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Cue Competition During Phonotactic Processing in Bilingual Adults as Measured by Eye-Tracking

Katherine Manrique

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Cue Competition During Phonotactic Processing in Bilingual Adults as Measured by Eye-Tracking

by

Katherine Manrique

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science
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June 15, 2018

Keywords: bilingualism, phonotactics, word processing, competition

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Abstract

It is well documented in the literature that bilingual speakers simultaneously activate both languages during spoken language processing (e.g., Marian & Spivey, 2003). However, parallel activation can lead to competition between the two languages (e.g., Blumenfield & Marian, 2013; Freeman, Shook, & Marian, 2016). The Unified Competition model (UCM) provides a theory as to how bilingual speakers navigate through two languages while different linguistic cues are competing (MacWhinney, 2005). The UCM proposes that cues are used to process language, based on cue validity (the product of how reliable and available a cue is), which is determined by cue strength (a measure based on conflict reliability; how reliable a cue is when it directly conflicts with others). Two likely cues bilingual speakers use while processing a novel spoken word are linguistic environment (the language being spoken around them) and phonotactic probability (the probability of the sounds making up a novel word). Applying the theory of the UCM this study sets to answer the following general question: How do Spanish/English bilingual adults assign language membership to nonwords when linguistic environment and phonotactic cues are competing?

The current study consisted of twenty-two Spanish/English adults who listened to 96 nonwords that corresponded to three different groups based on phonotactic probability: Language Exclusive (the phonotactics of the nonwords designated them as either Spanish only or English only), High-Low (the nonwords had high phonotactic
probability in one language and low probability in the other), and Ambiguous (the nonowords had similar phonotactic probability in both languages). The participants were tested in one of two linguistic environments (primarily English with some Spanish code-switching or primarily Spanish with some English code-switching) and partook in a two-alternative forced choice listening test (participants determined if each nonword was either Spanish or English). The language membership decision was measured via verbal response and eye-tracking using EyeLink 1000 Plus measuring eye gaze, number of fixations and switches.

In general, results indicated that Spanish/English bilingual adults relied only on phonotactic probability when making language membership decisions, but not as strongly as may be suggested by the UCM. The results of this study suggest that environmental cues are not strong enough to impact spoken language processing in Spanish/English bilingual adults and that phonotactic probability is likely a more easily accessible (and therefore more commonly used) cue.
Chapter One:
Introduction

Language projections from 2010 to 2020 made by the U.S. Census Bureau indicate that the use of languages other than English will continue to increase over a ten-year span (Shin, & Kominski, 2010). Although the use of more than one language (i.e., bilingualism) will continue to rise, it is still not clearly understood how bilingual children process two languages. Understanding how bilingual adults process spoken language can provide information on how bilingual children process spoken words, which can provide insight into how bilingual children learn new words. In an attempt to better understand how bilingual speakers process two languages, researchers have often used computational models of bilingual language processing (e.g., BIMOLA, Grosjean 1997; BLINCS, Shook & Marian, 2013; SOMBIP, Li & Farkas, 2002). These computer models have allowed for the manipulation of various variables to predict what could affect bilingual language processing. However, these models have varying levels of evidentiary support. Therefore, the question still stands; how do bilingual speakers navigate through two languages during spoken language processing?

Bilingual spoken language processing is a complex process, which includes processing of phonetics (speech sounds), phonotactics (legal sequences in a language), and lexical semantics (word meaning) in two languages simultaneously (Marian & Spivey, 2003). Parallel activation of two languages during spoken language processing can indicate competition between the two languages (e.g., Blumenfield &
Marian, 2013; Freeman, Shook, & Marian, 2016). One model that could be used to investigate bilingual processing is the Unified Competition Model (UCM; MacWhinney, 2005).

**Unified Competition Model**

The UCM is not a computational model but rather a psycholinguistic model, which provides a theory of language acquisition and processing (MacWhinney, 2005) based on the competition model originally proposed by Bates & MacWhinney (1987). The underlying idea of this model is competition between cues, indicating that one’s language processing system selects between cues based on relative cue strength. Cue strength refers to how reliable a cue is when it directly conflicts with other cues (conflict reliability: MacWhinney, 2005). In other words when two cues are competing the one that “wins” is said to have high conflict reliability. Validity refers to the product of how reliable and how available (how often a cue is present) a cue is over a period of time (MacWhinney, 2005). Therefore, when cues are competing, bilingual adults weigh the validity of the cues and utilize the stronger cue in order to make an appropriate interpretation.

Tuninetti, Warren, and Tokowicz (2015) performed an eye-tracking study that investigated cue strength and language transfer (applying knowledge of one language to other) with regards to word-order violations in native Arabic and Mandarin speakers’ L2 (second language, in this case English). In this study participants were given sentences to read and asked to rate if they were grammatically correct or not. Each sentence consisted of one of the following violations: an article followed by a noun (high cue strength and validity) or an adjective appearing after a noun (should
indicate language transfer). Arabic and English have similar article-noun structures (articles come before nouns); however Mandarin does not use articles. Therefore, taking the UCM into consideration it was hypothesized that the violation of the article-noun condition would be easier to recognize for Arabic/English bilinguals. However, Mandarin/English bilinguals’ recognition of the noun-article violation would be attributed to their L2. In regards to noun-adjective violations, Mandarin and English have similar noun-adjective structures (adjectives come before nouns), however Arabic does not. Therefore, it was hypothesized that Mandarin/English bilinguals would experience language transfer and Arabic/English speakers would not. Eye-tracking methodology was used to track participants’ eyes during the judgment task. In this study language transfer was not apparent, indicating that cues from the participant’s L1 were weaker than those of L2. Tunietti et al., (2015) suggest that participants receiving explicit instruction on word order during L2 instruction could have affected evidence of language transfer. However, longer first-pass regressions out and the longest go-past reading times across Native Arabic, Mandarin, and English speakers during judgment of ungrammaticality of noun-article violations, indicated overall sensitivity to the ungrammaticality of noun-article condition. This suggests that stronger cues were encountered in the ungrammaticality of noun-article condition. Overall, cue strength was used, which is in accordance with the basic principles of the UCM.

The current study employed the basic principle of the UCM in regards to competition and the use of strong cues with high validity during spoken language processing. Two likely cues used by a bilingual speaker during spoken language
Phonotactics in Word Processing in Bilinguals. Phonotactics refers to the legal and illegal segment sequences in a language (Freeman, Blumenfeld, & Marian 2016). For example, initial /s/ consonant clusters are illegal in Spanish (e.g., “stop”), however they are legal in English (Freeman et al., 2016). However, phonotactics do not only refer to legal and illegal segment sequences, but also include sequences that could be more or less frequently probable (Frisch, Large, & Pisoni, 2000). The statistical chance of a sound or legal segment sequence occurring in a language is referred to as phonotactic probability (Zamuner, 2013). For instance, the /tr/ sequence occurs more often in comparison to the /fr/ sequence at the beginning of words in English, therefore /tr/ has a higher phonotactic probability in English (Prahland, & Jamie, 2009). Additionally, computational models (e.g., BIMOLA, Grosjean 1997; BLINCS, Shook & Marian, 2013; SOMBIP, Li & Farkas, 2002) of bilingual word processing indicate that word processing consists of three general levels: phonetic (speech sounds), phonological (sequences allowed in a language), and lexical-semantic (word meaning), with phonotactic probability being processed at the phonetic level of word processing.

At the phonological level of word processing Freeman et al., (2016) suggest that Spanish/English bilinguals may activate phonological constraints of the non-target language during a language comprehension task. But it is still unclear what cues bilingual speakers use to navigate through both active phonological constraints to make a language decision (i.e., assign language membership). Messer, Leseman,
Boom, and Mayo (2010) found that high phonotactic probability words were recalled quicker than low probability nonwords in bilingual Turkish/Dutch children. Indicating that high phonotactic probability cues are reliable. Additionally, they found that, overall, bilingual Turkish/Dutch children recalled high phonotactic probability nonwords quicker than low probability nonwords, even though they recalled high phonotactic nonwords quicker in their native language (Turkish) than in their second language (Dutch). Therefore suggesting that at the phonological level of word processing high phonotactic probability cues have high reliability conflict.

However, it is unclear which cue will “win” when phonotactic probability cues (i.e., stronger cue) are neutralized. Which is the case in the current study. For example, two of the ambiguous nonwords used in this study are /kesel/ and /inan/ both of which have high phonotactic probabilities in Spanish and English. In this case the stronger cue (phonotactic probability) has been neutralized. Based on the UCM when the stronger cue is neutralized the next strongest cue will dominate (MacWhinney, 2005). This study proposes that linguistic environment is likely the next strongest cue.

Linguistic Environment Effects in Bilingual Word Processing. The second likely cue to effect spoken language processing at the phonological level is linguistic environment. As linguistic diversity in the United States increases (Shin, & Kominski, 2010), more individuals are living in a bilingual environment where code-switching (alternating between two languages) is common, resulting in bilingual speakers being in bilingual or intermediate mode (Grosjean, 2001).
Molnar, Ibáñez-Molina, and Carreiras (2015) studied the interaction between language co-activation and participants’ knowledge of the language the conversationalist or interlocutor speaks (i.e., linguistic environment). Specifically, the study consisted of two experiments: one with highly proficient Basque/Spanish bilingual adults and the other with low proficient Basque/Spanish bilingual adults. The experiments consisted of an audio-visual presentation of interlocutors. The interlocutors were either monolingual Basque or Spanish, or bilingual Basque/Spanish speakers. They first introduced themselves in order to familiarize participants with their linguistic identity before verbalizing words and nonwords, which the participants were told to rate as either being a word or a nonword. Results from the first experiment showed that proficient bilingual’s responded quicker when the interlocutor’s language matched the stimuli in comparison to when there was a mismatch. This phenomenon was not found in the low proficient bilingual group. However, the low proficient bilingual group showed preference to their native language. In sum, the study suggests that proficient bilinguals adapted to the linguistic environment, implying that linguistic environment cues are accessible and used.

The current study takes linguistic environment into consideration to better understand how and if bilingual speakers use linguistic environment cues when other cues (i.e., phonotactic probability) are neutralized. As previously mentioned based on the UCM it is predicted that when phonotactic probability cues are neutralized linguistic environment cues will be used. In the current study participants were
exposed to one of two linguistic environments: Primarily English with some Spanish code-switching or primarily Spanish with some English code-switching.

As stated, spoken language processing consists of three general levels: phonetic (speech sounds), phonological (sequences in a language), and lexical-semantic (word meaning). To account for influence of other indicators of language membership (e.g., semantics) nonword stimuli were used.

**Using Nonwords to Test Phonotactic Processing**

Historically nonwords have been used as stimuli for word repetition tasks. Nonword repetition tasks have been shown to be useful dynamic assessments to analyze language processing in children (e.g., Gutierrez-Clellen, & Simon-Cereijido, 2010). Nonwords are useful for word repetition tasks because they are processed at the sub-lexical level (Vitevitch, & Luce, 2005). Which is beneficial because it allows for assessment of the underlying processes of language processing required for vocabulary acquisition without interference of vocabulary knowledge (Gutierrez-Clellen, & Simon-Cereijido, 2010). This is also important to this study because the aim is to assess how bilingual adults process phonotactics while cues are competing. However, two linguistic cues that might confound the ability to measure participants’ phonotactic processing are phonetic (acoustic) and lexical-semantic cues.

The use of nonword stimuli is valuable because they are void of lexical meaning (Brea-Spahn, 2009). This is important for the current study because nonwords force participants to focus on phonotactic sequences during processing (Betancourt, 2013). For example, if a participant is presented with the nonword /katol/ the participant would have to rely on phonotactic sequences during processing rather than semantics.
In addition, to account for phonetic cues the nonwords in this study were synthesized. In other words the nonword stimuli were digitally manipulated to nullify acoustic factors. Accounting for phonetic cues is important because phonetic cues can affect the ambiguity of the nonwords (e.g., the /r/ in Spanish is trilled while the /ɹ/ is retroflexed in English).

Finally, using nonwords allows for manipulation of varying phonotactic probabilities (e.g., Betancourt, 2013; Messer et al., 2010; Zamuner, 2013). This is an important factor for the current study because it allows for investigation of the influence of phonotactic cues during word processing. For example, Zamuner (2013) used high and low probability nonwords to investigate if Dutch children were better at recognizing segmental contrasts that occur in high probability environments compared to low probability environments. Results indicated that children perceived segmental contrasts found in high phonotactic probability environments better than those found in low phonotactic probability environments.

All in all, using acoustically and phonotactically ambiguous nonwords to investigate phonotactic processing will force bilingual adults to access both languages concurrently at the phonological level. However, it’s not just important to know what the bilingual speakers’ final language membership decision is; it’s also important to understand some of the cognitive processing that goes into that decision. One way of doing that is via eye-tracking.

**Eye-Tracking Methodologies to Test Word Processing**

The use of eye-tracking methodology is advantageous because eye movements provide a continuous measure of spoken language processing, it can be used during
natural tasks, and it allows for real-time language comprehension information (Tanenhaus, Magnuson, Dahan, & Chambers, 2000). Furthermore, eye-tracking methodology has been used to measure continuous variables in studies investigating bilingual language processing (e.g., Blumenfeld, & Marian, 2007; Kaushanskaya, & Marian, 2007; Marian, Spivey, & Hirsch, 2003).

The current study is an expansion on Betancourt (2013), which investigated how bilingual kindergartners process the phonotactic probabilities of their two languages using mouse-tracking methodology. In Betancourt (2013) children were provided with a game like paradigm, with the objective being to help robots get on the correct bus based on what language they think the robot speaks. Participants were told to click a small box on a computer screen to hear a word and then decide if the word they heard sounded like Spanish or English by clicking on a red bus for Spanish and blue bus for English. However, Betancourt (2013) could not make any speculations about the process behind the decision because children were not using the mouse appropriately (e.g., drawing pictures on the screen with the cursor before finally making a decision). Because of this, it was suggested that eye-tracking methodology could provide more reliable information than that of mouse-tracking during a decision making task.

This study seeks to test the eye-tracking methodology on Spanish/English adults with aspirations to replicate the current study on Spanish/English bilingual kindergarteners. In the current study SR Research EyeLink 1000 Plus eye-tracking instrumentation was used to record the number of fixations and switches. Number of fixations were assumed to provide continuous information during binary decision task.
While number of switches (number of times the participant looks at each visual stimuli before a final answer is given) was thought to represent the complexity of the decision-making process. It was hypothesized that the more switches observed the more difficult the decision.

Purpose

The current study consisted of Spanish/English bilingual adults partaking in a two-alternative forced choice listening test. The language membership decision was measured via verbal response and eye-tracking using EyeLink 1000 Plus measuring eye gaze, number of fixations and switches. The stimuli were a set of 96 nonwords split into three different word types (Betancourt, 2013): language exclusive (composed of phoneme sequences that were unique to English or Spanish), high/low (had high phonotactic probability in one language and low phonotactic probability in the other) and ambiguous (the phonotactic sequences used were characteristic of both languages) were used. Additionally, to keep participants in bilingual mode (Grosjean, 2001) they were tested in one of two linguistic environments (primarily English with some Spanish code-switching or primarily Spanish with some English code-switching). The primary purpose of the study was to test eye-tracking methodology as a means to measure the decision in the face of competing linguistic cues. However, two additional questions were addressed:

(Q1) When the cues of linguistic environment and phonotactic probability obviously (mis)match, how do bilingual speakers assign language membership to a novel word?
(H1) Nonwords with obvious phonotactic cues will be sorted with less effort resulting in less switches and linguistic environment cues will not be used.

(Q2) When the cues of linguistic environment and phonotactic probability are ambiguous, how do bilingual speakers assign language membership to a novel word?

(H2) Ambiguous nonwords will take longer to sort resulting in more switches and linguistic environment will have an effect on language membership.
Chapter 2:

Methods

Participants

Upon IRB approval (see Appendix A) Spanish/English bilingual adults 18-40 years of age were recruited from the Tampa Bay community via flyers placed in various locations including the University of South Florida (USF) Tampa campus. All participants were required to have no history of speech, language, or hearing problems. In addition, all participants had normal or corrected to normal vision. The only form of compensation given was to students from USF, who were offered extra credit in their courses.

A total of 28 Spanish/English bilingual participants were recruited; however, 6 participants were excluded from the data analysis process due to having 10 or more trials containing no data because of calibration and validation malfunction. Of the 22 remaining participants 17 were females between the ages of 18-34 (M= 22.5) and 3 were males between the ages of 21-24 (M=22.3). The participants answered a language experience questionnaire which included questions regarding their age, gender, education level, where they were born, when they began speaking English and Spanish, which language they feel more comfortable using when reading, writing, speaking, and understanding, and how much of the day they spend speaking English and Spanish including in what situations.
Nearly all participants reported they were born on U.S. territory (19/22) and that they began learning English and Spanish from birth to ~6 years of age (20/22). When asked which language they read, write, and speak better most of the participants reported that English was better than Spanish (73%). However, when asked which language they understand better 54.5% of participants reported they understand English better, 13.6% understand Spanish better, and 31.8% stated they understand both Spanish and English the same. Participants appeared to spend most of their day speaking English, with 72.7% of participants reporting speaking English 60-80+% of the day. See Table 1 for participant details.

Table 1. Participant Characteristics

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<th>Participant #</th>
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<th>Sex</th>
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<th>Lang. read better</th>
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Note: E= English S=Spanish B=Both Spanish and English
Stimuli
The nonwords used in this study were the same nonwords used in Betancourt (2013). The stimuli consisted of 96 nonwords, which were made up of three different groups each containing 32 nonwords (see Appendix B for a full list of the stimuli with their IPA transcription). The three groups were based on phonotactic probability: Language Exclusive (the phonotactics of the nonwords designated them as either Spanish only [16 nonwords] or English only [16 nonwords]), High-Low (the nonwords had high phonotactic probability in one language and low probability in the other [16 High English-Low Spanish, 16 High Spanish-Low English]), and Ambiguous (the nonwords had similar phonotactic probability in both languages with 16 high probability and 16 low probability nonwords). Figure 1 adapted from Betancourt (2013) depicts how the nonwords were divided. Stimuli were recorded by a Spanish/English and English/Spanish bilingual female. All final nonwords were then made phonteically ambiguous by merging Spanish and English accented productions using TANDEM-STRAIGHT (Kawahara, Takahashi, Morise, & Banno 2009).

Figure 1. Visual Depiction of how Nonwords were Divided
Instrumentation

The stimuli were presented once randomly via a single KEF stereo speaker. The 96 nonwords were divided into three blocks with rest periods in between to avoid participant fatigue. Eye movements were recorded with an SR Research EyeLink 1000 Plus eye-tracking system. The eye-tracker consisted of a 16 mm lens placed in monocular remote mode (i.e., only tracking one eye without head stabilization), which only tracked each participant’s left eye.

Participants were seated approximately 60 cm away from the eye-tracker lens and a BenQ monitor with a screen resolution of 1920x1080, which presented visual stimuli. Verbal responses were recorded via a Sound Tech CM-1000 tabletop microphone.

Experiment Paradigm

Because the stimuli were synthesized (and this was originally designed for children), the experimenters needed to account for robotic sounding speech. Therefore, the experiment paradigm consisted of three cartoon video clips about red robots and blue robots going to school and the languages they spoke. During the first cartoon, participants were told “red robots speak Spanish like your mom and dad at home and blue robots speak English like your teachers at school.” After watching the short instructional video clip participants’ knowledge of which robot speaks which language was tested. Three robots appeared on the screen, one wearing blue on the top left or right portion of the screen, one wearing red on the top left or right portion of the screen, and a generic robot not wearing any color in the middle of the screen (see Figure 2). Participants heard the words “English” or “Español” via a speaker and were asked to indicate which robot spoke the corresponding language. Once a
language was assigned participants received immediate feedback. A sad face appeared if the incorrect answer was provided and a happy face appeared if the correct answer was provided. Participants had to obtain at least 80% accuracy on this task before they could move on. In order to avoid participants obtaining 100% accuracy from only one training trial researchers coded the program to run at least 6 trials before allowing the participant to continue. The maximum number of trials was set to 20 indicating participants had to obtain 16/20 correct to continue. If the accuracy was not met the experiment ended.

Figure 2. Screen Shot from the First Task

The second cartoon video clip was similar to the first; however, this task trained participants on the buses the robots took to school. At the end of this clip the participants’ knowledge was again tested. They were presented with two buses, one blue and one red (see Figure 3) and a generic robot presented on the bottom middle of the screen. Again, participants were tested on their knowledge and heard the words “English” or “Español” via a speaker and had to choose which bus was correct. Feedback identical to the first task was provided.
Finally, the third cartoon video clip told a story about the robots going to school. They lost their colored hats at the playground and mixed up their shoes during naptime. At the end of the day they did not know which bus to ride home. The participants were asked to help the robots get on the correct bus by listening to the word they spoke and deciding if it sounded like English or Spanish. The visual provided for the experiment portion was the same one provided in the second task (see Figure 3). For the experiment portion feedback was not provided.

![Figure 3. Screen Shot of Robot Bus Video Clip](image)

**Procedure**

Before entering the testing room the linguistic environment (primarily English with some Spanish code-switching or primarily Spanish with some English code-switching) and experiment version (red robots/busses on either left or right) were pre-assigned to each participant. In an attempt to control the amount of code-switching used, scripts were written for both linguistic environments (see Appendix C and D). The linguistic environment began the moment the participant entered the
research lab. The experiment consisted of four versions ERL, SRL, EBL, and SBL. The first letter of each version pertained to the linguistic environment (i.e., ERL=Primarily English with some Spanish code-switching). The second and third letters pertain to the bus location and color. For example EBL indicates the blue bus is on the left (Figure 2). The red bus was always Spanish and the blue bus was always English. The experiment versions were created to counterbalance the bus location (left/right).

Depending on what linguistic environment was assigned to the participant, s/he was greeted and spoken to primarily in English with Spanish code-switching or vice versa by a Spanish/English bilingual researcher. Upon arrival participants were provided with a consent form (see Appendix E) and a language experience questionnaire to complete (see Appendix F). All participants were kindly asked to remove any mascara or eye makeup due to interference with the eye-tracking device.

Participants were then seated in a sound proof booth in front of a computer screen and SR Research EyeLink 1000 Plus eye-tracking system with a researcher sitting next to them. To begin, the eye-tracker was calibrated. During calibration, participants were instructed to fixate their gaze on a dot until it disappeared. A total of nine dots appeared on the screen. This allowed the eye-tracking system to determine each participant’s visual field in relation to the display screen. Following calibration, validation occurred. To validate the calibration, participants fixated on the same nine points as during calibration. The calculated fixation locations were then compared to the known fixation locations to determine the degree of visual error. At this point, the software displayed information about the degree of visual
error for each fixation point, the average error across all points, and the maximum error across all points.

Once calibration and validation were completed the experiment began following the paradigm discussed earlier. All video clips were followed by verbal instructions to participants (see Appendix C and D) to first look at their choice and then verbally state their decision. Once participants stated their answer aloud the researcher pressed 1 or 2 (1=Spanish, 2=English) on the keyboard in order to record their response and progress the experiment. The 96 nonwords were presented randomly and were divided into three blocks with rest periods in between to avoid participant fatigue. In between blocks participants were told they could take a short break if needed. After each break a brief review of procedures was provided via verbal instruction.

Data Analysis

Due to a significant number of fixations falling outside of the set interest areas (top left and top right), roughly 90% of fixations were manually manipulated to the nearest interest area (see Figure. 4 and 5). The interest areas and fixations were on an X-Y-axis grid, which was visually split into four quadrants in order to assess which interest area was closest to the original fixation point. Once the nearest interest area was identified for a given fixation point the fixation point’s coordinates were manually changed. Once all fixations were manipulated a fixation report was exported providing information on how a nonword was sorted (English or Spanish), the total number of fixations made during a trial, and the number of switches made between answer choices before a final answer was given.
Figure 4. Screen Shot of Fixations Before Manual Manipulation

Figure 5. Screen Shot of Fixations After Manual Manipulation
Chapter Three:

Results

Two basic research questions were addressed in this study:

(1) When the cues of linguistic environment and phonotactic probability obviously (mis)match, how do bilingual speakers assign language membership to a novel word?

(2) When the cues of linguistic environment and phonotactic probability are ambiguous, how do bilingual speakers assign language membership to a novel word?

To answer these questions, three different dependent variables were examined: how a nonword was sorted (English or Spanish), the total number of fixations made during a trial, and the number of switches between answer choices made before a final answer was given. Due to researchers pushing 1 or 2 on the keyboard for participants’ responses reaction time could not be measured without interference of the researchers’ latency. Also, two independent variables were accounted for: word type and linguistic environment.

Generalized linear mixed-effect models (GLMs) were used to analyze the data. Unlike Analysis of Variance (ANOVA) GLMs allow the researcher to account for random effects while looking for significant relationships between fixed effects. GLMs also allow for hierarchical structure within the data which means level one (trials) is
nested within level two (participants) which allows for robust results with a small number of level two data, which was of importance in this study.

In the current study, the random effects were the items and the participants with the fixed effects of word type and linguistic environment. The hierarchical structure consisted of two levels: (1) trials (n=96 per participant) and (2) participants (n=22), giving a total number of 2,112 observations. For the continuous dependent variables (total number of fixations and switches) poisson regression was computed using the glmer function from lme4 package (version 1.1-17) within the R Environment for Statistical Computing (R Development core Team, 2015). For the binary dependent variable of sorted language (Spanish [code as 0] vs. English [coded as 1]), logistic regression was computed using the glmer function from lme4 package.

**Obvious (Mis)match of Cues**

When bilingual speakers were asked to sort the language exclusive nonwords (English Only or Spanish Only) there was a significant main effect of word type ($p<.001$) such that English Only nonwords were significantly more likely to be sorted as English compared to Spanish Only nonwords, but there was no main effect of linguistic environment and no interaction effect (Figure 6). There were also no significant results for the continuous variables of number of fixations and switches indicating no significant influence of phonotactic cues nor linguistic environment on either of those two variables (Figure 7).
As with the language exclusive nonwords, when bilingual speakers were asked to sort the ambiguous nonwords (HELS, HSLE, HB, LB) there was a significant main effect of word type ($p<.0001$) such that High English-Low Spanish nonwords were significantly more likely to be sorted as English compared to the other words types, but there was no effect of linguistic environment (Figure 8). Again, the dependent
variables of total number of fixations and number of switches were not significantly affected by phonotactic cues nor linguistic environment (Figure 9).

**Figure 8. Language Sorting of Ambiguous Nonwords**

**Figure 9. Average Number of Switches for All Word Types**
Chapter Four:
Discussion

The present study used eye-tracking methodology to investigate how Spanish/English bilingual adults process nonwords while linguistic cues (i.e., phonotactic probability and linguistic environment) are competing. Based on the UCM it was hypothesized that nonwords with obvious phonotactic probabilities would be sorted using the linguistic cue of phonotactic probability. In addition, the decision would be made with less effort resulting in less number switches between answer choices. On the other hand, it was hypothesized that nonwords with ambiguous phonotactic probability would be sorted using linguistic environment cues and that the decision would take longer and consist of more switches. In general, the findings suggest that participants did not use linguistic cues during language membership, regardless of whether or not phonotactic probability was a useful cue.

When asked to sort language exclusive nonwords, Spanish/English bilingual adults appeared to use phonotactic probability cues as hypothesized. These results support the notion of the UCM that phonotactic probability has high overall validity (reliable and accessible). In the case of language exclusive words, the phonotactic probability cues are the stronger cue. However, the number of fixations and number of switches provided online information about the decision making process. Results
were non-significant indicating there was no influence of phonotactic probability nor linguistic environment.

When asked to sort ambiguous nonwords, based on the UCM, participants should have used linguistic environment cues because the stronger cue (phonotactic probability) was neutralized (ambiguous words). In this case High English-Low Spanish nonwords were significantly more likely to be sorted as English compared to other word types with no effect of linguistic environment. In addition, the number of fixations and switches indicated no influence of phonotactic cues nor linguistic environment.

Overall, linguistic environment cues were not used indicating that they are a weak cue. Also, phonotactic probability was found to be a strong cue but not as strong as indicated by UCM. These findings support what has been shown in computational models (e.g., BIA+), indicating that linguistic environmental cues are weak and do not impact bilingual spoken language processing. However, two factors that could have affected the results of this study have been identified: (1) participant’s knowledge of linguistic background and (2) participants familiarity with English.

The first factor to consider is the participants’ background knowledge of the linguistic environment. The study took place in a predominantly English-speaking university (i.e., USF). Most of the participants were students attending USF. Also, most of the participants were familiar with the researchers, which they did not normally engage with in Spanish or in a code-switching manner. These factors could have resulted in the participants primarily tuning into English phonotactics, therefore
possibly inhibiting linguistic environmental cues of the less familiar language (i.e., Spanish). Furthermore, as previously mentioned, Molnar et al. (2015) investigated the interaction between language co-activation and participant’s knowledge of the language the conversationalist or interlocutor speaks (i.e., linguistic environment). They found that proficient bilinguals adapted to their linguistic environment; however, the low proficient bilingual group did not. In addition, the low proficient group showed bias toward their L1. In the current study, the bilinguals were considered low proficient, which could be why linguistic environment cues did not influence their language membership decisions.

This brings me to the second factor that could have affected the results of this study, which is the participant’s language experience. Most of the participants reported to be more familiar with English than Spanish. Therefore, it is suggested that, like in the findings of Molnar et al. (2015), the Spanish/English bilinguals in this study were exhibiting bias from their L1 causing a main effect of word type (High English-Low Spanish) while sorting ambiguous nonwords. Additionally, it was reported that Spanish was mostly used in social settings. However, this study required participants to complete a structured task. This could have also influenced the inability to tune into and use environmental linguistic cues. Lastly, according to Beatty-Martinez and Dussias (2017) code-switching experiences have been linked to code-switching comprehension. In this study the linguistic environment consisted of only code-switching. Suggesting that perhaps the participants in this study did not regularly engage in code-switching which caused the linguistic environment cue in this study to be weak.
Future Directions

English and Spanish are relatively similar languages, which could be why the continuous variable measures indicated the decision was fairly easy even when processing ambiguous nonwords. It would be interesting to see this study replicated with bilinguals who speak two languages that are more dissimilar than English and Spanish (e.g., English/Mandarin). Also, in this study the linguistic environment consisted of code-switching in a setting where it would not naturally occur. Therefore, it would be interesting to conduct the study in a community setting where participants regularly engage in code-switching in order to provide a more natural code-switching environment. However, this may prove to be a difficult task. Therefore a more viable solution would be to conduct the study in monolingual mode (Grosjean 2001) in settings where each language is regularly and naturally used.

Limitations

The current study was a pilot study to test eye-tracking methodology. Two limitations regarding eye-tracking methodology have been identified. The first limitation identified was insufficient knowledge of how to troubleshoot inadequate calibration and validation outcomes. Six participants’ data were not used during data analysis due to each participant containing 10 or more trials without fixations. When accurate calibration and validation is not completed the eye-tracker cannot accurately track the participant’s eye. Therefore, faulty calibration and validation is thought to have been a contributing factor. The second limitation was the size of the interest areas. Many fixations fell outside the set interest areas, and this could have been a result of the interest areas being set too small.
Conclusion

The primary purpose of this study was to test eye-tracking methodology as a means to measure the decision in the face of competing linguistic cues. As well as to investigate how Spanish/English bilingual speakers assign language membership to novel words while cues are competing. In addition, the study employed the UCM to investigate which cue would have high overall validity. All in all, results suggest that Spanish/English bilingual speakers used phonotactic probability cues to a certain extent (e.g., sorting language exclusive words). Indicating that phonotactic probability is a reliable cue and relatively strong, however not as strong as indicated by the UCM. However, linguistic environment appears to be too weak of a cue to influence spoken language processing. Clinically, this could be a positive finding for monolingual clinicians/teachers teaching bilingual children vocabulary. Since overall the results suggest that linguistic environment would have little, if any effect on language processing. Lastly, the lack of insight provided into the cognitive processing that occurred during the decision task could be attributed to the limitations listed earlier. Therefore, it is suggested that those limitations be addressed before continuing the study on bilingual children.
References


Appendix A:

IRB Approval

March 20, 2017

Kyna Betancourt, PhD
Communication Sciences and Disorders
4202 E. Fowler Ave
PCD 1017
Tampa, FL 33620

RE: Expedited Approval for Initial Review
IRB#: Pro00028371
Title: Cue competition during phonotactic processing in bilingual adults as measured by eye tracking

Study Approval Period: 3/20/2017 to 3/20/2018

Dear Dr. Betancourt:

On 3/20/2017, the Institutional Review Board (IRB) reviewed and APPROVED the above application and all documents contained within, including those outlined below.

Approved Item(s):
Protocol Document(s):
IRB Protocol.docx

Consent/Assent Document(s)*:
Informed Consent.docx.pdf

*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab. Please note, these consent/assent documents are valid until the consent document is amended and approved.

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review

33
research through the expedited review procedure authorized by 45CFR46.110. The research proposed in this study is categorized under the following expedited review category:

(4) Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing.

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval via an amendment. Additionally, all unanticipated problems must be reported to the USF IRB within five (5) calendar days.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

[Signature]

Kristen Salomon, Ph.D., Vice Chairperson
USF Institutional Review Board
## Appendix B:

### List of Stimuli Nonwords

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<th>Word Type</th>
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Appendix C:

Linguistic Environment Mainly English Script

Instructions in English

1. If you have any mascara on, por favor remove it with these wipes.
2. Once you’ve removed it, please sit inside the sound booth.
3. I’m going to place this target sticker on your forehead. No duele, it’s just one way the eye-tracking device can maintain calibration.

Calibration

4. Gracias. Now I am going to calibrate the equipment. You will see a black dot on the screen por favor sigalo con tus ojos hasta que se desaparezca; don’t try to predict where it is going to show up next.

Validation

5. Okay, now the calibration is finished, we will move on to validate the calibration. Again, you will see the black dot moving around the screen. When you see it, por favor sigalo con tus ojos hasta que se desaparezca. Remember, only look at the dot when you see it; don’t try to predict where it is going to show up next.

Practice portion- robot

6. Now we will start the practice portion of the experiment. You will see a short video con instrucciones.

Play the Video

7. Once you’ve looked at your answer please say it out loud (Red or Blue) so that I can record your response. La computadora will give you feedback on the accuracy of your response.

Please give your answer in English. Empezemos.
Practice portion- buses

8. Now I will show you another short video. Again, it will provide you with instructions.

Play the Video

9. Once you’ve looked at your answer please say it out loud (Red or Blue) so that I can record your response. La computadora will give you feedback on the accuracy of your response.

Please give your answer in English. Empezemos.

Experiment

10. Now the experiment will begin. Voy a presentar un video mas con instrucciones. |

Play the Video

11. Remember, when you hear the robot say a word you must choose which bus she should take home, Spanish or English. Look at the bus you choose then tell me your answer by saying “English” or “Spanish” out loud. Please give your answer in English.

12. Si tienes preguntas, please ask them now so I can clarify them before we start the experiment. You will have the opportunity to take a few short breaks if you’d like.

When break screen pops up

13. You can now take a short break if you’d like. If you move, we’ll need to recalibrate the eye tracker and take some measurements again. However, if you feel like you’re ready to continue, dejame saber.

If break was taken: Now we will take some measurements again and calibrate the equipment once more.

14. Great, let’s continue. Remember, when you hear the word from the robot, look at the bus she should take home and tell me your answer by saying either “English” or “Spanish.”
Appendix D:

Linguistic Environment Mainly Spanish Script

**Instrucciones en Español**

1. Por favor si tienes rímel, please remove it con estas toallitas mojadas.
2. Cuando los has removido please sit in the sound booth.
3. Voy a colocar este sticker en su frente. No te va a doler, solo es una forma en que el eye-tracker puede mantener la calibración.

**Calibration**

4. Gracias. Vamos a comenzar a calibrar el eye-tracker. Ahora vas a ver un punto negro en la pantalla, please follow it with your eyes hasta que se desaparezca. Solo mires al punto cuando lo veas: no intentes a adivinar cuando o donde se va a aparecer después.

**Validation**

5. Ya la calibración ha sido finalizada, ahora empezaremos a validar la calibración. Una vez más, verás el punto negro moviéndose alrededor de la pantalla. Cuando lo veas, please, look at it until it disappears. Recuerde sólo mira al punto cuando lo veas, no intentes a adivinar dónde se va a aparecer después.

**Practice portion- robot**

6. Ahora empezaremos the practice portion of the experiment. Vas a ver un video corto con instrucciones.
7. Después de que hayas mirado a la respuesta que has escogido, tell me your answer out loud (rojo o azul) para que yo pueda presionar su respuesta. The computer responderá con la precisión de su respuesta. Por favor responda en Español. Empezaremos.

_Practice portion- buses_

8. Ahora voy a enseñar un video más y se va a proveer instrucciones.

_Play the Video_

9. Después de que hayas mirado a la respuesta que has escogido, dime la respuesta en voz alta (rojo o azul) so that I can record your response. Por favor responda en Español. Empezaremos.

_Experience_

10. Ahora comenzará el experimento. Voy a presentar un video más with instructions.

_Play the Video_

11. Acuérdate, cuando escuchas el robot decir una palabra, tienes que escoger cual bus el robot debe de tomar a la casa, Español o Ingles. Mira al bus que escoges y después tell me your answer out loud by saying Español o Ingles. Por favor dime tu respuesta en Español.

_When break screen pops up_

13. Ahora puedes tomar un receso si deseas. Si te mueves, tendremos que calibrar el eye-tracker y tomar measurements again. Pero si sientes que estas listo/a para continuar, let me know.

_If break was taken: Ahora vamos a tomar unos measurements otra vez y calibrar el eye-tracker una vez mas._

14. Perfecto, empecemos de nuevo. Acuérdate, cuando escuchas la palabra que dice el robot mirar al bus que debe tomar el robot a la casa and tell me your response out loud in Español o Ingles. Por favor responda en Español.
Appendix E:

Consent Form

Informed Consent to Participate in Research Involving Minimal Risk and Authorization to Collect, Use and Share Your Health Information

Pro # 00028371

You are being asked to take part in a research study. Research studies include only people who choose to take part. This document is called an informed consent form. Please read this information carefully and take your time making your decision. Ask the researcher or study staff to discuss this consent form with you, please ask him/her to explain any words or information you do not clearly understand. The nature of the study, risks, inconveniences, discomforts, and other important information about the study are listed below.

We are asking you to take part in a research study called: Cue competition during phonotactic processing in bilingual adults as measured by eye tracking.

The person who is in charge of this research study is Dr. Kyna Betancourt. This person is called the Principal Investigator. However, other research staff may be involved and can act on behalf of the person in charge.

The research will be conducted at the Eye Tracking Lab in the Communication Sciences and Disorders Department.

Purpose of the study

The purpose of the proposed study is to investigate cue competition in bilingual speakers during a nonword sorting task. Specifically, we are asking which linguistic cue (environment or phonotactic probability) bilingual speakers will use to sort nonwords by language. We will answer this question using eye tracking methodology.

Why are you being asked to take part?

You are being asked to participate in this research because you are a bilingual Spanish-English speaker and we want to obtain information as to which linguistic cue (environment or phonotactic probability) bilingual speakers will use to sort nonwords by language.
Study Procedures:

If you take part in this study, and you are bilingual, you will be asked to:

- Listen to 96 nonwords and sort them into English or Spanish.
- While doing the task, your eye movements will be recorded using the SR Research EyeLink 1000 Plus eye tracking system with a 16 mm lens in monocular, remote mode (i.e., only tracking one eye without head stabilization). You will be seated in sound proof booth along with a research assistant and have a target sticker placed in the middle of you forehead to help with eye tracker calibration.
- Participants will answer a questionnaire in regards to their age, gender, use of both English and Spanish, whether they learned English sequentially or simultaneously, their education level, language spoken by parents, and language they feel most comfortable speaking.

Total Number of Participants

About 50 bilingual individuals will take part in this study at USF.

Alternatives / Voluntary Participation / Withdrawal

There are no alternatives to participating in this study. You do not have to participate in this research study. You should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study. You are free to participate in this research or withdraw at any time. There will be no penalty or loss of benefits you are entitled to receive if you stop taking part in this study.

Benefits

The potential benefits of participating in this research study include making a contribution to existing research concerning bilingual speech production.

Risks or Discomfort

The following risks may occur:

- Minimal risk due to adhesive on forehead from calibration sticker

Compensation

You will receive no payment or other compensation for taking part in this study.

Costs

It will not cost you anything to take part in the study.

Conflict of Interest Statement

This study will be performed objectively and the researchers in this study have no affiliations or involvement with any entity with financial interest or non-financial interest. The study will solely be used to contribute to the body of knowledge concerning bilingual articulatory settings.
Privacy and Confidentiality

We will keep your study records private and confidential. Certain people may need to see your study records. Anyone who looks at your records must keep them confidential. These individuals include:

- The research team, including the Principal Investigator and all other research staff.
- Certain government and university people who need to know more about the study, and individuals who provide oversight to ensure that we are doing the study in the right way.
- Any agency of the federal, state, or local government that regulates this research.
- The USF Institutional Review Board (IRB) and related staff who have oversight responsibilities for this study, including staff in USF Research Integrity and Compliance.

We may publish what we learn from this study. If we do, we will not include your name. We will not publish anything that would let people know who you are.

You can get the answers to your questions, concerns, or complaints

If you have any questions, concerns or complaints about this study, or experience an unanticipated problem, call Kyna Betancourt at 813-974-1388.

If you have questions about your rights as a participant in this study, or have complaints, concerns or issues you want to discuss with someone outside the research, call the USF IRB at (813) 974-5638.
Consent to Take Part in this Research Study
And Authorization to Collect, Use and Share Your Health Information for Research

I freely give my consent to take part in this study. I understand that by signing this form I am agreeing to take part in research. I have received a copy of this form to take with me.

Signature of Person Taking Part in Study

Date

Printed Name of Person Taking Part in Study

Statement of Person Obtaining Informed Consent

I have carefully explained to the person taking part in the study what he or she can expect from their participation. I confirm that this research subject speaks the language that was used to explain this research and is receiving an informed consent form in their primary language. This research subject has provided legally effective informed consent.

Signature of Person obtaining Informed Consent

Date

Printed Name of Person Obtaining Informed Consent
Appendix F:
Language Experience Questionnaire

Language Experience Questionnaire

Part I. Demographic Information
1. Date of birth (month/year):
2. Gender: M F
3. Where were you born?
   a. If you weren’t born in the US, when did you arrive here (month/year)?
4. Are you: Monolingual Bilingual Multilingual
   a. If bilingual, what two languages do you speak?
   b. If multilingual, what languages, besides Spanish and English, do you speak?
5. Have you ever been diagnosed with a speech, language, or hearing disorder? Yes No
   a. If yes, please explain:
6. Highest level of education: Some high school High school diploma Some undergraduate
   Bachelor’s Degree Some graduate school Graduate Degree

Part II. Language Use
1. When did you first begin to learn Spanish?
2. When did you first begin to learn English?
3. Which language do you read better in? English Spanish
4. Which language do you write better in? English Spanish
5. Which language do you speak better in? English Spanish
6. Which language do you understand better? English Spanish
7. How much of the day do you spend speaking English?
   0-10% 20-30% 40-50% 60-70% 80+%
   a. In what situations?
8. How much of the day do you spend speaking Spanish?

0-10%  20-30%  40-50%  60-70%  80+% 

a. In what situations?

9. Indicate with an “X” your strong points in each language

<table>
<thead>
<tr>
<th>Area</th>
<th>Spanish</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vocabulary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grammar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading Comprehension</td>
<td></td>
<td></td>
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<tr>
<td>Speaking Fluently</td>
<td></td>
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</tbody>
</table>