vowel detection, lexical decision) out of three tasks, combining word recognition with either a vowel detection or lexical decision task is an important next step. Perceptual effects have been observed consistently on explicit measures of vowel perception (e.g., vowel detection: Cuetos et al., 2011, Carlson et al., 2016; Parlato-Oliveira et al., 2010), but not consistently on implicit measures (e.g., Parlato-Oliveira et al., 2010). Thus, more explicit measures of vowel perception are suitable for the examination of activation and perceptual processes in bilinguals. It is predicted that with higher metalinguistic demands in the perceptual portion of the task, a relation between activation and perception would emerge. Bilinguals who activate the Spanish phonotactic constraint during L2 English processing, as evidenced by an increased proportion of looks to Spanish-conflicting competitors relative to fillers, would also demonstrate a greater response-time difference to Spanish-conflicting words and non-words, relative to controls in either vowel detection or lexical decision.

6.4.6 ***Replication with Other Phonotactic Constraints.*** This dissertation focused on a single phonotactic constraint, the Spanish v+s+c rule. A potential next step is to examine whether similar findings could be established with other phonotactic-constraint contrasts across languages. For example, in Japanese and Portuguese, syllable clusters must follow a VCVC sequence (e.g., *ebuzo*), where a VCCV sequence (e.g., *ebzo*) is illicit. The AX discrimination task can be modified to examine this constraint with Japanese-English and/or Portuguese-English bilinguals. English stimuli that do not conform to the VCVC rule (e.g., A stimulus: *magnet*) followed by a form that does conform to the VCVC rule (e.g., B stimulus: *magunet*). It is expected that bilinguals would not be able to detect the difference between the A and X stimuli, as indicated by slower response times when one or both of the words they hear conflicts with L1 phonotactic constraints. If this were to be the case, results would highlight that perception of L1 phonotactic constraints during L2 processing is not unique to a single phonotactic constraint, ensuring generalizability of the results. Moreover, it is expected that these results would directly expand upon previous studies examining L1 perceptual repair of non-native (but not L2) speech sounds (Cuetos et al., 2011; Dupoux et al., 1999; Hallé et al., 2008).

6.5 Conclusions

Across three experiments, this dissertation demonstrated that bilinguals accessed and perceived their native language when listening to the second language. To support this conclusion, the dissertation addressed three main objectives. Dissertation Objective 1 was to identify whether bilinguals activated L1 phonotactic constraints while listening to L2 words. Results from Experiment 1 suggested that bilinguals indeed accessed L1 phonotactic constraints during L2 processing, with stronger activation with non-cognate than cognate stimuli that conflicted with L1 phonotactic constraints (e.g., *strong*/*fuerte* versus *strict*/*estricto*). This finding demonstrates the extent to which bilinguals activate lexical and sub-lexical structures across languages, at the level of phonotactic constraints. Dissertation Objective 2 investigated whether bilinguals perceived sounds according to L1 phonotactic constraints during L2 processing. Findings from Experiments 2a and a follow-up lexical decision task provided evidence that bilinguals perceived L2 sounds to conform to L1 rules in tasks that explicitly (vowel detection), but not implicitly (AX discrimination) measured perception. Dissertation Objective 3 examined the relation between activation and perception of L1 phonotactic constraints during L2 comprehension. Experiment 3a found that bilinguals with lower L2 (English) proficiency activated the L1 phonotactic constraint while reading L2 words on a visual display, when only the target word's onset was heard. Experiment 3b replicated Experiment 3a's findings, but did not find a relation between linguistic activation and perceptual processes in bilinguals. Although it was predicted that a relation would be found between activation and perception of L1 phonotactic constraints during L2 processing within Experiment 3b, the nature of the perceptual task may not have been sufficiently sensitive to capture L1 perceptual repair during L2 processing.

Taken together, this dissertation underscores the dynamic connections within the bilingual language system. Specifically, current findings contribute to theory on the extent to which parallel processing occurs during single-language comprehension in bilinguals. Bilinguals activate and perceive L1 structures, such as phonotactic constraints, during L2 processing. These results also contribute to how the language system is organized in the bilingual brain. Bilinguals are not two monolinguals in one mind, and their languages are not completely dissociable, given the amount of cross-linguistic interplay demonstrated here as well as in previous studies on bilingual language processing.

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Appendix

A. Freeman, Blumenfeld, and Marian (2016, Chapter 2), Lexical characteristics of prime stimuli, mean (SD). (All *p*s > .05.)

Characteristic	*Cognate prime*	*Non-cognate prime*	*Control*
English Letters	6.10 (1.12)	6.00 (1.53)	6.47 (1.17)
Spanish Letters	7.50 (1.22)	7.20 (2.40)	7.37 (2.71)
English Syllables	1.67 (0.55)	1.40 (0.50)	1.63 (0.61)
Spanish Syllables	3.20 (0.55)	3.03 (1.00)	3.00 (1.08)
English Frequency	20.89 (31.75)	14.73 (18.91)	29.73 (56.97)
Spanish Frequency	23.09 (36.21)	17.14 (38.24)	41.33 (82.13)
Orthographic	2.53 (3.32)	3.00 (2.99)	3.57 (3.35)
Neighbors			
Phonological Neighbors	4.03 (5.23)	5.67 (4.73)	6.23 (5.72)
Number of Phonemes	5.57 (1.17)	4.93 (1.31)	5.03 (0.93)

CLEARPOND (Marian, Bartolotti, Chabal, and Shook, 2012): SUBTLEX frequency in English and in Spanish, orthographic neighborhood size, phonological neighborhood size.
English Lexicon Project (Balota et al., 2007): number of phonemes.

B. Freeman, Blumenfeld, and Marian (2016, Chapter 2), Lexical characteristics of target stimuli, mean (SD).

Characteristic	*Phono constraint + form Non-word*	*Phono constraint only Non-word*	*Non-word control*	*Word control*
English Letters	7.97 (1.25)	7.97 (1.25)	7.97 (1.25)	7.97 (1.25)
Bigram Sum	18295.87 (5383.68)	16593.90 (3800.36)	1648.00 (4047.21)	16414.77 (3784.89)
Eng. Bigram Mean	2617.00 (505.73)	2449.34 (684.87)	2419.71 (657.53)	2370.00 (449.41)
Bigram Position	1591.07 (673.44)	1748.63 (537.86)	1875.47 (490.77)	1954.70 (813.22)
LDT RT*	876.37 (75.95)	862.71 (100.30)	852.54 (109.83)	737.52 (70.39)
LDT Zscore*	-0.32 (0.25)	-0.29 (0.31)	-0.24 (0.30)	-0.18 (0.21)
LDT SD	324.09 (77.26)	306.82 (73.88)	297.60 (87.02)	254.55 (65.42)
Observances	29.68 (3.18)	31.38 (3.07)	29.86 (3.05)	30.60 (3.11)
LDT ACC	0.88 (0.09)	0.91 (0.09)	0.89 (0.12)	0.93 (0.09)
Ortho. Neighbors	1.07 (0.25)	1.10 (0.40)	1.20 (1.10)	1.00 (0.00)
Total Neighbors	0.73 (0.45)	0.79 (0.90)	0.97 (1.10)	0.73 (0.64)

*$p < .05$.

English Lexicon Project (Balota et al., 2007): summed bigram frequency, average bigram frequency, summed bigram frequency by position, mean lexical decision time latency raw (LDT RT), mean lexical decision time standardized latency (LDT Zscore), standard deviation of lexical decision time latencies (LDT SD), number of observances, mean lexical decision accuracy (LDT ACC). CLEARPOND (Marian, Bartolotti, Chabal, and Shook, 2012): orthographic neighborhood size, total neighborhood density

C. Stimuli and lexical characteristics for Vowel Detection Task (Experiment 2a). Words and non-words.

Word	Sp_Trans	Condition	Log_Freq	Eng_Ortho_N	Eng Letters	Log_SP_Freq	Spa_Ortho_N	Spa Letters
spa	balneario	S+Cons	3.67083009	7	3	2.97197128	0	9
space	espacio	S+Cons	4.81993068	7	5	4.89691294	2	7
speaker	altavoz	S+Cons	3.83897495	2	7	3.05300157	0	7
special	especial	S+Cons	5.17192703	1	7	5.22201583	3	8
specific	específico	S+Cons	4.25051515	1	8	4.00929364	2	10
spider	araÒa	S+Cons	4.00423537	2	6	4.18093691	1	5
spiral	espiral	S+Cons	3.25146788	1	6	3.53319991	1	7
spirit	espíritu	S+Cons	4.69331268	1	6	4.75492141	1	8
split	dividido	S+Cons	4.58335409	5	5	3.4812706	2	8
sponge	esponja	S+Cons	3.82645707	1	6	3.84777619	1	7
spotless	inmaculado	S+Cons	3.07059193	0	8	2.8280647	1	10
spread	difundir	S+Cons	4.49546247	1	6	3.05300157	0	8
stable	estable	S+Cons	4.1204456	5	6	4.11490442	3	7
starch	almidÛn	S+Cons	3.1312657	1	6	2.94910689	0	7
station	estación	S+Cons	4.89805787	1	7	4.75234428	0	8
stench	hedor	S+Cons	3.34551096	0	6	3.39375064	0	5
stereo	estéreo	S+Cons	3.77530455	1	6	3.55700163	0	7
stocking	media	S+Cons	3.41954272	4	8	4.96353804	5	5
stoic	estoico	S+Cons	2.61464416	0	5	2.22600471	0	7
stricken	afligido	S+Cons	3.16908636	0	8	3.12126431	1	8
strict	estricto	S+Cons	3.84631237	0	6	3.61895759	2	8
strong	fuerte	S+Cons	4.93883332	2	6	5.28794162	4	6
study	estudiar	S+Cons	4.69054338	3	5	4.55554786	3	8
stumble	trastabillar	S+Cons	3.2924333	4	7	2.15905792	0	12
behavior	comportamiento	control-consonant	4.35009676	1	8	4.39416614	1	14
blessing	bendición	control-consonant	3.9871745	1	8	4.17189604	1	9
breadth	ancho	control-consonant	2.63484994	1	7	3.7292134	4	5
friend	amigo	control-consonant	5.62251875	3	6	5.84959365	2	5
hammer	martillo	control-consonant	4.07918125	4	6	4.0772625	1	8
lawyer	abogado	control-consonant	4.90042066	3	6	5.07883295	3	7
nickname	apodo	control-consonant	3.83150504	2	8	3.93600073	3	5
quirk	manía	control-consonant	2.59346329	5	5	3.21341149	4	5
rascal	pillo	control-consonant	3.59562847	2	6	3.13678396	0	6
thrive	prosperar	control-consonant	3.24182032	2	6	2.87226836	0	6
topping	cobertura	control-consonant	2.94564089	8	7	3.97903453	0	9
travel	viajar	control-consonant	4.52338874	3	6	4.22971255	2	6
village	pueblo	control-consonant	4.52593323	2	7	5.16423832	1	6
window	ventana	control-consonant	4.93449845	2	6	4.86463684	2	7
worker	trabajador	control-consonant	4.03906496	4	6	3.91366023	2	10
yeast	levadura	control-consonant	2.93588497	4	5	2.65966027	0	9
beginning	principio	control-consonant	4.80015048	1	9	4.89678077	1	9
century	siglo	control-consonant	4.31896231	0	7	4.47257363	5	5
clearance	liquidación	control-consonant	3.83649501	1	9	3.36317935	0	11
clingy	dependiente	control-consonant	2.76955455	2	6	3.1870975	0	11
crumble	desmoronarse	control-consonant	3.14370163	1	9	2.85802792	0	0
cross	cruzar	control-consonant	4.74067211	6	5	4.33029605	4	6
propeller	hélice	control-consonant	3.18452109	1	9	3.12126431	0	6
toying	jugando	control-consonant	3.04828639	4	6	4.841504	2	7

Word	Sp_Trans	Condition	Log_Freq	Eng_Ortho_N	Eng Letters	Log_SP_Freq	Spa_Ortho_N	Spa Letters
afford	permitirse	control-vowel	4.64769	0	6	3.37213842	3	10
acorn	bellota	control-vowel	2.86063143	3	5	2.70312596	0	0
aisle	pasillo	control-vowel	3.87107064	2	5	4.50865898	2	7
alley	callejón	control-vowel	4.21203038	7	5	4.18844191	0	8
annoy	bendición	control-vowel	3.39963911	1	5	4.1897934	7	8
apology	disculpa	control-vowel	4.19768571	0	7	5.09682662	7	8
argue	discutir	control-vowel	4.29545934	3	5	4.5549662	2	8
arise	surgir	control-vowel	3.47140907	3	5	3.37213842	1	6
ashes	cenizas	control-vowel	3.99399582	6	5	4.0884763	1	7
assignment	tarea	control-vowel	4.25242581	1	10	4.61668762	5	5
award	premio	control-vowel	4.10999678	3	5	4.60205999	4	6
earn	ganar	control-vowel	4.18619042	11	4	5.06611078	7	5
easily	fácilmente	control-vowel	4.35350462	0	6	4.33029605	0	10
edge	borde	control-vowel	4.37124893	5	4	4.23399561	4	5
egg	huevo	control-vowel	4.41562764	2	3	4.28236604	6	5
elbow	codo	control-vowel	3.78797735	1	5	3.72529894	16	4
elevator	ascensor	control-vowel	4.3875998	1	8	4.30363229	1	8
elope	fugarse	control-vowel	3.1184962	2	5	2.9249767	0	7
ember	brasa	control-vowel	2.34242268	2	5	2.89942061	4	5
embrace	abrazo	control-vowel	3.87901555	2	7	4.30518579	4	6
enroll	inscribir	control-vowel	2.82391091	0	6	2.88605665	0	9
ensure	asegurar	control-vowel	3.69555172	3	6	4.21849612	4	8
erase	borrar	control-vowel	3.79349005	4	5	3.96183383	2	6
exit	salida	control-vowel	4.19224956	4	4	4.86648642	8	6
icebreaker	rompehielos	control-vowel	2.61464416	10	10	0	0	11
imprison	encarcelar	control-vowel	2.59346329	0	8	2.97197128	0	10
improve	mejorar	control-vowel	3.90837777	2	7	4.35495698	4	7
injure	herir	control-vowel	3	3	6	3.88605621	1	5
intrude	meterse	control-vowel	3.40301751	1	7	4.12363281	3	7
issue	asunto	control-vowel	4.53322917	3	5	5.13966724	3	6
itch	picazón	control-vowel	3.62081249	9	4	3.29473069	0	7
old	viejo	control-vowel	5.78457536	12	3	5.53478254	3	5
oncoming	venidero	control-vowel	2.63484994	8	8	2.38090667	0	8
onward	adelante	control-vowel	3.19005142	2	6	5.43078335	5	8
open	abierto	control-vowel	5.5057085	5	4	4.65529502	3	7
outfit	traje	control-vowel	4.39963911	2	6	5.1120118	5	5
outline	contorno	control-vowel	3.30945982	3	7	2.76111791	0	8
overcome	vencer	control-vowel	3.79211842	8	8	4.19581942	7	7
owe	deber	control-vowel	4.87015157	12	3	4.46189302	6	5
own	dueño	control-vowel	5.66199819	8	3	4.62863411	4	5
umbrella	paraguas	control-vowel	3.87449341	1	8	3.55408921	0	8
unable	incapaz	control-vowel	4.01093143	2	6	3.92868256	0	7
unlock	abrir	control-vowel	3.73958817	0	6	4.80790558	4	5
unpack	deshacer	control-vowel	3.50991456	0	6	3.6731592	2	8
untangle	desenredar	control-vowel	2.462398	1	8	2.33514918	0	10
update	actualización	control-vowel	3.69383243	2	6	3.3493941	0	13
upper	superior	control-vowel	4.08200941	3	5	4.47502871	0	8
understand	comprender	control-vowel	5.68345321	1	10	4.20372894	4	10

D. Stimuli and lexical characteristics for Vowel Discrimination Task (Experiment 2b), Word Recognition Task (Experiment 3a), and Word Recognition AX Task (Experiment 3b).

Word	Sp_Trans	Condition	Log_Freq	Eng_Ortho_N	Eng Letters	Log_SP_Freq	Spa_Ortho_N	Spa Letters
spa	balneario	S+Cons	3.67083009	7	3	2.971971276	0	9
space	espacio	S+Cons	4.81993068	7	5	4.896912942	2	7
speaker	altavoz	S+Cons	3.83897495	2	7	3.05300157	0	7
special	especial	S+Cons	5.17192703	1	7	5.222015834	3	8
specific	específico	S+Cons	4.25051515	1	8	4.009293637	2	10
spider	araÒa	S+Cons	4.00423537	2	6	4.18093691	1	5
spiral	espiral	S+Cons	3.25146788	1	6	3.533199907	1	7
spirit	espíritu	S+Cons	4.69331268	1	6	4.75492141	1	8
split	dividido	S+Cons	4.58335409	5	5	3.481270597	2	8
sponge	esponja	S+Cons	3.82645707	1	6	3.847776187	1	7
spotless	inmaculado	S+Cons	3.07059193	0	8	2.828064701	1	10
spread	difundir	S+Cons	4.49546247	1	6	3.05300157	0	8
stable	estable	S+Cons	4.1204456	5	6	4.114904417	3	7
starch	almidÛn	S+Cons	3.1312657	1	6	2.949106891	0	7
station	estación	S+Cons	4.89805787	1	7	4.752344282	0	8
stench	hedor	S+Cons	3.34551096	0	6	3.39375064	0	5
stereo	estéreo	S+Cons	3.77530455	1	6	3.557001634	0	7
stocking	media	S+Cons	3.41954272	4	8	4.963538036	5	5
stoic	estoico	S+Cons	2.61464416	0	5	2.226004709	0	7
stricken	afligido	S+Cons	3.16908636	0	8	3.121264305	1	8
strict	estricto	S+Cons	3.84631237	0	6	3.618957592	2	8
strong	fuerte	S+Cons	4.93883332	2	6	5.287941622	4	6
study	estudiar	S+Cons	4.69054338	3	5	4.555547862	3	8
stumble	trastabillar	S+Cons	3.2924333	4	7	2.15905792	0	12
edge	borde	E+Onset	4.37124893	5	4	4.233995614	4	5
egg	huevo	E+Onset	4.41562764	2	3	4.282366037	6	5
elder	mayor	E+Onset	3.8475233	4	5	5.262804552	1	5
elevator	ascensor	E+Onset	4.3875998	1	8	4.303632293	1	8
effort	esfuerzo	E+Onset	4.28674605	1	6	4.499171395	2	8
ember	brasa	E+Onset	2.34242268	2	5	2.899420609	4	5
embrace	abrazo	E+Onset	3.87901555	2	7	4.30518579	4	6
empty	vacío	E+Onset	4.67426668	0	5	4.49384686	2	5
enable	permitir	E+Onset	3.16749456	3	6	4.439332694	3	8
enact	promulgar	E+Onset	2.25527251	1	5	2.226004709	0	9
elbow	codo	E+Onset	3.78797735	1	5	3.725298943	16	4
encroach	invadir	E+Onset	1.77815125	0	8	3.603620644	1	7
endeavor	esfuerzo	E+Onset	3.17324456	1	8	4.499171395	2	8
ending	finalizando	E+Onset	4.20198671	8	6	2.65966027	0	11
endless	interminable	E+Onset	3.82134974	0	7	3.463698931	1	12
enforcement	aplicación	E+Onset	3.82263221	0	11	3.426234656	0	10
engaged	comprometido	E+Onset	4.41530062	3	7	4.039869988	2	12
engine	motor	E+Onset	4.50355101	1	6	4.46008861	2	5
enjoy	Disfrutar	E+Onset	4.91794798	2	5	4.247784295	5	9
essay	ensayo	E+Onset	3.78797735	1	5	4.375224526	1	6
enroll	inscribir	E+Onset	2.82391091	0	6	2.886056648	0	9
ensure	asegurar	E+Onset	3.69555172	3	6	4.218496118	4	8
envelope	sobre	E+Onset	4.00254617	1	8	6.052366463	6	5
exchange	intercambiar	E+Onset	4.30568878	2	8	3.677570456	0	12

Word	Sp_Trans	Condition	Log_Freq	Eng_Ortho_N	Eng Letters	Log_SP_Freq	Spa_Ortho_N	Spa Letters
acorn	bellota	control	2.86063143	3	5	2.70312596	0	0
afford	permitirse	control	4.64769	0	6	3.37213842	3	10
aisle	pasillo	control	3.87107064	2	5	4.50865898	2	7
alley	callejón	control	4.21203038	7	5	4.18844191	0	8
annoy	bendición	control	3.39963911	1	5	4.1897934	7	8
apology	disculpa	control	4.19768571	0	7	5.09682662	7	8
argue	discutir	control	4.29545934	3	5	4.5549662	2	8
arise	surgir	control	3.47140907	3	5	3.37213842	1	6
ashes	cenizas	control	3.99399582	6	5	4.0884763	1	7
assignment	tarea	control	4.25242581	1	10	4.61668762	5	5
award	premio	control	4.10999678	3	5	4.60205999	4	6
beginning	principio	control	4.80015048	1	9	4.89678077	1	9
behavior	comportamiento	control	4.35009676	1	8	4.39416614	1	14
blessing	bendición	control	3.9871745	1	8	4.17189604	1	9
blind	ciego	control	4.66108826	7	5	4.3895063	6	5
breadth	ancho	control	2.63484994	1	7	3.7292134	4	5
century	siglo	control	4.31896231	0	7	4.47257363	5	5
clearance	liquidación	control	3.83649501	1	9	3.36317935	0	11
clingy	dependiente	control	2.76955455	2	6	3.1870975	0	11
crumble	desmoronarse	control	3.14370163	3	7	2.85802792	0	0
cross	cruzar	control	4.74067211	6	5	4.33029605	4	6
desk	mesa	control	4.64248431	5	4	5.03987157	12	4
demand	exigir	control	4.23344287	1	6	3.23824689	1	6
frozen	congelado	control	4.18563563	1	6	3.83422354	4	9
flatten	aplastar	control	3.09177244	2	7	3.52391547	2	8
flavor	sabor	control	3.69897	2	6	4.29046201	3	5
furnish	amueblar	control	2.97367269	0	7	1.98296666	0	10
friend	amigo	control	5.62251875	3	6	5.84959365	2	5
hammer	martillo	control	4.07918125	4	6	4.0772625	1	8
imprison	encarcelar	control	2.59346329	0	8	2.97197128	0	10
improve	mejorar	control	3.90837777	2	7	4.35495698	4	7
injure	herir	control	3	3	6	3.88605621	2	5
intrude	meterse	control	3.40301751	1	7	4.12363281	3	7
issue	asunto	control	4.53322917	3	5	5.13966724	3	6
itch	picazón	control	3.62081249	9	4	3.29473069	0	7
lawyer	abogado	control	4.90042066	3	6	5.07883295	3	7
lazy	perezoso	control	4.06401598	4	4	3.45278279	2	8
leisure	ocio	control	3.40301751	0	7	3.07986834	4	4
little	pequeño	control	2.25527251	0	0	5.36295158	2	7
narrow	escaso	control	6.16028607	0	6	3.1590556	3	6
nickname	apodo	control	3.83150504	2	8	3.93600073	3	5
nightmare	pesadilla	control	4.35009676	1	9	4.49216929	1	9
old	viejo	control	5.78457536	12	3	5.53478254	3	5
onward	adelante	control	3.19005142	2	6	5.43078335	5	8
open	abierto	control	5.5057085	5	4	4.65529502	3	7
outfit	traje	control	4.39963911	2	6	5.1120118	5	5
outline	contorno	control	3.30945982	3	7	2.76111791	0	8
overcome	vencer	control	3.79211842	8	8	4.19581942	7	7
owner	dueño	control	4.36614828	3	5	4.62863411	4	5

Word	Sp_Trans	Condition	Log_Freq	Eng_Ortho_N	Eng Letters	Log_SP_Freq	Spa_Ortho_N	Spa Letters
propeller	hélice	control	3.18452109	1	9	3.12126431	0	6
quirk	manía	control	2.59346329	5	5	3.21341149	4	5
rascal	pillo	control	3.59562847	2	6	3.13678396	0	6
record	grabar	control	4.93241389	1	6	4.05851333	3	6
thrive	prosperar	control	3.24182032	2	6	2.87226836	0	6
topping	cobertura	control	2.94564089	8	7	3.57403127	1	12
target	blanco	control	4.57933536	1	6	5.04733095	5	6
trade	intercambio	control	4.54649454	5	5	4.20438048	0	11
travel	viajar	control	4.52338874	3	6	4.22971255	2	6
umbrella	paraguas	control	3.87449341	1	8	3.55408921	0	8
unable	incapaz	control	4.01093143	2	6	3.92868256	0	7
unlock	abrir	control	3.73958817	0	6	4.80790558	4	5
unpack	deshacer	control	3.50991456	0	6	3.6731592	2	8
untangle	desenredar	control	2.462398	1	8	2.33514918	0	10
update	actualización	control	3.69383243	2	6	3.3493941	0	13
upper	superior	control	4.08200941	3	5	4.47502871	0	8
understand	comprender	control	5.68345321	1	10	4.20372894	4	10
village	pueblo	control	4.52593323	2	7	5.16423832	1	6
wallow	revolcarse	control	3.20623202	5	6	2.70312596	0	0
woman	mujer	control	5.6381172	2	5	5.72121191	0	5
window	ventana	control	4.93449845	2	6	4.86463684	2	7
worker	trabajador	control	4.03906496	4	6	3.91366023	2	10
wrangler	pendenciero	control	2.30103	0	1	2.61135559	0	0

Word	Sp_Trans	Condition	Log_Freq	Eng_Ortho_N	Eng Letters	Log_SP_Freq	Spa_Ortho_N	Spa Letters
itch	picazón	control	3.62081249	9	4	3.29473069	0	7
lawyer	abogado	control	4.90042066	3	6	5.07883295	3	7
lazy	perezoso	control	4.06401598	4	4	3.45278279	2	8
leisure	ocio	control	3.40301751	0	7	3.07986834	4	4
little	pequeño	control	2.25527251	0	0	5.36295158	2	7
narrow	escaso	control	6.16028607	0	6	3.1590556	3	6
nickname	apodo	control	3.83150504	2	8	3.93600073	3	5
nightmare	pesadilla	control	4.35009676	1	9	4.49216929	1	9
old	viejo	control	5.78457536	12	3	5.53478254	3	5
onward	adelante	control	3.19005142	2	6	5.43078335	5	8
open	abierto	control	5.5057085	5	4	4.65529502	3	7
outfit	traje	control	4.39963911	2	6	5.1120118	5	5
outline	contorno	control	3.30945982	3	7	2.76111791	0	8
overcome	vencer	control	3.79211842	8	8	4.19581942	7	7
owner	dueño	control	4.36614828	3	5	4.62863411	4	5
propeller	hélice	control	3.18452109	1	9	3.12126431	0	6
quirk	manía	control	2.59346329	5	5	3.21341149	4	5
rascal	pillo	control	3.59562847	2	6	3.13678396	0	6
record	grabar	control	4.93241389	1	6	4.05851333	3	6
thrive	prosperar	control	3.24182032	2	6	2.87226836	0	6
topping	cobertura	control	2.94564089	8	7	3.57403127	1	12
target	blanco	control	4.57933536	1	6	5.04733095	5	6
trade	intercambio	control	4.54649454	5	5	4.20438048	0	11
travel	viajar	control	4.52338874	3	6	4.22971255	2	6
umbrella	paraguas	control	3.87449341	1	8	3.55408921	0	8
unable	incapaz	control	4.01093143	2	6	3.92868256	0	7
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update	actualización	control	3.69383243	2	6	3.3493941	0	13
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understand	comprender	control	5.68345321	1	10	4.20372894	4	10
village	pueblo	control	4.52593323	2	7	5.16423832	1	6
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woman	mujer	control	5.6381172	2	5	5.72121191	0	5
window	ventana	control	4.93449845	2	6	4.86463684	2	7
worker	trabajador	control	4.03906496	4	6	3.91366023	2	10
wrangler	pendenciero	control	2.30103	0	1	2.61135559	0	0

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Education

May 2016- present	Ph.D. candidate in Communication Sciences and Disorders M.S. student in Speech, Language, and Learning, pursuing CCC-SLP certification Expected completion: Spring 2018. Northwestern University Committee: Dr. Viorica Marian (Northwestern University), Dr. Megan Y. Roberts (Northwestern University), Dr. Henrike Blumenfeld (San Diego State University), Matthew T. Carlson (Pennsylvania State University).
September 2013- May 2016	M.A. Master's in Communication Sciences and Disorders Northwestern University.
August 2007- May 2010	B.A. Psychology & B.A. Spanish Minor in International Studies The Pennsylvania State University *(Summa Cum Laude)*.

Publications

1. **Freeman, M. R.,** Blumenfeld, H. K.,& Marian, V**.** (in prep). Bilinguals' second language comprehension is influenced by native-language rules.

2. **Freeman, M. R.,** & Marian, V. (in prep). Activation and perception of native-language phonotactics in bilinguals.

3. **Freeman, M. R.,** Blumenfeld, H. K., & Marian, V. (2017). Cross-linguistic phonotactic competition and cognitive control in bilinguals. *Journal of Cognitive Psychology, 29*(7), 783-794. doi: 10.1080/20445911.2017.1321553. PMCID: PMC5649739

4. **Freeman, M. R.,** Blumenfeld, H. K., & Marian, V. (2016). Phonotactic constraints are activated across languages in bilinguals. *Frontiers in Psychology, 7*(702). doi: 10.3389/fpsyg.2016.00702. PMCID: PMC4870387

   *Republished in eBook:

   Freeman, M. R., Blumenfeld, H.K., & Marian, V. (2018). Phonotactic constraints are activated across languages in bilinguals. In Darcy, I., Tremblay, A., Simonet, M. (Eds.), *Phonology in the Bilingual and Bidialectal Lexicon*, Frontiers Media SA. ISBN: 9782889452101. Available for download from http://frontiersin.org/books/b/1243

5. **Freeman, M. R.,** Shook, A. & Marian, V. (2016). Cognitive and emotional effects of bilingualism in adulthood. In E. Nicoladis, & S. Montanari (Eds.), *Lifespan Perspectives on Bilingualism* (pp. 285-303). Berlin, Germany: APA and De Gruyter. doi: 10.1037/14939-016

6. Blumenfeld, H. K., Schroeder, S. R., Bobb, S. C., **Freeman, M. R.,** & Marian, V. (2016). Auditory word recognition across the lifespan: Links between linguistic and nonlinguistic inhibitory control in bilinguals and monolinguals. *Linguistic Approaches to Bilingualism, 6*(1), 119-146. doi: 10.1075/lab.14030.blu

   *Republished as a book chapter:

   Blumenfeld, H.K., Schroeder, S.R., Bobb, S.C., **Freeman, M.R.,** & Marian, V. (2017). Auditory word recognition across the lifespan: Links between linguistic and nonlinguistic inhibitory control in bilinguals and monolinguals. In Ellen Bialystok & Margot D. Sullivan (Eds.), *Studies in Bilingualism (vol. 53): Growing Old with Two Languages: Effects of Bilingualism on Cognitive Aging.* John Benjamins Publishing Company.

7. Konishi, H., Kanero, J., **Freeman, M. R.**, Hirsh-Pasek, K., & Golinkoff, R. M. (2014). Six principles of language development: Implications for learners of English as a SecondLanguage. *Developmental Neuropsychology, 39*(5), 404-420. doi: 10.1080/87565641.2014.931961

Presentations

1. **Freeman, M. R.,** & Marian, V. (2018, June). *Bilinguals hear their first language during second language comprehension*. Paper presentation at the 2018 Latin American School for Education, Cognitive and Neural Sciences, Santiago, Chile.

2. **Freeman, M. R.**, Leung, A., AlKhuwaiter, M., & Marian, V. (2018, March). *Bilinguals hear their first language during second language comprehension*. Poster presentation at the 2018 American Association for Applied Linguistics Conference, Chicago, IL.

3. **Freeman, M. R.** & Marian, V. (2017, November). *Cross-linguistic perception of phonotactics in bilinguals*. Poster presentation at the 2017 ASHA Convention, Los Angeles, CA.

4. **Freeman, M. R.,** Blumenfeld, H. K., & Marian, V. (2016, November). *Cross-linguistic Activation of Phonotactic Constraints and Cognitive Control in Bilinguals.* Paper presentation at the 2016 ASHA Convention, Philadelphia, PA.

5. **Freeman, M. R.,** Blumenfeld, H. K., & Marian, V. (2016, May). *Cross-Linguistic Phonological Rule Access and Cognitive Control in Bilinguals.* Poster presentation at the 28th Association for Psychological Science Annual Convention, Chicago, IL.

6. **Freeman, M. R.,** Blumenfeld, H. K., & Marian, V. (2016, May). *Non-target language phonological rule activation in bilinguals*. Poster presentation at the 2016 International Meeting of the Psychonomic Society, Granada, Spain.

7. **Freeman, M. R.,** Blumenfeld, H. K., & Marian, V. (2016, March). *Phonological rule access across languages in bilinguals*. Poster presented at the 2016 Latin American School for Education, Cognitive and Neural Sciences, Buenos Aires, AR.

8. **Freeman, M. R.,** Blumenfeld, H. K., & Marian, V. (2015, November). *Cross-linguistic phonological rule access in bilinguals*. Poster presented at the 2015 Psychonomic Society Meeting, Chicago, IL.

9. **Freeman, M. R.,** Blumenfeld, H. K., & Marian, V. (2015, November). *Phonological rule access across languages in bilinguals*. Poster presented at the 2015 ASHA Convention, Denver, CO.

10. Blumenfeld, H. K., Schroeder, S. R., **Freeman, M. R.**, Bobb, S. C., & Marian, V. (2015, May). *Bilinguals show fewer age-related changes than monolinguals in lexical competition resolution.* Paper presentation at the 2015 InternationalSymposium on Bilingualism, New Brunswick, NJ.

11. **Freeman, M. R.**, & Roberts, M. Y. (2015, March). *The Relationship between African American English and Expressive Language Skills in Children with and without Language Impairments.* Poster presentation at the 2015 Society for Research in Child Development, Philadelphia, PA.

12. **Freeman, M. R.**, Ramsook, K. A., Iglesias, A., Hirsh-Pasek, K., & Golinkoff, R. M. (2013, November). *Verb usage patterns in English language learners*. Poster presented at the 2013 ASHA Convention, Chicago, IL.

13. **Freeman, M. R.**, Aravind, A., Mahajan, N., Johanson, M., Ridge, K., Damonte, J., Golinkoff, R. M., Hirsh-Pasek, K., de Villiers, J., Iglesias, A., & Wilson, M. S. (2013, November). *Developing a computer-administered language assessment for bilingual preschoolers*. Poster presented at the 2013 ASHA Convention, Chicago, IL.

14. Ridge, K., Johanson, M., **Freeman, M. R.**, Damonte, J., Mahajan, N., Aravind, A., Golinkoff, R. M., Hirsh-Pasek, K., Iglesias, A., de Villiers, J., & Wilson, M. (2013, November). *Using Developmental Science to Create a Computer Administered Language Assessment for 3- to 6-Year-Olds*. Poster presented at the 2013 ASHA Convention, Chicago, IL.

15. de Villiers, J., Iglesias, A., Wilson, M. S., Golinkoff, R. M., Hirsh-Pasek, K., **Freeman, M. R.**, Aravind, A., Damone, J., Ridge, K., Mahajan, N., & Johanson, M. (2013, November). *Screening 3-6 year old children's language abilities: A computer based assessment*. Oral seminar presentation at the 2013 ASHA Convention, Chicago, IL.

16. Johanson, M. A., **Freeman, M. R.**, Aravind, A., Ridge, K. E., Mahajan, N., Damonte, J. C., Golinkoff, R. M., Hirsh-Pasek, K., de Villiers, J., Iglesias, A., & Wilson, M. (2013, July). *A Computer-Based Assessment of 3-6 Year Old Children's Language Abilities*. Poster presented at the ASHA Schools Conference, Long Beach, CA.

17. Miller, H., Damonte, J. C., Johanson, M., Ridge, K., **Freeman, M. R.**, Aravind, A., Ranganathan, S., Mahajan, N., de Villiers, J., Iglesias, A., Wilson, M. S., Hirsh-Pasek, K., & Golinkoff, R. M. (2013, April). *Adjectives are tricky: Children default to noun interpretations of novel adjectives.* Poster presented at the Society for Research in Child Development 2013 Conference, Seattle, WA.

18. Mahajan, N., **Freeman, M. R.**, Aravind, A., Johanson, M., Damonte, J., Miller, H., Ranganathan, S., Smith, L., Wilson, M. S., de Villiers, J., Iglesias, A., Hirsh Pasek, K., & Golinkoff, R. M. (2013, April). *Using developmental science to design a computerized preschool language assessment*. Poster presented at the Society for Research in Child Development 2013 Conference, Seattle, WA.

19. Aravind, A., **Freeman, M. R.**, Tejada, J., Mahajan, N., Iglesias, A., de Villiers, J., Golinkoff, R. M., Hirsh Pasek, K., & Wilson, M. S. (2013, April). A computer administered language assessment for Spanish English Language Learners. In C. Ebanks (Chair), *New tools for the new preschool context: The development of measures to assess the school readiness skills of young dual language learners.* Poster symposium presented at the Society for Research in Child Development 2013 Conference, Seattle, WA.

20. Aravind, A., de Villiers, J., **Freeman, M. R.**, & Iglesias, A. (2013, April). *Assessing bilingual 3-5 year-olds' language.* Talk given at UMass-UConn-Smith Language Acquisition Workshop (UUSLAW).

21. **Freeman, M. R.**, Mahajan, N., Miller, H., Ranganathan, S., Aravind, A., Damonte, J., Smith, L., Wilson, M. S., Golinkoff, R. M., Hirsh-Pasek, K., de Villiers, J., & Iglesias, A. (2013, April). *Developing a research-based computerized preschool language assessment*. Poster presented at the Council for Exceptional Children 2013 Convention, San Antonio, TX.

22. Damonte, J. C., Johanson, M. A., Ridge, K. E., Mahajan, N., **Freeman, M. R.**, Aravind, A., de Villiers, J., Iglesias, A., Wilson, M., Hirsh-Pasek, K., & Golinkoff, R. M. (March, 2013). *Assessing preschoolers' language abilities using a touch-screen computer*. Poster presented at the 3rd Latin American School for Education, Cognitive and Neural Sciences, Bahia, Brazil.

23. Miller, H., **Freeman, M. R.**, Aravind, A., Ranganathan, S., Mahajan, N., Damonte, J., Golinkoff, R. M., Hirsh-Pasek, K., de Villiers, J., Iglesias, A., & Wilson, L. S. (2012, July). *Developing a computer-assisted language assessment for preschoolers*. Poster presented at the ASHA Schools 2012 Conference, Milwaukee, WI.

24. **Freeman, M. R.**, Kroll, J. F., McClain, R., Martín, M. C., Macizo, P., & Bajo, M. T. (2011, February). *Does the phonology of red prevent bilinguals from getting caught in the net: Exploring how phonological overlap influences the time course of language inhibition*. Poster presented during PIRE/NSF week, University Park, PA.

Honors and Awards

The 2018 Latin American School for Education, Cognitive and Neural Sciences: Fully funded award, June 2018, Santiago, Chile.

The Conference Travel Grant, The Graduate School, Northwestern University, October 2017. Amount: $1,000

The 2016 Latin American School for Education, Cognitive and Neural Sciences: Fully funded award, March 2016, Buenos Aires, Argentina.

The Conference Travel Grant, The Graduate School, Northwestern University, September2015. Amount: $1,000

The 2015 Latin American School for Education, Cognitive and Neural Sciences: Fully funded award, March 2015, San Pedro de Atacama, Chile.

The National Science Foundation Graduate Research Fellowship Program: Honorable Mention, March 2013 & April 2014, 1000172724, 1000117287.

Student Marshal at graduation for the Department of Spanish, Italian, Portuguese (valedictorian) (Penn State), May 2010.

Certificate of Excellence in Spanish (Penn State), May 2010.

The Evan Pugh Scholar Award for 3.98 GPA and above. This award is given to the top 0.5% of all graduating seniors (Penn State), May 2010.

Mr. and Mrs. Bolze Study Abroad Scholarship (Penn State College of the Liberal Arts), Spring 2009.

The Catherine Rein Trustee Scholarship (Penn State College of the Liberal Arts), Fall 2008 & 2009.

President's Freshman Award for 4.0 GPA (Penn State), Spring 2008.

Work and Research Experience

September 2013- present **Graduate Research Assistant**, Department of Communication Sciences and Disorders, Northwestern University. Advisor: Viorica Marian.

- Dissertation Prospectus, *Activation and perception of native-language phonotactics in bilinguals.* Committee: Viorica Marian (Northwestern University), Megan Y. Roberts (Northwestern University), Henrike Blumenfeld (San Diego State University), Matthew T. Carlson (Pennsylvania State University).
- Qualifying Research Project, *Parallel phonological rule activation and cognitive processes in bilinguals*. Committee: Viorica Marian (Northwestern University), Megan Y. Roberts (Northwestern University), Henrike Blumenfeld (San Diego State University).

Spring 2014 **Graduate Research Assistant**, Department of Communication Sciences and Disorders, Northwestern University. Supervisor: Megan Y Roberts.

June 2011- June 2013 **Laboratory Coordinator**, The Temple University Infant and Child Laboratory, Temple University. Supervisor: Dr. Kathy Hirsh-Pasek.

October 2011 **Research Assistant**, The Art & Science of Play at the Inner Harbor: An Evaluation of the Baltimore Ultimate Block Party (UBP) IRB#: IRB00003912, Johns Hopkins University. Supervisors: Dr. Philip Leaf and Dr. Christina Pate.

May 2011 fMRI training workshop, Pennsylvania State University, Dr. Arturo Hernandez and Dr. Michele Diaz.

May 2010- June 2011 **Research Technologist/Laboratory Manager**, Center for Language Science, Pennsylvania State University. Supervisors: Dr. Judith Kroll and Dr. Giuli Dussias.

August 2009- May 2010 **Undergraduate Research Assistant**, The Language and Cognition Lab (Center for Language Science), Pennsylvania State University. Supervisor: Dr. Judith Kroll.

August 2008- December 2008 **Undergraduate Research Assistant**, The Relationship Research Lab, Pennsylvania State University. Supervisor: Dr. Amy Marshall.

Summers of 2008 & 2009 **Junior Counselor**, The Employment and Training Administration of Orange County, New York. Supervisor: Yolanda Perez.

Skills

Methodologies:

- Event-related potentials (ERP), eye tracking, reaction time, habituation

Software:

- Praat, NIH Toolbox, E-Prime, SuperCoder, Superlab, MATLAB, R, SPSS, Habit X, Tobii Studio, Final Cut Pro, Adobe Photoshop, Filemaker Pro, Neuroscan

Statistics:

- Analysis of variance, linear regression and multiple regression, Bayesian modeling and inference

Other skills:

- Bilingual speaker of English and Spanish, study abroad in Salamanca, Spain, hiring of research assistants and lab personnel (post-docs, laboratory coordinators, consultants), grant writing and submission (NIH NRSA & R01, IES 84.305A, NSF Graduate Fellowship), grant administration and accounting, writing, submitting, and renewing IRB protocols.

Teaching Interests

Interest in teaching:

- Psycholinguistics, bilingual language acquisition, language development, atypical language development, language and culture, research methods in communication sciences and disorders

Teaching Experiences

Teaching Assistant, Northwestern University

- Clinical Assisting in Speech and Language Pathology (CSD 332)
- Clinical Methods: Pediatrics (CSD 473)
- Clinical Methods: Adults (CSD 474)

- Clinical Speech Anatomy, Physiology, and Motor Control (CSD 455)
- Language, Culture, and Learning (CSD 309)
- Phonetics (CSD 305)
- Statistics in Communication Sciences and Disorders (CSD 304)
- Typical and Atypical Development in Infants and Toddlers (CSD 342)
- Language Development and Usage (CSD 392)

Guest Lecturer, Northwestern University

- Freshman Seminar on Bilingualism (CSD 207) Lecture title: Bilingual Cognition (10/2/17)
- Language, Culture, and Learning (CSD 309). Lecture title: Bilingual Cognition (5/4/15)

Advising and Mentorship

Undergraduates advised:

- Sarah Svonavec (Pennsylvania State University)
- Kylee Jo Cook (Pennsylvania State University)
- Jacklyn Zhang (Pennsylvania State University)
- Shannon Ens (Temple University)
- Laura Dennis (University of Pennsylvania)
- Oumoul Ba (Temple University)
- Justin White (Northwestern University)
- Kathryn Ficho (University of Wisconsin at Madison)
- Bennett Magliato (Northwestern University)

Masters students advised:

- Anna-Maria Brenson, M.S. (Texas State University, Northwestern University)

Other research assistants advised:

- Munirah AlKhuwaiter, MS, CCC-SLP (King Saud University, Northwestern University)
- Ashley Leung (University of Chicago)

Professional Activities

January 2016- Reviewer: *ASHA 2016 Topic Committee for Cultural and Linguistic Issues*

February 2014- Reviewer: *Cognitive Science Society Annual Meeting*

Winter 2014- Spring 2015 Bilingual Clinician Reading Group, Northwestern University

Fall 2013- Spring 2014 Language Area Reading Group, Northwestern University

Fall 2007- May 2010 Liberal Arts Undergraduate Council, Pennsylvania State University.

- Position held: President’s Assistant
- Completed various tasks with the President, including serving as a liaison between faculty/administration and students in the College of The Liberal Arts.

Membership in Professional Societies

National Student Speech Language Hearing Association (NSSLHA)

Golden Key International Honour Society

Psi Chi Honor Society

Community Outreach

Fall 2013- present Northwestern University Queer Pride Graduate Student Association

- Organized and participated in various community service activities including feeding LGBT youth at local teen shelters.
- Participated in various LGBT awareness events on campus.

Fall 2007- May 2010 Phi Mu Delta fraternity, Mu Epsilon chapter.

- Positions held: Community Service Chair, Philanthropy Chair, Historian
- Organized philanthropic events that benefitted St. Jude Children’s Research Center (2008-2010).
- Organized community service events that benefitted the Food Bank of State College, Inc., including food drives and donations of Thanksgiving and Easter food baskets to local needy families. Worked with the Centre Hall PSPCA, walked dogs and gave attention to other animals in the shelter (2008-2010).