Nonword processing in bilingual five year olds: Do phonotactics count?

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Nonword processing in Bilingual Five Year Olds: Do Phonotactics Count?

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
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DEDICATION

I dedicate this dissertation to the two most influential and important men in my life: My best friend and husband, Salvador, and my father and mentor, George. Salvador, you have been my confidant, partner in crime, and support system for over half my life. Your undying support and motivation has been invaluable to completing this dissertation and the entire Ph.D. experience. I’m looking forward to moving on to the next exciting chapter of our lives!

Dad, you have been my scientific mentor and teacher of all things “life” since my first breath. From leading me through my first experiments to pushing me on when I wanted to quit, you have been there every single step of the way. I cannot begin to explain what your support and love has meant to me. Here’s to another 30 great years of sharing life’s special moments and challenging each other to think beyond the norm!
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ABSTRACT

Phonotactic processing is foundational to the word processing task in both monolingual and bilingual children (Li & Farkas, 2002; Pierrehumbert, 2001; Shook & Marian, 2013; Storkel & Morrisette, 2002). While the use of phonotactic information in word processing in monolingual children is relatively well documented, it is less well understood in bilingual children. The purpose of this study was to investigate how bilingual kindergartners process the phonotactic probabilities of their two languages. A set of nonwords was developed that manipulated the strength of phonotactic probability across both Spanish and English while also controlling the language environment of the experimental task (i.e., whether children were tested in Spanish or English). Hence, this study allowed for a unique investigation into how bilingual children process two languages and their associated phonotactic probabilities. Specifically, this study provided answers to: whether or not bilingual children benefitted from a high probability processing advantage, if the phoneme systems of two languages were stored as one unit or separate units, and if there was an effect of language environment (i.e., an assimilation effect, Burki-Cohen et al., 1989).

By varying the phonotactic probabilities of nonwords and the language environment), the answers to several research questions were sought. First, language
exclusive nonwords (nonwords that had phonotactic probabilities unique to English or Spanish) were used to investigate the presence of a high phonotactic probability processing advantage in bilingual children. Second, high/low nonwords (nonwords with a high phonotactic probability in one language and a low phonotactic probability in the other language) were compared with the language exclusive nonwords to determine if the phonotactic systems of a bilingual child’s two languages are stored together such that they interact during word processing. Finally, ambiguous nonwords (those with equal phonotactic probability in both languages) were used to investigate the influence of language environment on phonotactic processing. The nonwords were created by manipulating phonotactic probabilities in each language, recorded by two bilingual speakers, standardized for fundamental frequency and synthesized to become phonetically and acoustically ambiguous. Wordlikeness judgments in each language were obtained from monolingual English and bilingual Spanish-English adults. These results determined that adults were processing the varying phonotactic probabilities of the nonwords as designed and the words were appropriate stimuli for use in a word sorting task with bilingual children.

In an attempt to replicate aspects of a natural language environment, the current study first divided children into two bilingual testing groups: one where mostly English was spoken and another where mostly Spanish was spoken. Children watched cartoons illustrating the need for sorting nonwords into two languages before completing the word sorting tasks. The experiment was presented using MouseTracker (Freeman, 2011), which recorded the participant’s response and mouse cursor movement (as a measure of decision complexity) as the child selected either Spanish or English.
Mixed level modeling results indicated significant differences in language choice but not decision complexity across the nonword types. First, bilingual children sorted language exclusive nonwords by focusing on whether the word was more probable in English or Spanish than whether the nonword had high or low probability within a language. Hence, these participants did not appear to benefit from a high phonotactic processing advantage. When children were sorting the high/low nonwords, they tended to ignore the fact that the nonwords had phonotactic probability in both languages, and treated them as belonging to the language in which they had the highest phonotactic probability. This finding would suggest that bilingual children do not appear to store the phonotactic systems of two languages together. Finally, results showed no effect of language environment when children were sorting the ambiguous nonwords. Overall, it appears that bilingual children focus on the overall phonotactic probability of a nonword (i.e., whether it is more probable in Spanish or English) during processing, while ignoring any dual phonotactic probabilities from two languages. These results are incorporated within a proposed model of bilingual word processing and a brief discussion of how these findings can be expanded to explain bilingual word learning is provided.
CHAPTER ONE: INTRODUCTION

Word processing in monolingual children is a complex process involving perception of acoustic signals (Munson, Edwards & Beckman, 2005), processing of phonotactic probabilities (Storkel & Morrisette, 2002), and lexical word-form development (Luce & Pisoni, 1998). This process is likely more difficult for a bilingual child who has to pay attention to and process phonetics, phonotactics, and lexical semantics from two languages. Phonotactic processing in bilingual children has been relatively understudied. For instance, it is unknown how a bilingual child processes and stores two sets of phonotactic probabilities. It is also unclear how bilingual children use phonotactic probability when learning new words. Investigating these issues is crucial given that bilingual children currently make up 21% of school-age children in the U.S. (National Center for Educational Statistics, 2011) and are currently falling behind their monolingual peers in important language tasks, like reading (U.S. Department of Education, 2011).

Much of the information about bilingual phonotactic processing comes from two sources: Hypotheses based on results from monolingual children, and computer models simulating bilingual language processing. However, results from monolingual children cannot be assumed to apply to bilingual children since monolinguals do not have potentially competing phonetic and phonotactic interpretations of a speech stream. Further, while the computer models simulate bilingual processing of incoming phoneme
sequences (Li & Farkas, 2002; Shook & Marian, 2013; Zhao & Li, 2010), hypotheses from these models have not, for the most part, been tested with bilingual children. Therefore, research specifically looking at how bilingual children process phonetic and phonotactic information is necessary.

The current study focused exclusively on the task of nonword processing at the phonotactic level. Previous bilingual studies have asked children to repeat nonwords derived from Spanish or English phonotactic probabilities and presented in a monolingual environment (e.g., Brea-Spahn, 2009; Summers, Bohman, Gillam, Peña & Bedore, 2010), however, this task does not force bilingual children to process phonotactic probabilities in a bilingual mode (Grosjean, 1989). In the bilingual mode, an individual must process two phonotactic systems simultaneously because the speakers do not explicitly state in which language they are speaking. In a natural language setting, bilingual children must determine to which language they are listening. To establish language membership, bilingual children must be acting in a bilingual mode, where they activate and expect to hear both languages (Grosjean, 1989).

In an attempt to replicate aspects of a natural language environment, the current study first divided children into two bilingual testing groups: one where mostly English was spoken with some Spanish words intermingled (i.e., Spanish code-switching occurred), and another where mostly Spanish was spoken with some English words intermingled. The children were presented with specially created nonwords that were to be judged as belonging to either English or Spanish. Specifically, three types of nonwords were created: *language exclusive* (nonwords with phonotactic probability in only English or Spanish), *high/low* cross-language probabilities (nonwords with a high
probability in one language and low probability in the other), and *ambiguous* (nonwords with similar phonotactic probability in both languages). These nonwords were synthesized to neutralize any acoustic effects on processing and presented in a language environment designed to make phonetic information about the nonwords’ language ambiguous. The children were asked to sort these nonwords into Spanish or English. Each child’s decision was the result of either their processing of the nonword’s phonotactic probabilities, the language environment in which they were being tested, or a combination of the two.

Since bilingual children were restricted to using phonotactic probabilities or the language environment to make language membership decisions (i.e., whether a nonword belonged to English or Spanish), results of this study will shed light on how bilingual children process phonotactic probabilities in ambiguous phoneme sequences presented in a natural setting where there is the expectation of two languages being spoken. A better understanding of phonotactic processing in bilingual children will strengthen future research in the area of bilingual word processing and, eventually, bilingual word learning.

**The Role of Phonotactics in Word Processing in Children**

Phonotactics, in general, refer to the “permissible sequences of segments allowed in a language” (Parker & Riley, 2010, p. 124). However, it has been shown that phonotactic knowledge extends beyond the permissible and impermissible to include more or less probable sequences (Frisch, Large, & Pisoni, 2000). The frequency with which segment sequences appear in any given language is known as phonotactic probability (Storkel, 2001). For example, in English the phoneme sequence /sg/ cannot begin a word, the sequence /sk/ has a moderate frequency, and the sequence /st/ is
common. However, /sg/ can occur between words (as in “bass guitar”). The phonotactic probability of /s/ ending a word is .08 and the probability of /g/ starting a word is .02 (Vitevitch & Luce, 2004). Hence, when an infant learning English hears /sg/ in the speech stream, he/she recognizes that it is much more statistically probable that he/she is hearing two separate words, one that ends with /s/ and one that starts with /g/ as opposed to one word. Through this reasoning, the infant parses the speech stream between the /s/ and /g/ and continues listening to the incoming speech. By contrast, an /st/ sequence would be ambiguous and potentially parseable either as an onset or word boundary (setting aside, for the moment, phonetic differences in segments based on context). This process of paying attention to the statistical properties of a language is called statistical learning, and is hypothesized to be one of the first steps in language acquisition (Saffran, Aslin, & Newport, 1996).

Statistical learning has been described as an “experience-dependent mechanism” (Saffran, et al., 1996, p. 1928) and has been shown to exist in neonates (Teinonen, Fellman, Naatanen, Alku, & Huotilainen, 2009) and infants as young as 6 ½ months (Thiessen & Saffran, 2003). Findings of statistical learning in infants supports the notion of usage-based language acquisition (Ellis, 2002). This general account of language acquisition posits that as an infant gains experience with a language, he/she begins to extract patterns from the language (Ellis, 2002; Munson, Edwards, & Beckman, 2005). One of the patterns that infants extract from their surrounding language is phonotactic probabilities (Pierrehumbert, 2003). Infants continue to use these statistical properties to parse the daily incoming speech stream, and by the time they are comprehending words,
infants are parsing speech streams into probable word candidates waiting to be mapped onto a concept (Graf Estes, Evans, Alibali, & Saffran, 2007; Saffran, 2001).

Phonotactic probability continues to play a supporting role in language development even after children have learned to parse their language. For example, during the period when young children are learning to comprehend and produce new words, they learn words more quickly and accurately if they are composed of phoneme sequences with high phonotactic probability, suggesting that the constituents used in parsing the speech stream are also integrated with lexical information (Pierrehumbert, 2003; Pitt & McQueen, 1998; Storkel, 2001).

To date, the role of phonotactic probability in bilingual language acquisition has been relatively understudied. It has been shown that young infants (as young as 8 ½ months) are sensitive to the statistical properties of a novel language (Pelucchi, Hay, & Saffran, 2009) and that bilingual infants and young children can identify legal and illegal phonotactic patterns, as well as phonotactic probabilities, in both of their languages (Messer, Leseman, Boom, & Mayo, 2010; Sebastián-Gallés & Bosch, 2002). These findings would suggest that infants learning two languages recognize two sets of phonotactic probabilities in their language environment and use those probabilities to parse their two languages (as supported by several computational models; Li & Farkas, 2002; Shook & Marian, 2013; Zhao & Li, 2010).

As bilingual children continue to develop, there is evidence that they learn the phonotactic probabilities for both of their languages, but are more proficient with the native language (L1) due to the fact that the native phonotactic knowledge is more entrenched and has access to more resources, like short-term memory (Messer et al.,
2010) and vocabulary (Munson et al., 2005). However, there is little to no research on exactly how bilingual children use two phonotactic systems to learn new words in either language. Monolingual children have been shown to use their language-specific phonotactic knowledge when mapping new word forms to objects such that they will not map word forms that violate native phonotactics (Mackenzie, Curtin & Graham, 2012). If this were true of bilingual children as well, it would suggest that bilingual children may be aware of their two phonotactic systems, but will have difficulty mapping new word forms in their second language (L2) and are biased to access their first language (L1) until the L2 phonotactic system is completely developed.

It is also probable that a bilingual child’s two phonotactic systems interact with each other. In monolingual children, phonemes and words facilitate activation of each other (Storkel & Morrisette, 2002), and activation has been shown to occur across languages in bilingual computational models (e.g., Li & Farkas, 2002). These models suggest that as bilingual children acquire phonotactic probabilities for each of their two languages, the probabilities interact such that one phoneme sequence can activate phonotactic probabilities in both L1 and L2.

This hypothesis was supported in adults completing an on-line visual lexical decision task. Duyck (2005) found evidence supporting “pre-lexical language-independent activation of phonological representations” (p. 342) in bilingual adult reading. In other words, phonological representations in L1 activated similar phonological sequences in L2 before the phonological strings were given lexical status. However, the ability to detect cross language activation may depend on the nature of the task. Frisch and Brea-Spahn (2010) asked English monolingual and Spanish-English
bilingual adults to complete an off-line task of making well-formedness judgments (determinations about how word-like a stimulus sounds) about nonwords with phonotactic probabilities characteristic of Spanish or English. Specifically, the monolingual adults were asked to judge English nonwords while the bilingual adults were asked to judge both English and Spanish nonwords. Their results indicated that the bilingual adults made wordlikeness judgments similarly to the monolinguals, suggesting that bilinguals operated within each language independently during the wordlikeness judgment task (Frisch & Brea-Spahn, 2010). This result suggests that the two phonotactic systems of a bilingual adult can stay separate during off-line nonword processing because the adult has time to actively suppress the other language. Since these results suggest that cross-language interaction depends on the type of task a bilingual adult is completing (on-line vs. off-line), it is important to consider task demands in phonotactic experiments with bilingual children.

**Child Models of Word Processing**

Several models of monolingual and bilingual word processing in children suggest that it occurs on three levels (phonetic, phonological, and lexical) and begins with the processing of phoneme sequences (Li & Farkas, 2002; Li, et al., 2004; Shook & Marian, 2013; Storkel & Rogers, 2000; Zhao & Li, 2010). Bilingual models, which must account for the presence of two languages during word processing, further organize the phonological and lexical levels by language (Li & Farkas, 2002; Shook & Marian, 2013; Zhao & Li, 2010). Based on behavioral and simulated data from these models, the full process of bilingual word processing can be hypothesized as follows (see Figure 1).
Bilingual word processing likely begins with phoneme\textsuperscript{1} processing (Luce, Goldinger, Auer & Vitevitch, 2000). In this step, the phonemes of the incoming word are sequenced and neural connections between each phoneme are activated. This sequencing information is sent to the phonological level where phonotactic probabilities are stored (Luce et al., 2000). The incoming phoneme sequence then activates stored phoneme sequences (Luce et al., 2000). Extending this finding to bilingual speakers, if similar phoneme sequences from both languages are stored together (as hypothesized by

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Schematic of bilingual word processing}
\end{figure}

\textsuperscript{1} Luce et al. (2000) use “allophone” instead of “phoneme” to signify that the model accepts any phone – not necessarily something categorically perceived as a phoneme. However, the word “phoneme” will be used here for consistency across models. Additionally, in the case of bilinguals, phonetic information may be expected to provide information about the language being spoken (Pierrehumbert, 2003), but the degree of phonetic variability across speakers and speaking environments means this information is likely probabilistic and another indexical factor in the perception process (Munson et al., 2005).
bilingual neural network models; e.g., Li & Farkas, 2002), then their activation would occur across languages. This could increase the overall number of phoneme sequences receiving activation since there could be multiple items across languages that share similar phonotactic patterns. This type of cross-language activation was described in the Self-Organizing Model of Bilingual Processing (SOMBIP; Li & Farkas, 2002). During testing of this neural network model, the program was asked to process the Cantonese word *sik* (eat) and the English word *it* was activated due to its similar phonotactic structure. If it is assumed that these phonotactic sequences are stored at the phoneme pattern level, then it is likely that this level in a bilingual child contains phonotactic sequences for both languages (Li & Farkas, 2002; Shook & Marian, 2013; Zhao & Li, 2010).

After the incoming word is processed at the phoneme pattern level, the system must make a decision as to the lexical status of the word (Storkel & Morrisette, 2002). If the phoneme sequence is determined to be a word in the child’s lexicon, then activation is sent to the lexical level and the word is processed (see Figure 1). If the word does not have lexical status, then it must be added to the system. This is done in two ways. First, information on the phoneme sequence is sent back to the phoneme pattern level so it can be stored in long-term memory for future encounters with the word (Zhao & Li, 2010). At the same time, Hebbian (or associative) learning is pairing the new phoneme sequence with word meaning (Li & Farkas, 2002; Robinson, 2006; Shook & Marian, 2013; Zhao & Li, 2010). This creates a new item at the lexical level which can be activated in the future.

At the lexical level, information on word meaning and semantic category is stored (Storkel & Morrisette, 2002). In the bilingual child, this level is likely organized similarly
to the phonological level with lexical items organized by language (i.e., L1 and L2). Within each language, lexical items are stored in neighborhoods (Luce & Pisoni, 1998). Neighborhoods are groups of phonologically similar words. These neighborhoods can be described using two parameters: density and frequency. Density refers to the number of “neighbors” that reside in the neighborhood, (i.e., the number of words that share similar phoneme sequences\(^2\)) while frequency refers to the average frequency of the neighbors in a neighborhood (Luce & Rodriguez, 2004).

These neighborhood parameters have been found to influence word processing in monolingual adults via competition. Generally, the incoming phoneme sequence activates other items in the lexicon, and the word that becomes activated above a threshold for selection is deemed the “winner” (Luce & Pisoni, 1998). However, this process of activation is influenced by the neighborhood parameters of density and frequency, as well as the frequency of the word to be processed. Specifically, there are eight potential patterns of word processing influence from neighborhood density, neighborhood frequency, and word frequency (Vitevitch & Rodriguez, 2005). The hardest condition for word processing (i.e., word processing would take longer and be less accurate) would be a word with low frequency residing in a dense, high frequency neighborhood. In this scenario, the word starts with a low level of activation (due to its low frequency) and must compete with a large number or neighbors (dense neighborhood) all with relatively high frequency. Conversely, the easiest condition for word processing would be a word with high frequency residing in sparse, low frequency neighborhood. In this scenario, the word begins with a high level of activation from having a high frequency and only has to

\[^2\] A neighbor for a target word can be informally described as being one phoneme different from the target via substitution, addition or omission (Luce & Pisoni, 1998)
compete against a few neighbors (sparse neighborhood), none of which have a high phonotactic probability (low frequency).

It is also important to note, however, that influences from phonotactic probability are related to lexical status. When adults are asked to repeat nonwords, they do so more accurately and faster when the nonword has a high phonotactic probability. However, when adults are asked to repeat real words, they do so more accurately and faster when the word comes from a sparse neighborhood (which is composed of low probability words; Vitevitch & Luce, 1998). In other words, only stimuli that “resonate” at the lexical level will be subjected to neighborhood density effects while words that do not have lexical status will be subjected to phonotactic probability effects at a sub-lexical level (Vitevitch & Luce, 2005, p. 194).

Finally, it should also be noted that this pattern of influence from neighborhood density may depend on the language being processed. Vitevitch and Rodriguez (2004) asked Spanish-speaking adults to complete a lexical decision task using words and nonwords that differed on the parameters of neighborhood density and frequency as well as word phonotactic probability. Among the pertinent results was the fact that these Spanish speaking adults responded faster and more accurately to words from dense and high frequency neighborhoods (Vitevitch & Rodriguez, 2005). This finding contradicts findings from English-speaking adults, and the authors hypothesize that the difference could be the result of a different processing mechanism used by Spanish speakers to process longer words, which tend to be more frequent in Spanish compared to English. The authors conclude that, whatever the exact nature of this difference, it is important to
remember that speakers from different languages may perform differently in word or nonword processing tasks.

These frequency and density effects have not been well tested in bilingual children, but some of the computational models have shown a similar neighborhood structure in the bilingual lexicon (e.g., Shook & Marian, 2013; Zhao & Li, 2010). In general, all of the computational models have shown that the lexicon is roughly organized by language. However, the boundaries are not strict, and overlap does occur for words sharing similar phonological sequences (i.e., cognates like piano and “piano”; words with shared onsets such as tenedor (fork), Tortuga (turtle), and “tent;” Shook & Marian, 2013). This overlapping structure results in cross-language activation for phonologically similar words.

In sum, when a bilingual child processes a word, it is perceived by the child and the phoneme sequence is processed (Luce et al., 2000). The phoneme sequence is sent to the phonological level where phonotactic patterns are activated and the system decides if the pattern is likely to have lexical status (Gupta & MacWhinney, 1997; Luce & Pisoni, 1998; Storkel & Morrisette, 2002). If the incoming phoneme sequence is likely to have lexical status, activation is sent to the lexical level where neighborhood frequency and density effects influence activation of possible word candidates (Luce & Pisoni, 1998; Storkel & Morrisette, 2002; Vitevitch & Luce, 1998; Vitevitch & Luce, 2005). If one candidate receives enough activation to be deemed the winner, the word is processed (Luce & Pisoni, 1998). If no lexical status exists, the phoneme sequence is learned and stored in the phoneme pattern layer for later access (Zhao & Li, 2010).
It is important to note that this process does not include the presence (or absence) of language nodes to indicate to which language a bilingual child is listening. Language nodes have been hypothesized in some models to be unspecified systems that use patterns of word activation to tell the word processing system to which language a word candidate belongs (e.g., Dijkstra & Van Heuven, 1998; Dijkstra & Van Heuven, 2002). However, some researchers have objected to the notion of including unspecified cognitive processes (the language nodes) in a model of bilingual word processing and have proposed that language environment (i.e., the language being spoken “around” a target word) tells the system which language is being processed (Grosjean, 1997; Lemhofer & Radach, 2009). However, the more recent computational models of child bilingual word processing do not include language nodes or language environment. Instead they suggest that a child only needs to pay attention to the phonotactic probabilities of the incoming words to sort them into L1 or L2 (Li & Farkas, 2002; Shook & Marian, 2013; Zhao & Li, 2010). Given the importance of phonotactic probabilities in these models, the current study attempts to investigate phonotactic processing in nonwords in a bilingual language environment without phonetic or lexical cues to language identity.

In conclusion, phonotactic processing is foundational to the word processing task in both monolingual and bilingual children. While the use of phonotactic information in monolingual children is relatively well documented, hypotheses about the additional role that phonotactic processing may have in bilingual computational simulations have not been tested in bilingual children (Li & Farkas, 2002; Shook & Marian, 2013; Zhao & Li, 2010). It is therefore important to study phonotactic processing in bilingual children to determine the validity of the existing computational hypotheses. In doing so, it is
important to avoid both the phonetic and lexical levels of processing so that results reflect only what is happening at the phonotactic level. This can be done by using synthesized nonwords. As reported earlier, Vitevitch and Luce (1998) found that nonwords are processed in a different manner (i.e., more directly based on phonotactic probability) than real words. Similarly, Pitt and McQueen (1998) found that transitional probabilities (phonotactic probability of sequences of two phonemes) are represented pre-lexically. Pierrehumbert (2001) has suggested that processing of the phonotactic probability before activating the lexicon is accomplished by a Fast Phonological Preprocessor which is used to parse a speech stream based on phonotactic information. Based on this literature, it is probable that asking bilingual kindergartners to process nonwords will test word processing at the pre-lexical or sub-lexical level.

**Nonword Stimuli and Phonotactic Probability Effects in Bilingual Word Processing**

Using nonwords as stimuli in word processing studies is advantageous for several reasons. First, as mentioned earlier, nonwords have the advantage of being processed at the pre-linguistic level (Pitt & McQueen, 1998; Vitevitch & Luce, 1998). In other words, they have no semantic meaning to any participant and processing can be dominated by the phonotactic level of word representation (Storkel & Morisson, 2002). For example, presenting a bilingual child with the word /inan/ and asking him/her to decide if it is an English or Spanish word forces the child to focus on the phonotactic sequence of the word without vocabulary knowledge to make the decision.

Second, nonwords permit manipulation of phonotactic probabilities which allows for the investigation of the influence of phonotactic properties on word processing. For example, in studying the effects of phonotactic probability in word learning, Storkel
(2001) created nonwords where all of the constituents of the nonword had high phonotactic probability (creating highly probable nonwords) or low phonotactic probability (creating rare nonwords). She found that children mapped semantic meaning to nonwords with high phonotactic probability significantly faster and more accurately than to words with low phonotactic probability. The accuracy rates reported in nonword repetition (NWR) tasks in both monolingual and bilingual children have also shown several phonotactic effects. Specifically, children are more accurate at repeating nonwords with higher phonotactic probability (Brea-Spahn, 2009; Edwards, Beckman, & Munson, 2004), shorter length (Brea-Spahn, 2009; Gathercole, Willis, Emslie & Baddeley, 1991) and higher adult word-likeness ratings (Brea-Spahn, 2009; Dollaghan, Biber & Campbell, 1995). In bilinguals, the amount of time they have spent speaking and hearing a language, irrespective of language ability, has been shown to positively influence NWR with bilingual children performing better in their L1 (Windsor, Kohnert, Lobitz & Pham, 2010), especially if they are exposed to L2 later in life (Summers, et al., 2010).

In bilingual research, the ability to control the phonotactic probability of nonwords also allows for research into phonotactic processing of nonwords that are language ambiguous. For example, Lemhofer and Radach (2009) created a set of nonwords that could be read as either German or English. Using these ambiguous nonwords allowed the researchers to examine how bilingual adults processed phonotactics in the absence of explicit language membership information. Burki-Cohen, Grosjean, and Miller (1989) embedded phonetically ambiguous words in French and English context sentences and found that bilingual adults used the surrounding language
context to determine to which language the ambiguous words belonged; they termed this the assimilation effect.

Crucially, both of these studies used printed stimuli so the participants were reading the stimuli, eliminating any acoustic-phonetic differences that would have disambiguated the stimuli. The current study asked bilingual kindergartners, who could not read, to process auditory stimuli. In this case, it is very likely that acoustic information could disambiguate the stimuli (e.g., the /ɾ/ in Spanish is trilled while the /ɹ/ is retroflexed in English). Therefore, the stimuli in the current study had to be digitally manipulated to neutralize any acoustic factors that could have potentially disambiguated the stimuli. Using phonotactically and acoustically ambiguous nonwords to study phonotactic processing in bilingual children forces them to access their two languages simultaneously which should address the question of phonotactic interaction between two languages. It can also investigate the extent to which bilingual children rely on their language environment to process ambiguous nonwords.

To date, NWR studies with bilingual children have utilized nonwords that were either phonotactically based in English or Spanish. This required children to process words in one language or another. What remains to be examined is if the phonotactic influences on nonword processing occur across two languages when a bilingual child is accessing both languages simultaneously. For instance, when told to separate words into Spanish or English, will the two phonotactic systems interfere with each other? When confronted with a nonword that has high phonotactic probabilities in one language but low phonotactic probabilities in another, will the high phonotactic advantage for repetition accuracy still arise? These questions can be answered by presenting children
with nonwords from both languages within the same task, which would require them to keep both phonotactic probability systems active.

To investigate language competition from bilingual word processing, on-line rather than off-line behavioral data should be collected. Nonword processing has historically been measured using reaction time (RT) and accuracy, both of which are off-line behavioral measurements (e.g., Brea-Spahn, 2009; Dollaghan et al., 1995; Lemhofer & Radach, 2009). RT can speak to how fast a person can make a judgment and accuracy indicates whether or not the judgment was correct, but neither can provide insight into the time course of the decision making process. This project used a relatively new methodology that tracks the path of a computer mouse during task performance in order to investigate the on-line decision process during bilingual word processing.

**Using Mouse Tracking Methodologies in Bilingual Nonword Processing**

To measure the “fine-grained temporal components” of a decision (Freeman & Ambady, 2010, pg. 226), researchers have previously used eye-tracking and/or event-related potentials (ERP); however these can be costly and are not always readily available (Freeman & Ambady, 2010). One relatively new method for measuring on-line processing is continuously recording the trajectory of a motor movement.

Computer mouse cursor trajectories have been measured as a means of studying spoken language processing (Spivey, Grosjean & Knoblich, 2005). Working with monolingual adults, these researchers presented a spoken target word along with two pictures: one corresponding to the target and the other to an alternative. The alternative was either an unrelated picture (e.g., *pickle* for the target *candy*) or a phonologically related distracter (e.g., *candle* for *candy*). The researchers found that by tracking mouse trajectories, they were able to visually measure the influence of the distracters in
processing target words. Specifically, they found a general trend that a listener’s mouse cursor was attracted to a phonologically similar distracter before making a definitive movement to the correct picture. This general pattern of mouse movement demonstrated that “the continuous processing of a spoken word is observable in the continuous execution of motor output” (Spivey et al., 2005, p.10398).

MouseTracker (Freeman, 2011) is a newly developed computer program that allows for the creation and execution of experiments while recording the continuous motor output of computer mouse cursor trajectories. Along with decision accuracy, MouseTracker records mouse cursor movements and computes several analyses based on the mouse trajectory. Mouse cursor movement is tracked by sampling the x-, y-coordinates of the cursor 60 – 70 times every second (Freeman, 2011). Based on these samples, mouse trajectories can be recorded and analyzed.

The primary analysis used by MouseTracker to investigate word processing is spatial attraction (Spivey et al., 2005). This determines how “attracted” the mouse is to an alternate picture choice. In other words, it visually displays the strength of a foil or a prime’s influence on a word processing decision. Spatial attraction is measured by drawing a reference line from the starting fixation point directly to the correct picture. The cursor trajectories are then plotted against this reference line and the area between the cursor’s path and the reference line is computed. The larger the area between the mouse trajectory and the reference line, the stronger the attraction to the distracter (Area Under the Curve [AUC]; see Figure 2). If a listener makes a fairly straight line from the start position at the bottom of the screen to one of the choices, then it can be said that he/she was fairly certain about his/her response and was not attracted to the other option.
However, if the cursor makes a large arc from the start position, out towards the left side option and finally back to the right side option, it can be said that the picture on the left acted as a strong attractor; the listener was unsure of his/her answer.

Figure 2. Computation of Spatial Attraction using the reference line and the mouse trajectory. AUC=Area Under the Curve. Adapted from Freeman (2011).

**Research Questions and Hypotheses**

In sum, while an emerging base of empirical evidence exists to explain word processing in sequential bilingual children, many gaps exist. For instance, if a word has phonotactic probabilities in two languages, can the bilingual child still benefit from the high probability processing advantage? Further, the influence of cross-language phonotactic interaction during word processing is not understood. Are a bilingual child’s
phonotactic systems stored together? And, if so, how do the phonotactic systems interact to affect word processing? Finally, while it is assumed that bilingual children do not use language nodes to determine to which language they are listening, it is unclear how they would make a language determination on a word that has the same phonotactic probabilities in both languages. In order to begin filling these evidentiary gaps, the proposed study will answer the following questions:

(Q1) Do bilingual children benefit from the high probability advantage during nonword processing?

(H1) Bilingual children will sort high probability language exclusive nonwords more accurately and with a smaller AUC.

(Q2) Are the phoneme systems of a bilingual child’s two languages stored together as one unit, as suggested by neural network modeling?

(H2) Bilingual children will sort language exclusive nonwords “accurately” (i.e., English only words as English, Spanish only words as Spanish) more often than the high/low nonwords.

(Q3) Does a bilingual child’s language environment influence his/her sorting of ambiguous words?

(H3) Bilingual children will show an assimilation effect (Burki-Cohen et al., 1997) when sorting the ambiguous nonwords.
CHAPTER TWO: METHODOLOGY

Adult Study: Stimulus Development and Wordlikeness Ratings

The main purpose of this dissertation was to determine the effects of phonotactic probability on a bilingual child’s ability to determine the language membership of a novel word. The first step in doing this was to create phonetically ambiguous nonwords having varying combinations of Spanish and English phonotactic sequences. After the nonwords were created, they were presented to Spanish-English bilingual adults and English monolingual adults who judged them on how wordlike they sounded. Ideally, phonotactic probability would be correlated with judgments of wordlikeness. The following sections will first describe how the nonword stimuli were created and finish with a description of the wordlikeness study completed with the adults.

Stimulus Development

Three word types. Three groups of two-syllable spondee nonwords were created: Language Exclusive (phonotactic constituents unique to Spanish or English), High/Low (phonotactic constituents that are present in both languages, but with high phonotactic probability in one language, low phonotactic probability in the other), and Ambiguous (constituents with equal phonotactic probability in both languages). All nonwords were spondees created by combining stressed onsets and rimes from each language. Each stimulus group consisted of 32 nonwords with half of the nonwords having high phonotactic probability and the other half having low phonotactic probability (see Figure
3). Based on inspection of the constituent phonotactic probabilities using a scatterplot of all stressed initial onsets in both languages (discussed in more detail below), it was determined that no stressed initial onset existed that clearly distinguished Spanish and English. Therefore, the two most common stressed initial onsets (/k/ and empty onset) were used for all nonwords. Phonotactic probability differences between the languages (if any) occurred after the initial onset for all nonwords.

![Continuum of ambiguity from unambiguous to ambiguous](image)

**Language Exclusive (32)**
- English Only (16)
- High Probability (8)
- Low Probability (8)
- Spanish Only (16)
- High Probability (8)
- Low Probability (8)

**High/Low (32)**
- High English-Low Spanish (16)
- High Spanish-Low English (16)

**Ambiguous (32)**
- High Both (16)
- Low Both (16)

Figure 3. Nonword stimuli represented on a continuum of ambiguity. The Language Exclusive nonwords are least ambiguous.

In the Language Exclusive group of nonwords, 16 nonwords were English exclusive (having a phonotactic probability of 0 in Spanish for at least one constituent) and 16 were Spanish exclusive (having a phonotactic probability of 0 in English for at least one constituent). Within each language, half of the nonwords had an overall high phonotactic probability and half had an overall low phonotactic probability.
In the High/Low group of nonwords, 16 nonwords had a high probability in Spanish and low probability in English (High Spanish-Low English) while 16 nonwords had a high probability in English and a low probability in Spanish (High English-Low Spanish). Finally, in the Ambiguous nonwords, all 32 nonwords had similar probabilities in both languages; however half of the nonwords had high probability in both languages (High Both) and half had low probability in both languages (Low Both).

**Computation of phonotactic probability.** To obtain the phonotactic probabilities of all nonwords, the Hoosier Mental Lexicon (HML; Nusbaum, Pisoni & Davis, 1984) and the University of South Florida Spanish Frequency Lexicon (USFL; Brea-Spahn & Frisch, submitted) were analyzed by onset and rime constituents as in Frisch, Large, and Pisoni (2000). This analysis resulted in frequency counts for each English and Spanish onset and rime based on word position and stress. For instance, in the English word /brat/ the onset /br/ has the probability of .0055 and the rime /at/ has a probability of .0057. Multiplying these probabilities together (and taking the log) provides an overall phonotactic log probability for /brat/ in English of -4.5. This method of computing nonword probability comes from Coleman and Pierrehumbert (1997) who determined that multiplying probabilities for the constituents of a nonword together and taking the log resulted in a phonotactic measure of nonword probability that significantly correlated with word-likeness judgments. The authors suggested that this log product probability allowed for general probability of the whole word to be expressed such that if one constituent had a low probability it could be counterbalanced by other high probability segments.
Language exclusive nonwords. To create the Language Exclusive nonwords, onsets and rimes that occur only in Spanish or English were compiled. The English exclusive nonwords contained vowels not found in Spanish (e.g., /æ/), and the Spanish exclusive nonwords contained consonants not found in English (e.g., /ɲ/). Because each language was to have high and low probability nonwords, it was important to clearly indicate if a probability was high or low. To do this, the log probabilities of all language exclusive nonwords in each language were plotted on a bell curve. Only nonwords whose probability fell more than two standard deviations from the mean were used. The result was nonwords that reflected the extremes of probabilities for two syllable nonwords within each language.

High/low nonwords. To create the High/Low nonwords, the stressed onsets and rimes that occurred in both languages were compiled. The probabilities of the constituents were graphed on a scatterplot so that onsets and rimes with high probability in one language and a low probability in the other language could be selected (see Figure 4). Those constituents were then concatenated (within each language) to create the High/Low nonwords and the log product probabilities were computed for each potential stimulus item. Nonwords that were greater than two standard deviations from the mean were selected as high or low probability nonwords in each language. For example, the nonword /kusar/ has a Spanish log probability of -4.97 and an English log probability of -6.07. This gives the nonword high probability in Spanish, but low probability in English. As a point of reference, the range of Spanish phonotactic probabilities in all nonwords was from -4.18 to -8.81 and the range of English phonotactic probabilities in all nonwords was from -4.58 to -9.00.
Ambiguous nonwords. To create the Ambiguous nonwords, a similar process was used; however constituents with equal probabilities in both languages were chosen. Those constituents were concatenated into nonwords and the product log probabilities were computed. Again, nonwords that were greater than two standard deviations from the mean were selected as high or low probability ambiguous nonwords. As with the Language Exclusive nonwords, half of the Ambiguous nonwords had high phonotactic probability (in both languages) and half had low phonotactic probability (in both languages). For example, the nonword /kulan/ has a Spanish phonotactic probability of -5.85 and English phonotactic probability of -5.84; therefore, it is considered to have high phonotactic probability in both languages. The nonword /keltes/ has a Spanish log

![Figure 4. Scatterplot of stressed medial onsets occurring in both Spanish and English. Point A demonstrates a constituent with a high probability in English and a low probability in Spanish.](image)

probability of -7.33 and an English log probability of -7.53, making it a low probability Ambiguous nonword.

**Stimulus set.** The final set of stimuli consisted of 96 nonwords, 32 from each nonword group (Language Exclusive, High/Low, Ambiguous). In the Language Exclusive group, 16 nonwords were English Exclusive with eight of those having high English phonotactic probability and eight having low. The other 16 nonwords were Spanish Exclusive and were again split into high and low phonotactic probability. In the High/Low group, 16 nonwords were High Spanish-Low English and 16 were High English-Low Spanish. In the Ambiguous group, 16 nonwords had high phonotactic probability in both Spanish and English and 16 had low phonotactic probability in both languages. Figure 5 graphically demonstrates how the 92 words were divided. For a full list of the final stimuli with their IPA transcription and orthographic representation, please see Appendix A.

Figure 5. Graphic depiction of final stimuli division
**Statistical analysis.** Once the nonwords were created for each group, t-tests were computed to ensure that each set of nonwords met the following parameters: 1) high phonotactic probability nonwords must have statistically higher phonotactic probabilities than low phonotactic probability nonwords; 2) high English phonotactic probability nonwords must be significantly more probable in English than in Spanish, and vice versa; and 3) phonotactic probabilities of the ambiguous nonwords must not be significantly different between Spanish and English. As shown in Table 1, all of these requirements were met: in the Language Exclusive nonwords, the high probability nonwords were significantly more probable than the low probability nonwords, in the High/Low group, words considered to be high probability in one language were significantly higher in that language than in the other, and for the ambiguous nonwords, there was no significant difference between languages; however, the high probability words were significantly more probable than the low probability words.

Table 1

*Results of t-tests for nonword stimuli*

<table>
<thead>
<tr>
<th>Nonword Type</th>
<th>t-Test Comparison</th>
<th>df</th>
<th>t-Stat</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language Exclusive</td>
<td>English high vs. English low</td>
<td>14</td>
<td>10.55</td>
<td>( p &lt; .0001 )</td>
</tr>
<tr>
<td>Language Exclusive</td>
<td>Spanish high vs. Spanish low</td>
<td>14</td>
<td>11.63</td>
<td>( p &lt; .0001 )</td>
</tr>
<tr>
<td>Spanish High-English Low</td>
<td>Spanish prob vs. English prob</td>
<td>30</td>
<td>8.46</td>
<td>( p &lt; .0001 )</td>
</tr>
<tr>
<td>English High-Spanish Low</td>
<td>English prob vs. Spanish prob</td>
<td>30</td>
<td>10.48</td>
<td>( p &lt; .0001 )</td>
</tr>
<tr>
<td>Ambiguous-High Both</td>
<td>English prob vs. Spanish prob</td>
<td>30</td>
<td>-.747</td>
<td>( p &gt; .05 )</td>
</tr>
<tr>
<td>Ambiguous-Low Both</td>
<td>English vs. Spanish</td>
<td>30</td>
<td>1.74</td>
<td>( p &gt; .05 )</td>
</tr>
<tr>
<td>Ambiguous</td>
<td>High prob vs. Low prob</td>
<td>62</td>
<td>18.8</td>
<td>( p &lt; .0001 )</td>
</tr>
</tbody>
</table>
Recording and synthesis. With the final stimulus list completed, the nonwords were recorded by both a native, female Spanish-English bilingual and a native, female English-Spanish bilingual. The target nonwords were compiled into two lists: a Spanish list and an English list. Within each list, the nonwords were embedded in a carrier phrase in either Spanish or English to ensure that each target nonword was spoken with an English or Spanish accent. All recordings were done in a sound proof booth using a MicroMic C420 headset microphone connected directly into a Dell computer with the Praat software program (version 5.3.2.5, Boersma & Weenik, 2011) and recorded at a sampling rate of 22.05 kHz. In Praat, each nonword was excised from the carrier phrase and the F0 was manipulated using the Pitch Manipulation process in Praat. Each word was opened in the manipulation window and all pitch points were deleted. Then one pitch point, set to 180 Hz (the average F0 for the two speakers) was created at the beginning of the word and one was created at the end of the word. This created a flat pitch contour of 180 Hz for every word.

Once the nonwords were standardized for F0, the Spanish and English version of each nonword from each speaker were morphed together to make final auditory stimuli that were phonetically (and acoustically) ambiguous. In order to do this, the speech synthesis tool TANDEM-STRAIGHT (Kawahara, Takahashi, Morise & Banno, 2009) was used. This program took the Spanish and English version of each nonword from each speaker and morphed them together based on time and formant frequencies. This created an auditory version of each word that was half Spanish-half English for each speaker. To create the final auditory stimulus set, the stimuli from each speaker were quasi-randomly
selected such that the final stimuli lists for each nonword type were equally comprised of words from the English-Spanish speaker and the Spanish-English speaker.

**Wordlikeness Ratings**

After the stimuli were created, Spanish-English bilingual and English monolingual adults were asked to judge the words on how much like real words they sounded. These results were used to confirm that the High/Low and Ambiguous nonword stimuli could be accepted as possible nonwords in both languages, and also to assign an average wordlikeness rating to each nonword for future use in other studies.

**Participants.** Two groups of adults (ranging in age from 19 – 42 years, $M = 24.9$ years) were asked to participate: 31 monolingual English speakers and 30 bilingual Spanish-English speakers. All participants were students (undergraduate and graduate) at a university in west central Florida and self-reported no history of speech, language or hearing difficulties. The monolingual speakers reported no significant bilingual experience. All bilingual speakers completed a short questionnaire reporting on their dialect of Spanish spoken and the amount of Spanish and English spoken during the day. The majority of bilingual speakers were native Spanish speakers from Columbia, Puerto Rico and Mexico and reported using Spanish for social situations and English for academic situations, with English being used more often during the day ($M = 75.6\%$ of the day).

**Procedure.** The experiment was presented using Praat on a desktop computer in the laboratory or on a laptop in a quiet room. After signing informed consent forms, each listener was seated at the computer, given headphones, and the experiment was started. Every experimental session started with on-screen instructions explaining that the
participant was going to hear a nonword and should judge how much like a real word it sounded using a scale of 1-7, with 1 meaning that the nonword could definitely not be a word in the language and 7 meaning that it sounded very much like a word in the language. Monolingual participants were always judging in English while bilingual participants were judging once in English and once in Spanish.

For the bilingual participants, four different experiments were created in order to counterbalance the task (judging in English and Spanish) and to ensure that each participant only heard each nonword once, in either the English or Spanish setting. The nonwords were first quasi-randomly assigned to either a Spanish or English list. Those lists were used as Experiment A with participants hearing the English list first (given English instructions and asked to judge the words in English) followed by the Spanish list (given Spanish instructions and asked to judge the words in Spanish). For Experiment B, the order of presentation was switched so that the Spanish portion was completed first followed by the English portion. Experiment C switched the lists so that words previously heard in English were now being presented in Spanish and vice versa with English being presented first. Experiment D was the same as Experiment C except that Spanish was presented first. Bilingual listeners were randomly assigned to one experiment. Monolingual participants heard all the nonwords (except for the Spanish Exclusive) presented randomly.

All experiments were self-paced so that participants controlled when the next nonword was presented. Participants were also offered two short breaks during the session. The total amount of time for both the monolingual and bilingual experiments was roughly 15 minutes including time to complete the short history questionnaire.
Data Reduction and Analysis

The output from Praat was a data table that recorded each participant’s wordlikeness rating for each nonword stimulus along with RT. In order to investigate the effect of word type on participant rating and the relationship between nonword probability and average wordlikeness rating, the data for all adult participants was collated into one SPSS data sheet. Each nonword was treated as a subject with the independent variables of word type, English log probability, and Spanish log probability. Each participant’s judgments were averaged for each word type such that each nonword had an average monolingual rating, and average bilingual in English rating and an average bilingual in Spanish rating.

To determine the effect of word type (and, hence, phonotactic probability) and language of a speaker on his/her wordlikeness ratings, two repeated measures ANOVAs were completed; one compared monolinguals and bilinguals judging in English and the second compared bilinguals judging in English to those judging in Spanish. Post hoc tests, in the form of t-tests with Bonferroni corrections, were then completed to tease out the specific differences leading to an overall interaction effect. To assess the relationship between phonotactic probability and wordlikeness judgments, probability predictiveness was calculated by computing correlations between individual phonotactic probability and average wordlikeness ratings for each nonword (Frisch, Large, Zawaydeh & Pisoni, 2001; Frisch & Brea-Spahn, 2010).

Results

Word type and language effects. In order to determine the effect of word type and language of a speaker on wordlikeness ratings, two one-way mixed repeated
measures ANOVAs were completed. The between subjects factor for both analyses was word type and the average wordlikeness rating by listeners was the repeated dependent variable. For the first analysis, the word types compared were English Only, High English-Low Spanish, High Spanish-Low English, High Both, and Low Both. The two listener group ratings compared were from the monolingual speakers and the bilinguals judging in English. There was a small but significant main effect of average wordlikeness rating, $F(1, 74) = 6.752, p = .011, \eta^2 = .084$, suggesting that the two groups of listeners, overall, rated the words differently with the ratings by bilinguals being slightly higher. However, there was no interaction effect, suggesting that this rating difference was not influenced by word type.

The second repeated measures ANOVA used the word types High English-Low Spanish, High Spanish-Low English, High Both, and Low Both as the between subjects factors and compared the ratings of bilinguals judging in English those judging in Spanish. There was no main effect of average rating, but there was a significant interaction effect between rating and word type, $F(1,60) = 17.898, p < .0001, \eta^2 = .472$, suggesting that word type influenced wordlikeness ratings differently for the bilinguals judging in English and those judging in Spanish. Post-hoc testing revealed that, bilinguals judging in English rated the High English-Low Spanish nonwords as more wordlike than the bilinguals judging in Spanish, $t(15) = 5.26$, $p < .0001$. This pattern was reversed for the High Spanish-Low English nonwords with bilinguals judging in Spanish rating those as more wordlike than bilinguals judging in English, $t(15) = 4.986$, $p < .0001$ (see Figure 6). These patterns of results suggest that bilinguals were perceiving the High English-Low Spanish nonwords as more English-like when testing in English and the High
Spanish-Low English nonwords as more Spanish-like when testing in Spanish, confirming that the phonotactic probabilities of the nonwords were being perceived as designed.

![Figure 6. Average wordlikeness ratings by adult listeners across all word types.](image)

**Probability predictiveness.** As mentioned earlier, probability predictiveness is the correlation between a nonword’s phonotactic probability and the average wordlikeness rating it was given by participants (Frisch et al., 2001). For this analysis, all nonword types (language exclusive, high/low, and ambiguous) were included. Since the language exclusive nonwords did not have a probability in one of the languages (and using 0 is not possible for log probability), estimated low probabilities were used in the
computation. As an upper limit to the probability of a non-occurring constituent, the numerator in the probability computation was set to .5 (indicating that a certain constituent occurred less than once in the lexicon) and the denominator was the total number of constituents in a certain position (this is the same denominator used to calculate all positional probabilities for all constituents in the corpus). For example, the Spanish phoneme /ɲ/ would have an English phonotactic probability of .5/11442, or .0000437.

A positive, modest significant correlation between the English log probability of a nonword and its mean wordlikeness rating in English was found for monolingual English listeners, $r = .27$, $p < .05$, and bilingual listeners judging in English, $r = .26$, $p < .05$. A similar positive, modest significant correlation was found between Spanish log probability of a nonword and its mean wordlikeness rating in English for bilingual listeners judging in Spanish, $r = .35$, $p < .01$. Overall probability predictiveness is shown in Figure 7. These findings are similar to previous findings on probability predictiveness in monolingual English adults and bilingual Spanish-English adults (Frisch & Brea-Spahn, 2010) and suggest that adults were sensitive to the phonotactic composition of the nonwords. Therefore, it was determined that these nonwords could be used with bilingual children to test the research hypotheses.
Figure 7. Probability predictiveness scatterplots for English log probabilities for monolinguals and bilinguals judging in English and Spanish log probabilities for bilinguals judging in Spanish.

Child Study: Effects of Phonotactics on Perceived Language Membership

Once the stimuli were created and tested, they were used with bilingual kindergartners in a language sorting task. The experimental task was designed to realize the main purpose of the dissertation: to determine the effect of phonotactic probability on a bilingual child’s ability to determine nonword language membership.

Bilingual kindergartners heard nonwords presented on the computer and were asked to decide if each nonword sounded like English or Spanish. Their responses were recorded using MouseTracker software (Freeman, 2011). This program records mouse
cursor movement as a means of measuring fine-grained decision processes, similar to eye-tracking. Analyzing these data will provide insight on how phonotactics of the two languages interact during nonword processing.

**Participants**

The purpose of this study was to investigate how bilingual children process the phonotactics of their two languages during language acquisition. Therefore, it was important to test bilingual children who were relatively unbalanced bilinguals (i.e., more familiar with their L1, in this case Spanish, than their L2, English). In order to find children at this unbalanced bilingual phase, children needed to relatively young with very little experience with English. However, it was also important that children were old enough to successfully complete the computer task using the mouse appropriately.

Therefore, a total of 21 bilingual kindergartners (12 females) were recruited to participate in this study. All students were between 5 and 6 years of age (M = 5.52 years old) and were attending kindergarten for the first time. All children were from Title 1 schools with large populations of bilingual Spanish speaking children. After receiving permission from a public school district in west central Florida, principals were contacted and asked for permission to conduct research in their school. Once permission was granted, all kindergarten teachers were given envelopes containing the informed consent and parental questionnaire. The teachers were asked to send the envelopes home with any student who spoke mostly Spanish at home, was in kindergarten for the first time, and had no hearing, speech or language concerns. Parents returned the envelope to the teacher who placed it in a lockbox located in the lead kindergarten teacher’s room or the front office. The

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3 Schools are considered Title 1 when more than 50% of their students are on free or reduced lunch.
researcher checked the lockbox weekly and called the parents who returned the forms to schedule the two testing sessions.

**Inclusion criteria.** To be included in the proposed study, children had to be 5-6 years of age, speak mostly Spanish at home, have received one year or less of formal schooling in English before entering kindergarten, pass a hearing screening, and have no speech or language concerns. These criteria are considered relatively representative of the average young bilingual school-age population.

**Age.** Children had to be 5-6 years of age and currently attending kindergarten for the first time. This age range was important for two reasons. First, children had to be young enough that they had not had more than one year of official schooling in English. This served to strengthen the possibility that English had not become a dominant language for the child (Kohnert, Bates & Hernandez, 1999). Second, previous studies using MouseTracker (Cargill, Farmer, Schwade, Goldstein & Spivey, 2007) and other mouse tracking programs found that children younger than five years of age had difficulty in smoothly and accurately controlling the mouse of a computer (Joiner, Messer, Light & Littleton, 1998). The latter researchers discovered that this age disadvantage was present regardless of what type of mouse was being used (e.g., external mouse or touch pad). Therefore, in order to ensure that the measured mouse trajectories were accurate, the children in the proposed study had to be at least 5 years of age.

**Parental questionnaire.** A parental questionnaire was used to determine the language exposure and experience of the bilingual children. The questionnaire asked about home language, when the child began formal schooling in English, the amount of time during the day each child heard and spoke Spanish and English, as well as when the
child first began speaking English, and if there were any speech and/or language concerns (see Appendix B for full questionnaire). Questionnaires like this are commonly used to determine language experience of bilingual children (e.g., Brea-Spahn, 2009; Summers et al., 2010). The parental questionnaire was provided in Spanish with English translations underneath. The questions were presented as yes/no or rank scales. From parental report, the majority of child participants spent 60-80% of their day speaking Spanish and 40-60% of their day speaking English. Further, 13 of the children attended less than one year of pre-K.

**Hearing screening.** A portable audiometer calibrated to ANSI S3.6-1996 standards was used. Each child was required to respond to 500, 1000, 2000, and 4000 Hz pure tones at 25 dB HL (American Speech-Language and Hearing Association, 1997). Due to participant age, visual reinforcement techniques were used to train the response behavior and elicit reliable responses.

**Language skills.** In a previous study of normal and language impaired bilingual children, Windsor et al. (2010) administered the Recalling Sentences and Concepts and Following Directions subtests of both the English and Spanish versions of the *Clinical Evaluation of Language Fundamentals*, Fourth Edition (CELF-4; Semel, Wiig & Secord, 2003). In order to allow for lack of language experience, Windsor et al. (2010) considered bilingual children to be typically developing if they scored within one standard deviation of the mean in either Spanish or English, but not necessarily both. Further, children had to score within one standard deviation of the mean on the *Test of Nonverbal Intelligence*, Third Edition (TONI-3; Brown, Sherbenou & Johnsen, 1997). Using these criteria Windsor et al. (2010) found significant group differences between
typically developing bilingual children and their language impaired peers on nonword repetition tasks.

It was important for the current study that the children being tested were not language impaired as this could negatively impact the word learning process. To make this determination, the testing procedures of Windsor et al. (2010) were replicated. All children were given both the English and Spanish CELF-4 subtests along with the Test of Nonverbal Intelligence-Primary (TONI-P; Ehrler & McGhee, 2008), the TONI normed for younger children. While all of the children passed the TONI-P, the majority of children did not pass either the English or the Spanish CELF-4 (four passed English only, four passed Spanish only, one passed both, and twelve did not pass either). Given that neither the parents nor the teachers had concerns about any of the participants' speech, language or academic abilities, it was decided that the inclusion criteria should be altered to parent and/or teacher report of language difficulties. The investigator felt that in this case, the CELF-4 was testing academic language instead of general language ability and that the participants had the necessary language skills to be successful in this experiment. It was decided to use the CELF-4 results as a possible covariate in the statistical analyses instead of as exclusionary criteria.

**Procedure**

After receiving signed parental consent, child assent, and completed parental questionnaire, each child was scheduled for his/her one hour criterion testing session. During this session, the child was spoken to in both Spanish and English depending on which test was being given. Either the English or the Spanish CELF-4 was given first (order was counterbalanced) followed by the hearing screening, the TONI-P and the
second version of the CELF-4 in the other language. Children were given stickers during testing as positive reinforcement. At the end of each testing session, the children were allowed to choose a short, age-appropriate book to show appreciation for participation and to encourage literacy practice at home.

Following the criterion testing session, the experimental session was scheduled. When possible, there was no more than three weeks between the two testing sessions (11 of 21 children were tested less than three weeks later, $M = 7.2$ days). However, due to the schedules of the parents, standardized testing in the school and the number of students being tested by one researcher, some sessions were separated by more than three weeks (8 of the 21 children were tested more than three weeks later, $M = 36.8$ days), with the longest period of separation being two months due to child illness and parental rescheduling (2 of the 21 children).

The children were quasi-randomly divided into two groups based on their CELF-4 results so that each group had an equal number of students who passed or failed the different versions of the CELF-4. One group was spoken to mostly in Spanish with English words inserted during testing (i.e., code-switching) and the other group was spoken to in English with Spanish words inserted during testing. One female English-Spanish bilingual examiner conducted all experimental sessions. The experimental session began with the examiner reintroducing herself and carrying on a casual conversation with the child about his/her day at school in the base language of the group to which he/she had been assigned. During the conversation, the examiner used code-switching, thus putting the child in bilingual mode (Grosjean, 1989).
After the investigator and child participated in the introductory conversation, each child was seated at a table in a quiet room at his or her school. Each child was told he/she was going to play a computer game. The child then watched three short cartoons, made using Adobe Flash, introducing red and blue robots who were going to school for the first time. The red robots spoke Spanish like mom and dad at home while the blue robots spoke English like teachers at school. The first cartoon introduced the two types of robots and the languages they spoke. The children then saw two robots on the screen and were asked to click on the robot who spoke English like their teachers at school (see Figure 8). The short test continued with the child hearing either the word “English” or “Spanish” and having to click on the correct robot. If the child answered incorrectly, he/she saw a red “X” on the screen. The test was continued until the child correctly completed 8 consecutive trials to ensure the child understood which robots spoke English and which spoke Spanish.

Figure 8. Screen shot from the first MouseTracker task.
Then the second cartoon was played. This cartoon introduced the busses the robots took to school, with the red robots riding a red bus and the blue robots riding a blue bus. Again, when the cartoon was finished, the children saw two busses on the screen and were asked to complete a short test where they again heard either the word “English” or “Spanish” and had to click on the correct bus (see Figure 9). Each child continued the task until he/she received 8 correct answers in a row. Again, these trials were used to ensure that the child knew which color bus was for Spanish robots and which was for English robots.

Finally, the third cartoon was played. This cartoon was longer and showed the robots enjoying their first day of school. They go to the playground where they jump and play so much that they lose their colored hats. Then they go inside to take a nap and must take off their shoes and put them in a big pile. However, when the robots wake up, they don’t remember which shoes are theirs. When it’s time to go home, the robots no longer
have their colored hats and shoes, and so they don’t know which bus they should take to get home. At this point, the children were asked if they would help the robots get on the right bus. The children were then given instructions to click a small box on the computer screen to hear a word. If the word sounded like Spanish, they should click on the red bus. If the word sounded like English, they should click on the blue bus thus helping the robots get on the right bus and get home safely. As in the previous tasks, children saw two busses on the screen with bus position counterbalanced across participants (see Figure 9 above). Each child was then asked if he/she understood. When the child said "yes", the practice trials began.

The practice trials were completed without headphones so that both the examiner and the child could hear the nonword. The child was asked if he/she could hear the words and were allowed to adjust the volume as needed. The child was prompted to click on the box on the screen and listen to the word. Then the child was asked if that word sounded like something mom would say at home in Spanish or something like a teacher would say at school. When the child clicked on his/her choice (red bus or blue bus), the next practice word was played. No feedback was given to the child about his/her choice; the practice session was simply to train the behavior of listening to a word and making a choice. Further, due to software constraints, the trials could not be animated, so children could not see a robot get on the bus which would have been a good visual reinforcement. Therefore, these practice trials reinforced the child’s behavior of making a decision after hearing a word.

After the five practice trials were complete, the researcher fitted the child with insert headphones (Etymōtic mc5™ insert headphones) and started the experimental
trials. The 96 nonwords were randomly presented in three blocks of 32 nonwords. The blocks were separated by three minutes of play time in order to reduce fatigue and/or boredom. During play time, the researcher interacted with the child using red and blue school busses and red and blue robots to reinforce the research paradigm. During all trials, the MouseTracker software recorded the cursor’s path and speed for later analysis (Freeman & Ambady, 2010).

**Data Reduction and Analysis**

Two dependent variables were measured and used in the statistical analysis: Area under the Curve (AUC) and Listener Judgment. As described earlier, AUC represents how much interference the distractor (i.e., response alternative) posed to the participant. In other words, a large AUC for any one trial would indicate that the child was very distracted by the alternate choice. The second dependent variable reflected the listener's judgment of the language to which the nonword belonged. This was a dichotomous variable with a 1 being recorded if the child sorted a word as English and a 0 being recorded if the child sorted the word as Spanish.

In order to account for both subject and item variability, the investigator decided to use mixed level modeling (MLM) or crossed random factors multilevel modeling (Locker, Hoffman & Bovaird, 2007). This methodology is preferred over an Analysis of Variance (ANOVA) because the researcher can take into account the variability of both subjects and items while looking for significant effects within the independent variables. MLM also assumes a hierarchical structure within the data with level 1 observations nested within level 2 observations, so on and so forth. By analyzing the data within this hierarchical structure, the results are robust to a relatively small number of level 2 data points (Locker et al., 2007). This aspect of MLM was important for the current data set.
since the number of children and stimulus groups (level 2) was relatively small (n=15 children and n = 16 or 8 stimulus items in a particular probability group), but the number of total observations (level 1) was large (n= 1440; each child made a judgment on 96 novel words, 96 x 15 = 1440).

Before performing MLM, the data had to be sorted and coded into specific variables and several different data tables had to be created. For all data tables, the data had to be organized in a stacked format such that each subject had 96 lines, one for each word he/she sorted into Spanish and English. Next, word type had to be coded as a 0 or 1. This coding is what necessitated the use of several different data sheets since a word could only be coded as 0 or 1 because in SPSS, coding other than 0 and 1 is treated as ordinal data and not categorical data. Therefore, using numerical codes 1-6 for each type of word would negatively impact the results of the model. For example, the first research question only examined the language exclusive nonwords so were coded as 0 for the Spanish only words and 1 for the English only words. All the data for the other types of nonwords had to be deleted from the data sheet for research question 1 or else they would have been erroneously included in the model. This question was also interested in a difference between the high and low probability of each word within its language group. Therefore, probability was coded with 0 for low and 1 for high. Putting these codes together, an English only word with high probability would be coded as 1, 1.

A third variable, listener judgment, was coded with 0 representing a Spanish language judgment and 1 representing a English language judgment. With this method of coding, any reported means were always interpreted as the percent of English judgments made on any one word type. For example, if a child made four English judgments and
one Spanish judgment, his mean judgment score would be 4/5 or .8. This means that 80% of his judgments on a certain word type were English. A fourth variable, AUC, was included as a continuous variable and did not need to be re-coded for the purposes of the MLM. The final variable, Language Group, coded the child as 1 if he/she was in the group of children spoken to in English and 0 if he/she was spoken to in Spanish.

The second research question was concerned with comparing performance on the language exclusive nonwords to the high/low phonotactic probability nonwords to investigate the effect of dual phonotactic probabilities on nonword processing. The data for this analysis were coded similarly to the data for research question 1. Therefore, it consisted of the Spanish Only vs. English Only variable to code the language exclusive nonwords as well as a new variable, High Spanish-Low English vs. High English-Low Spanish, which coded the High Spanish-Low English nonwords as 0 and the High English-Low Spanish nonwords as 1. Finally, RQ 3 was interested in how the children sorted the ambiguous nonwords. Therefore, a variable called LOWvHIGH was included and coded all the low both nonwords as 0 and the high both nonwords as 1.

Once the data was coded appropriately, the MLM analysis proceeded through several steps. The first step was to determine how much variability was explained by the subjects and items before adding any of the independent variables (predictors) into the model (Locker et al., 2007). To do so, an empty model was created that only contained the dependent variable (either listener judgment or AUC) and one error term (i.e., the overall variance in the model). The results of the empty model produced a restricted log likelihood, an intercept, and an estimated residual variance. The restricted log likelihood was compared to more complex models to determine if adding more factors (like subject
and/or item variance) made the model any better. The intercept was the overall average of
the dependent variable, in this case, the average percent of English judgments made
across all children and all items or the average AUC across all children and all items.
Lastly, the estimated residual variance was the amount by which the data differed from
the overall mean that could not be explained by subject factors, item factors or
independent variables. In other words, each data point differed from the mean, and this
difference could be due to subject factors, item factors, the independent variables, or
something not accounted for by any of those three types of factors. This left-over,
unexplained variance is the residual variance and is included in every model.

After creating the empty model, the next step was to add in the random effect for
subjects (Locker et al., 2007). Random effects account for individual differences between
data points, which in this case accounted for individual differences between children. The
results of this model were similar to the empty model. However, it was important to
examine the restricted log likelihood of the new model to determine if it was significantly
different than that of the empty model. If it was, then it could be said that the new model
“fit” the data better. In other words, by accounting for variability of subjects, the total
amount of residual (or unexplained) variance was reduced.

The third step was to add in the random effect for items (Locker et al., 2007). This
third model now accounted for variability of subjects and variability of items. Again, the
restricted log likelihood was compared to the previous model (the one containing only the
subject random effects) and a significant difference determined if the newest model fit
the data even better. If it did, then this meant that accounting for both subject variability
and item variability reduced the residual variance and made for a stronger model.
After accounting for the random effects, the final step was to add the independent variables, or predictors (Locker et al., 2007). For the current data set, the predictors used were always Language Group (the language the child heard during the experiment) and some variable of word type (e.g., language exclusive, high/low phonotactic probability, ambiguous). When the predictors were added into the model, the main effect of each predictor was computed along with interaction effects. The output of this model should be similar to the previous models with one important distinction: the significance of the independent variables was computed. The full predictor model indicated which, if any, main and interaction effects were statistically significant. It also provided information on the nature of any statistically significant differences and the estimated marginal means (the means of each independent variable accounting for the random effects of subjects and items). This information, while similar to the results of an ANOVA, more accurately accounts for subject and item variance before estimating the effects of the independent variables.
CHAPTER THREE: RESULTS

The current study considered the effects of phonotactic probability and language environment on nonword sorting in bilingual children. Results were recorded using MouseTracker, transformed and coded into a variety of dummy variables in SPSS, and analyzed using mixed level modeling (MLM). The two main dependent variables were listener judgment (whether a child sorted a nonword as English or Spanish) and AUC (a measure of decision complexity).

Before computing MLM, a general frequency count of overall responses was computed to determine if bilingual children perceived the nonwords as one language more often than the other. As can be seen in Figure 10, bilingual children tended to perceive the nonwords (regardless of nonword type) as Spanish. It is also evident that this decision depended very little (if at all) on the language environment in which they were tested. These results indicate that children were performing above chance which suggests that they were not simply guessing during the language sorting tasks.
RQ 1: High Probability Advantage During Nonword Processing?

It was hypothesized that when bilingual children were presented with nonwords that could only exist in one language or another, words with high probability would be sorted appropriately, with a smaller AUC. A crossed random effects MLM was estimated to examine this prediction. Models were created for both dependent variables of listener judgment and AUC. The models for listener judgment will be discussed first. The dependent variable, listener judgment, was a dichotomous variable where 0 meant a nonword was judged as Spanish and 1 meant it was judged as English. Therefore, all the means reported represent the average proportion of English judgments a nonword received out of the total number of judgments.

To start, an empty model was created which did not account for either the random effects of subjects or items. This was done to provide a basis for comparison of more complex models. The MLM revealed that model fit was significantly improved by adding
random effects of subjects, $-2\text{LL} \Delta(1) = 17.7, p < .0001$, as well as random effects of items, $-2\text{LL} \Delta(2) = 31.5, p < .0001$. These significant changes in the restricted log likelihood values (-2LL) meant that both subject and item random effects (i.e., variability) needed to be accounted for in the final predictor model.

For the final predictor model, the subject predictor Language Group (0 = children spoken to in Spanish, 1 = children spoken to in English) was included, as well as the item predictors of language exclusivity (0 = Spanish Only, 1 = English Only) and phonotactic probability (0 = low probability, 1 = high probability). The main effect of each of these predictors was estimated, as well as the two-way interaction between language exclusivity and phonotactic probability and a three-way interaction between Language Group, language exclusivity, and phonotactic probability. Results showed a significant main effect for language exclusivity, $F (1, 31.43) = 21.15, p < .001$. This finding would suggest that the estimated marginal mean of English judgments of Spanish Only words was 19.9% lower than the estimated marginal mean of English judgments of English Only words, $t (42.78) = -2.31, p = .026$, 95% CI = -0.372 - -0.025. In other words, the English Only words were more likely to be judged as English than the Spanish Only words. There was no effect of Language Group meaning that language environment did not impact how the children sorted the English Only or Spanish Only nonwords. However, the predictor phonotactic probability approached significance, $p = .092$. In general, language exclusive nonwords with low probability were more likely to be judged as English compared to the language exclusive nonwords with high phonotactic probability. Using the software program G*Power 3.1 (Faul, Erdfelder, Lang & Buchner, 2007), which estimates the required sample size for significance at $p < .05$, and power at
.8, the phonotactic probability predictor would likely have been significant at the $p < .05$ level with 19 more subjects. There were no significant interaction effects.

Figure 11 shows the results of the predictor model with estimated marginal means for each word type grouped by high or low probability. These results were collapsed across language group since there was no significant main effect for that predictor. The English Only words were judged more often as English than the Spanish Only words, and there was a trend for the low probability words to be judged more often as English than the high probability words. This result is somewhat surprising, as the English Only words with higher phonotactic probability were not more likely to be judged as English than the English Only words with lower phonotactic probability.

Figure 11. Results of predictor model for Research Question 1 with judgment as the dependent variable. Error bars represent 95% Confidence Intervals. EO = English Only words; SO = Spanish Only words; * $p = .026$
The same modeling process was completed with AUC as the dependent variable. After estimating the empty model, model fit was significantly improved by adding random effects of subjects, \(-2\text{LL } \Delta(1) = 6.007, p = .01\). However, there was no improvement in the model after adding the random effects of items. This suggests that for AUC, only individual differences of the children (e.g., decision strategy, overall confidence), not the items, contributed to the explained variance from the mean. The final predictor model was estimated using the same predictors as in the model for listener judgment; however no main effects or interaction effects were significant. This indicates that neither language group, nor word type nor word probability had a significant effect on AUC.

**RQ 2: Phonotactic Probability Storage in Bilingual Children**

It was hypothesized that a bilingual child has one phonological system that stores the phonemes and phonotactic rules of both languages. This was hypothesized to be seen in the behavioral data as a difference in the language judgments made by children when hearing high/low phonotactic probability nonwords compared to the language exclusive nonwords. It was also hypothesized that children would show larger AUCs for the high/low phonotactic probability nonwords compared to the language exclusive nonwords. A crossed random effects MLM was estimated to examine this prediction.

Four sets of models were estimated to make the following comparisons: English Only vs. High English-Low Spanish, English Only vs. High Spanish-Low English, Spanish Only vs. High English-Low Spanish, and Spanish Only vs. High Spanish-Low English. Four separate models were necessary due to the dichotomous nature of the variables. If a word was English Only, but the model to be run was comparing Spanish Only to something
else, then the English Only words would have neither a 0 nor a 1 in the column (i.e., the column would be blank). Instead of ignoring blank cases, SPSS included them as missing data points which negatively impacted the model. Therefore, data sets had to contain only the comparisons of interest and models had to be run for just those comparisons. Models were again created for both dependent variables of listener judgment and AUC; the models for listener judgment will be discussed first.

The first set of models was estimated to investigate the difference between English Only and High Spanish-Low English nonwords. The empty model was created which did not account for either the random effects of subjects or items. Model fit was significantly improved by adding the random effects of subjects, -2LL Δ(1) = 15.133, p = .0001, as well as the random effects of items, -2LL Δ(2) = 22.516, p < .0001. Due to these significant changes, both subject and item random effects (i.e., variability) were accounted for in the final predictor models.

For the predictor model, the subject predictor, Language Group, was included, as well as the item predictor, English Only and High Spanish, Low English nonwords. The main effects of each of these predictors were estimated as well as the two-way interaction between both predictors. Results revealed a significant main effect for English Only vs. High Spanish-Low English nonwords, F (1, 33.003) = 6.699, p = .014. In examining this significant effect, it was determined that the estimated marginal mean of English judgments on English Only words was 23.75% higher than the estimated marginal mean of English judgments on High Spanish-Low English words, t (91.492) = 2.743, p = .007, 95% CI = .066 - .409. This finding suggests that the English Only nonwords were judged more often as English than the High Spanish-Low English nonwords. As with the first
research question, there was no effect of Language Group and no interaction effect (see Figure 12).

The second set of models estimated the difference between Spanish Only and High English-Low Spanish nonwords. The empty model was improved by adding the random effects of subjects, $-2LL \Delta(1) = 31.251, p < .0001$, as well as the random effects of items, $-2LL \Delta(2) = 27.923, p < .0001$. The predictor model included both subject and item effects, as well as the subject predictor Language Group and the item predictor Spanish Only vs. High English-Low Spanish. The main effects of each predictor were estimated, as well as the interaction effect between the two predictors. Results showed a significant main effect for Spanish Only vs. High English-Low Spanish, $F (1, 36.453) = 50.991, p < .001$. In examining the significant effect, it was determined that the estimated marginal mean of English judgments on Spanish Only words was 36.25% lower than the estimated marginal mean of English judgments of High English-Low Spanish words, $t(176.05) = -5.144, p < .001$, 95% CI = -223. This suggests that High English-Low Spanish nonwords were judged as English more often than Spanish Only nonwords (Figure 12). Again, there was no effect of language group or an interaction effect between language group and word type.
The third set of models examined the difference between English Only and High English-Low Spanish nonwords. The empty model was improved by adding the random effects of subjects, $-2\text{LL} \Delta(1) = 39.591$, $p < .0001$, as well as the random effects of items, $-2\text{LL} \Delta(2) = 9.703$, $p = .008$. The predictor model included both of these random effects along with the subject predictor of Language Group and the item predictor English Only vs. High English-Low Spanish. There were neither significant main effects nor a significant interaction effect. This finding suggests that children perceived the High English-Low Spanish nonwords similarly to the English Only words.
The final set of models examined the difference between Spanish Only and High Spanish-Low English nonwords. The empty model was improved by adding the random effects of subjects, $-2LL \Delta(1) = 37.904, p < .0001$, as well as the random effects of items, $-2LL \Delta(1) = 9.403, p = .009$. The predictor model included both of these random effects along with the subject predictor Language Group and the item predictor Spanish Only vs. High Spanish-Low English. As with the previous set of models, there were neither significant main effects nor a significant interaction effect. This supports the previous suggestion that children perceived the mixed nonwords similarly to the language exclusive nonwords. In this case, children perceived the High Spanish-Low English nonwords the same way they did the Spanish Only nonwords.

The same modeling process was completed for all four comparisons (Spanish Only vs. High Spanish-Low English, Spanish Only vs. High English-Low Spanish, English Only vs. High English-Low Spanish, and English Only vs. High Spanish-Low English) with AUC as the dependent variable. After estimating the empty model, model fit was significantly improved by adding random effects of subjects for all comparisons except English Only vs. High English-Low Spanish. There was no improvement for these models after adding the effects of items. Further, none of the predictor models were significant. This suggests that for AUC, only individual differences of the children, not the items, contributed to the explained variance from the mean and neither language group, nor word type had a significant effect on AUC.

RQ 3: Language Environment and Ambiguous Nonwords

It was hypothesized that when sorting nonwords with equally high or low probability in both languages, children would more often sort the words into the language
being spoken during testing, thus showing an assimilation effect (Burki-Cohen et al., 1989). A crossed random effects MLM was estimated to examine this prediction. Models were created for both dependent variables of listener judgment and AUC. The models for listener judgment will be discussed first.

The empty model was estimated first, and then improved by adding the random effects of subjects, \(-2\text{LL} \Delta(1) = 33.067, p < .0001\), but there was no improvement when adding the random effects of items. The predictor model consisted of the subject predictor Language Group and the item predictor Low Both vs. High Both. Estimated effects were calculated for both main effects and the interaction effect. The results did not reveal a significant effect for Language Group or Low Both vs. High Both. These findings suggested that children sorted the ambiguous words equally between the two languages and did not use the language environment to make decisions on whether the words sounded like English or Spanish.

Similar results were found for AUC. The empty model was improved by adding only the random effects of subject, \(-2\text{LL} \Delta(1) = 17.154, p < .0001\). The predictor model again included Language Group and Low Both vs. High Both, with neither the main effects nor the interaction effect being significant. This finding suggests that neither language group nor word type had an effect on AUC.

**Summary of Effects by Hypothesis**

*Hypothesis 1: Bilingual children will sort high probability language exclusive nonwords more accurately and with a smaller AUC.*

Results showed that children sorted English Only nonwords as English more often than they did the Spanish Only nonwords. There was a trend for children to sort language
exclusive nonwords with a low phonotactic probability more often as English than the language exclusive nonwords with a high phonotactic probability, but this result did not reach significance at the $p < .05$ level ($p = .09$). There was no effect of word type on AUC.

Hypothesis 2: Bilingual children will sort language exclusive nonwords “accurately” (i.e., English only words as English, Spanish only words as Spanish) more often than the high/low nonwords.

Results showed that when the language exclusive nonwords were in the same language as the high probability language of the mixed words (e.g., English Only vs. High English-Low Spanish), the children did not sort the words differently. However, if the exclusive nonwords were from a different language than the high probability language of the mixed nonwords (e.g., English Only vs. High Spanish, Low English), then the children sorted the language exclusive nonwords into the appropriate language more often than the mixed nonwords. There was no effect of word type on AUC.

Hypothesis 3: Bilingual children will show an assimilation effect (Burki-Cohen et al., 1997) when sorting the ambiguous nonwords.

There was no effect of language or word type on how the children judged the ambiguous nonwords. All ambiguous nonwords were treated similarly. Again, there was no effect of word type or language group on AUC.
The purpose of this study was to investigate how bilingual kindergartners process the phonotactic probabilities of their two languages. A set of nonwords was created by manipulating phoneme sequences such that three types of nonwords were created: language exclusive (possessed 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). The result was 96 nonwords which were presented to 21 bilingual kindergartners who were asked to sort them as to whether they sounded like Spanish or English. As an additional variable, the language environment of the sorting task was manipulated so that one group of children completed the experiment while being spoken to primarily in Spanish and the other group spoken to primarily in English. This study allowed for a unique investigation into how bilingual children process two languages and their associated phonotactic probabilities, as well as controlling for the language environment, which is considered to be an essential variable in several of the computational models of bilingual language processing (e.g., Shook & Marian, 2013). Specifically, this study provided answers to: whether or not bilingual children benefited from a high probability processing advantage, if the phoneme systems of two languages were stored as one unit or separate units, and if there was an
assimilation effect (Burki-Cohen et al., 1989) present for processing ambiguous phonotactics.

**The High Probability Processing Advantage**

The first research question determined if bilingual children could process high better than low phonotactic probability nonwords. Results showed no high phonotactic probability processing advantage. This finding contradicts the results of several studies on monolingual children which have found that high probability nonwords are processed faster and more accurately than low probability nonwords. Specifically, Storkel (2001) found that words with high phonotactic probability were learned faster than words with low phonotactic probability. Beckman and Edwards (2000) found that highly probable nonwords were repeated more accurately, and Munson (2001) found they were repeated more fluently than words with low phonotactic probability.

There has also been some research to suggest this processing advantage for high phonotactic probability exists in bilingual children. For example, Brea-Spahn (2009) found that bilingual children were more accurate when repeating nonwords judged by adults to be more word-like with word-likeness being highly correlated with high phonotactic probability. More recently, Lee and Gorman (2013) found that bilingual children were more accurate at repeating nonwords with high phonotactic probability in English. However, it is important to point out that both of these bilingual studies tested children in a monolingual mode (Grosjean, 1989), meaning they were spoken to in one language and asked to complete the NWR task using nonwords with phoneme sequences characteristic of only one language.
The current study differed from the other bilingual studies in that children were tested in a bilingual mode (Grosjean, 1989) and were being asked to judge nonwords that had phonotactic probability in both of their languages. This could be the reason why the current study did not find a significant high probability processing advantage. Specifically, regardless of whether a word had high or low probability, children sorted it as English if it was an English Only nonword and Spanish if it was a Spanish Only nonword. Overall, these findings suggest that children were making language membership judgments based on whether a nonword was more probable in English or Spanish and were not influenced by the low or high probability of the word within one language.

**Storage Structure of Two Phoneme Systems**

The second research question examined how a bilingual child’s two phonotactic systems were stored. The literature suggests that the phonotactic systems are stored together, which has been supported by several computational models simulating phonotactic processing in bilingual children (Li & Farkas, 2002; Shook & Marian, 2013; Zhao & Li, 2010). For example, Shook and Marian (2013) created a computer simulation of the language processing of a Spanish-English bilingual child and found that words with similar phoneme sequences, regardless of language membership, were stored together. Based on these findings, it was suggested that activating the phonotactic probabilities of one language would simultaneously activate the phonotactic probabilities of the other language when the words were close to each other on the phonological map (Shook & Marian, 2013). These simulations also showed a cross-language interaction at the phonological level. For example, when the word *tenedor* “fork” was presented to the
model for processing, the English words “tunnel” and “tent” were also activated due to the similar initial onsets. While these findings are interesting, they were never supported by behavioral data from bilingual children. However, this cross-language phonological interaction has been shown to exist in Spanish-English (Ju & Luce, 2004) and Russian-English (Marian & Spivey, 2003) bilingual adults.

Based on the reported computer model simulations and adult findings, it would be expected that the bilingual children in the current study would show similar cross-language interactions at the phonological level. However, evidence for an interaction was weak. The language exclusive nonwords were sorted similarly to the high/low phonotactic probability nonwords when the high probability language and the exclusive language were the same (e.g., Spanish only nonwords were sorted the same as High Spanish-Low English; see Table 2).

Table 2.

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These results suggest that bilingual children are perceiving nonwords, processing the phonotactic rules, and the language for which the nonword has the highest phonotactic probability is receiving more activation than the other language. Once the activation reaches a particular threshold, that language is deemed the “winner,” and the other language is deactivated.
The Assimilation Effect

The last research question considered whether or not bilingual children showed an assimilation effect when sorting phonotactically ambiguous nonwords (Burki-Cohen et al., 1989). The assimilation effect hypothesizes that when a bilingual listener perceives an unknown word, he or she is likely to use the surrounding linguistic context (i.e., what language is being spoken when the word is presented) to determine the language membership of the unknown word (Burki-Cohen et al., 1989). This has been found to occur in French-English bilingual adults (Burki-Cohen et al., 1989) and German-English bilingual adults (Lemhofer & Raddach, 2009). Based on these previous findings, it was expected that the bilingual children in the current study would sort ambiguous nonwords as English if they were in the English group and as Spanish if they were in the Spanish group; however this language group difference was not found. There was also no effect of word type (ambiguous with high probability in both languages or ambiguous with low probability in both languages) on how the words were sorted, likely due to the fact that the children could not rely on the phonotactic probability of the nonwords to determine language membership. These findings indicate that bilingual kindergartners were not using the language environment and could not use the phonotactic probabilities to determine to which language a novel word belongs. Taken with the other results of this study, it seems that bilingual children are putting much more emphasis on the overall phonotactic probability of a nonword than other cues, like language environment, when determining language membership.
Complexity of the Decision

Thus far, the results have been discussed in terms of how children judged the nonwords (as English or Spanish). In addition, the complexity of their decision process was also measured in terms of the Area Under the Curve (AUC); the larger the AUC, the more distracted the child was by the other language option. Such responses would suggest that their decision making process was more complex (Freeman & Ambady, 2010). It was hypothesized for all three research questions that word type and/or language group would significantly impact AUC, but this was not the case. AUC was never significantly different as a result of any of the independent variables. Therefore, the bilingual children heard the nonword, made their language membership judgment, and did not appear to be distracted by the other language option while responding. This finding strengthens the argument that children are processing the nonwords as either one language or the other without taking into account mixed phonotactic probability or language environment. If children were aware of this dual phonotactic probability, then the AUC would likely be significantly larger on words that could belong to either language. However, the lack of a significant AUC difference suggests that bilingual children were not distracted by a nonword’s dual phonotactic probability.

Phonotactic Processing in Bilingual Children

By taking the results of the current study and applying them to the model of child bilingual word processing presented in Chapter 1, the model can be refined in some important ways. Figure 13 displays the new hypothesized process of word processing in bilingual children using the nonword /kusal/. This nonword was one of the High Spanish-Low English nonwords with a Spanish log probability of -5.18 and an English log
probability of -7.02. To begin, the word is first perceived at the Phoneme Processing level, and the individual phonemes /k/ /u/ /s/ /a/ /l/ are identified. The phoneme sequence is then sent to the Phonotactic Level (previously termed the Phoneme Pattern Level) where the phonotactic probability of /kusal/ is computed. Since this word has a higher probability in Spanish, Spanish receives more activation than English, and becomes the “winner.” Thus, the Phonotactic Level determines that /kusal/ is a phoneme sequence characteristic of Spanish. At this point, lexical status is not determined (as was hypothesized in the earlier version of this model). Instead, the Phonotactic Level simply sends along the information that the incoming word, /kusal/, should be processed as Spanish\(^4\). This information is sent to the Lexical Level where Spanish words with similar phoneme sequences (e.g., \(\text{cupón} \text{ “coupon,”}^5\) cultura “culture”) likely receive the majority of the activation, but do not receive enough activation to be chosen as the word being processed. Instead, the Lexical Level fails to find a lexical match for /kusal/, and creates a new node for it, likely close to the lexical items that just received some activation (i.e., neighbors for / kusal/; Luce & Pisoni, 1998). At this point processing for the word /kusal/ stops, and the system continues processing other incoming words. The previous model hypothesized that novel phoneme sequences were sent back to the Phoneme Pattern Level so they could be learned for future encounters with that sequence. However, the new model suggests that this step is unlikely since the Phonotactic Level is just computing

\(^4\) This information is similar to earlier notions of a language tag being used to inform the processing system which language it should be processing (e.g., Dijkstra & Van Heuven, 1998). However, earlier models described language tags as some unspecified mechanism to help in processing. The currently proposed model is hypothesizing that language membership is determined based on processing phonotactic probabilities and this membership information is sent to the lexical level.

\(^5\) Here is an example of where cross-language activation may occur. Cupón is a cognate to the English word “coupon” so the activation of cupón likely activates “coupon,” but this activation would not be enough to cause much competition (Shook & Marian, 2013).
phonotactic probabilities. In other words, it is not storing phoneme strings that it compares with new incoming words; it is storing the phonotactic probabilities of two languages, something that was developed very early in the language acquisition process (Pierrehumbert, 2001; Pitt & McQueen, 1998; Saffran, 2001).

In sum, word processing in sequential bilingual children appears to begin with computing phonotactic probabilities in each language. The children in the current study appeared to use overall phonotactic probability of a nonword to determine to which language it belongs before looking at finer details like whether a nonword had a high or low phonotactic probability in a particular language. Further research in fast mapping and

Figure 13. Schematic of new proposed model of child bilingual word processing
word meaning can provide more detail on what bilingual children do with a word once it is processed at the phonotactic level.

**Strengths and Limitations**

There major strength of the current study was the creation and use of the nonword stimuli. The stimuli were carefully created and controlled phonotactically and acoustically to answer questions on bilingual phonotactic processing. Currently, these are the only stimuli published that have mixed phonotactic probabilities between two languages and were synthesized to reduce the effects of acoustic cues to language membership. The method of creation, along with these particular stimuli, could be used by a variety of researchers to study many different aspects of bilingual language interaction. Since the stimuli will be made available to the broader research community, this study contributes significantly to the field.

One of the weaknesses of the study was the small number of children from which data was collected. This weakness was ameliorated by the use of MLM to analyze the data. The other weakness of the current study was the lack of a clear measure of language proficiency. Language proficiency is often a difficult variable to measure and control for in bilingual research (Bedore et al., 2012), and the current study tried to measure proficiency following previously used methods (Windsor, et al., 2010). However, children in the current study performed poorly on these measures likely due to the fact that the measures used required more academic experience than these children had in either English or Spanish. Future studies in bilingual phonotactic probability processing will need to find a more accurate means of estimating language proficiency. For example, Bedore et al. (2012) suggests refining parental questionnaires to ask more about current
usage of a language; a variable they found to be more indicative of language test performance than age of first exposure. Further, the Bilingual English Spanish Assessment (BESA) is currently being developed as a test of English and Spanish proficiency in bilingual children based on their semantic and morphosyntactic knowledge. Bedore et al. (2012) suggest that this test may better separate a bilingual child experiencing a language difference from one experiencing a language disorder.

**Future Directions**

There are several ways in which this study could be expanded in the future. First, it would be interesting to collect cross-sectional data on children throughout elementary school. The children from the current study were in their first year of kindergarten and had experienced less than one year in English schooling prior to entering kindergarten. Based on these facts, it was assumed that their experience with English, at least in an educational setting, was very little and limited to television, radio, and possible interaction with older siblings. This relative inexperience with English likely accounts for the overall bias toward sorting the nonwords as Spanish. This could also be one reason the children relied so heavily on overall nonword phonotactic probability and were not sensitive to the dual phonotactic probability of some words. It has been shown that as bilingual Spanish-English children have more academic exposure to English, they transition from Spanish dominant, to balanced bilingualism, to English dominant (Kohnert, et al., 1999). It would be interesting to see how this dominance shift correlates with phonotactic processing in these bilingual children.

Beyond gaining a deeper understanding of phonotactic processing in bilingual children, it would be beneficial to extend the findings of the current study into the process
of fast mapping. During fast mapping, children hear a nonword, see a picture (i.e., are given a word meaning) and then tested to see if they are able to associate the meaning with the word (Storkel, 2001). This process has been tested in monolingual children and results have shown that nonwords with high phonotactic probability are learned faster and more accurately than nonwords with low phonotactic probability (Storkel, 2001). It would be interesting to use the stimuli from the current study to see how bilingual children fast map words that have phonotactic probability in both languages. An experiment that asks bilingual children to first sort a word into Spanish or English, and then learn what that word means could test the model of word processing presented in the current study while also investigating what a bilingual child does with the newly created lexical node in the Lexical Level. Results from this kind of study would allow for the creation of a larger model explaining the full process of bilingual word learning starting from the basic task of bilingual word processing.

Eye tracking provides another means to track bilingual phonotactic and/or word processing. This methodology may provide interesting information on the decision process involved in judging these nonwords as English or Spanish. The current study used MouseTracker, which has been likened to eye tracking in the sense that a person’s decision process is demonstrated via mouse cursor movements (Freeman & Ambady, 2010). However, this assumes that participants are making their decision while moving the mouse cursor. The children in the current study did not show any effect of stimulus composition or language group on mouse cursor trajectory, but that does not necessarily mean that their judgments were simple. It could be that children made their decision prior to moving the mouse, and then went straight to their decision. In this case, their thought
process is not captured by the computer software. Eye tracking software, on the other hand, would capture their thought processes since eye movement is recorded continuously and the children cannot wait move their eyes as they make a decision. Using eye tracking could provide more fine-grained information on the phonotactic decision process and may show that bilingual children are sensitive to dual phonotactics of a nonword, just not at the point when the final decision is made. For instance, when the child hears a mixed nonword, they may initially look at one language, and then switch to the other language. Or they may look between the two languages before finally making a decision. The different gaze patterns would be captured by eye tracking technology and could be suggestive of more complex processing of the mixed nonwords. Alternatively, ERP may be another methodology that could shed more light on the decision process involved by measuring higher levels of cognitive processing in response to the nonword stimuli.
REFERENCES


APPENDICES
### Appendix A: Nonword Stimuli Characteristics

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Appendix A: Nonword Stimuli (Continued)

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Appendix B: Parental Questionnaire

1. Where was your child born? ____________________________
   ¿Donde nació su hijo/a?

2. How long has your child been living in the US? ________________
   ¿Hace cuanto tiempo ha vivido en los Estados Unidos su hijo/a?

3. Since living in the US, how much time has your child spent visiting your home country? (Circle one)
   ¿Desde que vive en los Estados Unidos, cuánto tiempo ha pasado su hijo/a visitando su país nativo? (Circula uno)

   Just short vacations   Several months each year   1 year   More than 2 years
   Solo vacaciones cortas  Varios meses cada año   1 año   Más de dos años

4. Who lives at home with you and your child? ____________________________
   ¿Quien vive en casa con Usted y su hijo/a?

5. What languages do the family members at home speak to each other? __________
   ¿Cuales lenguajes habla la familia con cada uno en casa?

6. How much of your child’s day is spent speaking or hearing Spanish? (Circle one)
   ¿Qué cantidad del día su hijo/a se pasa hablando o escuchando español? (Circula uno)

   0-20%  20-40%  40-60%  60-80%  More than 80%
   Mas que 80%

7. With whom does your child speak Spanish? ____________________________
   ¿Con quién habla español su hijo/a?

8. How much of your child’s day is spent speaking or hearing English? (Circle one)
   ¿Qué cantidad del día su hijo/a se pasa hablando o escuchando inglés? (Circula uno)

   0-20%  20-40%  40-60%  60-80%  More than 80%
   Mas que 80%

9. With whom does your child speak English? ____________________________
   ¿Con quién habla inglés su hijo/a?
10. How old was your child when s/he started saying words in Spanish? ________________
¿Cuántos años tenía su hijo/a cuando empezó a decir palabras en español?

11. How old was your child when your family started speaking Spanish to him/her? _____
¿Cuántos años tenía su hijo/a cuando la familia empezó hablar español con él/ella?

12. How old was your child when s/he started saying words in English? ________________
¿Cuántos años tenía su hijo/a cuando empezó a decir palabras en inglés?

13. How old was your child when your family started speaking English to him/her? _____
¿Cuántos años tenía su hijo/a cuando la familia empezó a hablar inglés con él/ella?

14. Did your child attend English speaking school before kindergarten? (Circle one)

   Yes   No

   ¿Asistió su niño a una prescolar o jardín infantil de habla inglesa antes de empezar el kinder? (Circula uno)

   Sí   No

15. If yes, for how many months? (Circle one)
¿Sí sí, para cuántos meses? (Cirula uno)

   0-3 months   4-6 months   7-9 months   10-12 months   More than 1 year
   0-3 meses   4-6 meses   7-9 meses   10-12 meses   Más que 1 año
Appendix C: IRB Approval Letter

August 24, 2012

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

RE: Expedited Approval for Initial Review
IRB# P00007795
Title: Nonword processing in bilingual kindergarteners: Do phonotactics count?

Dear Ms. Betancourt:

On 8/23/2012, the Institutional Review Board (IRB) reviewed and APPROVED the above referenced protocol. Please note that your approval for this study will expire on 8/23/2013.

Approved Items:
Protocol Document(s):
Betancourt IRB protocol.pdf

Consent/Assent Documents:
Parental Consent English.pdf
Parental Consent Spanish.pdf

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 research through the expedited review procedure authorized by 45 CFR 46.110 and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review categories:

(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,
Appendix C: IRB Approval Letter (Continued)

focus group, program evaluation, human factors evaluation, or quality assurance methodologies. Per CFR 45 Part 46, Subpart D, this research involving children was approved under the minimal risk category 45 CFR 46.404: Research not involving greater than minimal risk.

Please note, the informed consent/assent documents are valid during the period indicated by the official, IRB-Approval stamp located on the form. Valid consent must be documented on a copy of the most recently IRB-approved consent form.

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 by an amendment.

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,

John Schinka, Ph.D.
Chairperson
USF Institutional Review Board
Kyna Rhae S. Betancourt received her BA in Language, Speech and Hearing from the University of South Florida in 2006. She then spent a year in Europe where she received her MS in Clinical Linguistics through the Erasmus Mundus Program. This program allowed her to study in Italy, Finland, and Germany. Upon returning to the U.S., Ms. Betancourt began her M.S. in Speech-Language Pathology and her Ph.D. in Communication Sciences and Disorders at the University of South Florida. Due to her fluency in Spanish and her love of the Hispanic culture, Ms. Betancourt began studying phonology and word learning in Spanish-English bilingual children. She was also a Fellow in the Doctoral Leadership Institute at the University of South Florida which provided her the opportunity to intern with the Senior Vice President of International Research and Global Affairs at the university. This experience coordinated nicely with Ms. Betancourt’s international experiences, and led her to continue working on internationalizing the curriculum at the University of South Florida. During her Ph.D. career she has co-authored a peer-reviewed article, presented at multiple national conferences, and won awards in both research and teaching. Ms. Betancourt is currently a full-time instructor at the University of South Florida in the Department of Communication Sciences and Disorders.