WORD LENGTH AND SYLLABLE SHAPE EFFECTS ON SEGMENTAL ACCURACY IN BILINGUAL CHILDREN WITH COCHLEAR IMPLANTS AND THEIR PEERS WITH NORMAL HEARING

by
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Abstract

Purpose: The purpose of this study is to analyze speech production patterns of bilingual Spanish- and English-speaking bilingual children with hearing loss who use cochlear implants and their peers with normal hearing by specifically focusing on how hearing status, language, syllable complexity, and word length affect segmental accuracy.

Method: Forty bilingual Spanish- and English-speaking children between the ages of 5;3 and 7;9 (years; months) from the greater Houston metropolitan area participated in the study. Twenty participants were cochlear implant users and 20 had normal hearing. The participants were matched across groups on chronological age, gender and socio-economic status as closely as possible. Cochlear implant users received their implants before they turned 3 years old (i.e., early implanted) and had at least 3 years of implant experience. A single-word elicitation task was used to prompt the target words in each language, using culturally- and age-appropriate items consisting of about 80 words in each language. A subset of the items was selected for the analyses to test the effects of hearing status (cochlear implant users versus their age-matched peers with normal hearing), language (Spanish versus English), word length in syllables (monosyllabic, disyllabic, and trisyllabic), and syllable complexity (no clusters versus including clusters) on segmental accuracy (percent segments correct). A repeated measures analysis of variance was conducted with hearing status as the between-subjects variable as well as three within-subjects factors: language, word length in syllables, and syllable complexity with segmental accuracy (percent segments correct) as the dependent variable.

Results: There was a statistically significant main effect of hearing status [F (1, 35) = 40.24 at p < 0.001, partial η^2 = 0.54], language [F (1, 35) = 4.57 at p = 0.040 , partial η^2 = 0.12], word

length in syllables [F (2, 70) = 13.42 at $p < 0.001$, partial $\eta^2 = 0.28$], and syllable complexity [F (1, 35) = 52.63 at $p < 0.001$, partial $\eta^2 = 0.60$] on segmental accuracy. Statistically significant interactions included hearing status by word length in syllables [F (2, 70) = 5.88 at $p = 0.004$, partial $\eta^2 = 0.14$], hearing status by syllable complexity [F (1, 35) = 18.20 at $p < 0.001$, partial $\eta^2 = 0.34$], language by word length in syllables [F (2, 70) = 18.03 at $p < 0.001$, partial $\eta^2 = 0.34$], language by word length in syllables by hearing status [F (2, 70) = 4.63 at $p = 0.013$, partial $\eta^2 = 0.12$], language by word length in syllables by syllable complexity [F (2, 70) = 10.67 at $p < 0.001$, partial $\eta^2 = 0.23$].

Conclusions: Hearing status, language, word length in syllables, and syllable complexity all had statistically significant effects on segmental accuracy, as predicted. Furthermore, interdependence between hearing status by syllable complexity suggests that more complex syllables are disproportionally more challenging for bilingual cochlear implant users than their peers with normal hearing. The interactions of hearing status by syllable complexity, language by word length, language by word length by hearing status, as well as language by word length by syllable complexity indicate the interdependence of these factors, painting a complex picture that is as informative for researchers in the field as it is for practicing speech-language pathologists, audiologists, and educators who work with bilingual children with hearing loss and their peers with normal hearing.

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Introduction

According to the National Institute on Deafness and Other Communication Disorders (NIDCD), as of December 2012, approximately 38,000 children have received cochlear implants in the United States. In addition, the NIDCD reports that there are more than 324,000 individuals worldwide with cochlear implants (NIDCD, 2013). Because the number of cochlear-implant users is still growing exponentially, there is an urgency to focus on research on speech processing and production in this area (Zeng, 2004). Moreover, there is an increasing number of children from households where the language spoken is other than the language of the majority, so it is becoming more common to have young cochlear implant (CI) users grow up speaking more than one language.

Bilingualism is common and is on the rise in many parts of the world, with perhaps one in three people being bilingual or multilingual (Wei, 2000). In the US, the number of individuals under 5 years of age who speak a language other than English at home has also been growing steadily (US Census Bureau, 2010), including individuals with hearing loss who may either use or will need cochlear implants. Lack of knowledge of speech development in bilingual individuals with hearing loss who use cochlear implants is a problem, because it is an understudied area that needs to be addressed. Therefore, understanding speech development in bilinguals with hearing loss who use cochlear implants is critical. This study aims to ameliorate this issue by analyzing consonant cluster patterns in varying syllable word shapes produced by bilingual children with cochlear implants (CIs) and their peers with normal hearing (NH).

Phonological Skills of Bilingual Children with Normal Hearing

Before turning to investigating the phonological skills of bilingual CI users, it is essential to examine the phonological system of bilingual children with normal hearing (NH) to gain insights into their speech sound production and perhaps a better understanding of the differences between bilingual children with CIs and their peers with NH.

In order to gather the information on bilingual children with typically developing phonological systems, the literature of previous studies in this area needs to be reviewed. Hambly, Wren, McLeod, and Roulstone (2012) conducted a systematic review of the influence of bilingualism on speech production and found that there was an overuse of standardized measures designed for monolingual speakers being implemented in bilingual speakers, resulting in potential mis- or under-representation of the true phonological abilities because speech patterns of bilinguals may differ in both qualitative and quantitative ways from the patterns attested in monolingual children (Hambly et al., 2012).

Additionally, the data collected for the systematic review yielded a set of patterns that were common across various studies. One can use these commonly occurring patterns as a reference to interpret the essential characteristics of the development of phonological systems of bilingual children (Hambly et al. 2012). Specifically, the authors reviewed articles investigating various aspects of speech development in children who are exposed to a bilingual or multilingual environment, aiming to describe the effects of the number of languages they were exposed to, age and timing of exposure, and degree of proficiency in each language (Hambly et al., 2012).

Most articles found in the systematic review by Hambly et al. (2012) gathered data in the form of audio or video recordings of spontaneous or prompted speech. Speech acquisition studies involved phoneme repertoires and phonological error patterns attested in bilingual children between 2 and 6 years of age as well as other aspects of speech (such as speech perception and speech production skills). The studies reviewed used a variety of measures such as the Goldman-Fristoe Test of Articulation (Goldman & Fristoe, 2000), South Tyneside Assessment of Phonology (STAP) (Armstrong & Ainley, 2012), Cantonese Segmental Phonology Test (So, 1993), or the Bilingual English-Spanish Assessment (BESA) (Peña, Gutierrez-Clellen, Iglesias, Goldstein & Bedore, 2014). Some of the most common patterns attested in the speech of bilingual children relative to those of their monolingual peers were lower accuracy in consonant cluster production (Gildersleeve-Neumann et al. 2008) and lower consonant accuracy (as measured by percentage of consonants correct) for Spanish than English with earlier developing sounds (Fabiano-Smith and Goldstein 2010). However, the authors concluded that there is not enough evidence to demonstrate whether or not bilingual children acquire language at a slower or faster rate than their monolingual peers.

Related to language use, proficiency and cross-linguistic interaction, Paradis and Genesee (1996) studied transfer to account for interaction between the two language systems in bilingual children. The authors investigated the grammars of two- to three-year-old French- and English-speaking bilingual children from Canada to find out whether their language systems were autonomous or if there was evidence of interdependence, meaning the influence of a language system on another during acquisition, thus creating a differential pattern and rate of development in contrast to their monolingual peers.

Paradis and Genesee (1996) proposed the idea that interdependence works as the influence of the grammar of one language on the grammar of the other language during bilingual language acquisition, which can cause differences in bilingual patterns and rates of development in comparison to their monolingual peers. The authors also illustrated three potential manifestations of interdependence: transfer, acceleration, and delay. Transfer is defined as the incorporation of a grammatical property from one language into another. Acceleration is defined as the capacity for interdependence to cause the acquisition of certain grammatical properties in a bilingual's language to be acquired earlier than in their monolingual peers. Opposite of acceleration, delay, is defined as the influence that bilingual acquisition can have on an individual, causing them to acquire certain grammatical properties later than their monolingual peers.

Fabiano-Smith and Barlow (2010) examined the interaction that contributes to phonological acquisition in bilingual children through acceleration, deceleration (analogous to Paradis and Genesee's "delay") and transfer based on the work conducted by Paradis and Genesee (1996) to find if there was an interaction of the bilingual phonological systems of the participants. Fabiano-Smith and Barlow concluded that bilingual phonetic inventories were commensurate with their monolingual peers in that bilingual children organized their phonemic inventories in the same hierarchical fashion as their monolingual peers (2010), but specific differences were found in that bilingual children demonstrated slower acquisition of certain English and Spanish sounds. Regarding accuracy in English, slower acquisition was found in fricatives and glides, and in Spanish, acquisition was slower for stops relative to monolingual peers in each language. However, the overall patterns for bilingual children and their monolingual peers were commensurate, despite specific differences between bilingual and monolingual children as was found by Fabiano-Smith and Goldstein (2010). Furthermore, bilingual children presented with evident patterns of deceleration and transfer in their phonological profiles; a finding that has been replicated (cf. Fabiano-Smith & Goldstein, 2010;

Gildersleeve-Neumann, Davis, & Stubbe, 1996; Yavas & Goldstein 1998). Fabiano-Smith and Barlow (2010) also found evidence of transfer between English and Spanish in the phonetic inventories of bilingual children that the authors took as evidence for cross-linguistic interaction between the two languages, but linguistic autonomy was also found in the Spanish versus English productions of their participants. For example, when the authors examined the levels of complexity in English and Spanish, most bilingual children were at level D in Spanish, but level E in English, which the authors attributed to bilingual children recognizing the differences between their target languages.

In a similar study, Fabiano-Smith and Goldstein (2010) reviewed phonological acquisition in bilingual Spanish- and English-speaking children referring to the findings of Paradis and Genesee (1996) to explain the relationship between two phonological systems as interdependent or interacting with each other during bilingual phonological acquisition. Fabiano-Smith and Goldstein (2010) hypothesized that bilingual children perceive phonetically similar sounds (such as /p/ or /b/ that occur in both languages) as common ("shared") between the two languages and categorize them into the same phonemic category despite their fine phonetic distinctions (such as aspiration in stops). Fabiano-Smith and Goldstein (2010) found evidence that bilingual children have two separate phonological systems, and the systems interact with each other to improve the rate of language acquisition. However, the results of their study were not consistent with Paradis and Genesee's (1996) hypothesis of acceleration. "Rather, they demonstrated phonological skills that fall within the typical range for their monolingual peers." (Fabiano-Smith & Goldstein, 2010, p. 174). The findings of Fabiano-Smith and Goldstein (2010) indicate that although bilingual children demonstrate separation between their two phonological systems, those systems interact and affect the rate of phonological acquisition. Although the authors found that bilingual children demonstrated a slower rate of acquisition than their monolingual peers on some measures (e.g., segmental accuracy), the skills in the bilingual children were within the normal range of those for monolingual children in both English and Spanish.

Watson (1991) examined phonological acquisition in bilingual children and presented the idea that to master phonology, a child has to "(a) learn to recognize distinct, but non-invariant, acoustic patterns, (b) deduce the set of oppositions that constitute the phonological structure of the language; (c) associate the acoustic patterns with the phonological system, despite the non-invariance of the former; (d) and master the correct articulatory routines to produce acoustic patterns that satisfy other native speakers as being adequate realizations of different phonemes." (p. 27)

Bunta, Davidovich, and Ingram (2006) explored the relationship between the phonological complexity of a child's produced words and those of the target words being attempted. Their study was conducted on an English-Hungarian-speaking 2-year-old child to explore the similarities of the child's word shapes and consonant inventories of the two languages to prove whether a bilingual phonological system works as one or two systems. The authors claimed that the basic phonological building blocks (such as phonological features or syllable shapes) were common to the two languages, but the Hungarian and English phonological systems of the child were differentiated, and the child appeared to approximate her target languages differently and in a language-specific fashion.

Early versus late acquisition and relative complexity of the target sound were factors explored in Bunta et al. (2006) that may influence the development and understanding of phonological acquisition. The authors suggested elements that may influence when and how acquisition takes place, such linguistic markedness of segments or phonological properties of the target language, proposing a target-driven hypothesis where the need to match the specific linguistic targets drives phonological development. Bunta et al. (2006) suggest the idea that phonological acquisition may not be motivated just by a need to increase word complexity, but it may also be motivated by a need to maintain a constant relationship between the child's production and their targets. Their findings justify the idea that surface differences exist across the target languages, supporting theories of separation in bilingualism, but there also exist underlying phonological building blocks on which those disparate systems are built.

Gildersleeve-Neumann, Kester, Davis, & Peña (2008) conducted a study on English speech sound development in preschool-aged children from bilingual English-Spanish environments. The authors examined the speech of 33 participants (3;1 to 3;10 years old) divided into groups of monolingual English speaking, predominantly English-speaking bilingual, and balanced bilingual English-Spanish groups. Gildersleeve-Neumann et al. (2008) used a single-word list to elicit items with words that varied in length and phonotactic complexity. The authors studied the background information on English and Spanish phonology as well as their general phonological properties, taking into account the fact that the phonemes /p, b, t, d, k, g, m, n, j, tʃ, s, w, l/ occur in both Spanish and English. "If children have already mastered the production system for a phoneme, they can more readily transfer it to support word-level accuracy in a second language." (Gildersleeve-Neumann et al., 2008, p. 323). Word complexity and final consonant deletion results showed differences between predominantly English-speaking bilingual children and the balanced English-Spanish speaking group. For final consonant deletion, the balanced English-Spanish group displayed higher proportion of it than the other groups, because this group had the least exposure to English word-final consonants due to the fact that Spanish permits only five final consonants and many words end in open syllables (i.e., vowel-final). Gildersleeve-Neumann et al. (2008) found that consonant clusters were less frequent and cluster types were more constrained in Spanish than in English, and the results of the balanced English-Spanish speaking bilingual group showed higher errors for cluster production in contrast to the predominantly English-speaking group. The authors stated that "cluster reduction is a late disappearing production system effect, which is likely related to difficulty in producing differing consonant closures in a sequence" (p. 323).

Phonological Skills of Young Cochlear Implant Users

Monolingual English-Speaking Young Cochlear Implant Users

A cochlear implant (CI) is a device that bypasses damaged hair cells in the cochlea (the inner ear) and stimulates the auditory nerve directly. This device helps provide sensation of sound to an individual who has severe to profound sensori-neural hearing loss that also allows the individual to understand speech. However, the signal that the CI provides is qualitatively different from the sound perceived by an individual with normal hearing (NH) or with a hearing aid (HA), because the CI bypasses damaged portions of the ear to stimulate the auditory nerve directly, but in doing so, there is signal loss. Specifically, fine temporal cues are especially vulnerable to loss, because the CI does not represent the range of accessible sounds audible to the human ear with largely intact anatomy. Naturally, the diminished signal has various effects on not only the perception of speech, but also how CI users produce speech (Ji, Galvin, Xu, & Fu, 2013).

When a child is unable to perceive a sound accurately, as it happens with certain sounds by CI users, s/he may develop speech patterns that substitute, modify or delete the target sound. Serry and Blamey (1999) conducted a 4-year investigation into phonetic inventory development in young cochlear implant users. Nine children with CIs were monitored during the first 4 years of implant use. Targetless criterion (the child producing a phonetically recognizable sound spontaneously) and target criterion (sound produced 50% correctly in meaningful words) were used to analyze phonemes from spontaneous speech samples. The authors found that the order of acquisition of the sounds was directly related to the frequency of occurrence in the words used by the children with CIs, and the order of acquisition was similar to that of children with normal hearing. At 4 years post-implantation, 40 out of the 44 phones had been acquired using the targetless criterion by 5 or more children. The consonants had a steady rate of acquisition, and all of them reached the targetless criterion by the end of the study except for /ð/ and /ʒ/, which had very low frequency of occurrence in the words of the 69 samples. Serry and Blamey (1999) found that there was a significant correlation between speech perception scores in the auditory-visual condition and speech production results at 48 months post-implant.

Blamey, Barry, and Jacq (2001) conducted a 6-year follow-up study involving 9 profoundly deaf children with CIs, and used the same participants as in Serry and Blamey (1999). The authors collected speech samples at 5 and 6 years post-implantation. After 6 years of implant use, 8 of the 9 children had reached the target criterion for each of the phones. Blamey, Barry, and Jacq (2001) found that after 4 years of implant use, 9 children had reached the target criterion /m, w, b, d, h/. The authors had hypothesized that at least 5 out of 9 children would reach the phones /ɔɪ, t, k, ŋ, ð, dʒ, g, s, tʃ, z/ between 5 and 6 years post-implantation, but this target was not realized. However, after 6 years of implant use, children reached target criterion on all segments but /t, s, z, ʈʃ/.

Blamey and colleagues (2001) found that the speech sounds that occurred more frequently as targets would receive the most practice and might be expected to develop faster into adult-like production than the phones that occurred less frequently. The authors explained that articulatory differences could be a factor that contribute to sounds developing at slower rates, such as /t, s, tʃ, z/, which have the same alveolar/palato-alveolar place of articulation (Blamey et al., 2001).

Ertmer and Goffman (2011) investigated speech production accuracy and variability in young cochlear implant users in comparison with typically developing (TD) peers. The authors investigated the developmental issues in children with cochlear implants at 3;0 (years; months) of implantation and employed TD gender- and age-matched peers as controls to assess progress toward age-appropriate speech production abilities during the first 2 years of device use. Ertmer and Goffman (2011) compared the children with cochlear implants and their TD peers using a naming task with 3 repetitions of each item. Their results supported the idea that CI users had lower accuracy in speech production and more variability than their peers with TD with the largest variability involving later acquired sounds. The authors also found atypical order of acquisition in the CI group in that certain sounds seemed to pose a disproportionate challenge for them (such as /s l/). The authors compared their participants' progress with the participants in Tobey, Brenner, Geers, and Altuna (2003) and found that the CI users appeared to be making rapid progress in speech production accuracy compared with the children in Tobey et al. (2003) who received CIs at an older age. These findings support other findings in a study by Connor, Craig, Raundebush et al. (2006) that implantation before 6 years of age provides added value for speech development.

Focusing on a different aspect of phonology, Flipsen and Parker (2008) studied the phonological patterns (also referred to as phonological processes in the relevant literature) in the conversational speech of CI users. The authors investigated the differentiation of developmental from non-developmental phonological patterns, the identification of patterns seen in CI users, and understanding the direction of pattern occurrence over time in CI users. The authors described developmental patterns as the ones that occur regularly in the speech of younger, typically developing children and non-developmental patterns as those that tend not to occur during typical speech development. The authors found that children with CIs presented largely with the same frequent developmental patterns observed in children with NH and HAs, demonstrating that the patterns of CI users mostly mirrored their peers’ developing systems. Non-developmental processes did occur in the speech of CI users, but they did so at minimal a rate of 2.4%. Flipsen and Parker (2008) identified that the speech development in children with CIs included cluster reduction, stopping, and diphthong simplification.

Chin and Pisoni (2000) conducted a study investigating the phonological system of a child after 2 years of cochlear implantation. The authors looked at the sound patterns of the child through sound production without comparing them to speech sound productions of the ambient language (English) by children with NH. Chin and Pisoni (2000) described the child’s phonological system on the basis of inventory of consonants and vowels as well as phonotactic constraints, or production restrictions in possible sequences of sound segments. The authors found that the participant did not produce /ɹ/ in any of the word samples. Furthermore, the authors claimed that the child had highly variable productions that were indicative of incomplete phonological representations.

Chin (2003) investigated consonant inventories after extended (minimum 5 years of) CI use, comparing CI users who used oral (auditory only) versus total (auditory and sign language) communication. Chin (2003) found that children in the total communication group had more non-English sounds than their peers in the oral communication group. Furthermore, children in the latter (oral communication) group also had larger phoneme inventories than their peers in the total communication group. Members of both groups displayed highly variable productions from a phonological perspective.

Chin and Finnegan (2000) studied the consonant cluster patterns in monolingual children with CIs. Nineteen word-initial consonant clusters were tested in 12 children that had at least 5 years of implant experience. The authors found that difficulty producing consonant clusters occurs, because cluster production relies on the integration and combination of the sounds. Greenlee (1973) conducted a study in realizations of consonant clusters in children with typical phonological development, and found that children progress through a series of stages in their acquisition of stop-liquid clusters: deletion of the entire cluster, reduction of the cluster to a singleton, production of the cluster with substitution of one of the segments, and correct cluster production. The findings of Greenlee (1973) provide insights into the importance of syllable positions, number of elements and how the consonant cluster is constituted.

Chin and Finnegan (2000) found that consonant cluster reduction occurs more frequently than consonant cluster deletion in the speech of CI users. Markedness and sonority of the constituent consonants in the cluster were claimed to have contributed to the accuracy of production of the clusters. Sonority constraints are explained with the Sonority Frequency

Principle and the Principle of Minimal Sonority Difference. The words tested included clusters with stops, liquids, and fricatives, such as: "plane", "blue", "brush", "tree", "clock", "glove", "green", and "sleep". Consonant clusters were considered correct if two contiguous consonants were produced, corresponding to the correct allophones of the target phonemes. Chin and Finnegan (2000) elicited 107 isolated words from each participant through a picture naming task, and the target words containing initial consonant clusters were divided into "fricative clusters" and "stop clusters". The authors found that children with CIs seemed to apply the same strategies used by children with NH in their development of clusters. Chin and Finnegan (2000) concluded that cluster realizations of children with 5 or more years of cochlear implant experience have similarities in the realizations of clusters to those of children with normal hearing.

Bilingual Young Cochlear Implant Users

As previously noted, children with hearing loss who use CIs may not have access to good spectral resolution, and that may affect certain aspects of speech – such as specific sounds – disproportionally. That means, for example, that certain sounds are not perceived clearly by CI users relative to individuals with normal hearing (NH) because of the sound's specific qualities that rely on good spectral resolution (such as centroid frequency of certain fricatives and affricates). Li, Bunta, and Tomblin (2017) found that among the sounds that are challenging to acquire for young children who use CIs tend to be fricatives and affricates; a finding that has been consistent in English speaking children and speakers of other languages such as Mandarin (Peng et al., 2008) and Croatian (Liker, Mildner, & Šindija, 2007; Mildner & Liker, 2008).

The study conducted by Li, Bunta, and Tomblin (2017) investigated the production of voiceless alveolar and post alveolar fricatives and affricates by bilingual and monolingual children with hearing loss (HL) who use CIs and their peers with NH. The divergent patterns in Spanish versus English fricatives and affricates and the diminished signal provided by CIs allow to investigate how bilingualism and the limited auditory signal provided by the device interact to produce unique speech patterns in bilingual children with HL who use CIs. Li et al. (2017) found that bilingual and monolingual children who use CIs and are learning Spanish and English simultaneously displayed unique patterns of fricative and affricate production. The authors looked at aspects of voiceless palatal and postalveolar fricatives and affricates such as mean centroid frequency of frication, frication duration, and rise time. On the basis of frication duration, rise time, and frequency in each language, the authors found that the participants across all groups were able to differentiate their target phonemes. However, for children with NH (both monolingual and bilingual), spectral mean frequency proved to be a more reliable and consistent cue than for CI users, which the authors claim can be attributed to the diminished signal provided by the device that affects fine temporal resolution disproportionally for CI users.

Sabri and Fabiano-Smith (2018) conducted a longitudinal study on the phonological development of a bilingual Arabic-English speaking child with bilateral cochlear implants. The authors compared their participant's speech production to that of her hearing age (HA) matched peers as well as her chronological age (CA) matched peers on traditional measures of phonological acquisition in English. The participant demonstrated consistent production of her later developing sounds at the beginning of the study, especially in English. Sabri and Fabiano-Smith (2018) proposed that the accuracy of their participant's production could be a result of earlier implantation in comparison to her peers from different studies.

Bunta, Douglas, Cantu, Dickson, Wickesberg, and Gifford (2016b) conducted a study on the effects of dual language versus English-only support on the English language skills of bilingual children with CIs. The participants were 20 Spanish- and English-speaking bilingual children with CIs, HAs or both. Each individual received their device before 5 years of age, had corrected pure tone averages (PTAs) of 40 dB HL or better. All individuals participated in oral communication programs for at least 1 year, and none of the participants had co-occurring disorders except for one that had a mild sensory processing disorder. To ensure consistency across groups, there were no statistically significant differences on hearing age, chronological age, age at initial device activation or maternal education across the two groups of participants.

Results indicated that the participants who received dual language support outperformed their bilingual peers who used English-only support on English language measures. The findings of Bunta et al. (2016b) supported the notion that providing support for the language spoken in the household is not detrimental for the language development of the child who has hearing loss and uses CIs or HAs. In fact, the results of Bunta et al.'s (2016b) study suggests that dual language support for bilingual children may promote and support the development of the language of the majority (in their case, English).

Bunta, Procter, Goodin-Mayeda, and Hernandez (2016a) studied the production of voicing contrast in initial stops in bilingual Spanish- and English-speaking CI users and their peers with NH. Voice Onset Time (VOT) and prevoicing were measured in their study using Wavesurfer to compare word-initial voiced and voiceless stop production. As previously mentioned, children with CIs receive qualitatively different spectral resolution from children with NH, but raw timing that is needed for VOT differentiation is transmitted relatively well by the CI. Bunta et al. (2016a) studied the speech production patterns in 22 bilingual children (11

NH aged 5;1, 11 CI users aged 5;1) where the participants produced a single word picture elicitation task with word initial singleton stop consonants. The authors found that children with NH and CI users were able to differentiate stop voicing in their languages using VOT and prevoicing reliably, supporting the idea that stop voicing is accomplished similarly between CI users and children with NH.

Bunta and Sosa (2019) conducted a study on the speech production accuracy and variability in monolingual and bilingual children with CIs in comparison to their peers with NH. The participants included 40 children divided into four groups (bilingual versus monolingual CI users and bilingual versus monolingual children with NH) who were between the ages of 5;6 and 5;9 years of age. The results showed that consonant accuracy in English displayed a hearing status effect but no monolingual versus bilingual difference. For the bilingual group, there was a hearing status effect and a language effect (Spanish consonants tended to be more accurate than English ones). Regarding whole-word variability, again, there was a hearing status effect but no monolingual versus bilingual effect on English. In terms for whole-word variability, just as for consonant accuracy, there was both a hearing status and a Spanish versus English language effect in that Spanish tended to display less variable productions than English. Bunta and Sosa (2019) concluded that children with CIs present with lower rates of PCC and PVC, as well as much higher rates of whole-word variability in comparison to their peers with NH.

The research on how bilingual children with HL who use CIs acquire their phonological systems is promising, but there are significant gaps in our understanding of how young CI users can acquire the phonological systems of two spoken languages, such as Spanish and English. To date, there has been no research done on consonant cluster productions or word length effects on the speech patterns of bilingual Spanish- and English-speaking children who use CIs. Through conducting this research on bilingual Spanish- and -English- speaking CI users and their peers with NH, more knowledge on consonant cluster production and on different word lengths will be gained.

The Current Study

The purpose of this research is to study the speech production patterns of bilingual children with hearing loss (HL) who use cochlear implants (CIs) and compare them to the speech patterns attested in their bilingual peers with normal hearing (NH) to better understand their phonological skills. Specifically, the goals of this research are to discover how Spanish- and English-speaking children with CIs compare to children with NH when producing words across the two languages that vary in word length and syllable complexity. The importance of this research lies in new discoveries regarding how language, syllable complexity, and word structures affect the speech production of bilingual CI users and their peers with NH that will inform theories of phonological development as well as clinical practice.

Research Questions and Hypotheses

Are bilingual Spanish- and English-speaking children with CIs able to produce consonant clusters and words of different lengths with the same accuracy as their peers with normal hearing in their spoken languages? I predict that both bilingual children with CIs and their peers with NH will have more difficulty producing words with consonant clusters and multisyllabic words. However, I expect that particularly CI users will have less accurate production of words that include clusters, due to the lack of accurate transmission of fine temporal cues by the implant. Considering increasing word length, I predict that it will reduce accuracy of cluster production.

Moreover, I expect there to be interactions between hearing status and syllable complexity, because children with CIs are expected to show more difficulty when producing complex syllables than their peers with NH. For the same reason, an interaction between hearing status and word length is also expected.

Methods

Participants

Forty functionally bilingual Spanish- and English-speaking preschool age children (20 with NH and 20 with CIs) from the greater Houston metropolitan area participated in the study. All of the children were early bilinguals with exposure to both languages before 3 years of age with at least 3 years of experience speaking both English and Spanish. Thirty-seven of the 40 children were born in the US, one arrived in the US at 16 months of age, one at 2;8, and one had no parental report on arrival to the US (see Tables 1 and 2). The participants were between the ages of 5;3 (years; months) and 7;9. CI users and children with NH were matched across groups on chronological age (within 3 months of chronological age per individual across groups to ensure comparable distributions), gender, and socio-economic status as closely as possible. Within each group, an effort was made to have a balanced distribution of male and female speakers. See Tables 1 and 2 for the background information of the children in the two groups and subsequent sections for details about members of both the NH and the CI group.

Children with Normal Hearing

Children with normal hearing who participated in the study included 9 female and 11 male speakers with an average chronological age of 6;2 (standard deviation: 0;10) and an age range of 5;3 to 7;9. A binaural pure-tone hearing test was administered at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz at a 25dB hearing level before collecting a speech sample, during the same session. All but one of the participants with NH were born in the US. The participants that arrived in the US at 2;8 had exposure to English earlier, and all participants had at least 3 years of experience with both languages and were able to communicate both in English and Spanish. The English variety spoken by the participants was American (either network standard or Southern American English). The Spanish dialects spoken by the children with NH consisted of Mexican (12 speakers), El Salvador (3 speakers), Colombian (3 speakers), Honduran (1 speaker), and there was one Castilian Spanish speaker. Table 1 displays the background information of each child with NH. See Table 1 for background information on the children with NH.

Cochlear Implant Users

CI users who participated in the study included 10 female and 10 male speakers with an average chronological age of 6;3 (standard deviation: 0;10) and a range of 5;3 to 7;9. All of the children with CIs received their implants before they turned 3 years old (i.e., early implanted) and had at least 3 years of implant experience (see Table 2). Specifically, the mean age at implant activation was 1;9 (standard deviation: 0;7) with a range of 1;0 to 2;11. The mean duration of implant use was 4;6 (standard deviation: 1;0) with a range of 3;3 to 6;7.

Their devices were checked for proper functioning before collecting the speech sample. All CI users had at least 3 years of experience with both spoken English and spoken Spanish and were able to communicate using both languages. The primary mode of communication for CI users was spoken language and they received oral/aural communication training. The English variety spoken by the participants was American (either network standard or Southern American English). The Spanish dialects spoken by the children with NH consisted of Mexican or Mexican/Central American (16 speakers), Argentinian (2 speakers), and unknown/not reported (2 speakers).

Eighteen of the 20 bilingual CI users who participated in the present study were born in the US, one arrived in the US at 16 months, and the parents did not report the age of arrival to the US for one child. Twelve of the 20 children with CIs had hearing loss from birth, two lost their hearing at 8 months, one at 3 months, one at 13 months, one at 18 months, one at 2;2, and one child's parents did not report age at hearing loss. The etiologies, type of device in each ear, and maternal education are also reported in Table 2.

Table 1: Background of Spanish- and English-speaking bilingual children with normal hearing

Participant Code	Gender	Chronological Age	Maternal Education	AOA to US	Spanish Dialect
14NHBES403	M	6;9 (81)	bachelor's degree	birth	Mexican
14NHBES411	F	5;6 (66)	GED	birth	Mexican
14NHBES250	M	7;0 (84)	bachelor's degree	birth	Colombian
14NHBES265	F	5;9 (69)	high school	birth	Mexican
14NHBES272	F	5;3 (63)	high school	birth	Mexican
14NHBES404	M	6;5 (77)	some high school	birth	Mexican
13NHBES204	F	5;3 (63)	high school	birth	Colombian
14NHBES260	M	5;10 (70)	some college	birth	Mexican
13NHBES220	M	7;2 (86)	GED	birth	Mexican
13NHBES214	M	6;10 (82)	some elementary school	birth	El Salvador
14NHBES271	F	7;9 (93)	high school	birth	Honduras
15NHBES470	M	5;8 (68)	elementary school	birth	El Salvador
13NHBES209	F	7;9 (93)	some graduate school	birth	El Salvador
14NHBES248	M	5;11 (71)	graduate school	2;8	Mexican
16NHBES530	M	6;2 (74)	bachelor's degree	birth	Mexican
14NHBES232	F	5;6 (66)	bachelor's degree	birth	Mexican
14NHBES245	M	5;5 (65)	high school	birth	Spain (Castilian)
14NHBES409	F	6;1 (73)	elementary school	birth	Mexican
15NHBES416	M	5;3 (63)	high school	birth	Mexican
15NHBES450	F	6;8 (80)	bachelor's degree	birth	Colombian

Table 2: Background of bilingual Spanish- and English-speaking children with cochlear implants

Participant Code	Gen-der	Chron. Age (mos)	Age at Implant (mos)	Duration of Implant Use (mos)	Device Type and Side (R= right, L = left ear)	Etiology	Age at Hearing Loss	AOA in US	Spanish Dialect	Maternal Education
14CIBES334	M	6;8 (80)	2;4 (28)	4;4 (52)	Nucleus 5 (R, L)	cytomegalo-virus	26 mos	birth	Mexican	high school
14CIBES259	M	5;9 (69)	2;7 (31)	3;3 (39)	Nucleus Freedom (R, L)	connexin 26	birth	birth	Argentina	bachelor's degree
14CIBES307	F	5;7 (67)	2;3 (27)	3;4 (40)	Nucleus 5 (R, L)	ear failed to develop	birth	birth	Mexican	elementary school
15CIBES422	M	6;9 (81)	2;11 (35)	3;10 (46)	Nucleus 6 (R, L)	unknown	18 mos	birth	Mexican	elementary school
15CIBES454	M	6;9 (81)	1;7 (19)	5;2 (62)	Nucleus 5 (R, L)	unknown	birth	birth	Mexican	some high school
15CIBES471	M	5;8 (68)	2;0 (24)	3;8 (44)	Nucleus 5 (R, L)	unknown	birth	birth	Not reported	elementary school
13CIBES205	M	5;10 (70)	1;0 (12)	4;10 (58)	Nucleus 5 (R), Nucleus Freedom (L)	unknown	birth	birth	Mexican	trade school
14CIBES239	F	5;6 (66)	2;3 (27)	3;3 (39)	Nucleus 5	neuropathic	birth	birth	Mexican	some college
14CIBES302	M	5;4 (64)	2;0 (24)	3;4 (40)	Nucleus 5 (R, L)	unknown	birth	birth	Mexican	no school
13CIBES201	M	6;8 (80)	2;0 (24)	4;8 (56)	Nucleus 6 (R), Nucleus 5 (L)	unknown	birth	birth	Mexican	unknown

Table 2 (continued): Background of bilingual Spanish- and English-speaking children with cochlear implants

Participant Code	Gen-der	Chron. Age (mos)	Age at Implant (mos)	Duration of Implant Use (mos)	Device Type and Side (R= right, L = left ear)	Etiology	Age at Hearing Loss	AOA in US	Spanish Dialect	Maternal Education
16CIBES627	F	5;3 (63)	1;3 (15)	4;0 (48)	Nucleus 6 (R, L)	connexin 26	birth	16 mos	Argentina	bachelor's degree
13CIBES226	M	7;3 (87)	1;4 (16)	5;10 (70)	Nucleus Freedom (R), Nucleus 5 (L)	unknown	13 mos	birth	Mexico	elementary school
13CIBES206	F	7;9 (93)	1;9 (21)	6;0 (72)	Nucleus 5 (R, L)	unknown	birth	birth	Mexico/ Honduras	elementary school
12CIBES035	F	5;10 (70)	1;5 (17)	4;6 (54)	Nucleus Freedom (R), Nucleus 5 (L)	unknown	8 mos	birth	Mexican	GED
11CIBES015	F	5;4 (64)	1;3 (15)	4;2 (50)	Nucleus 6 (R), Nucleus 5 (L)	unknown	birth	birth	Mexican	high school
15CIBES449	F	7;9 (93)	1;2 (14)	6;7 (79)	Nucleus 5 (R, L)	cytomegalo-virus	birth	birth	Mexican/ Salvador	high school
12CIBES006	M	6;3 (75)	1;5 (17)	4;10 (58)	Nucleus 6 (R, L)	unknown	3 mos	birth	Mexican	bachelor’s degree
12CIBES040	F	5;7 (67)	1;1 (13)	4;6 (54)	Nucleus Freedom (R, L)	not reported (NR)	NR	NR	NR	NR
13CIBES225	F	7;2 (86)	1;1 (13)	6;1 (73)	Nucleus Freedom (R), Phonak Naida III UP (L)	premature	birth	birth	Mexican	high school
14CIBES252	F	6;0 (72)	2;2 (26)	3;10 (46)	AB Harmony (R, L)	bacterial meningitis	8 mos	birth	Mexican	associate’s degree

Materials

Ten English words and 8 Spanish words were selected for analysis (see Appendix) out of a pool of approximately 160 words (about 80 from each language) so that different word lengths and syllable structures be targeted. Word length varied in both English and Spanish to include monosyllabic, disyllabic, and trisyllabic items in each language. Syllable structure complexity varied from "no cluster" (with only singleton onsets and codas without abutting consonants) to onset clusters, coda clusters (in English), cross-syllable clusters (i.e., abutting consonants), and multiple complex items. Structures unique to English were also marked (such as the coda cluster in the word "fork" or the word-initial cluster in "strawberry"). All the participants were tested using the same words to ensure consistency across the samples collected from different participants.

The word list used in the present study represents a selected subset of the original list of words chosen for their phonological content consisting of approximately 80 words in Spanish and 80 words in English. The word list is based on a single-word picture elicitation task and was designed by the primary mentor with the intent to probe various aspects of phonology, including phoneme inventories, and the items have been tested on over 100 children. The task included mostly pictures depicting common items via black and white line drawings, and a few of them had colors. The word lists were designed separately for Spanish and English focusing on the phonological characteristics of each language (cf. Bunta et al. 2016a). The majority of words used were nouns representing items familiar to young children and less than 5% of slides displayed colors (such as "yellow"). The pictures in the task were designed to be appropriate for the specific ages of the children being tested. They were also designed to avoid cultural bias. The vocabulary in the task was aimed to be familiar, effective and appropriate to the ages of the children tested. The sampling procedure is described in the subsequent (Procedures) section.

A Marantz PMD 661 MKII Professional Field recorder that captures uncompressed sound files onto a secured memory card was used to audio-record the children's productions digitally at 44 kHz and 16 bits. To ensure that the samples were consistent across participants, the recorder was places on a flat surface (such as a table) and the microphone was aimed toward the child approximately 10 inches (25.4 cm) away. The sound files were transferred onto a computer for analysis through a secured digital card.

Procedure

Parental consent and child's assent were obtained before collecting the data. To avoid code switching and code mixing, the children were tested one language at a time and in two different sessions. The Spanish and English sessions occurred within a week of each other (sometimes on the same day). The researchers were proficient speakers of the languages they tested and were familiarized with interacting with children from culturally and linguistically diverse backgrounds. After obtaining assent from the children with NH, the children completed a hearing screening using pure tones at 500, 1000, 2000, and 4000 Hz at 25 dB HL bilaterally, and CI users had their device checked on the day of the sample as previously described. A comprehensive background questionnaire was also completed by each child's parent or legal guardian. A speech and language assessment was administered to most participants using the Word Intelligibility Picture Identification (WIPI) (Cienkowski, Ross, & Lerman, 2009) and the

Preschool Language Scales to gauge the children's speech discrimination and language skills (Zimmerman, Steiner, & Pond, 2012).

Regarding the word elicitation task, first, each child was prompted to verbally identify each picture presented to him or her (e.g., "What is this?"). If the target word was not identified the first time, the child was given a description of the object such as "This is an animal that goes 'woof' What is it?". If the child had not said the target word at this point, then he or she was required to complete a sentence such as "A Dalmatian is a type of …". Lastly, the child was prompted to do delayed imitation if they had not identified the target word with the previous instructions. For example, the target word would be elicited by saying: "This is a dog. What is it?". In the overwhelming majority of the cases, resorting to delayed imitation was unnecessary.

The recorded speech samples were transcribed phonetically by trained research assistants who were proficient (native or near-native) speakers of the languages they transcribed. Dialectal variations were taken into account in that the phonemic target for a lexical item was adjusted if needed to accommodate for regional and social variants of each language so that the child was not penalized for producing their own dialectal form for a given word. All of the phonetic transcriptions were checked by at least two judges with over 90% inter-rater reliability. The transcripts were saved as computer files using the Logical International Phonetic Program (Oller & Delgado, 2000). Segmental accuracy was calculated using the program for overall percentage of segments correct (PSC), percentage of vowels correct (PVC), and percentage of consonants correct (PCC). PSC was also calculated individually by the program for each test item.

Statistical Analyses

The effects of hearing status, syllable complexity, word length, and language on accuracy of productions was analyzed. The specific English test items were: “duck”, “plate”, “yellow”, “zebra”, “potato”, and “screwdriver”. The Spanish test items were “pan” (= bread), “cruz” (= cross), “queso” (= cheese), “libro” (= book), “zapato” (= shoe), and “sombrero” (= hat). The phonological characteristics of the items are listed in the Appendix both in terms of word length and syllable complexity.

I predicted that as syllable complexity and word length increase, accuracy of productions (as measured by percentage of sound segments correct) will decrease. Hearing status (CI user versus child with NH) was also expected to have an effect on segmental accuracy as well as language. Thus, the independent variables of syllable complexity (no clusters versus clusters) word length (monosyllabic, disyllabic, and trisyllabic), language (English versus Spanish), and hearing status (CI user versus children with NH) were all expected to display main effects. Syllable complexity, word length, and language were within-subjects variables while hearing status a between-subjects one. Interactions were also predicted, as segmental accuracy was expected to show that the effects display differential and dependent patterns.

Results

A repeated measures analysis of variance revealed statistically significant main effects of all independent variables on the segmental accuracy of the test items. The only between-subjects factor, hearing status, had a statistically significant effect on segmental accuracy [F (1, 35) = 40.24 at $p < 0.001$, partial $\eta^2 = 0.54$]. All the within-subjects variables also had statistically significant main effects on segmental accuracy: language [F (1, 35) = 4.57 at $p = 0.040$, partial $\eta^2 = 0.12$], word length in syllables [F (2, 70) = 13.42 at $p < 0.001$, partial $\eta^2 = 0.28$], and syllable complexity [F (1, 35) = 52.63 at $p < 0.001$, partial $\eta^2 = 0.60$]. These findings support the prediction that hearing status, language, word length, and syllable complexity all have effects on how accurately bilingual children produce words from a segmental point of view. Tables 3 and 4 display the segmental accuracy of each item in English and Spanish, respectively.

Statistically significant two-way interactions included hearing status by word length in syllables [F (2, 70) = 5.88 at $p = 0.004$, partial $\eta^2 = 0.14$], hearing status by syllable complexity [F (1, 35) = 18.20 at $p < 0.001$, partial $\eta^2 = 0.34$], language by word length in syllables [F (2, 70) = 18.03 at $p < 0.001$, partial $\eta^2 = 0.34$], indicating that both word length and syllable complexity depended on hearing status and word length also depended on the language spoken (see Discussion for further interpretation of the results).

Table 3: Mean differences on segmental accuracy between bilingual CI users and children with NH on English words varying in length (1, 2, and 3 syllables) and syllable complexity

English Word and Structure	**Group**	**Mean**	**Std. Deviation**
duck (CVC)	CI	88.24	20.21
	NH	96.67	10.25
	Total	92.80	15.97
plate (CCVC)	CI	82.35	22.99
	NH	98.75	5.59
	Total	91.22	17.89
yellow (CV.CV)	CI	86.18	19.49
	NH	96.00	8.21
	Total	91.49	15.13
zebra (CV.CCV)	CI	71.76	17.41
	NH	88.00	11.96
	Total	80.54	16.66
potato (CV.CV.CV)	CI	67.16	20.93
	NH	92.49	8.52
	Total	80.85	19.92
screwdriver (CCCV.CCV.CVC)	CI	52.94	25.19
	NH	86.50	13.48
	Total	71.08	25.80

Table 4: Mean differences on segmental accuracy between bilingual CI users and children with NH on Spanish words varying in length (1, 2, and 3 syllables) and syllable complexity

Spanish Word and Structure	Group	Mean	Std. Deviation
pan (CVC)	CI	94.12	13.09
	NH	98.34	7.45
	Total	96.40	10.48
cruz (CCVC)	CI	60.29	31.9408
	NH	92.50	11.75
	Total	77.70	28.13
queso (CV.CV)	CI	88.24	17.94
	NH	97.50	7.69
	Total	93.24	14.01
libro (CV.CCV)	CI	80.00	17.32
	NH	95.00	8.89
	Total	88.11	15.25
zapato (CV.CV.CV)	CI	88.23	20.226
	NH	98.33	5.14
	Total	93.69	14.89
sombrero (CVC.CCV.CV)	CI	69.12	24.25
	NH	93.75	10.34
	Total	82.43	21.74

As for three-way interactions, language by word length in syllables by hearing status [F (2, 70) = 4.63 at p = 0.013, partial η^2 = 0.12] was statistically significant as well as language by word length in syllables by syllable complexity [F (2, 70) = 10.67 at p < 0.001, partial η^2 = 0.23]. These effects indicate that hearing status interacts with word length and language, and syllable complexity, word length and language also interact (please see Discussion for more details).

Summary of Findings

Overall, the findings based on the data support my predictions in that all of the independent variables (hearing status, language, syllable complexity, and word length) had statistically significant main effects on segmental accuracy. There were also interaction effects that revealed specific dependencies between the independent variables such that the phonological patterns of bilingual CI users were disproportionally affected by the item's syllable complexity and length. Nevertheless, the patterns emerging from the data paint a complex yet specific picture of how hearing status, syllable complexity, word length, and language shape segmental accuracy that deserve further exploration and interpretation in the subsequent section.

Discussion

My original research question inquired about how bilingual Spanish- and English-speaking children with cochlear implants produced consonant clusters and words of different lengths as compared to their peers with normal hearing in their spoken languages, measured by segmental accuracy. My predictions to find effects of hearing status, language, syllable complexity, and word length have materialized, and so did the proposition that young bilingual CI users would display disproportionally lower accuracy rates in more complex and longer words than bilingual children with NH. The analyses also indicated that for all bilingual children (CI users and their peers with NH), language interacted with word length in that segmental accuracy for relatively longer Spanish words was higher than for relatively longer English words, which may be due to the fact that the English lexicon (especially children's) contains relatively shorter words than its Spanish counterpart. This finding is similar to Sosa and Bunta's (2019) results that found higher segmental accuracy in the Spanish productions of bilingual CI users than in their English productions. Thus, when assessing the speech and language skills of bilingual children with CIs, word length in syllables may require differential treatment in the Spanish and English productions of these children. Moreover, a language by word length by hearing status interaction suggests that hearing status also contributes to this co-dependency.

The results presented here indicate that CI users present with significantly less accurate speech sound productions when compared to their peers with NH regarding segmental accuracy, suggesting that the diminished auditory signal CI users receive may hinder phonological development. My hypothesis that bilingual CI users would present with lower accuracy as word length and syllable complexity increased was confirmed by the findings of the study, but the results showed that even bilingual children with normal hearing found more complex items challenging and the difficulties manifested differently across Spanish and English. Nonetheless, use of a CI interacted with phonological complexity in such a way that CI users showed significantly diminished accuracy with more complex words than their peers with NH.

As Ji, Galvin, Xu, and Fu (2013) suggest, having access to sound via a CI not only has an effect on the way the speech is perceived, but it also influences how speech is produced. This influence is evident in qualitative and quantitative data of speech sound production of CI users, as it is illustrated by the mean accuracy of the individual items and their standard deviations presented in Tables 3 and 4. Future studies could aim to answer more specific questions regarding the patterns CI users present when it comes to syllable complexity, word length, and the language spoken.

A previous study looked at the sound patterns of bilingual children with NH and found that predominantly English-speaking children produced more accurate consonant clusters than their bilingual peers who spoke English and Spanish, comparatively (Gildersleeve-Neumann et al., 2008). Consonant cluster patterns of monolingual CI users were investigated by Chin and Finnegan (2000), and the authors suggested that the CI users have trouble producing the speech sounds because they are required to use the skill of integrating and combining the sounds presented to them. However, unlike the findings in this study, Chin and Finnegan (2000) supported the idea that monolingual English-speaking CI users have similar productions to their NH peers because at 5 or more years of cochlear implant experience, the CI users presented with similarities to the productions of their NH peers.

Clinical Implications

From a clinical perspective, the main contribution of the present study is that word length and syllable shape do affect segmental accuracy in bilingual CI users more than in bilingual peers with NH, and those differences may be language-specific. This suggests that when assessing bilingual children with hearing loss, speech-language pathologists and audiologists need to closely and carefully consider how the test items may impact the outcomes and must not only take into account the effects of each factor (hearing status, language, word length in syllables, and syllable complexity), but they should also consider the interactions of these variables and consider the uniqueness of speech productions patterns of the bilingual child who uses CIs.

Limitations and Directions for Future Research

Considerably more work needs to be conducted to disentangle the complex web of phonological development and speech production skills of bilingual and monolingual children with CIs, and while the current study provides valuable new information, it also highlights the need for further research. One of the limitations of this study (as it is the case of most comparable research) is the relatively small number of participants. While having 20 bilingual CI users and 20 carefully matched bilingual children with NH with samples from each language exceeds the number of participants in other similar studies, drawing definitive conclusions warrants the inclusion of more participants. A wider range of syllable structures and word length would also be informative to have a broader understanding of how word length and syllable complexity interact in a more specific fashion, which should be the aim of future studies using a larger pool of items.

This study focused on elicited single words, so future studies should incorporate analyses of connected speech samples, such as conversational samples or elicited sentences. Analyses should also include a variety of languages and language combinations, because the patterns found in Spanish-English bilinguals may not generalize to speech patterns seen in CI users acquiring other language combinations. In order to obtain a more complete picture of the phonological skills of bilingual CI users, a variety of speech and language analyses need to be completed, ranging from speech perception experiments to acoustic analyses of specific aspects of speech to establishing phoneme inventories. Finally, all of these analyses need to be done in a longitudinal fashion to not only get a snapshot of speech patterns at a given time but to understand the path of development of phonological structures of bilingual children with CIs to inform theoretical approaches to phonology as well as practicing speech-language pathologists to develop evidence-based best practices when it comes to the assessment and treatment of speech of this population.

Conclusions

Due to the growing number of bilingual children with hearing loss who use CIs, there is a critical need to increase research on speech perception and production in this area (Zeng, 2004). This study focused on the effects of different word lengths, syllable shapes, language spoken, hearing status, and the various interactions of these variables on segmental accuracy of bilingual Spanish- and English-speaking CI users and their peers with NH to provide new knowledge and insights into these issues for researchers as well as practicing speech pathologists and audiologists. The main contribution this study provides to the field of communication sciences and disorders is that word length and syllable shape do affect segmental accuracy in bilingual CI users at a significant level by diminishing segmental accuracy especially when compared to their NH peers, a pattern also dependent on the language being spoken. The main effects and their interactions found in the present study paint a complex picture whereby young bilingual CI users display unique speech production patterns that differ from those of their peers with NH, and those differences inform both research and clinical assessment and treatment.

The sample words provided in this study can be useful as a basis for future research on syllable complexity in regard to cluster production and word length. These findings are useful for researchers, clinicians, educators, and ultimately the CI user population, but the limited number of samples still does not provide a full picture of the range of consonant clusters and word shapes that pose challenges to bilingual children with CIs. Although these findings are novel for the field of research in the bilingual Spanish- and English-speaking CI population, further studies involving analyses with a wider range of word variability and length need to be conducted to expand the knowledge in this area.

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Appendix: Word List

Syllable Shape	English words	Spanish words	Word length in syllables	Syllable complexity	Unique or not
CVC	duck	pan	1	No cluster	Not
CCVC	plate	cruz	1	Onset	Not
CV.CV	yellow	queso	2	No cluster	Not
CV.CCV	zebra	libro	2	Onset	Not
CV.CV.CV	potato	zapato	3	No cluster	Not
CCCV.CCV.CVC	screwdriver	-----------	3	Multi-complex	Unique to English
CVC.CCV.CV	-------------	sombrero	3	Multi-complex	Not