Novel-Word Learning in Bilingual Children with Hearing Loss

by

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ABSTRACT

Purpose: The goal of this study was to examine how vocabulary size and inhibitory control affect word learning in bilingual (English-Spanish) children with hearing loss. Experiment 1 examined whether children with larger vocabularies learn and retain more words than children with smaller vocabularies. Experiment 2 examined whether children with better inhibitory control learn and remember more words than children with poorer inhibitory control. In addition, monolingual and bilingual children with and without hearing loss were compared on word learning and inhibitory control tasks.

Method: Seventy-three children between 8 and 12 years of age participated in the study. Forty children had normal hearing (20 monolingual and 20 bilingual) and 33 had hearing loss (20 monolingual and 13 bilingual). For Experiment 1, children completed a receptive vocabulary test in English and Spanish and three word learning tasks consisting of a training and a retention component in English, Spanish, and Arabic. For Experiment 2, children completed the flanker task for inhibitory control.

Results: In Experiment 1, larger total (English + Spanish) receptive vocabularies were predictive of better word training outcomes in all languages and better Spanish word retention, after controlling for age, degree of hearing loss, and maternal education. Children with hearing loss performed more poorly in Spanish and Arabic word training and retention than children with normal hearing. No differences were observed between children with normal hearing and hearing loss in English word learning. In Experiment 2, inhibitory control only predicted English retention outcomes. Children with hearing loss showed poorer inhibitory control than hearing peers. No differences were observed between monolingual and bilingual children, with and without hearing loss, in word learning or inhibitory control.

Conclusions: Language experience (measured by total vocabulary size) helps children learn new words and therefore children with hearing loss should receive well-fitted hearing aids and school accommodations to provide them with access to spoken language. Bilingual exposure does not impair nor facilitate word learning. Bilingual children showed similar difficulties with word learning and inhibitory control as monolingual peers with hearing loss. Hearing loss, probably via language deprivation, has broad effects on children's executive function skills.

A mis padres, por enseñarme que con voluntad y esfuerzo todo es posible.

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Introduction

A fundamental accomplishment of childhood is the acquisition of a broad and deep vocabulary. Normal-hearing children with larger vocabularies show higher reading and academic outcomes than children with smaller vocabularies (e.g., Lesaux, Rupp, & Siegel, 2007; Marchman & Fernald, 2008; Proctor, Silverman, Harring, & Montecillo, 2012). It has been shown that hearing loss significantly slows vocabulary development (e.g., Pittman, Lewis, Hoover, & Stelmachowicz, 2005; Yoshinaga-Itano, Sedey, Wiggin, & Chung, 2017). Across ages, children with hearing loss show lower vocabulary outcomes than children with normal hearing, even when the hearing loss is identified early through universal newborn hearing screening, children are aided with hearing aids or cochlear implants, and they receive early intervention (e.g., de Diego-Lázaro, Restrepo, Sedey, & Yoshinaga-Itano, 2018; Tomblin et al., 2015; Yoshinaga-Itano et al., 2017). The small vocabularies of children with hearing loss may explain, in part, their lower academic achievement when compared to hearing peers (Antia, Jones, Reed, & Kreimeyer, 2009; Traxler, 2000). In addition, small vocabularies in children with hearing loss have been associated with behavioral problems (Stevenson et al., 2010), phonological impairment (Briscoe, Bishop, & Norbury, 2001) and poor working memory capacity (Stiles, McGregor, & Bentler, 2012).

Bilingual children with hearing loss face unique challenges that cannot be determined by examining the effects of bilingualism or hearing loss separately. Bilingual (English-Spanish) children represent 19.4% of the total population of children who are deaf or hard of hearing (DHH) in the U.S. (Gallaudet Research Institute [GRI], 2013) and their academic performance is poorer than that of their monolingual DHH peers (e.g., Kluwin & Gonsher, 1994; Marschark, Shaver, Nagle, & Newman, 2015). However, the study of vocabulary and word learning abilities in bilingual children with hearing loss in previous literature has been anecdotal (Bunta & Douglas, 2013).

Previous studies have shown that vocabulary size influences word learning in normal-hearing children (e.g.,Maguire et al., 2018) and in children with hearing loss (e.g., Pittman et al., 2005; Walker, 2010). Other studies have found that children with larger vocabularies, such as bilingual children, possess greater inhibitory control than children with smaller vocabularies (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Costa, Hernández, & Sebastián-Gallés, 2008). Enhanced inhibitory control may facilitate word learning because children can focus on a new word while inhibiting irrelevant information such as other words that sound similar (Yoshida, Tran, Benitez, & Kuwabara, 2011). Given these factors, how do vocabulary size and inhibitory control affect word learning in bilingual children with hearing loss? Determining the factors that facilitate word learning in bilingual children with hearing loss will provide the basis for future interventions aimed to reduce the vocabulary gap between bilingual children with hearing loss, their hearing peers, and their monolingual peers with hearing loss.

Theories of Word Learning

By thirty months of age, typically developing monolingual children are able to produce around 400 words (Fenson, Marchman, Thal, Dale, & Reznick, 2007). Over the past 60 years, researchers have proposed different theories and models to explain the mechanisms children use to learn new words and what affects early vocabulary acquisition. These theories and models of early word learning come from cognitive and developmental psychology, in which children are typically involved in single-word learning trials using fast mapping. Fast mapping is a hypothesized mental process whereby a new concept is formed based only on a single exposure to a given unit of information (Blaiser, Nelson, & Kohnert, 2015; McMillan & Saffran, 2016; Riley & McGregor, 2012). Fast mapping allows children to gain at least partial information about the meaning of a word from how it is used in a sentence or what words it is contrasted with (Heibeck & Markman, 1987). Although some studies have found that children are able to retain a newly learned word for a week even with only one exposure (e.g., Markson & Bloom, 1997), other studies have reported that children are unable to remember the new word five minutes after the fast mapping (e.g., Horst & Samuelson, 2008). Therefore, fast mapping is not synonymous with long-term learning. Fast mapping experiments vary from those that use direct instruction ("This is a __.") to those that refer indirectly to new words in the context of a story to assess if children can learn the new words incidentally. Below, the main word learning theories are described.

Constraints or Principles theories. The Principles theory (also called Constraints theory) is based on a philosophical conundrum introduced by Quine (1960) about single word mappings. He claimed that when children listen to a new word it could have an infinite number of possible mappings and thus children may apply some principles that allow them to reduce the number of possible mappings. (Golinkoff, Mervis, & Hirsh-Pasek, 1994) offered a developmental model in which principles of word learning were organized in two tiers. Tier one includes those principles that are essential to word learning (principle of reference, extendibility, and object scope), whereas tier two includes principles that are more sophisticated due to word learning experience and increasing vocabulary size (conventionality, categorical scope, and novel name-nameless category). They proposed that these principles could be innate but need language exposure to emerge with development. These principles have been tested in different studies although it is not clear when they emerge and under what circumstances. These principles are:

1. The principle of reference means that when learning words, children associate words to objects, actions, or events. At the beginning of word learning, words co-occur with objects, but soon after, words can be used alone to refer to objects or people that are not present. It is not clear when this principle originates, but it is probably present before 12 months of age (Hollich et al., 2000), as infants are able to understand words when the object is not present.
2. The principle of extendibility means that when learning words, children extend their newly learned labels to other related objects similar in shape, size or color. By 12 months of age, children realize that words do not refer to a single exemplar, but can refer to categories of objects. For example, children may call all animals who have four legs a “dog” in the early stages of word learning (Golinkoff et al., 1994).
3. The principle of object scope indicates that when learning words, children associate the words to whole objects rather than to object’s parts or attributes (Markman & Wachtel, 1988).
4. The principle of conventionality means that when learning words and producing them, children match the phonological forms of words to the adult forms in order to be understood (Hollich el at., 2000).

5. The categorical-scope principle in word learning indicates that children are able to classify words in different semantic categories. For example, even if a basketball and an orange share many similar perceptual properties, children realize that they are not categorically linked (a basketball is a toy and an orange is a fruit). The principle of categorical scope restricts the extendibility principle as perceptual similarities are no longer enough for extensions (Hollich el at., 2000).
6. The novel name-nameless category principle indicates that when children learn new words, these words map onto novel objects. This principle helps children learn words more rapidly because they search out an unnamed referent when they hear a novel name. Similar to the novel name-nameless category principle, the mutual exclusivity principle (Merriman, Bowman, & MacWhinney, 1989) proposes that children map one novel word (and only one) to one novel object. The principle of mutual exclusivity has been found to be present in children as early as 17 months of age and to be dependent on language experience.

Social-Pragmatic theories of word learning. In contrast to the constraints or principles theories, social-pragmatic theories of word learning emphasize that children are guided by adults when learning new words (Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998). Children do not apply principles to restrict possible word-to-object mappings, but rather adults guess what the child is focusing on to supply the appropriate word (Nelson, 1988). Adults use language that is relevant to the child's interest (Bloom, 1993) and around 18 or 19 months of age children are able to read social cues when attaching a label to an object, action, or event in the environment (Hollich et al., 2000). For example, (Tomasello & Barton, 1994) conducted an experiment where they pretended to be looking for a "toma." As new objects were revealed, the experimenter said: "This is not the toma" and put it back in its hiding place. Only on the final toy, the experimenter looked excited and handed the object to the child. Nineteen-month-old children read the social cues and selected the correct toy as the "toma" on a multiple-object test.

How caregivers interact with their children and the type of socio-pragmatic strategies they use influence children's vocabulary acquisition according to this theory. Infants whose parents engage more in joint attention, follow their interests, and talk more about what children are looking at, tend to have larger vocabularies than children whose parents engage less in the interaction (Akhtar, Dunham, & Dunham, 1991; Tomasello & Farrar, 1986). Some strategies, however, may not support vocabulary learning. The use of prohibitions or commands, for example, has been found to be negatively correlated with vocabulary size in children between nine and thirty-six months of age (Hart & Risley, 1995). Previous research has shown that mothers having low socioeconomic status (SES) use more commands and fewer words than mothers having high SES (Hart & Risley, 1992; Erika Hoff, 2003). Because Latino families show the lowest level of education (SES) in the U.S. (Ryan, & Bauman, 2016), they may be at risk for delayed vocabulary development. In addition, Latino mothers tend to be more directive than Anglo-American mothers, and thus, they use more commands in their interactions with children (Gamble, Ramakumar, & Diaz, 2007).

Associationist view of word learning. According to this view, children do not need principles or constraints in learning words because words are learned by attentional mechanisms that focus on perceptual saliency, association, and frequency of the words (Plunkett, 1997). Children associate the most frequently used label with the most salient candidate and thus there is little ambiguity in the word-to-object mappings. These attentional mechanisms are part of global cognitive domains.

Samuelson and Smith (1998) postulated that the apparent ease children show in learning new words derives from general cognitive processes rather than from constraints or social cues. To test this hypothesis, they presented a novel noun to 48 children aged 18 to 28 months using a similar task as the one used by (Akhtar, Carpenter, & Tomasello, 1996). In their study, 24-month-old children, caregivers, and two investigators played with three objects novel to the children. Then, one of the investigators and the caregiver left the room while the other investigator played with the child with a fourth novel object, the target of the experiment. They put all the toys in a transparent box. When the caregiver and the investigator entered the room, they said, “Look, I see a gazzer. A gazzer!” for the experimental condition, and “Look, look at that!” for the control condition. In the testing phase, they asked children for the “gazzer” and found that more children in the experimental group than in the control group interpreted the novel name as referring to the target object. Akhtar and colleagues concluded that children used social cues to map the novel noun to the object because the only object that was new for the caregiver and the investigator was the fourth object. Samuelson and Smith followed the same procedure but instead of asking the caregiver and the investigator to leave the room, all played with the fourth object on the other side of the room. Then, they placed the four objects in the transparent box and asked for the “gazzer.” Like in the Akhtar et al. study, children in the experimental condition mapped the novel noun with the target object. Because they played with the target object in a different location, it created a situation that was unique to the children in comparison to the other three objects. The authors concluded that the new situation is what caught children’s attention and why they associated the novel noun with the target object.

Emergentist coalition model of word learning. Emergentist proponents explain the word-learning process by combining theories. They state that “without recognizing the enormity of the word learning problem, a [single] theory cannot support the weight of lexical acquisition…different accounts are often explaining the same phenomenon from different points or levels of analyses” (Hollich et al., 2000, p. 14). During word learning, children differentially weigh certain cues (social, linguistic or attentional cues) over the others and the principles children use to learn new words emerge with experience (Golinkoff et al., 1994). The Emergentist model proposes that, to learn new words, children rely first on perceptual cues (such as the visual salience of an object) and on the characteristics of infant-directed speech. Later on, children are able to rely on social and linguistic cues (Brandone, Pence, Golinkoff, & Hirsh-Pasek, 2007; Golinkoff & Hirsh-Pasek, 2006; Hollich et al., 2000).

Different studies have put social, linguistic, and attentional cues into conflict to assess whether children rely more heavily on some cues over others when learning new words. Most of these studies have used the Intermodal Preferential Looking Paradigm (IPLP). In the IPLP, infants sit on their caregiver’s lap and look at a board or screen. Children are presented with two images side-by-side and with a linguistic stimulus that matches one of the pictures. Infants' language comprehension is measured by their differential visual fixation to the two images. For example, to test whether infants use perceptual cues to learn novel words or whether they can also use social cues such as eye gaze, (Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006) showed ten-month-olds an interesting object (e.g., a colorful noisemaker) and a boring object (e.g., a beige bottle cap opener) using the IPLP. After the experimenter gained the child's attention, she looked back and forth between the child and the objects while offering a novel name, e.g., "Look at the modi!" Infants mapped this name to the interesting object, suggesting that children were using perceptual cues (e.g., color) when doing the mapping. When eye gaze was put into conflict with perceptual salience (the investigator looked at and named the boring object), ten-month-olds still mapped the word onto the most salient object (the colorful noisemaker), suggesting that the social cues were either not noticed or ignored; however, twelve-month-olds did not mismap the name of the boring object onto the interesting object, although they failed to learn the name of the boring object (Hollich et al., 2000), suggesting that social cues may emerge at a later age.

Cross-situational learning model (Yu & Smith, 2007). According to the cross-situational learning model, children and adults learn new words through multiple exposures in different contexts (not just one exposure) using statistical or probabilistic learning. Multiple exposures of the same word in different contexts help reduce the uncertainty of the word's true meaning. Thus, the more frequent a word appears in different contexts, the faster children will learn it.

To test the cross-situational learning model, Yu and Smith (2007) exposed 38 monolingual English adults to a set of trials that contained multiple spoken words and multiple pictures of individual objects. The participants were presented with two pictures and two words, but did not receive any information about word-picture associations. Across trials, one of the pictures and one of the words were presented again in a different context, which allowed the participants deduce that the word and the picture must go together. The authors called this process cross-trial statistical learning, and concluded that, in addition to statistical learning, the participants applied the mutual exclusivity principle (one word-one picture) to map the pictures and the words. In a later study, Smith and Yu (2008) used a similar procedure with 12 and 14-month-old infants demonstrating that children were able to make the word-picture mappings just like the adults did. The authors suggested that the statistical learning mechanism is what allows infants to learn new words rapidly and that it would explain why children in rich language environments (more exposures to new words), are able to learn more words than children in impoverished language environments (fewer exposures to new words).

Word Recognition and Word Learning

Although the theories or models of word learning typically focus on the acquisition of first words, the speed of vocabulary learning is thought to peak between eight and twelve years of age, partly through reading. It is estimated that children can learn as many as 12 words per day, having around 60,000 words when they graduate from high school (Bloom, 2002). This remarkably rapid vocabulary growth leads to several questions: Can the theories of early word learning explain rapid learning in the grade-school years? Are some or all of the principles and cues used by young infants also used by grade-school children? Do current theories explain the breadth of vocabulary knowledge of school-age children (e.g., synonyms)? Research on word learning in school-age children and adults is primarily focused on speech perception and on factors that affect word learning, assuming they use the same cues and principles that infants use to detect and learn new words.

Since the 1960s, scientists have proposed different models and theories to explain how spoken word recognition is done (see for example the TRACE model [McClelland & Elman, 1986)], the Cohort Theory [Marslen-Wilson, 1984], or the Neighborhood Activation Model]). All of these models typically start with auditory input, i.e., the stream of speech from which words need to be extracted. Although these models recognize that word segmentation is not an easy task for a number of reasons (e.g., background noise, coarticulation, differences from speaker to speaker, etc.), they do not attempt to explain how word segmentation is done, but rather focus on lexical processing and accessing the mental lexicon. The word segmentation literature focuses on the cues that infants use to identify word boundaries and it is an ongoing area of research (e.g., Johnson & Jusczyk, 2001; Saffran, Aslin, & Newport, 1996; Singh, Steven Reznick, & Xuehua, 2012). In this section, the Neighborhood Activation Model will be described as well as more recent models of word learning.

Neighborhood Activation Model (NAM). Luce and Pisoni (1998) proposed the NAM to explain word recognition. The model focuses on how the linguistic system is able to recognize a given word by comparing it with other words stored in the lexicon using probabilistic information. Figure 1 shows the flowchart of the NAM. In this model, after words are segmented, the phonetic patterns are activated in memory allowing lexical processing to begin. The next step is the neighborhood activation or word decision unit. Here, perceived words are compared with existing words in the lexicon to decide which word was most likely heard. Although the model is presented in a serial format, the comparison of a perceived word with existing words in the lexicon is done in parallel. This means that words compete with each other for activation and this competition among words leads to excitatory and inhibitory connections. To match a perceived word with an existing word in the lexicon, the word in the lexicon needs to be activated, while other candidate words are inhibited. When there is a match between a perceived word and a word stored in the lexicon, the word is recognized. High-level lexical information such as semantic, syntactic, and contextual information reduces the number of possible words to be activated.

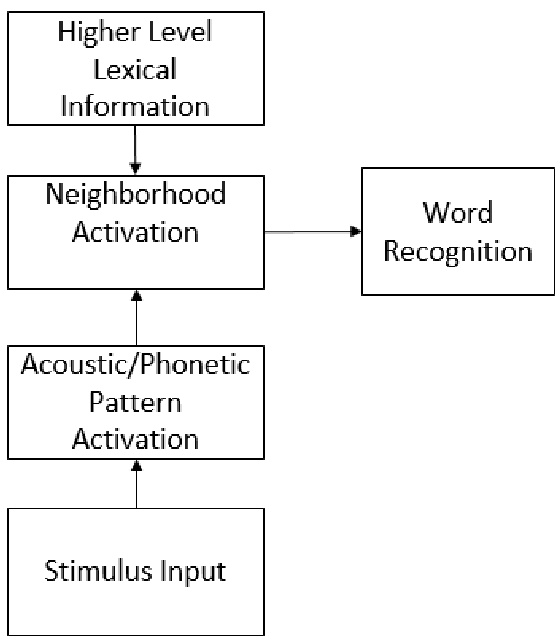

Figure 1. Flow chart for the neighborhood activation model from Luce and Pisoni (1998).

In the NAM, words in the lexicon are organized into neighborhoods. A neighborhood contains words that are phonetically similar to each other. The number of words or neighbors that a specific word can activate in the lexicon within a given language can be estimated. It has been referred to as neighborhood density and is an index for the number of words that differ from the target word by one phoneme within a given language (Luce & Pisoni, 1998). Words with high neighborhood density are recognized more slowly than words with low neighborhood density (Luce & Large, 2001; Vitevitch & Luce, 1999). Figure 2 shows the neighbors for the word *cat* and the neighbors for the word *monkey.* According to the NAM, the word *cat* is a high density word and it will take longer to be recognized than the word *monkey* because it has more neighbors. Therefore, low-neighborhood density words do not require as much time to be recognized, whereas high-density words require more time. In addition, high-density words require better hearing acuity than low-density words as they can be easily confused with many of its neighbors (Pittman & Rash, 2016). The NAM proposes that an unknown word will follow the same initial process as real words but it will not activate a matching word in the lexicon and therefore it will not be recognized.

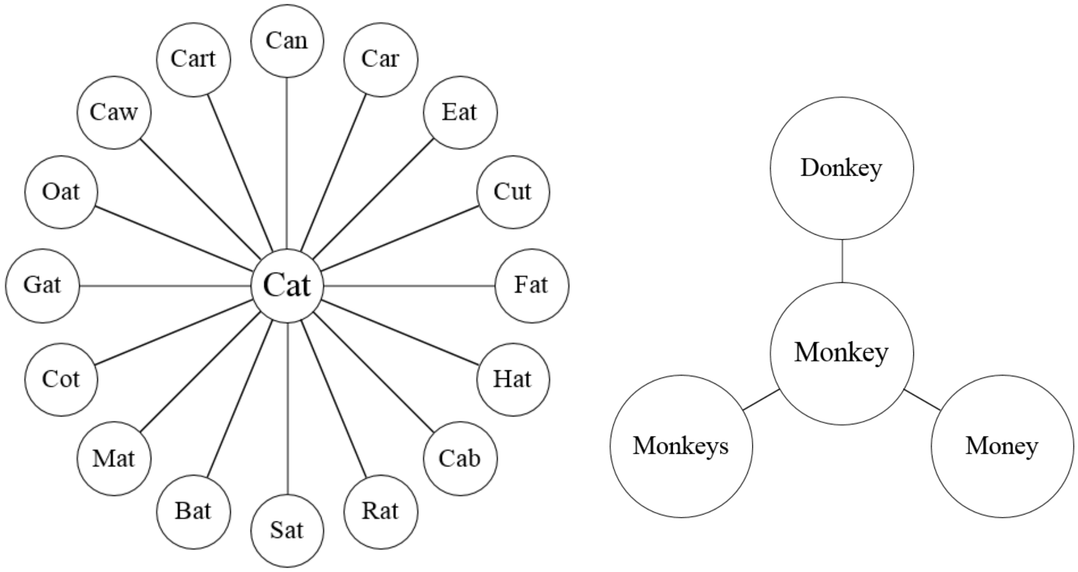

Figure 2. Total number of neighbors for the words *cat* and *monkey*. The total number of neighbors was calculated using the CLEARPOND online calculator (Marian, Bartolotti, Chabal, & Shook, 2012) by replacing, adding or deleting one phoneme to the target word. *Cat* neighborhood density = 33 (16 are represented in the figure). *Monkey* neighborhood density = 3.

Word learning stages. Recent research explains how new words are learned rather than focusing only on how known words are recognized. Word learning seems to comprise three stages. The first stage is detection of the new word or *triggering* (Storkel, Armbrüster, & Hogan, 2006; Storkel & Lee, 2011). During triggering, the sequence of phonemes is recognized as a word and it tries to activate the existing lexical representations. If the sequence of phonemes activates an existing word, then the word is recognized. If the sequence of phonemes fails to match an existing representation, then it is considered an unknown word. In natural speech, most new words are not highlighted in any way (e.g., Storkel et al., 2006), and thus, being able to detect a new word out of the continuous speech is required for word learning because it allows for the subsequent stages to occur. If the new word is very similar to a real word, it could be that the real word is activated instead of triggering learning, preventing the opportunity to learn a new word (Pittman & Rash, 2016; Storkel & Lee, 2011).

The second stage of word learning involves the creation of a lexical representation of the novel word. At a minimum, the lexical entry includes a phonological and/or orthographic representation, the meaning (typically context-specific), and its syntactic role(s) (Leach & Samuel, 2007). This first lexical entry is formed rapidly and contains partial information about the word. Over time, if the word is heard in different contexts, the lexical entry will be revised to include new information (Capone & McGregor, 2005; Storkel & Lee, 2011). For example, if a child hears the word *bat* for the first time when playing baseball, the meaning for that lexical entry will probably be an instrument to strike a ball or the action to strike a ball. If this word is heard when talking about animals, the child will be able to add that new definition to the word *bat.* Therefore, by being exposed to words in different contexts children can update lexical entries adding new information, not only about its meaning but also about its syntactic or phonological information. The combination of phonological and/or orthographic information, the meaning, and the syntactic role(s) associated with a word has been referred to as *lexical configuration* (Leach & Samuel, 2007).

The third stage of word learning is called *lexical engagement* or lexicalization and refers to the integration of a new representation in the lexicon. Engagement is defined as the competition among words that sound similar (Gaskell & Dumay, 2003). Lexical engagement presumably takes more time than initial lexical configuration (Dahan, Magnuson, Tanenhaus, & Hogan, 2001; Gaskell & Dumay, 2003; Magnuson, Tanenhaus, Aslin, & Dahan, 2003). Gaskell and Dumay (2003) studied lexical competition between 26 newly learned words and 26 existing words with the same onset (e.g., “cathedruke” and “cathedral”). Twenty-two adults were exposed to the novel words in a phoneme monitoring task, where they had to decide if a word modified in one phoneme was the same than the target word (e.g., “cathedruce” and “cathedruke”). The phoneme monitoring task does not provide a meaning for the word, only a phonological form. To test the effects of exposure to the novel words, in experiment 1 participants performed a lexical decision task with the real words before and after exposure to the novel words and their response latencies were measured. They found that after immediate exposure to the novel words, rather than increasing their response latencies, the novel words facilitated the activation of real words because the participants responded faster. This suggests that the novel words did not develop their own lexical representation. In experiment 2, the participants performed the same task as in experiment 1 for five days. The authors found that inhibitory lexical competition emerged for words with the same onset (e.g., “cathedruke” and “cathedral”), but not for words with different onset (e.g., “yothedral” and “cathedral”). In experiment 3, the participants were familiarized with the same words and nonwords in the phoneme-monitoring task and the effects of lexicalization were tested using a pause detection task. In this task, the participants had to judge whether or not a word contained a silent period. Response latencies were recorded. One week later, the pause detection task was repeated. They found that the lexicalization effects were absent immediately after exposure and did not emerged until one week later, without having any new exposure during that week. From this study, the authors concluded that integrating a novel word without a referent into the lexicon can be an extended process and that consolidation is a matter of time rather than number of exposures.

Following Gaskell and Dumay (2003), Leach and Samuel (2007) designed a set of experiments to distinguish between lexical configuration and engagement. Twenty monolingual graduate students had to learn 12 novel words in four days. The participants were exposed to the novel words in a phoneme monitoring task (experiment 1), in association with a novel picture (experiment 2), and in the context of a story (experiment 3). In all three experiments, the participants received 24 trials per day. In addition, on all five days, participants had to complete two tasks that assessed lexical configuration and engagement. The lexical configuration task was a word recognition task with background noise. The participants listened to a word completely masked with white-noise, which was reduced by 10% in every trial. The participants had to stop whenever they were able to recognize the word and write it down. In the lexical engagement task, participants listened to two lists of nonsense words and decided whether words in the second list were in the first list. Target words in the second list had a phoneme slightly mispronounced, for example for the word “gatersy” in the first list, participants had to compare it to “gater?y”, where ? was an artificial phoneme created by mixing s and sh. Then, the participants had to listen to an s-sh continuum and decide whether it was one phoneme or the other. The results showed that participants increased accuracy in the lexical configuration task each day (i.e., more exposures), being able to recognize the target words with more masking noise. The lexical engagement task showed different results depending on how the words were presented. Words presented with a novel picture or in the context of a story were sufficient to generate a lexical representation capable of engagement. However, when words were presented in the phoneme monitoring task (without having a meaningful association), they did not create a lexical representation sufficient to engage with existing words. These results suggest that lexical configuration and engagement are different processes and cab be studied separately.

In conclusion, previous research agrees that word learning occurs in three different phases: triggering, configuration, and engagement (e.g., Gray, Pittman, & Weinhold, 2014; Hoover, Storkel, & Hogan, 2010; Leach & Samuel, 2007; Storkel & Lee, 2011); however, the stimuli and the tasks used in the experiments led to conflicting results, especially when assessing lexical engagement. Leach and Samuel (2007) found that meaning is necessary to create a lexical representation able to compete with real words, however, other researchers found that a phonological form without meaning is enough to compete with real words (Gaskell & Dumay, 2003; Kapnoula, Packard, Gupta, & McMurray, 2015). In addition, it is not clear what is needed to integrate a new word into the lexicon. Some studies have found that time is needed to consolidate a new word, probably during sleep when memory consolidation occurs (Dumay & Gareth Gaskell, 2012; Dumay & Gaskell, 2007), but others have found that integration can be immediate whether the word is associated with meaning (Leach & Samuel, 2007) or not (Kapnoula et al., 2015; Lindsay & Gaskell, 2013). Although lexical configuration and engagement make sense conceptually and can be assessed separately, they are probably supported by the same learning mechanisms (Kapnoula et al., 2015).

Factors Associated with Word Learning

External factors refer to the elements in the environment that affect word learning such as phonotactic probability and neighborhood density or the number of exposures to a new word. Internal factors refer to those elements that every individual brings to the learning context, such as working memory capacity or vocabulary size.

Phonotactic probability and neighborhood density. These two characteristics are typically studied together because they are not mutually exclusive. Phonotactic probability is the frequency of occurrence of individual sounds and sound combinations in a word within a given language (Vitevitch & Luce, 1999). Neighborhood density is an index for the number of words that differ from a target word by one phoneme within a given language (Luce & Pisoni, 1998).

Previous studies reported that adults recognize, name, and recall high-phonotactic probability words more rapidly and accurately than low-phonotactic probability words (e.g., Frisch, Large, & Pisoni, 2000; Luce & Large, 2001; Thorn & Frankish, 2005; Vitevitch, Armbrüster, & Chu, 2004; Vitevitch & Luce, 1999). In contrast, high-phonotactic probability may slow or interfere with word triggering. Storkel et al. (2006) studied the effects of phonotactic probability and neighborhood density on adult word learning and examined the stage of word learning (triggering, configuration or engagement) influenced by each. Thirty-two adults were exposed 12 times to 16 nonwords paired with novel objects in a story context. Their picture/word association was tested with a picture-naming test. There were four words for each condition: (a) high-phonotactic probability/ high-neighborhood density, (b) high-phonotactic probability/low-neighborhood density, (c) low-phonotactic probability/high-neighborhood density, and (d) low-phonotactic probability/low-neighborhood density. The authors analyzed partially correct (i.e., 2 of 3 phonemes correct) and completely correct responses (i.e., 3 of 3 phonemes correct) together and separately. Partially corrected responses were considered as an index of early word learning, providing information about the factors that affect triggering and configuration, whereas completely correct responses were considered an index of engagement. Analysis of partially correct and completely correct responses combined showed that adults learned a smaller proportion of high-phonotactic probability words than low-phonotactic probability words (i.e., high-probability disadvantage). Also, they learned a larger proportion of high-neighborhood density words than low neighborhood-density words (i.e., high-density advantage). The authors concluded that phonological and lexical processing may influence different aspects of word learning. Phonotactic probability may aid in triggering new learning because low-phonotactic probability words stand apart from other sound sequences whereas high-probability words activate similar real words, slowing the detection of new words. Neighborhood density may influence the integration of a new lexical representation with existing representations, i.e., high-neighborhood density words are retained better. A similar effect of phonotactic probability and neighborhood density on word learning has been found in other studies with preschoolers (Storkel, Bontempo, Aschenbrenner, Maekawa, & Lee, 2013; Storkel & Lee, 2011).

Similar to Storkel and colleagues (2006), other studies have shown that adults recognize real words from high density neighborhoods more slowly and less accurately than words from low-density neighborhoods (e.g., Luce & Large, 2001; Luce & Pisoni, 1998; Vitevitch & Luce, 1999) whereas they recall and remember words from high-density neighborhoods better than words from low-density neighborhoods (e.g., Roodenrys & Hinton, 2002; Vitevitch, 1997, 2002). In addition, the effects of neighborhood density seem to be independent of word length. Although previous studies on working memory suggest that short words are more easily remembered than long words (e.g., Baddeley, 1992; Baddeley, 2000; Cowan, 1992), when words are equated in neighborhood size, the word-length effect disappears (Jalbert, Neath, & Surprenant, 2011).

The effects of phonotactic probability on word learning may be present very early in age. MacRoy-Higgins, Shafer, Schwartz, and Marton (2014) examined the influence of phonotactic probability on word recognition in toddlers using a preferential looking paradigm for high (cat, pig, and comb) and low (juice, teeth, and shoes) phonotactic probability familiar words. The participants' looking behavior was recorded in response to correctly-produced and incorrectly-produced forms of the words. The authors found that toddlers looked at high-probability mispronounced words for shorter periods of time that low-probability mispronounced words. These results suggest that toddlers were able to recognize faster high-probability than low-probability words.

Socioeconomic status and number of exposures. The number of exposures facilitates word learning; words with more exposures are remembered better than words with fewer exposures (e.g., Storkel et al., 2006). The socioeconomic status (SES) of the family, measured by maternal education or family income, has been related to the number of words children are exposed to. Hart and Risley (1995) found that children from low SES households heard, on average, 153,000 fewer words per week compared to children from high SES households, and 63,000 fewer words per week compared to children from middle SES households. In addition, children from low SES are typically exposed to lower quality input (fewer word types and shorter utterances [Hoff, Laursen, Tardif, & Bornstein, 2002]) and live in households where the noise levels are very high (Evans, 2004; Evans & Kantrowitz, 2002). Therefore, coming from a low SES family can affect children's quality and quantity of language input (Hoff, 2006), limiting the opportunities to learn new words.

Maguire et al., (2018) examined the link between SES (measured by maternal education) and word learning. In their study, 68 children aged 8-15 years performed a written word learning task where they were required to use the surrounding text to identify the meaning of an unknown word. The authors also assessed vocabulary, reading comprehension, decoding, and working memory abilities as possible mediators between SES and word learning. They found that vocabulary size mediated the relationship between SES and word learning. When controlling for vocabulary, the other mediators did not predict outcomes in the word learning task.

Working memory. Working memory can be defined as a cognitive system used to plan and carry out behavior (Baddeley, 1992). Working memory is what allows us to retain partial information while solving an arithmetic problem without paper, for example (Cowan, 2008). Although there are different working memory theories (Adams, Nguyen, & Cowan, 2018), in the context of word learning, working memory is typically conceptualized following the model introduced by Baddeley and Hitch (1974), updated in subsequent publications (Baddeley, 2000). In this model, working memory can be divided into a central executive component and two subsystems. The central executive component is a supervisory system that controls the information held in the subsystems. The subsystems include the phonological loop (to store and rehearse verbal information) and the visuo-spatial sketchpad (to store and rehearse visual and spatial information). The episodic buffer communicates the subsystems with the central executive system. These components are typically assessed using different tasks. Simple span tasks (e.g., the digit or word span tasks) where participants have to hold some information in memory and repeat it, evaluate the storage capacity of the subsystems. On the other hand, complex span tasks, where participants have to hold information while processing additional information, evaluate the central executive component (e.g., Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Both, simple span tasks and complex span tasks, have been included in word learning studies to examine the effect of working memory on word learning.

High phonological short-memory capacity seems to facilitate word learning. Gathercole, Hitch, Service, and Martin (1997) investigated the relationship between phonological short-term memory and word learning in 65 five-year-old children. Phonological-short term memory was measured by digit span and nonword repetition and word learning was measured by two word-recall tasks. Participants were presented with pairs of words (two real words or a real with a nonsense word) and they had to recall the second word of the pair after listening to the first word. Vocabulary size and nonverbal cognitive ability were also assessed. They found that recalling nonsense words was significantly correlated to phonological short-term memory and vocabulary size, whereas recalling real words was only related to vocabulary size. They concluded that both vocabulary size and phonological short-term memory play significant roles in the long-term learning of nonsense words. Similarly, Weill (2011) evaluated the contribution of phonological short-term memory (nonsense word repetition) and expressive vocabulary size to the word learning abilities of 31 children who were 24 to 30-months-old. Word learning was measured by recall and recognition tasks. Both phonological short-term memory and vocabulary size were correlated with word learning outcomes. Phonological short-term memory was a better predictor of word learning than vocabulary size, although phonological short-term memory and vocabulary size were strongly correlated.

High capacity in the central executive component seems to facilitate word learning. Hansson, Forsberg, Löfqvist, Mäki-Torkko, & Sahlén (2004) examined the effect of phonological short-term memory and central executive component on the word learning abilities of 18 children with hearing loss and 27 children with language impairment aged 9-12 years. The central executive component was assessed with a task where they had to judge the semantic acceptability of sentences and recall the last word of the sentences in each set. Vocabulary size, phonological short-term memory, sentence comprehension, and reading accuracy were also assessed. They found that children with hearing loss performed significantly better than children with language impairment on tasks assessing novel word learning, central executive capacity, sentence comprehension, and reading accuracy. The best predictor of novel word learning for both groups was central executive capacity. The authors did not find an effect of phonological short-term memory on word learning. While the different results across studies can be due to methodological variations (e.g., age of the participants, different populations, phonological familiarity of the new words), it seems that working memory, either measured as a phonological memory or central executive capacity, has a role in word learning, at least during the configuration phase.

Vocabulary size. Children with larger vocabularies seem to recall and recognize more new words than children with smaller vocabularies (e.g., Gathercole et al., 1997; Maguire et al., 2018). Although word learning ability comes first and is needed to increase vocabulary size, it is also possible that word learning ability improves as vocabulary size increases and children are able to use the words they know when detecting and learning new words (effects of phonotactic probability and neighborhood density). For example, infants with small vocabularies are able to learn unusual sound patterns; however, infants with large vocabularies do not learn sound patterns that conflict with their native language (e.g., Graf Estes, Gluck, & Grimm, 2016).

Previous studies have shown that vocabulary size influences word recognition tasks (e.g., Law & Edwards, 2015; Marchman & Fernald, 2008; Marchman, Fernald, & Hurtado, 2010). Law and Edwards investigated the relationship between vocabulary size and the speed and accuracy of word recognition in 34 children aged 30-46 months. Children's eye gaze patterns were tracked while they looked at two pictures (one familiar object, one unfamiliar object) on a computer screen and simultaneously heard one of three kinds of auditory stimuli: correct pronunciations of the familiar object's name, one-feature mispronunciations of the familiar object's name, or a nonword. They found that children with larger expressive vocabularies, relative to children with smaller expressive vocabularies, were more likely to look at a familiar object upon hearing a correct pronunciation and to an unfamiliar object upon hearing a novel word. Results also showed that children with larger expressive vocabularies were more sensitive to mispronunciations; they were more likely to look toward the unfamiliar object rather than the familiar object upon hearing a one-feature mispronunciation of a familiar object-name. They concluded that children with smaller vocabularies are at a disadvantage for learning new words and for processing familiar words.

Audibility. Previous research has found that having access to a clear signal (high audibility and signal-to-noise ratio) facilitates word learning (e.g., Blaiser et al., 2015; McMillan & Saffran, 2016; Riley & McGregor, 2012). For example, McMillan and Saffran (2016) investigated the effects of two-talkers speech noise on word learning in 40 younger (22 to 24 months) and 40 older (28 to 30 months) toddlers. Toddlers were exposed to four pairs of novel labels and objects in two conditions. First, toddlers were familiarized with the novel words by listening to sentences that included the novel words. Then, in the training phase, toddlers saw an object on the screen and heard its corresponding label. To test the effect of background speech on word learning, two-talker background speech was used during both the auditory familiarization and training phases. Half of the participants experienced background speech at a 10 dB SNR, while the other half experienced a 5 dB SNR. Finally in the testing phase, toddlers were presented in quiet with two objects and one label corresponding to one of the objects. The researchers assessed toddler’s looking time at the target label. They found that both age groups were able to learn label-object pairings when the words were presented 10 dB above the background noise, but not when the signal-to-noise ratio was 5 dB.

Word Learning in Children with Hearing Loss

Across the age range, children with hearing loss show smaller vocabularies than children with normal hearing, even when the hearing loss is identified early through universal newborn hearing screening, children are aided with hearing aids or cochlear implants, and receive early intervention (e.g., de Diego-Lázaro et al., 2018; Stevenson et al., 2010; Tomblin et al., 2015; Yoshinaga-Itano et al., 2017). Normal-hearing children with larger vocabularies show higher reading and academic achievement than children with smaller vocabularies (e.g., Lesaux et al., 2007; Proctor, Carlo, August, & Snow, 2005; Proctor et al., 2012). The small vocabularies of children with hearing loss may explain in part their lower academic achievement when compared to hearing peers (Antia et al., 2009; Traxler, 2000). In addition, small vocabularies in children with hearing loss have been associated with behavioral problems (Stevenson et al., 2010), phonological impairment (Briscoe et al., 2001), and poor working memory capacity (Stiles et al., 2012). Given the importance of vocabulary in child development, a better understanding of the effects of hearing loss on word learning is needed.

An integrated model for word recognition and learning. Pittman and Rash, (2016) proposed a model to integrate the Neighborhood Activation Model (NAM; Luce & Pisoni, 1998) and the word learning stages (triggering or detection, configuration, and engagement) introduced by Leach and Samuel (2007). This model is shown in Figure 3. The shaded boxes represent the NAM (from Figure 1) and the open boxes represent the word learning stages.

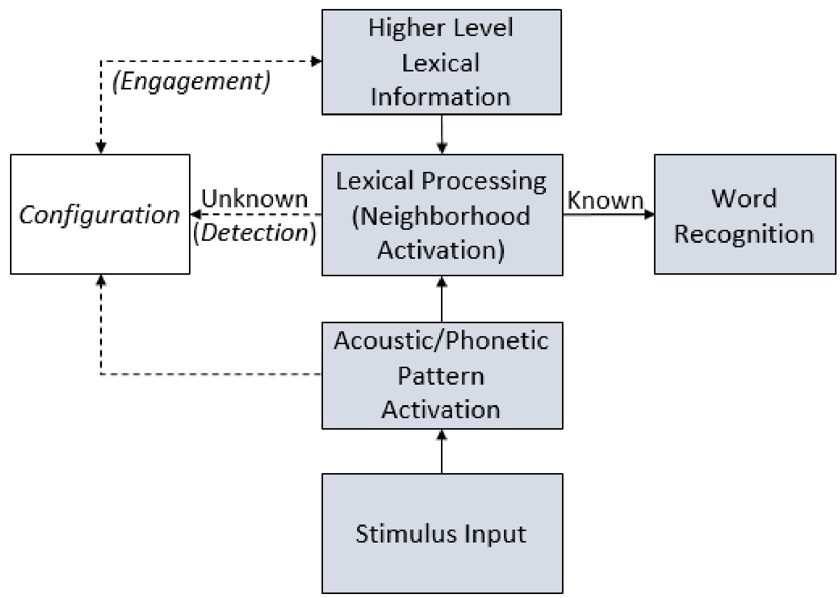

Figure 3. Word recognition and learning model from Pittman and Rash (2016). Shaded boxes and solid lines represent the Neighborhood Activation Model (Luce & Pisoni, 1998) and open boxes and dashed lines represent word learning stages (Leach & Samuel, 2007; Storkel & Lee, 2011).

The model illustrates how known words are recognized and how new words are detected and integrated into the lexicon. Pittman and Rash (2016) investigated the word detection abilities of 22 children with hearing loss and 11 normally hearing children ages 7-12 years. Children had to repeat aloud 100 real and nonsense words and decide whether the words were real or not. The words were presented in quiet and in multitalker babble. The authors found that normal-hearing children performed better than children with hearing loss, especially with real words in quiet. Performance for nonsense words decreased in multi-talker babble compared to quiet. The most common errors were misperceptions of real and nonsense words and substitutions of real words for nonsense words (for example, “lot” for “flot”). According to their model, nonsense words were replaced with real words because higher level lexical information imposed more weight on the perceptual process than the acoustic-phonetic pattern perceived. Children with hearing loss substituted nonsense words with real words even in quiet, suggesting that hearing loss promotes persistent errors of misperception and repair in children. The authors concluded that misperceptions and repairs may affect the lexicon of children with hearing loss differently. If misperceived words are stored in the lexicon, it could cause an accumulation of fragmented words that may hamper lexical processing because children would have to compare a perceived word with multiple fragmented representations. For example, if a child misperceives the word “spoon” as “poon” and stores the misrepresentation in the lexicon as a possible realization for “spoon,” it may hinder the recognition or production of the word “spoon.” If this is the case, this problem should be reduced as children accumulate exposures to words and update the configuration of the word, i.e., they realize that “poon” and “spoon” are the same word. Children could also store a fragmented word as a new lexical entry (for example “poon” for a specific type of spoon) causing confusion. On the other hand, although some repair is normal, the excessive repair by children with hearing loss may prevent them from learning new words and may be one of the reasons why children with hearing loss have reduced vocabulary scores compared with normally hearing children (Pittman & Schuett, 2013; Willis, Goldbart, & Stansfield, 2014).

The potential problem for triggering new words in children with hearing loss also has been suggested for children with cochlear implants. Han, Storkel, Lee, and Yoshinaga-Itano (2015) examined the effects of phonotactic probability, word length, word frequency, and neighborhood density on the expressive vocabularies of 49 children with cochlear implants at three different points in time from 8 months to 7 years of age: pre-implant, post-implant, and longitudinal follow-up. The expressive words under investigation came from standardized assessments used in a different longitudinal study (Yoshinaga-Itano, Baca, & Sedey, 2010). They found a robust effect of neighborhood density but they did not observe an effect of phonotactic probability nor word length, suggesting that children with cochlear implants may not use phonotactic probability to identify a perceived word as known or novel, resulting in erroneous triggering for word learning. Although word learning was not examined directly, hearing acuity appears to be a requirement for triggering word learning. Therefore, triggering may be particularly challenging for children with hearing loss due to the degraded acoustic signal they receive, even when using cochlear implants or hearing aids (Lorenzi, Gilbert, Carn, Garnier, & Moore, 2006; Rubinstein, 2004).

Factors associated with word learning in children with hearing loss. Most research has focused on factors that impact word learning rather than on a theoretical framework to better understand how children with hearing loss learn new words and to observe whether this process differs from that of normally hearing children. Some of these factors are the same as those in normally hearing children, such as vocabulary size or the number of exposures needed to learn a new word, but others are specific to children with hearing loss, such as the degree of hearing loss or characteristics of the amplification received. We can classify factors as being internal or external to the child although in the studies with children with hearing loss, these factors typically interact.

Among the internal factors, previous research has found that having a large vocabulary (Lederberg, Prezbindowski, & Spencer, 2000; Stelmachowicz, Pittman, Hoover, & Lewis, 2004; Walker, 2010), high audibility (Davidson, Geers, & Nicholas, 2014); Stiles, 2010), and better hearing (Pittman et al., 2005) correlates with better word learning abilities. Regarding the external factors, having more exposures to the new word (Pittman et al., 2005; Stelmachowicz et al., 2004), receiving a sufficiently amplified stimulus (Stelmachowicz et al., 2004), and amplification bandwidth (Pittman, 2008; Pittman, Stewart, Willman, & Odgear, 2017) correlates with better word learning abilities. For example, Stelmachowicz and colleagues assessed vocabulary using the Peabody Picture Vocabulary Test-III and novel-word learning in 31 children (six to nine years) with and without hearing loss. Children viewed a four-minute animated story containing eight novel words. Four words were nouns and four were verbs. The words were presented at different levels (50 and 60 dB SPL) and number of repetitions (four and six). Children were asked to identify each target word from an array of pictures after watching the story. The identification task consisted of 40 trials (five repetitions of each novel word) in a four-alternative, forced-choice format without feedback. They found that overall performance was higher for normally hearing children than for children with hearing loss (60% over 40%). In addition, the receptive vocabulary raw scores, stimulus level, and repetitions were significant predictors of performance on the word learning task. Chronological age, audibility, and word type (noun vs. verb) were not significant predictors.

Previous studies show conflicting results about the effect of wideband amplification on word learning. Pittman et al. (2005) examined the effects of age, vocabulary, and high-frequency amplification on the word learning abilities of 97 children with and without hearing loss aged 5-14 years. Children had to learn eight new words (four were low-pass filtered at 4 kHz and four were filtered at 9 kHz) while watching a four-minute animated story. After the story, children were asked to identify the new words in a four-alternative choice format. Each word was presented ten times for a total of 80 trials. Children received feedback for correct responses by using an interactive video game to help maintain interest in the task. They found that children with hearing loss had lower receptive vocabulary scores and performed poorer than the normally hearing children on the word learning task. Word learning performance was correlated with the receptive vocabulary scores across groups. Age of identification of the hearing loss, age of amplification, and high-frequency bandwidth were not correlated with word-learning performance.

In a later study, Pittman et al. (2017) found a significant effect of high-frequency amplification on word learning. They investigated the effects of digital noise reduction and high-frequency amplification in 73 children and adults with and without hearing loss across three tasks: word recognition, lexical decision, and word learning. For the word recognition task, participants had to repeat aloud 25 words from the Northwestern University NU-6 test. For the lexical decision task, they had to decide if a word was real or not and repeat it aloud. The stimuli were comprised of 12 real words and 12 nonsense words. For the word learning task, they had to learn the singular and plural forms of three nonsense words associated with three novel images using a computer game through a process of trial and error out of 120 trials. They found that children and adults with hearing loss improved significantly with the use of amplification, especially when children were learning new words and using wideband amplification. In background noise, however, performance for all tasks decreased for both groups with little to no benefit from amplification or digital noise reduction. The use of digital noise reduction did not provide a benefit nor jeopardize the individuals' ability to detect and learn new words. In a different study, however, the use of the digital noise reduction in older children (11-12 years of age) was shown to be beneficial for learning new words with background noise (Pittman, 2011).

In conclusion, although word learning improves with the use of hearing aids in children with hearing loss, learning continues to lag behind normally hearing peers. Previous research has focused on the factors that affect learning, more specifically on the triggering and configuration stages. Of all the factors included in previous research, receptive vocabulary (e.g., Lederberg et al., 2000; Pittman et al., 2005; Stelmachowicz et al., 2004) and the number of exposures to the new words (Pittman et al., 2005; Stelmachowicz et al., 2004) have been shown to be consistent predictors of performance on word learning tasks, although variation occurs across word learning tasks. For example, Walker (2010) found that speech perception and receptive vocabulary did not predict performance on a fast mapping task in children with cochlear implants, but were predictive of word retention a day later. Other studies have found an effect of receptive vocabulary size on word learning immediately after training (e.g., Pittman et al., 2005; Stelmachowicz et al., 2004).

Oral Bilingualism and Hearing Loss

Spanish is the second most common language spoken in the homes of children who are deaf or hard of hearing (DHH) in the United States. The Gallaudet Research Institute [GRI] survey (2013) found that 19.4% of children who are DHH live in homes where Spanish is spoken. This includes children in both monolingual Spanish environments as well as children whose families use varying proportions of Spanish, English, and/or sign language. The number of children who are DHH from Spanish-speaking families will continue to grow considering that the Hispanic population in the U.S. is expected to increase from 17.4% to 28.6% by 2060 (Colby & Ortman, 2015). Although it has been shown that the academic achievement of Spanish-speaking children who are DHH in the U.S. is lower than that of their monolingual DHH peers (Kluwin & Gonsher, 1994; Marschark et al., 2015) and the important role of vocabulary when predicting reading and academic achievement (e.g., Lesaux et al., 2007; Proctor et al., 2005, 2012), little is known about how children with hearing loss who grow up in oral bilingual environments learn new words.

Previous research has focused on demonstrating that, when receiving appropriate services, children with hearing loss have the capacity of becoming orally bilingual (Francis & Ho, 2003; Guiberson, 2014; McConkey Robbins, Green, & Waltzman, 2004; Teschendorf, Janeschik, Bagus, Lang, & Arweiler-Harbeck, 2011). For example, Bunta and Douglas (2013) examined the effects of dual-language instruction (English-Spanish) in a group of 20 preschoolers with hearing loss and compared their results in the English Preschool Language Scale-IV with a group of 20 monolingual-English preschoolers with hearing loss. They found that bilingual participants' English language skills were commensurate with those of their monolingual English-speaking peers. Bilinguals' Spanish and English total language scores were also comparable and highly correlated to each other. The authors concluded that both languages can be supported without having adverse effects on the children's language development.

Word Learning in Bilinguals

To investigate how bilingual children learn new words, one needs first to think about how languages are acquired and how the lexicon is organized in these children. Different theories have been proposed to explain how children learn two or more languages simultaneously. The unitary account suggests that early language learners (prior to 24 months) learn languages as if they are learning a single undifferentiated language that slowly differentiates into two languages. After 24 months, the unitary lexicon splits forming two separate linguistic systems or lexicons (Redlinger & Park, 1980; Volterra & Taeschner, 1978). This would explain why there are translation equivalents (e.g., *dog-perro*), code-mixing (e.g., *le mordió la tail,* he/she bit his/her tail), and blends (e.g., *lunchear*/to take lunch) in bilinguals. In contrast, the dual-language account holds that bilingual children learn their two languages independently from the beginning, having two different lexicons (e.g., Bosch & Sebastián-Gallés, 2001; De Houwer, Bornstein, & De Coster, 2006). In this case, code-mixing and blends are the result of pragmatic and sociolinguistic competence, not necessarily the result of lexical confusion (Genesee, Nicoladis, & Paradis, 1995).

Languages influence one another during development producing facilitation and inhibition processes (e.g., Broersma, Carter, & Acheson, 2016; Durlik, Szewczyk, Muszyński, & Wodniecka, 2016). Facilitation is defined as borrowing a linguistic element or structure from one language to use in the second language, for example borrowing the construction for the present perfect (*to have + past participle*) from English to Spanish (*haber + past participle*). Inhibition refers to the process in which bilinguals are able to activate a perceived word in the lexicon (receptive) or to choose a word within a specific language (expressive), while inhibiting that word in the other language (e.g., Broersma et al., 2016; Green, 1998). Languages do not only interact at the lexical level, interactions may occur via transfer of phonology (e.g., Knupsky & Amrhein, 2007), derivational morphology (e.g., Ramírez, Chen, & Pasquarella, 2013) or semantic associations, where learning a word in one language facilitates its acquisition in the second language (Bilson, Yoshida, Tran, Woods, & Hills, 2015).

In the context of word learning, mutual exclusivity is the process of assigning one label/name to one object (e.g., Byers-Heinlein & Werker, 2013; Houston-Price, Caloghiris, & Raviglione, 2010). It has been proposed that bilingual children show less reliance on mutual exclusivity or slower development of this principle during early word learning (e.g., Bialystok, Barac, Blaye, & Poulin-Dubois, 2010; Markman & Wachtel, 1988). Less reliance on the mutual exclusivity principle would allow bilinguals to learn two labels for the same object, but could also produce a slower word learning rate when learning the names for two related objects that have different meanings (Bilson et al., 2015). For example, learning the word “drink” after learning the word “water” should be more difficult to differentiate if the child believes that they could mean the same thing. However, previous research suggests a word-learning advantage for bilinguals compared to monolingual children and adults (e.g., Poepsel & Weiss, 2016; Yoshida et al., 2011).

Word learning in simultaneous bilinguals. Simultaneous bilingual children are those exposed to two languages during infancy and early childhood (Patterson, 2002). This group of children already show differences on word learning tasks when compared to monolingual children. For example, Mattock, Polka, Rvachew, and Krehm (2010) compared the performance of 17-month-old monolingual and bilingual infants on a word-learning task using a switch task. Sixteen children were monolingual English, 16 monolingual French, and 16 bilingual English-French. In the switch task, novel word-object pairs are presented during a familiarization phase until attention decreases. Then, during a testing phase, children are presented with the same word-object pairs they observed during the familiarization phase ("same trial") or in pairs where the object is paired with a different label than the one used during the familiarization phase ("switch trial"). The dependent variable measured was the time looking at the word-object pairs. An increase in the time looking at the pairs during the switch trials was interpreted as having encoded the word-object pairs taught during the familiarization phase. Object names contained English, French, and bilingual English-French phonemes. The authors found that the phonetic content of the words affected how monolingual and bilingual infants performed on the switch trials. Monolinguals (English or French) looked at the pairs for longer periods of time when the stimuli sounded like their native language and the time they looked at the pairs was reduced when the stimuli contained the phonemes of the other language or was mixed (bilingual stimuli). In contrast, bilinguals looked the longest time at the pairs with mixed (English-French) phonemes. These results suggest that infants are better able to learn words that are consistent with their language experience than words from languages for which they have less experience.

Byers-Heinlein and Werker (2009) demonstrated that early dual-language exposure affects the mutual exclusivity principle. They observed that 17-18 month-old infants with exposure to multiple languages relied less in the mutual exclusivity principle in the context of many-to-one mappings. Furthermore, this effect was greater for trilinguals than for bilinguals, suggesting that an increased exposure to language variation predicts less reliance on the assumption of mutual exclusivity in mapping. The authors suggested that the development of one-to-one or many-to-one mappings is influenced by the structure (i.e., being exposed to two or more languages) rather than the size of the vocabulary. However, vocabulary size was measured only in English by the MacArthur Child Language Inventory (CDI), limiting the interpretation of the connection between vocabulary size and the mutual exclusivity principle.

Word learning in sequential bilinguals. Sequential bilinguals are those who learn a second language (L2) after acquiring their first language (L1) (Kohnert & Bates, 2002), typically after the age of three. A word learning advantage has been reported in sequential bilinguals who have had L2 exposure for at least two to seven years (e.g., Kaushanskaya, Gross, & Buac, 2014; Kaushanskaya, Yoo, & Van Hecke, 2013). For example, Kaushanskaya and Marian (2009) examined novel word learning in 20 monolingual (English) and 40 bilingual (English-Spanish and English-Mandarin) adults. English-Spanish bilinguals began acquiring L2 at an average age of 5.44 years of age (sequential bilinguals) and English-Mandarin bilinguals at an average age of 2.21 years of age (simultaneous bilinguals). Novel words were created with an artificial phonological system that included four English phonemes and four non-English, non-Spanish, and non-Mandarin phonemes. Therefore, the nonsense words were unfamiliar to all participants. The words were presented in association with English words, acting as translations. In both tasks, the participants heard the nonsense words and provided the English translations. They found that both bilingual groups outperformed the monolingual group when recalling the words and when recognizing the words a week later. The authors concluded that bilingualism may facilitate word learning, although they did not offer an explanation about why this may be the case.

Bilinguals may show an advantage for word learning over monolinguals when mapping two labels to one object. Poepsel and Weiss (2016) compared young adult English monolinguals with Chinese-English and English-Spanish bilinguals. The participants began learning English when they were around 10 years of age. They participated in a cross-situational statistical learning task where they had to do one-to-one mappings and two-to-one mappings. The authors did not find significant differences in the learning of one-to-one mappings; however, bilinguals acquired two-to-one mappings faster than monolinguals, requiring fewer trials. They concluded that the fundamental statistical learning mechanism may not be affected by language experience, but when the input contains greater variability, bilinguals may be more prone to detecting the presence of multiple structures over monolinguals. They also concluded that sequential bilinguals may show a similar effect of the mutual exclusivity bias to the one observed in previous research with simultaneous bilinguals.

The bilingual advantage on word learning may be gradual and dependent on the amount of exposure to a L2. For example, Kaushanskaya et al., (2013) studied the effect of phonological familiarity and L2 experience on novel word learning for familiar vs. unfamiliar referents. They presented phonological-familiar novel words (constructed with

English sounds) and phonological-unfamiliar novel words (constructed with non-English and non-Spanish sounds) in association with familiar or unfamiliar referents. The words were presented to 81 native English-speaking adults with different levels of Spanish knowledge. They found that phonological familiarity facilitated word learning only for familiar referents. Participants with more L2 experience (7.21 years on average) outperformed those with less experience when phonologically-unfamiliar novel words were paired with familiar referents. These results indicate that bilinguals are able to add a second label to a familiar referent more easily than monolinguals, which is consistent with lower mutual exclusivity. Likewise, Kaushanskaya et al., (2014) compared monolingual English-speaking children with bilingual Spanish-English-speaking children aged 5 to 7 years and exposed to Spanish in the context of dual-immersion schooling for an average of two years. The children who received dual-immersion language in school had higher verbal working memories and were able to map novel words to familiar objects more accurately than the monolingual group.

Explanations for the bilingual advantage. Previous spoken word-recognition and learning models (e.g., Leach & Samuel, 2007; Luce & Pisoni, 1998; McClelland & Elman, 1986; Storkel et al., 2006) agree that in order for a word to be recognized, it needs to be compared to other possible candidates in the lexicon that sound similar to that word (i.e., neighbors). The more neighbors a word has, the longer it will take to be recognized because the comparison will take longer (e.g., Gaskell & Dumay, 2003; Luce & Pisoni, 1998). Whether bilinguals have one overall lexicon or separate lexicons for each language, word retrieval should require more time in bilinguals than in monolinguals. For example, the word “catalog” can activate two Spanish words “catálogo” and “cata” in addition to the English word "cat" (Norris & McQueen, 2008). Although sentence context helps identify the language and limits the activation of irrelevant items (Assche, Duyck, & Hartsuiker, 2012; Durlik et al., 2016), languages continue to be mixed in natural contexts such as in code-switching. Despite the additional processing time, bilingual children and adults show an advantage over monolinguals when learning new words (Kaushanskaya et al., 2014; Kaushanskaya & Marian, 2009).

It has been proposed that the bilingual advantage on word learning may emerge from other cognitive advantages associated with bilingualism, such as improved phonological working memory (e.g., Adesope, Lavin, Thompson, & Ungerleider, 2010; Bartolotti, Marian, Schroeder, & Shook, 2011; Majerus et al., 2008; Service, Simola, Metsänheimo, & Maury, 2002) or an enhanced inhibitory control (e.g., Bialystok, 1999; Bialystok et al., 2004; Costa et al., 2008; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011; Wang & Saffran, 2014). The idea that bilinguals may have an enhanced inhibitory control over monolinguals was first introduced by (Green, 1998) in the Inhibitory Control Advantage Hypothesis. This hypothesis states that bilinguals engage in inhibitory processes when selecting each of their languages. The switch back and forth between languages results in more efficient inhibitory processing for bilinguals, even when processing non-verbal stimuli.

Previous studies show conflicting results about whether bilinguals have a cognitive advantage over monolinguals. While some researchers have reported a bilingual advantage in a variety of working memory and executive function tasks (Bialystok et al., 2010; Prior & MacWhinney, 2010; Qu, Low, Zhang, Li, & Zelazo, 2016; Tao et al., 2011; Wiseheart, Viswanathan, & Bialystok, 2016), other researchers have argued against it (e.g., Arizmendi et al., 2018; Desjardins & Fernandez, 2018; Gathercole et al., 2014; Namazi & Thordardottir, 2010; Paap, 2014; Paap, Johnson, & Sawi, 2016). For instance, Paap and collegues compared monolingual to bilingual young adults on 13 different measures of executive function, including inhibitory control. They found no bilingual advantage on any measure. In fact, the only statistically significant findings were in favor of a monolingual advantage. Likewise, Arizmendi and colleagues examined differences in performance between 167 monolingual and Spanish-English bilingual 167 children aged 7-9 years old on executive function tasks assessing inhibition, shifting, and updating. They found no differences between the bilingual and monolingual groups on any of the executive function tasks. For two of the tasks, they found an advantage in favor of the monolingual group.

The inconsistency in the findings may be explained by the tasks included in the studies and their level of difficulty. Costa, Hernández, Costa-Faidella, and Sebastián-Gallés (2009) modified the flanker task in two versions, low and high-conflict versions. The flanker task measures inhibitory control because participants have to ignore a conflicting cue to respond to a target stimulus. In the low-conflict version, most of the trials were of just one type (either congruent or incongruent). In the high-conflict version, congruent and incongruent trials were more evenly distributed. They found that bilinguals outperformed monolinguals only in high-conflict trials, suggesting that when the bilinguals and monolinguals are compared in low-conflict tasks, the bilingual advantage may not be evident. In addition, it has been suggested that studies showing a bilingual advantage are more likely to be published than studies that do not show an advantage, creating a publication bias (De Bruin, Treccani, & Della Sala, 2015). A meta-analysis of

152 studies compared the performance of monolingual and bilingual adults on six executive function tasks (Lehtonen et al., 2018). They found a very small bilingual advantage for inhibition, shifting, and working memory before correcting estimates for publication biased. After correcting for bias, no evidence for a bilingual advantage was found.

In the context of word learning, enhanced inhibitory control has been related with better word learning abilities (Bartolotti et al., 2011; Yoshida et al., 2011). For example, Yoshida and colleagues studied the abilities of 20 English monolingual and 20 bilingual (English and another language) three-year-old children to learn adjectives. Languages other than English in the bilingual group included Spanish, French, Chinese, Vietnamese, Russian, and Urdu. Children were matched by SES. All children participated in two adjective tasks, a control task, and an experimental task. In the control task, children were familiarized with a known adjective (for example, “this is a bumpy duck”) and then their ability to pick the object labeled with the known adjective was evaluated. For example, children were presented with two ducks, one bumpy and one flat, and were asked to hand the bumpy duck to the examiner. The experimental task followed the same procedure but with modified objects (for example a horse covered by Velcro) and nonsense adjectives (e.g., “blickish”). The authors used adjectives because they believed that children had to inhibit the mutual exclusivity principle of one novel object-one novel noun in order to be able to learn the adjective. In addition, the authors measured attentional control with an adapted task similar to the flanker task. They found that performance did not differ between bilinguals and monolinguals on the control task, but bilinguals were faster and more accurate than monolinguals in the experimental task and in the flanker task. In addition, they found that accuracy and reaction time in the flanker task were significantly correlated with performance on the experimental adjective task only in bilinguals. In this study, vocabulary size was measured in all the languages spoken by the children, but neither vocabulary size nor vocabulary composition (amount of nouns, adjectives, or verbs) predicted adjective learning in either group. The authors concluded that bilingual children's experience managing two languages provided them an enhanced attentional control and adjective learning advantage over the monolinguals.

Similar to Yoshida et al. (2011), Bartolotti and colleagues (2011) examined the influence of bilingual experience and inhibitory control on word triggering. Twenty-four bilingual college students were divided into groups with high and low bilingual experience (per self-report) and with strong and weak inhibitory control based on results from the Simon task. In the Simon task, participants have to press a key to indicate the color of the stimuli (left for green or right for red) while ignoring the location of the stimuli on the screen. Participants listened to a continuous stream of words in a Morse code language to test their ability to segment words from the continuous speech. In a second task, participants listened to another Morse code language composed of new words that conflicted with the first Morse code language. The authors found that bilingual experience can improve word learning when interference from other languages is low, while inhibitory control ability can improve word learning when interference from other languages is high. Bilingual experience and inhibitory control scores were not correlated. According to the authors, bilingual advantages in inhibitory control are frequently observed in children and older adults, but not in younger adults who are in their cognitive prime. The authors do not offer an explanation about why some bilinguals included in the study show more inhibitory control than others. A comparison of the bilingual inhibitory control scores with a monolingual group may have led to a different interpretation. It is important to consider that the level of proficiency in both languages is self-report and not measured by an actual language measure (e.g., vocabulary size in each language). A measure of their language abilities in both languages may have revealed a correlation with inhibitory control.

Overall language experience may influence inhibitory control and not vice versa. Botting and colleagues (2017) investigated the relationship between executive function (including inhibitory control) and expressive vocabulary in 108 deaf and 125 hearing children. The authors claimed that children who are deaf show lower language skills because of the sensory loss and not because of a cognitive deficit per se, making them an ideal group to test the relationship between executive function and language skills. Participants were compared on visuospatial working memory, shifting, executive planning task, inhibitory control, nonverbal intelligence, speed of processing, and vocabulary skills in their primary language (oral or sign language). The authors found that children who were deaf performed significantly lower than hearing children on visuospatial working memory, shifting, and inhibitory control after controlling for nonverbal intelligence and speed of processing. They found that language mediated executive function (scores combined across tasks), but the reverse pattern was not evident, suggesting that language is a key element of executive function and not vice-versa. Although previous researchers reported deficits in executive function in monolingual children with hearing loss, including inhibitory control (e.g., Figueras, Edwards, & Langdon, 2008; Greiner, Walker, & Derek, 2009; Kral, Kronenberger, Pisoni, & O'Donoghue, 2016), it is unknown if bilingual children with hearing loss will show similar inhibitory control to monolingual children with hearing loss or if their experience with processing two languages provides them with an advantage in inhibitory control.

Another possible explanation for the bilingual advantage on word learning could be that bilinguals may have an improved phonological working memory (e.g., Adesope et al., 2010; Bartolotti et al., 2011; Majerus et al., 2008; Service et al., 2002), although this has not been fully supported in the context of word learning. (Kaushanskaya, 2012) examined word learning abilities in 18 bilingual (English-Spanish) and 36 monolingual (English) adults using phonologically-familiar and phonologically-unfamiliar novel words. Bilingual participants were native speakers of English who acquired Spanish around eight years of age. Phonologically-familiar novel words were constructed using the phonemes of English and phonologically-unfamiliar words were constructed using phonemes that do not exist in English nor in Spanish. Monolinguals and bilinguals were matched using a phonological short-term memory measure, where participants had to repeat nonsense words that increased in length from one to nine syllables. The authors hypothesized that if increased phonological memory capacity is at the root of the bilingual advantage for word learning, then bilinguals and monolinguals matched on the phonological memory task should perform similarly on the word-learning task. The results showed that bilinguals learned more words than monolingual participants for both phonologically-familiar and unfamiliar words. The authors concluded that phonological memory capacity, as measured in the study, did not account for the observed bilingual effects on learning.

Phonotactic probability and neighborhood density do not seem to explain the bilingual advantage. (Nair, Biedermann, & Nickels, 2017) compared the word learning abilities (recall and retention) of 20 monolingual English and 20 bilingual English-Mandarin adults. The authors used 15 English-type nonsense words that varied in phonotactic probability and neighborhood density (high vs. low). They found a similar effect in monolinguals and in bilinguals as in Storkel and colleagues (2006); high-neighborhood density advantage and high-phonotactic probability disadvantage when recalling new words. Bilinguals outperformed monolinguals in both recall and retention, but this advantage did not interact with phonotactic probability nor neighborhood density modifications. The authors concluded that bilingual and monolingual word learning abilities are probably constrained by the same learning mechanisms, but bilinguals probably have more cognitive resources due to language experience.

Summary

Previous research has shown that monolingual children with hearing loss perform poorer on word learning tasks than monolingual peers with normal hearing (e.g., Lederberg et al., 2000; Pittman et al., 2005; Walker, 2010). Having a large vocabulary size (e.g., Lederberg et al., 2000; Pittman et al., 2005; Walker, 2010), optimal audibility (e.g., Stiles, 2010), and more exposures to the new words (Pittman et al., 2005; Stelmachowicz et al., 2004) appear to facilitate learning in these children. How these factors influence the word learning abilities of bilingual children with hearing loss have not been studied yet.

Other studies have demonstrated that normally hearing bilingual children from high SES backgrounds outperform their monolingual peers on word learning tasks (e.g., Kaushanskaya et al., 2014; Yoshida et al., 2011). From these studies, it is not clear whether the bilingual advantage may be language dependent because vocabulary assessments and word learning tasks are typically done only in English. In the experiments where participants have to learn nonsense words with unfamiliar phonemes, bilinguals still outperform monolinguals (e.g., Kaushanskaya & Marian, 2009; Kaushanskaya et al., 2013). This suggests that the observed bilingual advantage is not entirely language dependent and that bilinguals may possess some enhanced cognitive skills that allow them to learn words more efficiently, regardless of the language. In fact, one of the proposed explanations for the bilingual advantage is that bilinguals have enhanced inhibitory control (e.g., Adesope et al., 2010; Green, 1998) especially present when there is conflict in the task (e.g., Costa et al., 2009; Yoshida et al., 2011). Although previous studies have reported that monolingual children with hearing loss have poorer inhibitory control than their normally hearing peers (e.g., Figueras et al., 2008; Kral et al., 2016), it is unknown whether bilingualism will produce a protective effect via better inhibitory control for bilingual children with hearing loss.

Purpose of the Study

The overall goal of this study was to examine how bilingual (English-Spanish) children with hearing loss learn new words compared to monolingual peers with and without hearing loss. Specifically, this study examined **how vocabulary size and inhibitory control affect the acquisition and retention of new words.** Two hypotheses were tested in two separate experiments. The effect of vocabulary size on word learning was examined in experiment 1 and the effect of inhibitory control was examined in experiment 2.

Experiment 1. Experiment 1 aimed to answer the following research questions: (1) Does vocabulary size predict word learning-training? (2) Does vocabulary size predict word retention? (3) Do language (monolingual vs. bilingual) and hearing status (normal hearing vs. hearing loss) interact to affect word learning? It was hypothesized that *if learning new words is facilitated by vocabulary size, then children with larger vocabularies will learn and retain more words than children with smaller vocabularies.* This hypothesis was based on studies that found vocabulary size to influence word learning in normally hearing children (e.g., Maguire et al., 2018) and in children with hearing loss (e.g., Pittman et al., 2005; Walker, 2010). To test the hypothesis, word learning was measured in children with different vocabulary sizes; monolingual and bilingual children with normal hearing and monolingual and bilingual children with hearing loss. It was predicted that bilingual children would show larger overall vocabularies, which would allow them to learn and remember more words than monolingual children, in both normal hearing and hearing loss groups. It was also predicted that normal-hearing children would have larger vocabularies and learn and remember more words than children with hearing loss.

Experiment 2. Experiment 2 aimed to answer the following research questions: (1) Does inhibitory control predict word learning-training? (2) Does inhibitory control predict word retention? (3) Do language (monolingual vs. bilingual) and hearing status (normal hearing vs. hearing loss) interact to affect inhibitory control? It was hypothesized that *if word learning is facilitated by inhibitory control, then children with higher* *inhibitory control would will and remember more words than children with lower inhibitory control.* This hypothesis was based on the neighborhood activation model for word recognition which proposes that similar words or neighbors compete with each other in order to be recognized (Luce & Pisoni, 1998). According to this model, competitors need to be inhibited so the target word can be activated and recognized. Children with larger vocabularies have more practice inhibiting competitor words than children with smaller vocabularies, which may enhance their inhibitory control. Enhanced inhibitory control may then facilitate word learning because children can focus on a new word while inhibiting irrelevant information such as other words that sound similar. It was predicted that bilingual children would show higher inhibitory control, which would allow them to learn and remember more words than monolingual children, in both normal hearing and hearing loss groups. Normal-hearing children would have higher inhibitory control and learn and remember more words than children with hearing loss. It was also predicted that inhibitory control and vocabulary size would be correlated, thus the larger the vocabulary size the higher the inhibitory control.

Method

Participants

Seventy-six children between 8 and 12 years of age participated in the study. Children with hearing loss had permanent unilateral or bilateral hearing losses requiring correction with amplification and had no communication disorders in addition to the hearing loss (e.g., auditory neuropathy, cognitive or speech impairments). Monolingual (English) children had no history of exposure to a second language at home or at school.

Three bilingual participants were excluded from the final sample because they showed a percentage of weekly Spanish use below 30%. These children were able to understand Spanish, but they were unable to use it expressively. The final sample was composed of 73 children: 20 monolingual children with normal hearing, 20 monolingual children with hearing loss, 20 bilingual children with normal hearing, and 13 bilingual children with hearing loss. Table 1 shows the participants' demographic characteristics by group. One notable difference between the groups was the maternal education level, which was more than high school for the majority of the monolingual children and less than high school for the majority of the bilingual families.

Table 1.

Demographic Characteristics

Characteristics	Monolingual NH (*n* = 20)	Monolingual HL (*n* = 20)	Bilingual NH (*n* = 20)	Bilingual HL (*n* = 13)
Age	10.9 (1.5)	11.1 (1.2)	11.6 (1)	11.1 (1)
Gender				
Male	55%	60%	45%	85%
Female	45%	40%	55%	15%
Maternal education				
College/University	85%	75%	25%	8%
High school or less	15%	25%	75%	92%
High school	15%	25%	35%	54%
Elementary	0%	0%	40%	38%

Notes. % or mean and (Standard Deviation). NH = Normal Hearing. HL = Hearing Loss.

Children with hearing loss. Figures 4 and 5 show the individual hearing thresholds for monolingual and bilingual children with hearing loss, respectively. Average unaided binaural hearing thresholds were 46.5 dB PTA (*SD* = 17.5) for the monolingual children and 39.8 dB PTA (*SD* = 17.4) for the bilingual children. Although unaided hearing was poorer in the monolingual than in the bilingual children, aided binaural hearing thresholds improved to 23 dB PTA for the monolingual children and 22 dB PTA for the bilingual children, showing similar aided thresholds.

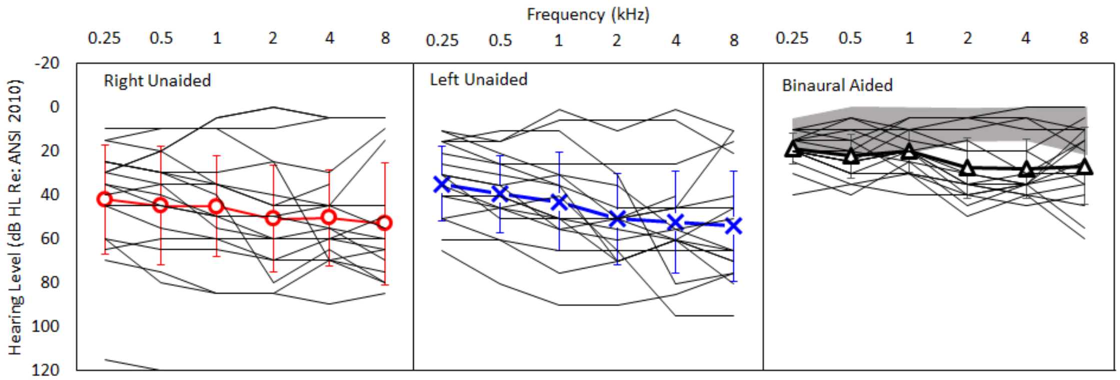

Figure 4. Individual and average (± 1 standard deviation) hearing thresholds for monolingual children with hearing loss. The shaded area in the binaural aided graph indicates the hearing thresholds' range for monolingual children with normal hearing.

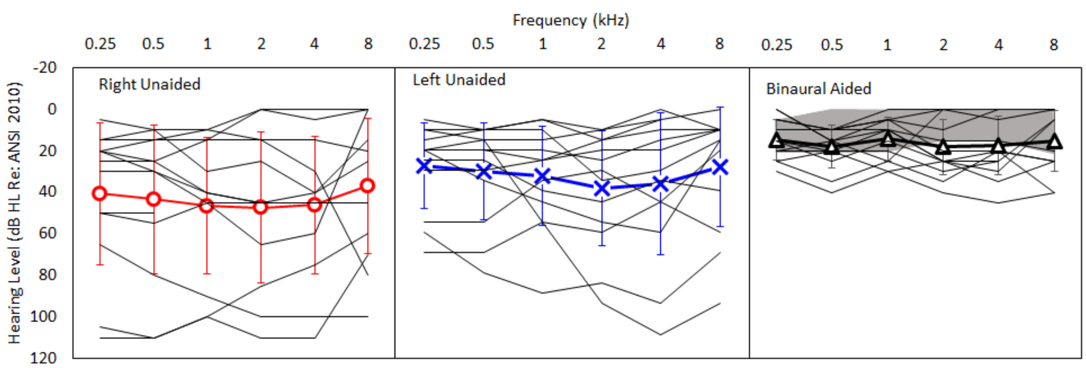

Figure 5. Individual and average (± 1 standard deviation) hearing thresholds for bilingual children with hearing loss. The shaded area in the binaural aided graph indicates the hearing thresholds' range for bilingual children with normal hearing.

Table 2 shows the hearing loss characteristics of the participants by language status (monolingual vs. bilingual). Monolingual children showed a mean age of identification of the hearing loss of 2.5 years (*SD* = 3.2) and a mean age of amplification of 2.8 years (*SD* =2.9). Eleven of the monolingual children received early intervention around 5 months of age (*SD* =5 months). Bilingual children showed a mean age of identification of the hearing loss of 4 years (*SD* = 3.2) and a mean age of amplification of 5.4 years (*SD* = 2.5). Only one of the bilingual children received early intervention at two years of age. Monolingual and bilingual children with hearing loss showed high speech perception scores similar to hearing peers. One notable difference between monolingual and bilingual children was the hearing loss configuration. The majority of the monolingual children had bilateral hearing loss whereas the majority of the bilingual children had unilateral hearing loss.

Table 2.

Participants' Hearing Loss Characteristics

Characteristics	Monolingual (*n* = 20)	Bilingual (*n* = 13)
HL Configuration		
Bilateral	80%	38%
Unilateral	20%	62%
Type of hearing aid		
BTE	85%	69%
BAHA implanted	5%	15%
BAHA softband	0%	8%
BTE and BAHA softband	5%	0%
None	5%	8%
English speech perception*	94%	94%
Spanish speech perception*	85%	94%

Notes. HL = Hearing Loss. BTE = Behind the ear. BAHA = Bone Anchored Hearing Aid. *20 English monosyllabic words (Mackersie, Boothroyd, & Minniear, 2001) and 20 disyllabic Spanish words (Haro, 2007).

Bilingual children. Participants in the bilingual group came mostly from monolingual Spanish-speaking homes and learned English when they entered preschool or kindergarten, thus they were sequential bilinguals. All participants were born in the U.S. except five children who were born in Mexico and moved to the U.S. between two and seven years of age. Table 3 shows the linguistic characteristics of the bilingual participants for English and Spanish by hearing status. The majority of the children attended English-only education schools and they reported higher self-proficiency ratings for English than for Spanish, particularly for reading.

Children with normal hearing were exposed to Spanish on average 51% of the time (weekdays and weekends) and they used it 50% of the time, according to child and caregiver report. Forty-five percent of the families reported that children used English-only at home when communicating with siblings. When asked in what language they would prefer to talk to someone who is equally bilingual, 15% of the children indicated that they would prefer English, 20% indicated Spanish, and 65% indicated no language preference. When asked in what language they would prefer to read a book, 65% of the children indicated that they would prefer to read in English, 5% in Spanish, and 30% indicated no language preference.

Children with hearing loss were exposed to Spanish on average 47% of the time (weekdays and weekends) and they used it 46% of the time, according to child and caregiver report. Sixty-nine percent of the families reported that children used English-only at home when communicating with siblings. When asked in what language they would prefer to talk to someone who is equally bilingual, 23% of the children indicated that they would prefer English, 8% indicated Spanish, and 69% indicated no language preference. When asked in what language they would prefer to read a book, 92% of the children indicated that they would prefer to read in English and 8% indicated no language preference. None of the bilingual children with hearing loss showed a preference to read in Spanish.

Table 3.

Bilingual Participants' Characteristics

Characteristics	Bilingual NH (*n* = 20)	Bilingual HL (*n* = 13)
English acquisition age (years)	3.5 (1.5)	3.8 (1.4)
Spanish acquisition age (years)	1.2 (1.1)	1.2 (0.8)
English-only school (years)	5.9 (3.4)	6.2 (1.4)
Spanish-only school (years)	0.6 (1.9)	0.6 (1.1)
Dual-language school (years)	1.4 (3.0)	0.4 (0.9)
English proficiency self-assessment		
Understanding	4.7 (0.4)	4.9 (0.2)
Speaking	4.7 (0.4)	4.9 (0.2)
Reading	4.6 (0.6)	4.6 (0.6)
Spanish proficiency self-assessment		
Understanding	4.1 (0.8)	3.9 (0.7)
Speaking	4.0 (0.8)	3.5 (0.7)
Reading	3.2 (1.4)	2.0 (0.9)

Notes. Mean and (Standard Deviation). NH = Normal Hearing. HL = Hearing Loss.
Self-assessment scale = 1 "very poor" to 5 "very good."

Measures and Stimuli

Hearing test. All participants received a hearing test comprised of an otoscopic examination, tympanometry, pure-tone threshold audiometry, and speech perception. Two lists of 10 words each in English and two lists of 10 words each in Spanish were used to assess speech perception using the Computer-Assisted Speech Perception Assessment test (CASPA; Mackersie et al., 2001).

Hearing aid verification. Test-box measures of the children's personal hearing aids were available for sixteen monolingual and for nine bilingual children with hearing loss. The output of the devices used by eight children (four bilingual and four monolingual) was not available because four of the children used bone-conduction rather than air-conduction devices, two did not use hearing aids, and test-box measures were not completed for two children during the test session. All but one of the monolingual children used their own personal hearing aids during testing. One monolingual child was provided with a hearing aid during the study because the hearing loss was identified six months earlier and the family was in the process of acquiring a hearing aid. For the monolingual children, amplification for 11 children approximated the Desired Sensation Level (DSL) or the National Acoustic Laboratories (NAL) targets while under- and over-amplification was observed at multiple frequencies for one and four children, respectively. For the nine bilingual children, eight children used their own hearing aids and two children were provided with hearing aids during the study. One child was under-amplified and the other child used a hearing aid at school but did not own it. Therefore, for the bilingual children, amplification for four children approximated DSL or NAL targets while under- and over-amplification was observed at multiple frequencies for four and one children, respectively.

Caregiver and child language questionnaire. Children and caregivers completed a questionnaire regarding their language history and demographic information (age, family composition, and maternal level of education). Children with hearing loss and their caregivers answered questions about the age of the hearing loss identification, use of amplification, and age of enrolment in early intervention services. Bilingual children and their caregivers answered questions about language exposure and use, which were used to calculate the amount of input and output children had in each language. Bilingual children answered questions about language preference and proficiency. Self-proficiency ratings went from 1"very poor" to 5 "very good" (see Table 2). Some of the questions for bilingual children and caregivers were adapted from the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, &

Kaushanskaya, 2007) and from the Bilingual English–Spanish Assessment (BESA; Peña, Gutiérrez-Clellen, Iglesias, Goldstein, & Bedore, 2014). The rest of the questions were created for the present study (see Appendix B). The researcher interviewed the caregivers and children in their dominant language.

Expressive vocabulary. The bilingual Expressive One-Word Picture Vocabulary Test-Bilingual Version (EOWPVT-IV; Martin & Brownell, 2010a) was developed for and normed on bilingual hearing children from the U.S. Although the bilingual EOWPVT-IV has not been previously used in studies with bilingual children with hearing loss, several investigators have used the English EOWPVT-IV with monolingual children with hearing loss (e.g., Gilbertson & Kamhi, 1995; Lederberg, Miller, Easterbrooks, & Connor, 2014; Yoshinaga-Itano et al., 2010). For example, Gilbertson and Kamhi (1995) showed a correlation between the EOWPVT-I and the Peabody Picture Vocabulary Test of .83 in 20 children with hearing loss. The EOWPVT-IV was adapted in both structure and administration for this study. The 180 items were presented once in English and once in Spanish starting at word one and ending when participants missed six consecutive words as recommended in the manual. The order of presentation was counterbalanced. The test was transferred to PowerPoint for ease of administration. Each slide contained a picture that participants named using a single word. The instructions for this test were given in English and Spanish (respectively) for bilinguals and in English for monolinguals. This test provided an estimate of the expressive words that children knew in English, Spanish, and in total (English + Spanish).

Receptive vocabulary. The bilingual Receptive One-Word Picture Vocabulary Test-Bilingual Version (ROWPVT-IV Martin & Brownell, 2010b) was developed in companion with the EOWPVT and normed on bilingual hearing children from the U.S. No previous study has used the ROWPVT with monolingual children with hearing loss. The ROWPVT was adapted in both structure and administration for this study. The 180 words contained in the ROWPVT-IV were divided into two lists of 90 Spanish words and two lists of 90 English words increasing in difficulty. These lists were counterbalanced across participants preventing the recollection of the pictures from one language to the other. The test was transferred to PowerPoint for ease of administration. Each slide contained one test item presented auditorily with a visual display of 4-alternative forced-choice pictures. One word was presented per slide. Participants pointed to the picture that corresponded to the word. If necessary, the word was presented again. The instructions for this test were given in English and Spanish (respectively) for bilinguals and in English for monolinguals. The test started at word one and ended when participants missed four out of six consecutive words as recommended in the manual. A few test items were better represented by the words used in the ROWPVT-I. These words were "sunder" in English and "vid," "romper," and "abigarrado" in Spanish. In addition, two Spanish words were changed to reflect dialectal use. "Travesaño" was changed by "montante" and "sobrescrito" was changed by "exponente." The appropriateness of these modifications were verified by seven bilingual speakers from Mexican origin. This test provided an estimate of the receptive words that children knew in English, Spanish, and in total (English + Spanish).

Word learning tasks. Children completed three rapid word-learning tasks, one in English, one in Spanish, and one Arabic which was a language foreign to all participants. The word learning tasks measured word configuration (i.e., the ability to associate a novel word with a novel image). Participants had to associate five nonsense words to five unfamiliar images through a process of trial and error. Words were presented in isolation one at the time. The five novel images were displayed on a computer monitor and the participants played an interactive game to associate the novel words with the novel images. Every time the child heard a nonsense word, he/she had to click on one of the pictures. If the child selected the correct image associated with the nonsense word, the game in the reinforcement area advanced one step (e.g., a piece of a puzzle appeared or a line was added to a dot-to-dot game). If the child chose incorrectly, the game did not advance. In this way, the child learned to associate each word with the correct image by remembering previous correct and incorrect responses. Figure 6 shows five novel images displayed on response buttons below a reinforcement area on a computer monitor. Children were instructed to listen to the words and pair them with their correct images. Bilingual children received the instructions in English and Spanish and monolingual children in English. Children received no pre-training regarding the word-image associations. However, they were familiarized with the task with 15 practice trials using unrelated words/images with feedback. Children received 100 randomized trials (20 repetitions per word) to learn the names of the unfamiliar images in each language. The words within each language were counterbalanced across images.

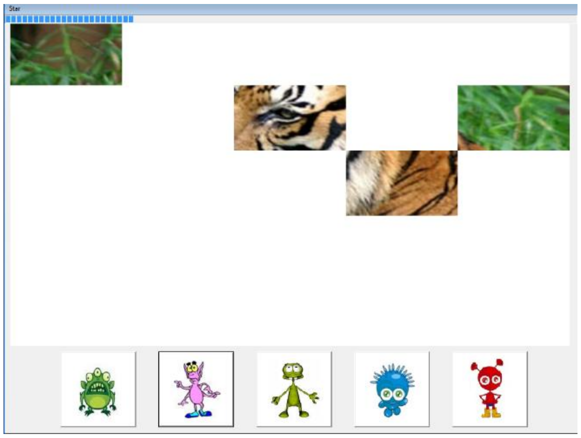

Figure 6. Screenshot of the word learning game.

Stimuli. Nonsense words were created following the phonotactic rules of each language. The proportion of consonants and vowels is the same for each set of words. Table 4 contains the distribution of consonants across languages. All the words have two syllables following CVCCVC or CCVCVC. Consonant clusters allowed for the inclusion of more consonants in the words than single consonant syllables. Having a variety of consonants that are repeated across words within each list of words required children to listen to the entire word instead of relying on the intelligibility of phonemes that are unique in each word (Pittman, 2008). The most common stress pattern for two syllable nouns in English is on the first syllable (Clopper, 2002) and on the penultimate syllable in Arabic and Spanish (Quilis, 1983; Halpern, 2009). Thus these nonsense words were produced with the stress on the first syllable. The words contain three sets of three consonants, three sets of two consonants, and five unique consonants (total of 20) in each language. The vowels included in the words are: /ɑ/ and /ə/ in English, /i/ and /e/ in Spanish, and /u/ and /i/ in Arabic. The vowels and consonants included in the English and Spanish nonsense words are medium or high frequency (Mines, Hanson, & Shoup, 1978;

Quilis, 1980). The consonants for the Arabic nonsense words were selected without considering their relative frequency of appearance in Arabic, but rather how different they were from English and Spanish. Arabic nonsense words contain five emphatic consonants that do not exist in English nor in Spanish, such that these phonemes should sound foreign to all participants.

Table 4.

Distribution of Consonants in the Novel Words

		English	Spanish	Arabic
Stop	B	0	1	1
	D	2	1	1
	P	0	1	
	T	3	2	1
	K	0	0	1
	tˤ			3
	Q			3
	ʔ			2
Fricative	H	1		0
	F	1	2	3
	Sh	1		0
	X		1	0
	Θ	1		0
	ɣ			2
	Z	1		0
	sˤ			2
	S	3	3	0
Affricate	tʃ	0	1	0
Nasal	m	2	3	0
	N	3	2	1
Liquid	L	2	3	0
Total		20	20	20

Table 5 shows the novel words that were used in each language, their phonotactic probability, and their neighborhood density within each language. Phonotactic probability and neighborhood density were calculated using CLEARPOND online calculator (Marian et al., 2012) for all but the Arabic words. The participants recruited for the study were not speakers of Arabic and thus adherence to phonotactic and neighborhood properties with the language were not considered to be necessary. Positional phonotactic probability was calculated by adding the probability of each phoneme occurring in that particular position within a word for a language (Vitevitch & Luce, 2004). The higher the positional phonotactic probability index, the more probable it is that a particular word will exist in a language. Within-language phonotactic probabilities for the English words were from .30 to .34 and cross-linguistic phonotactic probabilities (i.e., the probability of English words existing in Spanish) were from .14 to .19. Within-language phonotactic probabilities for the Spanish words were from .30 to .33 and cross-linguistic phonotactic probabilities (i.e., the probability of Spanish words existing in English) were from .19 to .22. Reducing the cross-linguistic phonotactic probabilities was impossible without increasing the within-language probabilities, given that English and Spanish share most of their consonants. Neighborhood density was held to zero or one for all the words to avoid certain nonsense words being easier to learn than others because they sound more like real words.

All the words were created and recorded by native female speakers. English words were recorded with a standard American accent, Spanish words with a Latino standard accent, and Arabic words with an Arabic standard accent. The words were recorded using a sampling rate of 22.05 kHz and a microphone with a flat frequency response to 10 kHz (AKG, C535EB). Then the words were digitally isolated from the original recording using Adobe Audition (V1.5) and saved as separate wave files. The words were presented at a conversational level (65 dB SPL) through sound field speakers.

Table 5.

Novel Words for the Word Learning Tasks

	Clearpond code	IPA	Orthographic	English Positional probability	English Biphone probability	English Neighborhood Density	Spanish Positional probability	Spanish Biphone probability	Spanish Neighborhood density
English	s.A.T.n.5.d	sɑθnəd	Sothnud	.33	.007	0	.14	0	0
	d.A.z.t.5.l	dɑztəl	Doztul	.33	.014	0	.19	0	0
	f.A.s.n.5.S	fɑsnəʃ	Fosnush	.30	.007	0	.16	0	0
	s.t.A.m.5.n	stɑmən	Stomun	.31	.059	0	.18	0	0
	h.A.m.t.5.l	hɑmtəl	Homtul	.34	.020	0	.17	0	0
Spanish	t.i.m.b.e.l	Timbel	Tímbel	.20	.007	0	.30	.022	0
	x.i.s.m.e.l	Xismel	Gísmel	.19	.002	0	.31	.025	0
	t.i.m.p.e.N	Timpeŋ	Timpen	.20	.014	0	.30	.029	0
	d.i.s.f.e.N	Disfeŋ	Disfen	.22	.004	0	.33	.036	0
	f.i.l.tS.e.s	filtʃes	Filches	.22	.005	0	.30	.029	1(filmes)
Arabic		quntˤif	قُنذِف						
		tˤuqsˤib	طَقصِب						
		tuɣfiʔ	قُبصِن						
		fuʔɣid	تُغفِئ						
		sˤuqtˤik	فُئغِد						

Note. IPA: International Phonetic Alphabet.

Retention task. One day after the rapid word learning task, children were asked to recognize the words they learned in the laboratory. The test was administered online and required adequate audibility to proceed. To do this, children completed a test comprised of four pictures. They were presented with a picture (e.g., cat) and four auditory minimal pairs (e.g., cat, mat, fat, and hat). Children were able to take this test as many times as they needed to find the best volume setting for their computer, but retention responses with three or more tests were not considered as it indicated that children were guessing or receiving insufficient audibility. After the test, children were presented with the same novel images they saw in the lab (five per language). Within each language, children selected the name of the five pictures among ten auditory choices. These auditory choices included the five nonsense words and five foils, one per word, created by changing one or two phonemes from the target word (see Table 6). These foils were produced by the same speakers as for the target words. Children had to recognize a total of 15 words (five in Spanish, five in English, and five in Arabic).

Table 6.

Auditory Foils for the Word Retention Task

English		Spanish		Arabic	
Othographic	IPA	Othographic	IPA	Othographic	IPA
Sothlum	sɑθləm	Timches	timtʃes	قُنصِك	qunsˤik
Doznud	dɑznəd	Gisnen	xisneŋ	طُقدِف	tˤuqdif
Fostud	fɑstəd	Timfen	timfeŋ	تُغبِد	tuɣbid
Stonud	stɑnəd	Filten	filteŋ	فُئبِص	fuʔbisˤ
Homstun	hɑmstən	Dísnel	disnel	صُقفِد	sˤuqfid

Note. IPA: International Phonetic Alphabet.

Inhibitory Control. The flanker task measures inhibitory control because it assesses the ability to suppress responses that are inappropriate in a particular context

(Eriksen, 1995). In this task, children indicated the direction of an arrow presented on the screen by pressing the right or left key. The central arrow was flanked by arrows in the same direction (congruent trials: →→→→→), opposite direction (incongruent trials: →→←→→), or no arrows (neutral trials: _ _ → _ _). The task was presented on a computer monitor using Psychopy software (Peirce, 2007). Participants had ten practice trials with feedback in which they were instructed to pay attention to the target arrow and indicate its direction (left or right) as quickly as possible using the keyboard. Children needed to get at least 80% accuracy in the practice trials to continue with the task to ensure that they understood the instructions. Instructions for bilingual children were provided in English and in Spanish. A fixation point was presented throughout the task in the center of the screen. Once children were familiarized with the task, they were presented with 48 trials; 16 congruent, 16 incongruent, and 16 neutral trials in random order.

Procedures

Testing was completed in a single two-hour session. Children were compensated for their visit to the lab and for completing the retention task within 24 hours of their lab visit. If children did not have access to a computer and internet at home, they had the opportunity to come to the lab to complete the task. Prior to participation, child assent and parental consent were obtained. Children were given a five-minute break at the halfway point and at other times if necessary. The informed consent, hearing test, and language questionnaire were obtained at the beginning of the session. The remaining tasks were divided into three blocks: English (expressive vocabulary, word learning, and receptive vocabulary), flanker task and Arabic word-learning task, and Spanish (expressive vocabulary, word learning, and receptive vocabulary). English and Spanish blocks were counterbalanced and the flanker task and the Arabic word learning task were always done in the middle of the session. Within the English and Spanish blocks, expressive vocabulary tests were done at the beginning to avoid priming responses from the receptive tests. Children with hearing loss wore hearing aids during testing.

Experiment 1

Analyses

Experiment 1 tested the hypothesis that *if learning new words is facilitated by vocabulary size, then children with larger vocabularies will learn and retain more words than children with smaller vocabularies.* Total vocabulary scores were computed by adding together the English and Spanish vocabulary knowledge for the receptive and for the expressive tests, separately. Total vocabulary scores were expected to reflect the degree of bilingualism in each group. The bilingual children (with and without hearing loss) were expected to have higher total vocabularies than the monolingual children.

Six hierarchical multiple regression analyses were used to answer question one and two by examining if vocabulary size predicted word learning. Separate regression analyses were conducted for each word-learning task (training and retention) in each language (English, Spanish, and Arabic). Chronological age, degree of hearing loss (binaural unaided PTA), and maternal education (high school or less vs. more than high school) were introduced first in the models. Language status (monolingual vs. bilingual) was not included as a covariate because total receptive vocabulary was expected to reflect the degree of bilingualism in the sample. Total receptive vocabulary was introduced in step 2 to assess the amount of variance in training and retention that was predicted by vocabulary size in addition to the covariates. Total receptive vocabulary, rather than total expressive vocabulary, was selected as a predictor because the word learning tasks were receptive in nature. Total expressive vocabulary was explored as a predictor of word learning, but receptive vocabulary was a better predictor.

Children with unilateral and bilateral hearing losses were grouped together because they did not differ significantly from one another in any of the independent or dependent measures. In addition, because degree of hearing loss was computed by averaging across the two ears, children with unilateral hearing loss showed better hearing thresholds than children with bilateral losses.

Two multivariate analyses of covariance (MANCOVA) were used to answer question three comparing word learning outcomes by language and hearing status. Two sets of outcome variables were used in the analyses. Set one included the word training scores and set two included the word retention scores in each language. Between-subjects factors were language (monolingual vs. bilingual) and hearing status (normal hearing vs. hearing loss). Chronological age was included in the analysis as a covariate. Main effects, their interaction, and pairwise comparisons were assessed controlling for type I error using the Bonferroni procedure (alpha = .05).

Results

Descriptive Data. Table 7 shows means and standard deviations for the vocabulary measures and word learning outcomes by group. As expected, bilingual children showed larger total expressive and receptive vocabularies than monolingual children, $t(71) = 10.26$, $p < .001$ and $t(71) = 9.26$, $p < .001$, respectively and regardless of the hearing status. Children performed very similarly in English word training and retention tasks. In Spanish and Arabic, children with hearing loss performed more poorly than hearing peers, particularly in the retention tasks, where children with hearing loss remembered half as many words as the children with normal hearing.

Table 7.

Vocabulary Measures and Word Learning Outcomes by group

Variable	Monolingual NH (*n* = 20)	Monolingual HL (*n* = 20)	Bilingual NH (n = 20)	Bilingual HL (n = 13)
Expressive Spanish[a]	0.5 (0.2)	0.2 (0.6)	75.0 (28.0)	51.3 (22.1)
Expressive English[a]	122.5 (12.7)	116.7 (14.6)	110.3 (12.1)	103.6 (12.0)
Expressive Total	*123.0 (12.6)*	*116.9 (15.0)*	*185.3 (32.1)*	*155.0 (27.0)*
Receptive Spanish[b]	4.3 (3.2)	4.3 (4.1)	49.7 (14.2)	41.3 (11.6)
Receptive English[b]	59.1 (9.7)	55.1 (11.5)	56.2 (10.2)	50.0 (6.8)
Receptive Total	*63.4 (11.3)*	*59.4 (14.1)*	*105.9 (18.9)*	*91.3 (17.0)*
English WT	59.1 (19.0)	53.8 (19.6)	59.7 (19.1)	57.5 (21.0)
Spanish WT	51.7 (16.5)	44.2 (12.7)	53.6 (14.5)	44.3 (15.8)
Arabic WT	59.3 (17.2)	45.5 (17.9)	63.6 (18.2)	47.1 (21.9)
English WR	49.0 (28.6)	40.0 (29.0)	40 (28.2)	43.0 (25.6)
Spanish WR	30.0 (29.3)	18.9 (15.5)	45 (25.0)	26.1 (23.6)
Arabic WR	50.0 (35.2)	23.1 (20.2)	49 (29.3)	24.6 (27.2)

Notes. Mean and (Standard Deviation). NH = Normal Hearing. HL = Hearing Loss; WT = Word Training; WR = Word Retention.
a Expressive vocabulary raw scores from the EOWPVT-IV, maximum 180.
b Receptive vocabulary raw scores from the ROWPVT-IV, maximum 90.

Table 8 shows correlations between the total vocabulary scores and demographic variables. Chronological age was positively correlated with receptive and expressive vocabulary scores indicating that older children had larger receptive and expressive vocabularies than younger children. Language status (monolingual vs. bilingual) was negatively correlated with maternal education, indicating that bilingual children tended to have mothers with lower levels of education than monolingual children. Language status also was positively correlated with receptive and expressive vocabulary scores, indicating that bilingual children had larger total receptive and expressive vocabularies than monolingual children. Maternal education was negatively correlated with receptive and expressive vocabulary, indicating that children whose mothers had a low maternal education level had larger vocabularies than children whose mothers had a high maternal education level. This was because the majority of the children in the high maternal education group were monolingual and they showed smaller total vocabularies than bilingual children. Degree of hearing loss was negatively correlated with receptive and expressive vocabulary, indicating that children with more severe hearing losses showed smaller receptive and expressive vocabularies than children with less severe hearing losses. Finally, receptive and expressive vocabulary scores were positively correlated, the larger the receptive vocabulary, the larger the expressive vocabulary.

Table 8.

Correlation Matrix of Demographic and Vocabulary Variables

Variable	Language status	Maternal education	Degree of HL	Receptive vocabulary	Expressive vocabulary
Age	.16	-.03	-.08	.31**	.26*
Language status		-.61**	-.16	.77**	.74**
Maternal education			-.01	-.37**	-.39**
Degree of HL				-.21*	-.25*
Receptive Vocabulary					.91**

Note. HL= Hearing Loss. Degree of HL from binaural unaided thresholds (500, 1000, and 2000 Hz).
*$p < .05$. **$p < .01$.

Table 9 shows correlations between word learning outcomes, demographic, and vocabulary variables. Results showed that older children scored higher in the English and Arabic training tasks than younger children. Bilingual children remembered more

Spanish words than monolingual children. Children whose mothers had a high education level learned more English and Arabic words than children whose mothers had a low education level and children with more severe hearing losses learned fewer Spanish and Arabic words than children with less severe hearing losses. No relationship between degree of hearing loss and English words was observed for training or retention. Receptive vocabulary was positively correlated with outcomes in each language for the training tasks and for Spanish retention, indicating that children with larger receptive vocabularies achieved higher success during training than children with smaller vocabularies. Likewise, children with larger expressive vocabularies learned more Spanish and Arabic words than children with smaller vocabularies. Word-training and retention measures were highly correlated (shaded boxes), indicating that the ability to retain words was directly related to success during training.

Table 9.

Correlation Matrix of Word Learning Outcomes, Demographic, and Vocabulary Variables

Variable	English WT	Spanish WT	Arabic WT	English WR	Spanish WR	Arabic WR
Age	.23*	.15	.27*	.15	.17	.14
Language status	.06	.07	.12	-.06	.25*	.04
Maternal education	.20*	.16	.19*	.28**	-.08	.16
Degree of HL	-.15	-.20*	-.31**	-.13	-.32**	-.35**
Receptive V	.21*	.27*	.30*	.11	.35**	.17
Expressive V	.17	.25*	.29**	.09	.29**	.17
English WT		.21*	.44*	.72**	.17	.34**
Spanish WT			.39**	.36**	.52**	.47**
Arabic WT				.43**	.31**	.65**

Note. HL= Hearing Loss; V = Vocabulary; WT = Word Training; WR = Word Retention.
Sample size for the retention correlations is 72 because of missing data.
**p* < .05. ***p* < .01.

Research Question 1: Does vocabulary size predict word-learning training? The first regression analysis examined the effect of receptive vocabulary on English word-training outcomes (see Table 10). Although Model 1 revealed that chronological age accounted for a significant portion of the variance (8%) in training for English words, this effect disappeared when receptive vocabulary was included in the analyses in Model 2. Receptive vocabulary predicted an additional 4% of the English word-training variance over the covariates and maternal education became significant. Together, maternal education and receptive vocabulary predicted 12% of the English word-training variance.

Table 10.

Summary of the Hierarchical Regression Analysis of Vocabulary Size on English-Learning Training

	Model 1			Model 2		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Chronological age	3.58	1.74	0.23*	2.42	1.80	0.15
Degree of HL	-0.12	0.10	-0.13	-0.07	0.10	-0.08
Maternal education	8.04	4.35	0.20	11.73	4.62	0.30*
Receptive vocabulary				0.20	0.09	0.26*
Adjusted R^2		0.08			0.12	
R^2 Change					0.04	
F for change in R^2		3.07*			4.14*	

Notes. HL= Hearing Loss.
*$p < .05$. **$p < .01$.

The second regression analysis examined the effect of receptive vocabulary on Spanish word-training outcomes (see Table 11). None of the covariates were significant in Model 1. In Model 2, receptive vocabulary predicted an additional 7% of the Spanish word-training variance over the covariates and maternal education became significant. Together, maternal education and receptive vocabulary predicted 12% of the Spanish word-training variance.

Table 11.

Summary of the Hierarchical Regression Analysis of Vocabulary Size on Spanish-Learning Training

	Model 1			Model 2		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Chronological age	1.72	1.39	0.14	0.56	1.41	0.05
Degree of HL	-0.13	0.08	-0.19	-0.09	0.08	-0.12
Maternal education	5.07	3.47	0.16	8.80	3.62	0.29*
Receptive vocabulary				0.20	0.07	0.33*
Adjusted R^2		0.05			0.12	
R^2 Change					0.07	
F for change in R^2		2.21			6.88*	

Notes. HL= Hearing Loss.
*$p < .05$. **$p < .01$.

The third regression analysis examined the effect of receptive vocabulary on Arabic word-training outcomes (see Table 12). In Model 1, chronological age and degree of hearing loss predicted a significant amount of variance for Arabic word training (16%). When adding receptive vocabulary in Model 2, the effect of chronological age disappeared and maternal education became a significant predictor. Receptive vocabulary predicted an additional 6% of the Arabic word-training variance over the covariates. Maternal education, degree of hearing loss, and receptive vocabulary predicted a total of 22% of the Arabic word-training variance.

Table 12.

Summary of the Hierarchical Regression Analysis of Vocabulary Size on Arabic-Learning Training

	Model 1			Model 2		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Chronological age	4.02	1.70	0.25*	2.68	1.73	0.17
Degree of HL	-0.27	0.10	-.029**	-0.22	0.10	-0.23*
Maternal education	7.89	4.24	0.20	12.17	4.45	0.30**
Receptive vocabulary				0.23	0.09	0.29*
Adjusted R^2		0.16			0.22	
R^2 Change					0.06	
F for change in R^2		5.79**			6.02*	

Notes. HL= Hearing Loss.
*$p < .05$. **$p < .01$.

Research Question 2: Does vocabulary size predict word retention? The first regression analysis examined the effect of receptive vocabulary size on English retention outcomes (see Table 13). Receptive vocabulary was not a significant predictor of English retention outcomes. Maternal education was the only significant predictor in Model 1 and 2, accounting for 10% of the variance.

Table 13.

Summary of the Hierarchical Regression Analysis of Vocabulary Size on English Word Retention (n =72)

	Model 1			Model 2		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Chronological age	3.37	2.54	0.15	2.04	2.63	0.09
Degree of HL	-0.14	0.15	-0.11	-0.08	0.15	-0.06
Maternal education	16.28	6.29	0.29*	20.68	6.75	0.37**
Receptive vocabulary				0.23	0.14	0.21
Adjusted R^2		0.08			0.10	
R^2 Change					0.02	
F for change in R^2		3.13*			2.75	

Notes. HL= Hearing Loss
*$p < .05$. **$p < .01$.

The second regression analysis examined the effect of receptive vocabulary size on Spanish retention outcomes (see Table 14). In Model 1, degree of hearing loss predicted a significant amount of variance for Spanish word retention (9%). In Model 2, receptive vocabulary predicated an additional 5% of the Spanish retention variance over the covariates. Degree of hearing loss and receptive vocabulary together predicted 14% of the Spanish retention variance.

Table 14.

Summary of the Hierarchical Regression Analysis of Vocabulary Size on Spanish Word Retention (n =72)

	Model 1			Model 2		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Chronological age	2.93	2.32	0.14	1.24	2.36	0.06
Degree of HL	-0.37	0.13	-0.30**	-0.30	0.13	-0.25*
Maternal education	-3.78	5.75	0.07	1.81	6.06	0.03
Receptive vocabulary				0.30	0.12	0.30*
Adjusted R^2		0.09			0.14	
R^2 Change					0.05	
F for change in R^2		3.37*			5.51*	

Notes. HL= Hearing Loss.
*p < .05. **p < .01.

The third regression analysis examined the effect of receptive vocabulary size on Arabic retention outcomes (see Table 15). Receptive vocabulary was not a significant predictor of Arabic retention outcomes. Degree of hearing loss was the only significant predictor in both models, ultimately accounting for 13% of the variance.

Table 15.

Summary of the Hierarchical Regression Analysis of Vocabulary Size on Arabic Word Retention (n =72)

Variable	Model 1			Model 2		
	B	*SE B*	*β*	*B*	*SE B*	*β*
Chronological age	3.02	2.76	0.12	1.89	2.89	0.07
Degree of HL	-0.50	0.16	-0.34**	-0.45	0.17	-0.31**
Maternal education	9.63	6.83	0.15	13.38	7.40	0.21
Receptive vocabulary				0.20	0.15	0.16
Adjusted R^2		0.12			0.13	
R^2 Change					0.01	
F for change in R^2		4.42**			1.65	

Notes. HL= Hearing Loss.
*p < .05. **p < .01.

Research Question 3: Do language and hearing status interact to affect word learning? Figure 7 and 8 show word-training and retention outcomes by hearing status. The first MANCOVA revealed a significant main effect of hearing status on word training outcomes after controlling for age, F (3, 66) = 4.45, p = .007, Wilks' Λ = .831, partial η^2 = .16. Pairwise comparisons revealed that children with normal hearing showed significantly higher performance during training than children with hearing loss for the Spanish words (F [1, 68] = 5.18, p = .026, partial η^2 = .07) and the Arabic words (F [1, 68] = 11.33, p = .001, partial η^2 = .14), but not for the English words (F [1, 68] = .48, p = .48, partial η^2 = .07). A main effect of language status and the interaction between hearing and language status were not significant.

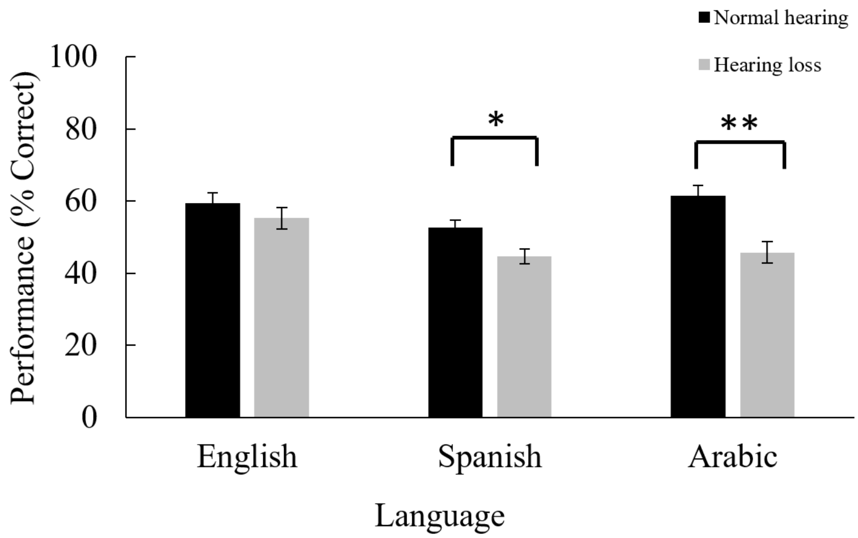

Figure 7. Word training outcomes by hearing status (means and standard error). *p < .05. **p < .01.

The second MANCOVA revealed a significant main effect of hearing status on word retention outcomes after controlling for age, *F* (3, 66) = 5.51, *p* = .002, Wilks' Λ = .797, partial η^2 = .20). Pairwise comparisons revealed that children with normal hearing showed significantly higher retention of the words than children with hearing loss in Spanish (*F* [1, 67] = 6.28, *p* = .015, partial η^2 = .08) and in Arabic (*F* [1, 67] = 13.11, *p* = .001, partial η^2 = .16), but not in English (*F* [1, 68] = .10, *p* = .74, partial η^2 = .002). A main effect of language status was not observed and the interaction between hearing and language status was not significant. These analyses were repeated using weighted means to adjust for unequal sample sizes in the groups, but the results did not differ from those reported above.

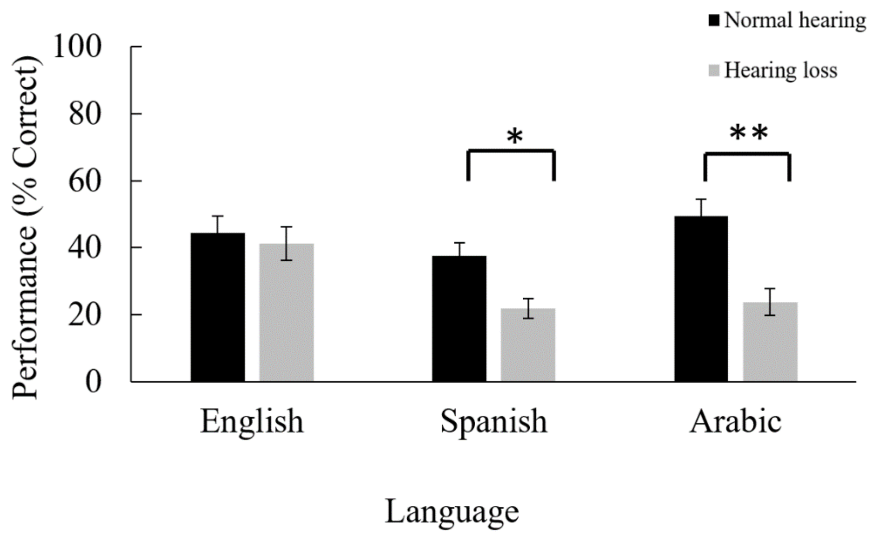

Figure 8. Word retention outcomes by hearing status (means and standard error). *p < .05. **p < .01.

Discussion

The purpose of Experiment 1 was to examine the effect of vocabulary size on word learning, specifically, whether children with larger vocabularies learn and retain more words than children with smaller vocabularies. This goal was accomplished by including children with different vocabulary sizes in the study; monolingual and bilingual children with normal hearing and monolingual and bilingual children with hearing loss. Larger vocabularies were predictive of better word training outcomes in all languages and better Spanish word retention. Children with hearing loss performed more poorly in Spanish and Arabic training and retention than children with normal hearing. Finally, the ability to retain words was directly related to success during training.

Larger total receptive vocabularies predicted better word training outcomes. These results are in line with previous studies in normal-hearing children (e.g., Gathercole et al., 1997; Maguire et al., 2018) and in children with hearing loss (e.g., Lederberg et al., 2000; Pittman et al., 2005), and suggest that large vocabularies represent more practice with word learning. The fact that vocabulary size contributed to performance for training in each language, particularly for the Arabic words that were foreign to all participants, indicates that language experience helps learn new words, regardless of the language. Word learning ability may improve as vocabulary size increases and children are able to use the words they know to detect and learn new words (effects of phonotactic probability and neighborhood density) (Graf Estes et al., 2016; Law & Edwards, 2015; Marchman & Fernald, 2008; Marchman et al.,2010).

In this study, vocabulary size did not predict word retention except for the Spanish words. It is possible that vocabulary size predicted Spanish word retention because it reflected the language status of the children in the sample (monolingual vs. bilingual) and because bilingual children remembered more words than monolinguals. Word retention could be predicted by phonological working memory. Although there is controversy over whether phonological working memory predicts immediate word learning (Gathercole et al., 1997; Gray, 2006; Hansson et al., 2004), phonological working memory may predict word retention. Children with higher phonological working memory may store more phonemes of the newly learned words than children with lower phonological working memory. This could allow children to create more complete word forms facilitating word retention.

The prediction that normal-hearing children would learn and remember more words than children with hearing loss was true for the Spanish and Arabic words, but not for the English words. Children with hearing loss did not differ from hearing peers on English training and retention outcomes. Interestingly, children with hearing loss showed comparable English expressive and receptive vocabularies to hearing peers. This is in contrast to previous investigations which have shown that monolingual children with hearing loss have significantly lower vocabularies and word learning abilities than normal-hearing peers (e.g., Lederberg et al., 2000; Pittman et al., 2005). While, by chance, this study may have recruited children with hearing loss with extraordinary high vocabularies, it is also possible that other factors may explain the vocabulary outcomes of the children with hearing loss in the sample, such as the language services received or nonverbal intelligence. The high English vocabulary scores of children with hearing loss may have helped them learn and remember English words as compared to Spanish and Arabic words. It could be that children with hearing loss created degraded representations of the Spanish and Arabic words, limiting the encoding of the foreign words in long-term memory and preventing them from remembering the word-picture associations the next day. However, for English words, children could have used their phonotactic knowledge to create more accurate word representations, allowing them to retain the English words better than in the otherlanguages.

Although a relationship between vocabulary and word learning was identified, it was not dependent on language status. Monolingual and bilingual children did not differ in any of the word learning tasks. The only task where bilinguals showed larger means than monolinguals in both normal hearing and hearing loss groups was in the Spanish retention task. It is likely that the differences between monolingual and bilingual children in Spanish retention were not significant due to the small sample size in the bilingual hearing loss group. Although no significant differences were found between monolingual and bilingual children, these results suggest that having experience with a language helps children remember words in that particular language, rather than an overall bilingual advantage as suggested in previous research (Kaushanskaya et al., 2014, 2013). If bilingual children were to show an overall word learning advantage, they should have outperformed monolinguals in the Arabic and English word learning tasks, which was not the case. Bilingual and monolingual children performed the same in the Arabic training and retention tasks. It is important to consider that the previous studies that found a bilingual advantage on word learning included children from high maternal education levels attending dual immersion schools, whereas the bilingual children in this study came mostly from low maternal education families attending English-only education. It is also possible that in order to observe a bilingual advantage, word learning tasks should pose some kind of conflict, such as mapping two labels to the same object (Poepsel & Weiss, 2016) or adding a second label to a known object (Kaushanskaya et al., 2014), which may more closely represent how bilinguals learn new words.

Higher maternal education levels were predictive of better training outcomes and English word retention. In contrast, children whose mothers had a low maternal education level had larger vocabularies than children whose mothers had a high maternal education level. This was because the majority of the children in the high maternal education group were monolingual and they showed smaller total vocabularies than bilingual children. When looking at English and Spanish receptive scores in monolingual and bilingual children separately, the relationship goes in the expected direction, the higher the maternal education, the larger the Spanish and English receptive vocabulary. The positive effect of high maternal education on vocabulary size is in line with many investigators who have reported that children with hearing loss from low socioeconomic/low maternal education backgrounds show lower vocabulary outcomes (and probably word learning abilities) than those from higher socioeconomic backgrounds (e.g., Ching et al., 2013; Quittner, Cejas, Wang, Niparko, & Barker, 2016; Yoshinaga-Itano et al., 2017).

Word-Retention Error Patterns

Another area of interest was the type of errors children made in the retention task. For each language in the retention task, children had ten auditory choices, five were the words learned during training (i.e., targets) and five were foils of the words created by changing one or two phonemes in the original words (see Table 6). Children's errors were classified into three categories: (1) selecting another learned word (e.g., /sɑθnəd/ for /dɑztəl/), (2) selecting the foil created for the target word (e.g., /dɑznəd/ for /dɑztəl/), or (3) selecting a foil for another learned word (e.g., /hɑmstən/ for /dɑztəl/). Figures 12, 13, and 14 show the average performance correct and incorrect responses as a function of group in English, Spanish, and Arabic, respectively. The most common error for all the children in the three languages was selecting one of the five words learned, followed by selecting an unrelated foil.

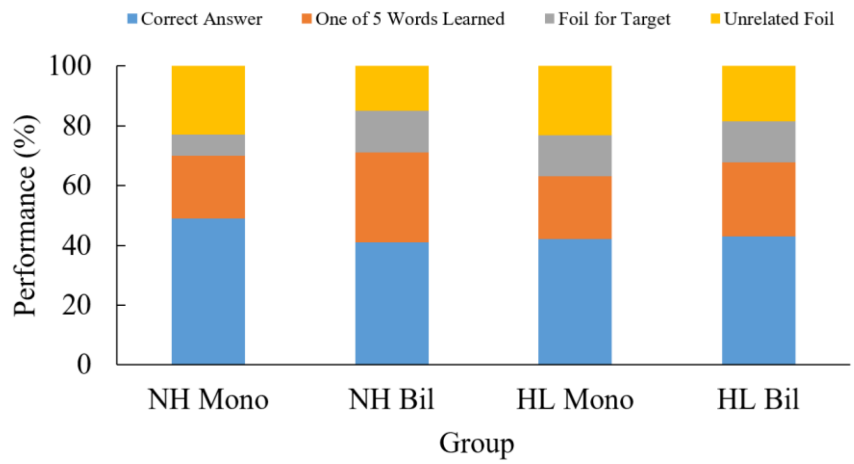

Figure 9. English word-retention and error categories for each group. NH = Normal Hearing; HL = Hearing Loss; Mono = Monolingual; Bil = Bilingual.

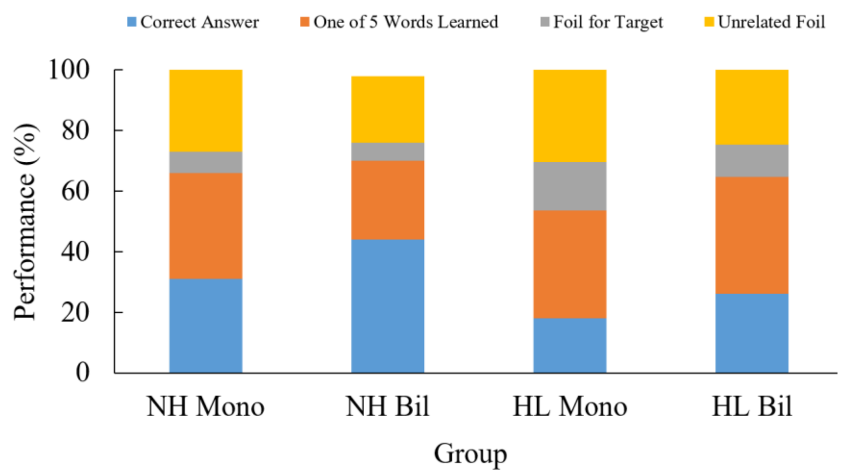

Figure 10. Spanish word-retention and error categories for each group. NH = Normal Hearing; HL = Hearing Loss; Mono = Monolingual; Bil = Bilingual.

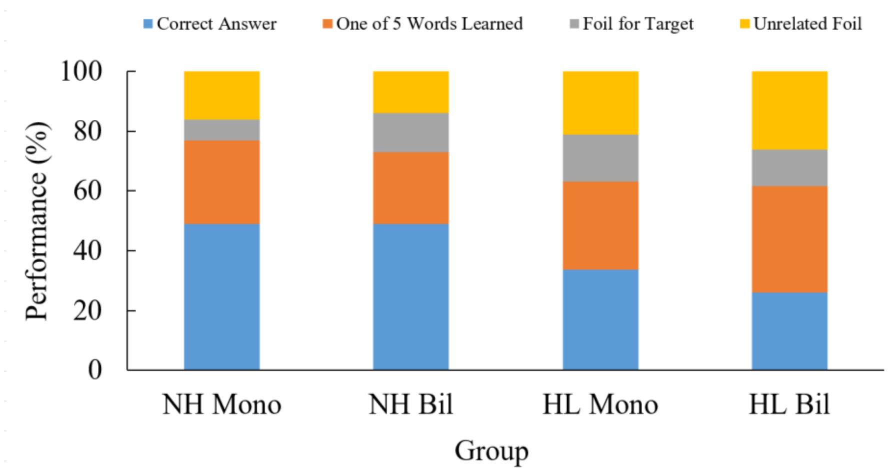

Figure 11. Arabic word-retention and error categories for each group. NH = Normal Hearing; HL = Hearing Loss; Mono = Monolingual; Bil = Bilingual.

Twelve intendent samples t-tests were performed per language to compare each type of error (3) across groups (4); monolingual normal hearing vs. bilingual normal hearing, monolingual hearing loss vs. bilingual hearing loss, monolingual normal hearing vs. monolingual hearing loss, and bilingual normal hearing vs. bilingual hearing loss. For each language, type I error was controlled using Bonferroni (alpha = .004). None of these tests revealed significant differences across word-retention errors in each language.

Overall, the results suggest that children received enough exposure during the training task to create lexical entries for the new words. For some words, children were able to associate the learned words with the correct pictures (i.e., correct responses). For other words, children were able to remember the word form but not in association with the correct picture (i.e., selecting another word learned). When children were not able to remember the learned words, they guessed the answer (i.e., unrelated foil). The fact that the related foil (same onset as the target word) was the least selected response, probably indicates that children created lexical entries for the new words right after exposure and thus the retention task did not reflect the lexicalization process. Less amount of exposures on different days may reflect the process of how children create lexical entries for the new words and may show that words that are similar to the target compete for activation, as suggested by previous studies (Gaskell & Dumay, 2003).

Experiment 2

Analyses

Experiment 2 aimed to test the hypothesis that if word learning is facilitated by inhibitory control, then children with higher inhibitory control will learn and remember more words than children with lower inhibitory control. The reaction time for the incongruent trials (correct responses only) of the flanker task was used as a measure of inhibitory control. Incongruent trials were chosen instead of neutral and congruent trials because children had to inhibit conflicting information to select the correct response.

Six hierarchical multiple regression analyses were used to answer question one and two by examining if inhibitory control predicted word learning. Separate regression analyses were conducted for each word-learning task (training and retention) in each language (English, Spanish, and Arabic). Chronological age, degree of hearing loss (binaural unaided PTA), maternal education (high school or less vs. more than high school), and language status (monolingual vs. bilingual) were introduced first in the models. Inhibitory control was introduced in step 2 to assess the amount of word training and retention variance predicted by inhibitory control in addition to the covariates.

One MANCOVA was used to answer question three comparing inhibitory control ability by language and hearing status. The outcome variables were reaction time and accuracy for the incongruent trials. Between-subjects factors were language (monolingual vs. bilingual) and hearing status (normal hearing vs. hearing loss). Chronological age was included in the analysis as a covariate. Main effects, their interaction, and pairwise comparisons were assessed controlling for type I error using the Bonferroni procedure (alpha = .05).

Results

Descriptive Data. Table 16 shows means and standard deviations for reaction time and accuracy in the congruent, incongruent, and neutral conditions from the flanker task. Reaction time was calculated for correct responses only. The sample size for the incongruent reaction time in the bilingual hearing loss group was 12 because one participant responded incorrectly to all trials and thus there were no correct responses upon which to calculate the reaction time for this child. Incongruent accuracy showed three outliers (2 standard deviations below the mean) with scores below 22.16% that were adjusted in the descriptive data and further analyses. Overall, children with hearing loss were slower and less accurate than hearing peers in all conditions. Bilingual children were slower than monolingual peers, but they performed similarly in all conditions.

Table 16.

Flanker Task Accuracy and Reaction Time by Group

Variable	Monolingual NH (*n* = 20)	Monolingual HL (*n* = 20)	Bilingual NH (n = 20)	Bilingual HL (n = 13)
Congruent RT	715 (114)	773 (166)	727 (169)	767 (112)
Incongruent RT	832 (146)	950 (199)	891 (202)	954 (218)
Neutral RT	682 (109)	761 (132)	718 (165)	740 (118)
Congruent accuracy	99 (3)	96 (7)	99 (1)	98 (2)
Incongruent accuracy	94 (7)	82 (27)	92 (7)	79 (26)
Neutral accuracy	99 (2)	97 (5)	99 (1)	97 (4)

Notes. Mean and (Standard Deviation). NH = Normal Hearing. HL = Hearing Loss. RT = Reaction Time in milliseconds for correct trials.

Table 17 shows correlations between inhibitory control, demographic variables, and word learning outcomes. Results revealed that older children and children whose mothers had a high education level responded faster than younger children and children whose mothers had a low education level. Also, children with more severe hearing losses responded more poorly in the incongruent trials than children with less severe hearing losses. Language status was not correlated with incongruent reaction time or accuracy.

When looking at the correlations between word learning outcomes and inhibitory control, all word training and retention scores (except Arabic retention) were correlated with incongruent reaction time. This indicates that children with higher word training and retention scores responded faster in the incongruent trials than children with lower scores. Word training and retention scores were not correlated with incongruent accuracy with the exception of Arabic training. Incongruent reaction time and accuracy correlated negatively with each other, indicating that children who responded faster (i.e., shorter reaction times) were more accurate than children who responded more slowly in the incongruent trials.

Table 17.

Correlation Matrix Inhibitory Control, Demographic Variables, and Word Learning Outcomes

Variable	Incongruent RT	Incongruent %
Age	-.35**	.07
Language status	.06	-.01
Maternal education	-.28**	-.01
Degree of HL	.19	-.21*
English WT	-.29**	.17
Spanish WT	-.24*	-.09
Arabic WT	-.20*	.24*
English WR	-.42**	.15
Spanish WR	-.23*	.09
Arabic WR	-.05	.07
Incongruent RT		-.49**

Note. HL= Hearing Loss; RT = Reaction time in milliseconds; WT = Word Training; WR = Word Retention. Sample size for the incongruent RT and retention correlations is 72 due of missing data. *$p < .05$. **$p < .01$.

The relationship between inhibitory control and vocabulary size was also of interest. Figure 9 shows the correlation between the incongruent reaction time and total receptive vocabulary. Reaction time was negatively correlated with vocabulary size, $r(72) = -27$, $p = .010$. Overall, children with smaller total vocabularies responded slower in the incongruent trials than children with larger vocabularies. Children with hearing loss (filled symbols) tended to be slower in the incongruent trials and have smaller vocabularies than hearing peers (open symbols).

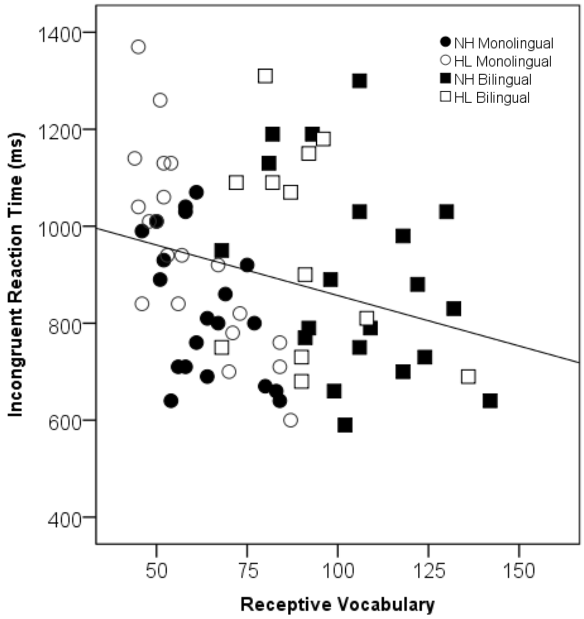

Figure 12. Relationship between vocabulary size and inhibitory control for monolingual (circles) and bilingual (square) children with normal hearing (filled symbols) and with hearing loss (open symbols).

Research Question 1: Does inhibitory control predict word learning-training? Table 18 shows the summaries of the hierarchical regression models assessing the effect of inhibitory control (incongruent reaction time) on word learning in addition to the covariates. Model 1 summaries (covariates only) are the same than those in Experiment 1, Tables 10 to 12. Given the large correlation between maternal education and language status ($r[73] = -.61$, $p < .001$), multicolinerarity was assessed in the regression analyses using variance inflation factors (VIF). VIF indicates to what extent the variance of a regression coefficient is inflated due to multicollinearity in the model. High VIFs (≥ 5) typically indicate multicollinearity issues. VIFs for all the variables in the models were below 1.79. Inhibitory control did not account for any additional variance in word-training performance over the covariates in any of the word training tasks. Chronological and degree of hearing loss predicted Arabic word training outcomes, accounting for 18% of the variance.

Table 18.

Summaries of the Hierarchical Regression Analysis of Inhibitory Control on Word- Training Outcomes

	English WT			Spanish WT			Arabic WT		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Chronological age	2.58	1.89	0.17	1.11	1.52	0.09	3.58	1.86	0.23
Degree of HL	-0.07	0.11	-0.08	-0.10	0.09	-0.14	-0.24	0.10	-0.26*
Language status	6.68	5.91	0.17	4.41	4.76	0.15	10.30	5.82	0.26
Maternal education	9.78	5.95	0.26	6.18	4.80	0.21	14.27	5.87	0.36*
Inhibitory control	-0.02	0.01	-0.16	-0.01	0.01	-0.13	0.00	0.01	0.01
Adjusted R^2		0.09			0.04			0.18	
R^2 Change		0.00			-0.01			-0.01	
F for change in R^2		1.53			0.97			0.01	

Notes. HL= Hearing Loss; WT = Word Training.
$*p < .05$. $**p < .01$.

Research Question 2: Does inhibitory control predict word retention? Table 19 shows the summaries of the hierarchical regression models assessing the effect of inhibitory control (incongruent reaction time) on word retention in addition to the covariates. Model 1 summaries (covariates only) are the same than those in Experiment 1, Tables 13 to 16. Inhibitory control predicted an additional 8% of the English word-retention variance over the covariates and it was the only significant predictor in the model. Inhibitory control did not predict word retention in any other language.

Table 19.

Summaries of the Hierarchical Regression Analysis of Inhibitory Control on Word Retention

	English WR			Spanish WR			Arabic WR		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Chronological age	0.95	2.67	0.04	1.40	2.50	.07	4.26	3.03	0.17
Degree of HL	-0.06	0.15	-0.04	-0.30	0.14	-.25*	-0.51	0.17	-0.35**
Language status	3.13	8.25	0.06	9.03	7.74	.18	4.03	9.37	0.07
Maternal education	11.97	8.30	0.22	-1.69	7.79	-.03	13.54	9.43	0.22
Inhibitory control	-0.05	0.02	-0.34**	-0.02	0.02	-.18	0.02	0.02	0.13
Adjusted R^2		0.15			0.12			0.17	
R^2 Change		0.08			0.03			0.06	
F for change in R^2		7.35**			2.07			1.10	

Notes. HL= Hearing Loss; WR = Word Retention.
*$p < .05$. **$p < .01$.

Research Question 3: Do language and hearing status interact to affect inhibitory control? Figures 10 and 11 show accuracy and reaction time for the incongruent trials by degree of hearing loss. A MANCOVA revealed a significant main effect of hearing status on inhibitory control after controlling for age, F (2, 66) = 3.31, p = .043, Wilks' Λ = .909, partial η^2 = .09. Pairwise comparisons revealed that children with normal hearing showed significantly higher accuracy in the incongruent trials than children with hearing loss (F [1, 67] = 5.19, p = .018, partial η^2 = .08). For reaction time, no main effect of hearing status was observed (F [1, 67] = 3.90, p = .052, partial η^2 = .05). Language status and the interaction between hearing and language status were not significant. These analyses were repeated using weighted means to adjust for unequal sample sizes in the groups, but the results did not differ from those reported above.

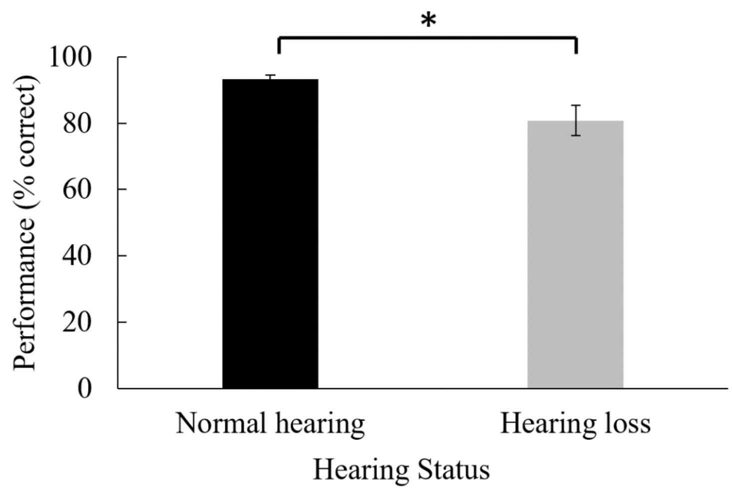

Figure 13. Incongruent accuracy by hearing status (means and standard error). *p < .05. **p < .01.

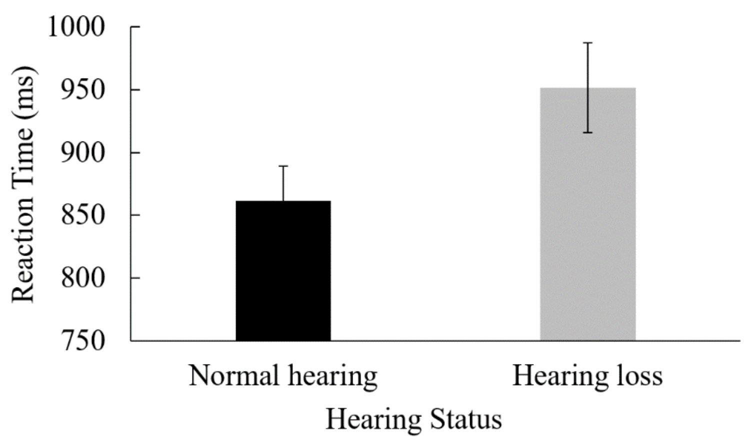

Figure 14. Incongruent reaction time by hearing status (means and standard error). *p < .05. **p < .01.

Discussion

The purpose of Experiment 2 was to examine the effect of inhibitory control on word learning, particularly, whether children with better inhibitory control learn and remember more words than children with poorer inhibitory control. This examination was accomplished by including children that differed in their inhibitory control; monolingual and bilingual children with normal hearing and monolingual and bilingual children with hearing loss. Children with better inhibitory control (i.e., shorter reaction times in the incongruent trials of the flanker task) learned and remembered more words than children with poorer inhibitory control. However, inhibitory control did not explain any variance in word learning in addition to chronological age, degree of hearing loss, and maternal education. Inhibitory control only predicted English retention outcomes. Children with hearing loss showed poorer inhibitory control than hearing peers, but differences were not observed by language status (monolingual vs. bilingual). Children with smaller vocabulary sizes showed poorer inhibitory control than children with larger vocabulary sizes.

As expected, children with hearing loss showed lower inhibitory control than children with normal hearing. While difficulties in executive function, including inhibitory control, have been well documented for children who are deaf (Figueras et al., 2008; Kral et al., 2016), studies are anecdotal for children with other degrees of hearing loss (Greiner et al., 2009). It has been suggested that the auditory deprivation that children with profound hearing loss experience early in life causes brain reorganization in which auditory areas are recruited to process other sensory information (Dorman, Sharma, Gilley, Martin, & Roland, 2007; Gilley, Sharma, & Dorman, 2008; Kral & Sharma, 2012). Brain reorganization could explain their language and executive function difficulties, including inhibitory control (Sharma, Campbell, & Cardon, 2015; Sharma, Dorman, & Spahr, 2002). Recent studies have shown that mild to severe and unilateral losses also cause brain reorganization and that reorganization occurs very soon after the onset of the hearing loss (e.g., Campbell & Sharma, 2014; Sharma & Glick, 2016;

Sharma et al., 2016). The results from the present study show that children with mild to severe hearing loss and children with unilateral losses demonstrate deficits in inhibitory control.

The prediction that bilingual children would show better inhibitory control than monolingual children was not supported by the data. All the children performed similarly in the incongruent trials. Therefore, bilingualism did not produce a protective effect for bilingual children with hearing loss. These results are in line with previous studies that did not find a bilingual advantage for executive function (e.g., Arizmendi et al., 2018; Desjardins & Fernandez, 2018; Gathercole et al., 2014; Namazi & Thordardottir, 2010; Paap, 2014; Paap et al., 2016) and in contrast with numerous studies that did find a bilingual advantage (Bialystok, 1999; Prior & MacWhinney, 2010; Wiseheart et al., 2016). Most of the studies arguing a bilingual advantage for executive function have been conducted in Canada and Europe, in bilingual communities where children receive bilingual education and languages show a similar status. Bilingual children in the present study were English-dominant who spoke Spanish at home and received English-only education. It is possible that, in order to experience a bilingual advantage, children need to be active bilinguals in different contexts, rather than using one language at home and one language at school. More practice activating and inhibiting words in both languages may produce an overall enhanced inhibitory control. It is also possible that inhibitory control tasks need to have high conflict for a bilingual advantage to show up (e.g., Costa et al., 2009).

The relationship between inhibitory control and vocabulary size can be explained by the Neighborhood Activation Model for word recognition. The model proposes that similar words or neighbors compete with each other in order to be recognized (Luce & Pisoni, 1998). It is possible that children with larger vocabularies had more practice inhibiting competitor words (i.e., words that sound similar) than children with smaller vocabularies, which may have enhanced their overall inhibitory control. The fact that better inhibitory control predicted vocabulary size and word retention in English (the dominant language for all participants) suggests that language experience may mediate inhibitory control and not the other way around. If inhibitory control were to have an impact on overall word learning, its effect should have been present for words in each language, not just English. This is in line with previous studies suggesting that language experience may influence inhibitory control and not vice versa (e.g., Botting et al., 2017; Zelazo et al., 2003).

General Discussion

The overall goal of this study was to examine how vocabulary size and inhibitory control affect word learning in bilingual children with hearing loss compared to monolingual peers with and without hearing loss. Experiment 1 examined whether children with larger vocabularies learn and retain more words than children with smaller vocabularies. Experiment 2 examined whether children with better inhibitory control learn and remember more words than children with poorer inhibitory control. Larger vocabularies were predictive of better word training outcomes in all languages and better Spanish word retention. Inhibitory control did not explain the variance in word learning, except for English word retention. Children with smaller vocabulary sizes showed poorer inhibitory control than children with larger vocabulary sizes. Children with hearing loss performed more poorly for Spanish and Arabic training and retention than children with normal hearing.

The results from this study suggest that language experience (measured by total vocabulary size) helps children learn new words, at least on immediate word training. However, inhibitory control does not seem to have an overall effect on word learning (training and retention). Two different explanations may help clarify this finding. First, language experience may influence inhibitory control but not vice versa. This is supported by the fact that children with larger vocabularies showed better inhibitory control, which in turn predicted English retention, the dominant language of all the children in the study. Second, inhibitory control may have predicted English retention because these words were learned more efficiently than words in the other languages, as indicated by the better word retention. It is possible that there was more competition among English words in the retention task, as compared to Spanish and Arabic, and thus inhibitory control was needed to activate the target words. Future studies should further explore the relationship between language experience, inhibitory control, and word learning.

The ability to retain words was directly related to success during word training. Training tasks provided children with word exposure whereas retention tasks required children to retrieve the stored words. Children with higher training scores were able to remember more words the next day than children with lower scores. Variance in training scores was explained by maternal education and vocabulary size. Children with large vocabularies and high maternal education levels showed the highest training scores. Variance in retention was explained by maternal education and inhibitory control for the English words and by degree of hearing loss for Spanish and Arabic words. Children with hearing loss remembered fewer words in Spanish and Arabic than hearing peers, but they did not differ on the type of errors made in the retention tasks. The most common error for all the children was selecting one of the five words learned during the training task, indicating that children remembered the words they learned, but not in association with the corresponding pictures. It is possible that the degraded input children with hearing loss receive may have limited their ability to create accurate representations of the words, especially words containing phonemes that do not exist in their native language (e.g., Arabic phonemes). These degraded word representations may limit the encoding of the words in long term memory, limiting retention of the word-picture associations on the next day. It is possible that having more exposures to the new words may help children with hearing loss create more accurate representations and remember the new words (Pittman et al., 2005; Stelmachowicz et al., 2004).

Of particular interest was to investigate whether or not the bilingual advantage due to better inhibitory control could mitigate the word learning difficulties associated with hearing loss. The results revealed that that bilingual children showed larger total vocabularies than monolingual peers and that vocabulary size predicted word training outcomes. However, language status by itself (monolingual vs. bilingual) did not reveal significant differences on word learning and inhibitory control. Bilingualism did not produce a protective nor detrimental effect on bilingual children with hearing loss who showed similar inhibitory control and word learning abilities as the monolingual children with hearing loss. The previous studies that found a bilingual advantage on word learning included children from high maternal education levels attending dual immersion schools, whereas the bilingual children in this study were drawn mostly from low maternal education families attending English-only education (Kaushanskaya et al., 2014; Poepsel & Weiss, 2016). The fact that bilingual children, despite coming from low maternal education backgrounds, show comparable vocabularies and word learning abilities to monolingual peers could be the demonstration of the bilingual advantage.

Limitations and Future Directions

The diversity in language and hearing status in this sample was both an asset and a limitation. It allowed for a range of vocabularies and hearing loss, but added complexity to the models in terms of the covariates. A clear example is maternal education. Maternal education was included in the analyses because it has been shown to affect vocabulary and word learning (Hoff, 2006; Maguire et al., 2018; Quittner et al., 2016), however, the majority of the children with low maternal educational levels were bilingual. While this represents the reality of this population, it limits the ability to separate the effects of hearing loss and maternal education on word learning in the bilingual hearing loss group. Future studies evaluating this relationship should include bilingual children with higher maternal educational levels.

Children with hearing loss are a heterogeneous group in terms of the degree, configuration, and involvement of the hearing loss, as well as the type of hearing aids used. Although all the children included in the study had permanent hearing loss, they varied in age of identification of the hearing loss, intervention with amplification and the educational services received. It is also important to note that the majority of the children in the bilingual group had unilateral hearing losses, exhibiting better hearing thresholds than monolingual peers, which could have provided bilingual children with better access to the novel words than monolingual children. All of the children were attending mainstream schools at the time of the study, but some children had received specialized education in the past, including early intervention, while others did not. Given this variability, it is important to be cautious when generalizing the results of this study.

Finally, this study assessed inhibitory control using a visual task (i.e., the flanker task). This allowed for comparisons with previous studies on executive function in children with hearing loss and bilingual children. However, it is unknown if different results could be found using a task that included linguistic or acoustic stimuli. Unfortunately, using linguistic or acoustic effects could be confounded by bilingualism and hearing loss. For example, other studies have assessed inhibitory control using dichotic listening tasks (e.g., Desjardins & Fernandez, 2018; Soveri, Laine, Hämäläinen, & Hugdahl, 2011), where children hear different words or syllables in each ear and they have to indicate the ear receiving the target stimulus. A dichotic listening task would have posed a problem in this study, even when playing stimuli at audible levels. Because some children had asymmetrical hearing losses, this would limit the ability to decide whether deficits in this task are associated with poor inhibition or asymmetric hearing loss. Future studies may examine whether there are differences in inhibitory control between linguistic and visual domains by creating inhibitory control tasks that take into account bilingualism and hearing loss.

Clinical Implications

Bilingual exposure does not impair word learning in children with hearing loss. Bilingual children showed similar difficulties with word learning and inhibitory control as their monolingual peers with hearing loss. This provides further evidence, in addition to previous studies, that children with language impairments can learn a second language if provided with appropriate support (e.g., Bird et al., 2005; Restrepo, Morgan, & Thompson, 2013). Professionals should encourage families to use whichever language is more natural for them in order to create rich language environments where new words can be learned.

Children with mild-to-severe hearing loss had difficulties with the visual inhibitory control task, suggesting that hearing loss, probably via language deprivation, has broad effects on children's executive function skills. This finding is in line with previous studies on executive function and children who are deaf (e.g., Figueras et al., 2008; Kral et al., 2016) and it has implications for both assessment and treatment practices. Clinical assessments should not be limited to language measures and should account for potential deficits in executive function to determine children's overall learning abilities. Poor executive function, such as reduced attention and inhibitory control, may affect reading and writing skills and subsequently academic achievement. Implementing strategies such as developing self-talk for planning and problem solving (e.g., Figueras et al., 2008), in addition to language support strategies, may help mitigate deficits in executive function in children with hearing loss.

Finally, having large vocabularies help children learn new words. It is crucial that hearing loss is identified early and that children receive well-fitted hearing aids to provide them with access to spoken language. Schools should provide accommodations for children with hearing loss, such as the use of remote microphones or reduced background noise in the classrooms. These accommodations should be also offered to children with unilateral losses as well because they show similar word learning difficulties as children with bilateral losses. Ensuring that children with hearing loss, both monolingual and bilingual, have appropriate access to spoken language will help prevent delays in word learning and thus in vocabulary.

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APPENDIX A

APPROVAL: EXPEDITED REVIEW

On 12/5/2016 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Principles of Word Learning
Investigator:	Andrea Pittman
IRB ID:	STUDY00005363
Category of review:	(7)(b) Social science methods, (7)(a) Behavioral research
Funding:	Name: Northwestern University Evanston
Grant Title:	
Grant ID:	
Documents Reviewed:	• IRB Protocol Application PoWL.docx, Category: IRB Protocol; • Word Learning Post Test, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • PoWL Assent Form - Child.pdf, Category: Consent Form; • PoWL Consent Form - Adults.pdf, Category: Consent Form; • Visual Pattern Completion Task, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Advertisement_Flyer_Children.pdf, Category: Recruitment Materials; • Advertisement_Flyer_Adults.pdf, Category: Recruitment Materials; • PoWL Consent Form - Parent.pdf, Category: Consent Form;

	• Knowles Grant Application, Category: Grant application; • Wright.Pittman.Knowles.Proposal.9.29.16.docx, Category: Sponsor Attachment;

The IRB approved the protocol from 12/5/2016 to 12/4/2017 inclusive. Three weeks before 12/4/2017 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 12/4/2017 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB

Administrator

APPENDIX B

CAREGIVER LANGUAGE QUESTIONNAIRE

I. Family information

How many family members live in the home?

How many siblings does your child have?

What is the birth order of the child among his/her siblings? 1º□ 2º□ 3º□ 4º □ 5º□ 6º□

What is the language you use at home?

Does the child speaks a language other than English or Spanish?

Who is with the child most of the time when the child is not in school?

Relationship to child	**Age**	**Highest Education Level**	In which language(s) does this individual **speak to** the child (combine if more than one)	In which language(s) does **the child respond** to this individual (combine if more than one)
☐ Mother		Years in education: □ Elementary □ High School □ College/University	□ Spanish □ English ☐ Other:	□ Spanish □ English ☐ Other:
☐ Father		Years in education: □ Elementary □ High School □ College/University	□ Spanish □ English ☐ Other:	□ Spanish □ English ☐ Other:
☐ Sister/Brother		Years in education: □ Elementary □ High School □ College/University	□ Spanish □ English ☐ Other:	□ Spanish □ English ☐ Other:
☐ Sister/Brother		Years in education: □ Elementary □ High School □ College/University	□ Spanish □ English ☐ Other:	□ Spanish □ English ☐ Other:
Other:(Explain, e.g. grandfather, uncle, baby-sitter, etc)		Years in education: □ Elementary □ High School □ College/University	□ Spanish □ English ☐ Other:	□ Spanish □ English ☐ Other:

(FOR CHILDREN WITH HEARING LOSS ONLY)

Age of hearing loss identification:

Age of first hearing aids:

Current hearing aids:

Age of enrolment in early intervention (if applicable):

(FOR BILINGUALS ONLY)

II. Child Information

Order of proficiency: *What language does your child speak best?*

1	2	3	4	5

Order of acquisition: *What language did your child learn first?*

1	2	3	4	5

Age when your child:

	Began acquiring	Became fluent	Began reading
Spanish			
English			
Other:			

Please indicate number of years in:

_______Dual Language School (English-Spanish)
_______English-Only Education
_______Spanish-Only Education

Time in a Spanish-speaking country:

1 = Very poor
2 = Poor
3 = Acceptable
4 = Good
5 = Very good

On a scale from zero to five, please rate your child's level of **proficiency** in:

Speaking			Understanding			Reading		
Spanish	English	Other:	Spanish	English	Other:	Spanish	English	Other:

Language **preference:**
When choosing to read a book, or a book to be read to, what language do you prefer?

_______English _______Spanish _______No preference

When choosing a language to speak with someone who is equally bilingual, what language do you prefer?

_______English _______Spanish _______No preference

We are interested in what a typical day during the week and during the weekend is like for your child. What activities s/he participates in, who s/he interacts with and what language(s) s/he uses and hears?

Typical weekday

	Participants	Activity	Waking hours	Languages					
	Parent, sibling, peer			Participant-Input			Participant-Output		
Time				Spanish	Both	English	Spanish	Both	English
7 am			1	2	1	0	2	1	0
8 am			1	2	1	0	2	1	0
9 am			1	2	1	0	2	1	0
10am			1	2	1	0	2	1	0
11 am			1	2	1	0	2	1	0
12 am			1	2	1	0	2	1	0
1 pm			1	2	1	0	2	1	0
2 pm			1	2	1	0	2	1	0
3 pm			1	2	1	0	2	1	0
4 pm			1	2	1	0	2	1	0
5 pm			1	2	1	0	2	1	0
6 pm			1	2	1	0	2	1	0
7 pm			1	2	1	0	2	1	0
8 pm			1	2	1	0	2	1	0
9 pm			1	2	1	0	2	1	0
10 pm			1	2	1	0	2	1	0
11 pm			1	2	1	0	2	1	0
			Sum weekday hours: (E)	______ + ______ = (A) Sum weekday input score:			______ + ______ = (C) Sum weekday output score:		

Typical weekend day (choose the day -- Saturday or Sunday -- when your child is involved in more activities)

	Participants	Activity	Waking hours	Languages					
	Parent, sibling, peer			Participant-Input			Participant-Output		
Time				Spanish	Both	English	Spanish	Both	English
7 am			1	2	1	0	2	1	0
8 am			1	2	1	0	2	1	0
9 am			1	2	1	0	2	1	0
10 am			1	2	1	0	2	1	0
11 am			1	2	1	0	2	1	0
12 am			1	2	1	0	2	1	0
1 pm			1	2	1	0	2	1	0
2 pm			1	2	1	0	2	1	0
3 pm			1	2	1	0	2	1	0
4 pm			1	2	1	0	2	1	0
5 pm			1	2	1	0	2	1	0
6 pm			1	2	1	0	2	1	0
7 pm			1	2	1	0	2	1	0
8 pm			1	2	1	0	2	1	0
9 pm			1	2	1	0	2	1	0
10 pm			1	2	1	0	2	1	0
11 pm			1	2	1	0	2	1	0
			Sum weekday hours: (F)	______ + ______ = (B) Sum weekday input score:			______ + ______ = (D) Sum weekday output score:		

Home language exposure profile worksheet

STEP		Enter		Enter			
A	Enter total weekday Input Score		Multiply weekday Input Score by 5		Add scores =		(input numerator)
B	Enter total weekend Input Score		Multiply weekend Input Score by 2				
C	Enter total weekday Output Score		Multiply weekday Output Score by 5		Add scores =		(output numerator)
D	Enter total weekend Output Score		Multiply weekend Output Score by 2				
E	Enter total weekday hours		Multiply weekday hours by 10		Add scores =		(denominator)
F	Enter total weekend hours		Multiply weekend hours by 4				

STEP								
G	Input numerator (from step A)		Divide scores (A ÷ F)		X100=	% Spanish input (SI)	Subtract from 100% =	% English input (EI)
	Denominator (from step F)							
H	Output numerator (from step D)		Divide scores (D ÷ F)		X100=	% Spanish output (SO)	Subtract from 100% =	% English output (EO)
	Denominator (from step F)							