ABSTRACT

Title of dissertation: THE ROLE OF AGE AND BILINGUALISM ON PERCEPTION OF VOCODED SPEECH

Arifi Waked, Doctor of Philosophy, 2020

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This dissertation examines the role of age and bilingualism on perception of vocoded speech in order to determine whether bilingual individuals, children, and bilingual individuals with later ages of second language acquisition show greater difficulties in vocoded speech perception. Measures of language skill and verbal inhibition were also examined in relation to vocoded speech perception. Two studies were conducted, each of which had two participant language groups: Monolingual English speakers and bilingual Spanish-English speakers. The first study also explored the role of age at the time of testing by including both monolingual and bilingual children (8-10 years), and monolingual and bilingual adults (18+ years). As such, this study included four total groups of adult and child language pairs. Participants were tested on vocoded stimuli simulating speech as perceived through an 8-channel CI in conditions of both deep (0-mm shift) and shallow (6-mm shift) insertion of the electrode array. Between testing trials, participants were trained on the more difficult, 6-mm shift condition. The second study explored the role of age of second language acquisition in native speakers of Spanish (18+ years) first exposed to English at ages ranging from 0 to 12 years. This study also included a control group of monolingual English speakers (18+ years). This study examined perception of target lexical items presented either in isolation or at the end of sentences. Stimuli in this study were either unaltered or vocoded to simulate speech as heard through an 8-channel CI at 0-mm shift. Items presented in isolation were divided into differing levels of difficulty based on frequency and neighborhood density. Target items presented at the ends of sentences were divided into differing levels of difficulty based on the degree of semantic context provided by the sentence.

No effects of age at testing or age of acquisition were found. In the first study, there was also no effect of language group. All groups improved with training and showed significant improvement between pre- and post-test speech perception scores in both conditions of shift. In the second study, all participants were significantly negatively impacted by vocoding; however, bilingual participants showed greater difficulty in perception of vocoded lexical items presented in isolation relative to their monolingual peers. This group difference was not found in sentence conditions, where all participants significantly benefited from greater semantic context. From this, we can conclude that bilingual individuals can make use of semantic context to perceive vocoded speech similarly to their monolingual peers. Neither language skills nor verbal inhibition, as measured in these studies, were found to significantly impact speech perception scores in any of the tested conditions across groups.

The Role of Age and Bilingualism on Perception of Vocoded Speech

By

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Chapter 1: Introduction

1.1 Overview

A cochlear implant (CI) is a sensory prosthesis that can partially restore speech perception to individuals with severe to profound sensorineural hearing loss. To reduce the risk of heterogeneity and confounding factors, often normal-hearing (NH) individuals listening to CI simulations are tested in lieu of CI users. Heterogeneity in CI users may be caused by a number of factors, including biological, device, and surgical differences. Variability in perception of CI-simulated speech has also been found among monolingual NH listeners (Davis et al., 2005; Rosen et al., 1999; Senan et al., 2018, Waked et al., 2017). This dissertation aims to explore potential causes of these differences.

Most studies on speech perception in both CI users and NH individuals listening to CI simulations have focused on monolingual adults. Worldwide, however, most people are bi- or multilingual (hereafter bi/multilingual). For NH bi/multilingual listeners, there are many factors known to make speech perception more difficult (e.g., Bialystok, 2008; Carlson et al.; 2016; Skoe et al., 2019). Use of bi/multilingual spoken language necessarily involves some level of competition in linguistic knowledge. Vocabulary in each language may also be negatively impacted. This is due to the fact that children receiving input in multiple languages are likely to receive less input in each individual language relative to a child receiving input in only one of these languages (e.g., Cummings, 2008, Knoors & Marschark, 2012, Schmidtke, 2016). This may lead to reduced vocabulary knowledge in all known languages. There is some evidence that this difference in vocabulary size remains reduced relative to monolingual peers throughout the lifespan (Bialystok & Luk, 2012; Friesen et al., 2014, Sullivan et al., 2017). These differences between monolingual and bi/multilingual individuals may make difficulties in speech perception even greater for bi/multilingual CI users as compared to their monolingual peers.

The age of an individual CI user may also impact their ability to understand speech. Child CI users may face relatively greater difficulties compared to adult CI users because adults have greater experience with language use. Adults are also likely to have more fully developed language processing abilities. This may lead adults to possess greater resources for perceiving degraded speech signals available through a CI. Child listeners also may not have reached similar levels of development and experience (Eisenberg et al., 2000, Miller et al., 2019; Nittrouer et al., 2009; Westerhaisen et al., 2015). For bi/multilingual individuals, the ability to accurately perceive speech may also be impacted by the age at which they were first exposed to their second language (L2). Bi/multilingual listeners exposed to their L2 later in life may also face greater difficulties in that language relative to both early bilinguals and monolinguals. Bilingual individuals exposed to their L2 at more advanced ages have been shown to have greater difficulty with speech perception in noise (Abrahamsson & Hyltenstam, 2009; Mayo et al., 1997, Regalado et al., 2019, Skoe & Karayanidi, 2019; Tabri et al., 2015) and with time-compressed speech (e.g., Conrad, 1989, Francis, 2019). It seems likely that limitations observed in these difficult listening conditions will also be found in later-exposed bilinguals listening to degraded speech signals through a CI.

In addition to either age at testing or age of acquisition, an individual's ability to inhibit irrelevant information may also contribute to perception of distorted speech. Verbal inhibition is one aspect of cognitive control, defined by Morton and Harper (2007) as a central part of higher-order thought. Inhibition allows an individual to behave in a goal-oriented way and reduce interference. Verbal inhibition is often found to be higher in bi/multilingual individuals than in their monolingual peers. It is hypothesized that this ability comes from the requirement to consistently suppress interference from one language while using another (e.g., Calabria et al., 2012, Calabria et al., 2018). Differences in inhibitory skill between monolingual and bilingual peer groups have been found across the lifespan (e.g., Anderson et al., 2017; Bialystok et al., 2005). This advantage may assist speech perception in bilingual individuals.

In the following studies, perception of CI-simulated speech will be examined in both NH monolingual English speakers and native speakers of Spanish who are also English language users. To attempt to better understand the cause(s) of variability found in NH individuals listening to CI simulations, the relationships among perception of unaltered and distorted speech, verbal inhibition, and linguistic skills will also be examined. Age-related factors, including age at testing and age of L2 acquisition, will also be examined.

1.2 General Research Questions

Given the prevalence of bi/multilingualism in the world, known language processing differences experienced by bi/multilingual speakers relative to their monolingual peers, and the heterogeneity of CI users, aside from their hearing impairment (HI) alone, this dissertation seeks to address the following key questions:

1. Do bilingual Spanish/English-speaking listeners understand distorted speech similarly to their monolingual, English-speaking peers?
2. Can variability of listening success within conditions be explained by individual differences in linguistic skills?
3. Can variability of listening success within conditions be explained by individual differences in verbal inhibition?
4. Does a difference in distorted speech perception exist between age groups?
5. Does a difference in distorted speech perception exist between those exposed to their L2 at earlier vs later stages of their development?

1.3 Bi/Multilingualism

A. Prevalence of Bi/Multilingual CI Usage

Monolingual individuals are estimated to represent approximately only 40% of the world's population. Even within the United States, a nation that officially recognizes only English as a national language (Maccagno, 2019; Stritikus, 2002), approximately 20% of citizens are reportedly bi/multilingual (Grosjean, 2020). The Central Intelligence Agency (2016) lists 241 countries and territories with two or more official or commonly used native languages. In many of these countries, such as Israel, which has three officially recognized languages (Israel Central Bureau of Statistics, 2016), use of CIs is on the rise (Cochlear Implants in Israel, 2017).

One of the most common languages spoken worldwide is English, which is estimated to be spoken as a first language by roughly 400 million people and as a non-native language by up to 1.5 billion individuals (Lyons, 2017). As such, it is likely that English is one of the languages spoken by many bi/multilingual CI users. We can benefit from study of how use of both English and other languages impact speech perception in CI users. This has potential implications for both aural rehabilitation and habilitation for these populations, as well as for best practices regarding integrating students with CIs into mainstream classrooms.

B. Inhibition in B/Multilingual Individuals

Bi/multilingual individuals have been shown to have greater abilities in inhibitory response as compared to their monolingual peers (Anderson et al., 2017; Bialystok et al., 2005; Calabria et al., 2012, Calabria et al., 2018; Filippi, et.al., 2015; Martin-Rhee & Bialystok, 2008). It is hypothesized that this ability comes from the need to consistently suppress interference from one or more languages while using another (Calabria et al., 2012; Calabria et al., 2018). This advantage is best observed when a task is particularly taxing. Costa et al. (2009) saw no bilingual advantage in congruent-heavy tasks, in which the majority of stimuli require no inhibition. A bilingual advantage was, however, observed in discongruent-heavy tasks, in which the majority of stimuli require inhibition. One such measure is the Stroop test, a test of verbal inhibition (Stroop, 1935).

C. Second Language Acquisition

Developmental limitations on the ability to naturally acquire a species-specific skill are referred to as critical periods (Hinde, 1962). The notion of a critical period was first linked to human language acquisition by Lenneberg (1967), who suggested that natural language acquisition can only take place during a critical period lasting between the age of 2 years and the onset of puberty. The lower bound of 2 years was chosen as it was assumed that before this age, language acquisition was impossible due to immaturity. Lenneberg assumed the upper boundary of this critical period to be puberty, as he hypothesized that after puberty, natural acquisition of language is blocked by the loss of "cerebral plasticity." He believed that this occurred after the completion of the "lateralization process," which was defined as the two hemispheres of the brain becoming permanently set and unchangeable.

However, research on typically developing children shows that infants begin to distinguish sounds in the phonemic inventory of the language(s) to which they are exposed during the first year of life (e.g., Potter & Lew-Williams, 2019, Werker & Tees, 1984). Studies on artificial language learning have shown that 8 month old infants can use transitional probabilities to identify reoccurring "words" in a stream of constant speech. Twelve-month-old infants have also been shown to have the ability to recognize correct grammatical patterns based on a brief familiarization period to an artificial language (Gomez & Gerken, 2000). Additionally, typically developing infants enter a period of rapid word learning between the ages of 13 and 18 months (e.g., Gongate & Maganti, 2019). This can be taken as evidence that language perception begins far earlier than production.

Werker and Byer-Heinlein (2008) analyzed literature exploring the nature of bilingual language acquisition, and concluded that before the age of 2 years, infants are able to use both lexical and non-lexical linguistic features to discriminate between the two languages in their environment. Previous research indicated that bi/multilingual children acquire all language characteristics from the languages to which they are exposed and, only after completing this combined acquisition, later separate linguistic features into the separate languages of their environment (e.g., Volterra & Teaschner, 1978). However, later work has indicated that newborn infants are able to discriminate between languages with different rhythmic classes, indicating that discrimination between the languages in an infant's environment begin at birth (Nazzi et al., 1998).

More recent work has also shown that bilingual infants reach linguistic milestones at ages similar to their monolingual peers in early linguistic development (e.g., Holowka et al., 2002). By 4 months of age, both monolingual and bilingual infants are able to distinguish languages from the same rhythmic class, such as French and Italian, which are both syllable-timed languages, in which syllables take approximately equal time to pronounce. This indicates that bilingual infants have an early ability to use some suprasegmental cues to distinguish between the languages in their environment, even if they belong to the same rhythmic class (Bosch & Sebastian-Galles, 2001). Due to this early experience and increased exposure via the multiple languages in their environment, at 8 months of age, bilingual infants retain the ability to distinguish between the different languages in their environments should the rhythms of these two languages differ from one another whereas monolingual infants lose this ability in order to better acquire the single language in their home environment (Weikum et al., 2007).

Bilingual infants have also been shown to have the ability to discriminate between both the phonemes and phonetic structure of their two languages by the age of 1 year, and have a different pattern of phonotactic acquisition as compared to their monolingual peers (Sebastian-Galles & Bosch, 2002). This is due to the fact that bilingual infants are exposed to two lexicons, each containing their own phonemes and phonotactic constraints. The ability to simultaneously acquire two phonological systems also allows infants to acquire lexical items with differing phonotactic structure simultaneously, allowing them to establish two unique mental lexicons. However, due to the fact that bilingual infants are exposed to fewer lexicons in each language, their lexical capacity in each language is reduced in each individual language relative to their monolingual peers (Pearson et al., 1993).

Many researchers believe that there is also a developmental stage after which an individual is unable to become truly bi/multilingual (e.g., Hartshorne et al., 2018). Bi/multilingualism is defined more explicitly here as the ability to both process and produce all languages of use with similar proficiency. Adults who have been exposed to multiple languages earlier in life seem to be at a particular advantage and show signs of true bi/multilingualism (DeKeyser, 2000; DeKeyser, 2010; DeKeyser, 2012; Flege, 1990; Mechelli, 2004; Singleton & Ryan, 2004). As such, there appears to be great advantage to exposing children to their non-primary language(s) at as early an age as possible in order to improve their chances of acquisition with native-like proficiency.

However, there are differing opinions regarding whether the concept of a critical period can be applied to bi/multilingual language acquisition. Part of this debate comes from the fact that different studies have focused on different aspects of language, such as accent and pronunciation (phonological production) (e.g., Flege, 1987), and grammatical awareness (morphosyntactic competence) (e.g., Johnson and Newport, 1989). Additionally, some studies have focused exclusively on short-term learning, where only the initial progress of L2 learners is monitored (e.g., Snow & Hoefnagel-Höhle, 1978), while others have examined only long-term outcomes, where L2 learning is studied over a period of years (e.g., Ortega & Iberri-Shea, 2005).

While those exposed to their L2 as children generally significantly outperform those exposed in adulthood in measures of morphosyntactic competence, some exceptions have been found. DeKeyser (2000) found that adults whose results were on par with those exposed to their L2 in early childhood also tended to score higher on measures of analytical problem-solving abilities. The author concluded that this ability is needed for adult learners to obtain morphosyntactic competence in their L2 because the implicit learning mechanisms used by children in language acquisition are no longer available past a certain developmental point. Without exceptional verbal analytical skills, it is unlikely that individuals exposed later in life will ever develop the same level of linguistic proficiency as those exposed during their childhood.

Similarly, current research on D/deaf children also shows that those exposed to auditory signals via a CI before the age of two years significantly outperform those implanted at later ages on nearly all oral language tasks. Children implanted between the ages of 12 and 16 months scored comparably with their NH peers at the age of 4.5 years, while those implanted between the ages of 17 and 24 months did not (Nicholas & Geers, 2007). Using developmental trajectory analysis, Svirsky et al. (2004) found that children implanted before the age of 2 years had significantly higher scores on measures of speech perception and linguistic skills as compared to children implanted at 3 or 4 years of age after a comparable period of CI use. McKinney (2017) found significant improvement in language use in infants implanted in the first year of life relative to their later-implanted peers. This indicates that regardless of the existence of a critical period, children in need of a CI who receive early implantation are far more likely to have improved linguistic outcomes relative to their later implanted peers.

D. Lexical Processing in Bi/Multilingual Individuals

Bi/multilingual spoken language use necessarily involves some level of competition in linguistic knowledge. As such, it has been linked to some negative linguistic outcomes in all known languages. In societies where the majority of people are monolingual, this may lead to potentially negative ramifications with regards to clinical and educational assessment of children, particularly those with speech, language, and/or hearing impairments (HI). This is because children receiving input in multiple languages receive less input in each individual language relative to a child receiving input in only one of these languages (e.g., Cummings, 2008, Knoors & Marschark, 2012, Schmidtke, 2016). This makes it difficult to accurately assess bilingual children using measures normed for monolingual speakers of either language. For NH bilingual children, although they may have a total number of vocabulary items across their languages matching that of their age-matched monolingual peers, the number of vocabulary tokens in each language is generally reduced (e.g., Altman et al., 2018; Uccelli & Paez, 2007). There is some evidence that this difference in vocabulary size remains reduced relative to monolingual peers throughout the lifespan (Anderson et al., 2017; Bialystok & Luk, 2012).

Bilingualism has also been linked to longer lexical retrieval times and more instances of the tip-of-the-tongue phenomena in NH adults due to the greater number of options made available by the two lexicons (Sullivan et al., 2018; Bialystok, 2008). NH bilingual adults also tend to have poorer word identification in noise as compared to their monolingual peers (e.g., Rogers et al., 2006, Roaunujan & Weeks, 2020). Given these issues of smaller vocabulary size, longer lexical retrieval time, and greater difficulty listening in noise, speech perception for bilingual CI users may be even more challenging than it is for monolingual CI users.

1.4. Deafness

A. Prevalence of CI Use

The World Health Organization (2020) estimates that there are approximately 460 million people with disabling HI. Thirty-four million of these people are children. At least 324,000 of these individuals use a CI. However, only roughly 96,000 of these CI users live in the United States (National Institute of Deafness and Other Communication Disorders, 2017). Most research on language acquisition and speech perception has been conducted using monolingual English speakers (e.g., Madsen et al., 2019). This is also true regarding studies assessing perception of CI-simulated speech (e.g., Casaponsa et al., 2019).

Despite the prevalence of bi/multilingual CI-users, few studies have been conducted on speech perception in these populations (Garcia et al., 2010; Goodwin et al., 2019; Looi et al., 2015; Popova et al., 2019; Robbins et al., 2004; Rogers et al., 2006; Schmidtke, 2016; Thomas et al., 2008; Waltzman et al., 2004). Examination of speech perception in this population is important, as a CI will distort the incoming signal under even ideal listening conditions. Studying how bi/multilingualism impact users' ability to understand speech through a CI relative to their monolingual peers may offer insight into how to best aid members of this population.

B. Deaf Education and Re/Habilitation for Bi/Multilingual Students

In a majority-monolingual society, such as the United States, it is quite likely that children with HI learning oral language(s) will receive therapy and education in only one language. In cases where a child's family belongs to a linguistic minority group, it is likely that they may also receive linguistic input at home in at least one other language (Cannon & Guardino, 2012; Tembe, 2008). This can lead to gaps in lexical knowledge, where so-called Basic Interpersonal Language Skills (BICS) may be known in the heritage language, while Cognitive-Academic Language Proficiency (CALP) may be more accessible in the majority language (Cummins, 1999; Cummins, 2008). Further exploration is required to better understand how bi/multilingualism and/or L2 learning may interact with learning to understand distorted speech in bi/multilingual CI users.

Children with CIs are unlikely to have a typical language acquisition experience in which they naturally develop representation of the rules of languages in their surroundings from exposure to ambient language alone. Some form of aural/oral therapy is generally needed to facilitate learning. Speech outcomes tend to be best for those who receive their CIs before the age of one year (McKinney, 2017). However, a child implanted at such a young age needs to begin working with practitioners soon after activation to lead to optimal oral/aural linguistic outcomes. This will help the child both learn how to produce speech as well as how to accurately perceive speech and other sounds in their environment (American Speech Language and Hearing Association, 2017).

With bilingual CI users, in addition to the fact that their language learning is atypical, there is also the risk of transfer when learning two languages, making it possible that learning the rules of one language will hinder correctly learning and use of the rules of another (Knoors & Marschark, 2012). These effects may slow progress in the language in which child CI-users are able to receive training, potentially causing them to fall behind both their NH and CI-using monolingual peers. It is for this reason that these CI users need specialized intervention in order to learn language skills. However, there is little evidence-based research on which teachers and clinicians can base their interventions in this population. Valente (2019) has suggested that deaf L2 learners be taught to use both visual and auditory cues beginning in preschool (ages 3-5 years) in order to better access linguistic cues in their L2. However, little clinical information regarding this population can be found, and the long-term efficacy of Valente's (2019) suggested approach has yet to be studied.

C. CIs and Challenges for Speech Perception

A great deal of variability is found in speech perception scores of CI users (e.g., Blamey et al., 2013; Cesur & Derinsu, 2020; Fontenot et al., 2019; Sarant et al., 2001). This is true not only of pre-lingually deafened individuals (e.g., Fontenot et al., 2019), but post-lingually deafened older children and adults as well (e.g., Cesur & Derinsu, 2020). Because later-deafened individuals experienced this hearing loss following typical linguistic and cognitive development, it is likely that there must be other factors contributing to success with a CI aside from those resulting from atypical language exposure.

One primary factor that has been identified to negatively impact speech perception in both pre- and post-lingually deafened CI users is the duration of deafness. This factor often plays a significant role on post-implantation outcome measures. After an extended period without stimulation, both the peripheral and central auditory pathways are not maintained and may degrade (Cesur & Derinsu, 2020; Teoh et al., 2004). Longer durations of deafness can also lead to degradation in the cochlea, cutting off sound transmission to the organ of Corti. This may lead to spinal ganglia death, which will in turn prevent sound transmission to the auditory nerve, brainstem, and relevant midbrain structures (Coco et al., 2009; Leake et al., 1999; Muise-Hennessey et al., 2019; Nayagam et al., 2011; Rejali et al., 2007; Sang-Yeon et al., 2020).

Another potential problem source in learning to understand speech through a CI is that the sound processing strategies in CIs greatly degrade the speech signal. This means that less information, with potentially greater distortion, is reaching the brain. Speech processing strategies in CIs use multi-channel stimulation in a series of electrical pulses. A bank of bandpass filters is used to analyze the incoming signal into a small number of frequency bands, typically ranging between 12 and 22 channels. Specific frequency ranges are then allocated to individual electrodes. The envelope of the signal, or slowly varying amplitude fluctuations of the signal in each band, is extracted from the output of each filter. This is then used to set the dynamic range for each frequency band. This process discards fine acoustic structure (Loizou, 2006). As such, CI users experience spectral smearing across channels as well as the loss of temporal fine structure. The final output differs greatly from what is present in an acoustic auditory signal. These differences between acoustic hearing and hearing through a CI lead to greater difficulty discriminating between different vowel sounds (Svirsky et al., 2001), tonally contrasted words in tonal languages (Wei et al., 2000), perception of speech signals in noisy environments (van Hoesel et al., 2002), and speaker identification (Fu et al., 2004). Discrimination between consonants that only differ in place of articulation (e.g., /d/ and /g/) is also severely degraded in CI users (Donaldson & Nelson, 2000).

There are also factors that are impacted by the surgical insertion of the electrode array. In optimal circumstances, it is difficult to insert an electrode array to the most apical portion of a normal-shaped cochlea. Potential biological variability may further complicate the physical insertion of a CI. Some etiologies of deafness, such as meningitis, can lead to ossification, which may make it impossible for the electrode to be fully inserted (Helmstaedtar et al., 2018). This may also make it more difficult to position electrodes near the modiolus. This can increase stimulation sensitivity due to its proximity to the spiral ganglia, which are attached to the auditory nerve (Balkany et al., 2009). In implantation of a cochlea without ossification, the most apical electrode is placed near the portion of the basilar membrane with best frequencies of 500 Hz or higher. This means that there will be at least some degree of frequency-to-tonotopic place mismatch in which the auditory stimuli are delivered to fibers of the auditory nerve that are tuned to frequencies higher than those present in the original signal. In cases where CIs are inserted at relatively shallow depths, this mismatch is more pronounced (Landsberger et al., 2016).

1.5. Vocoders

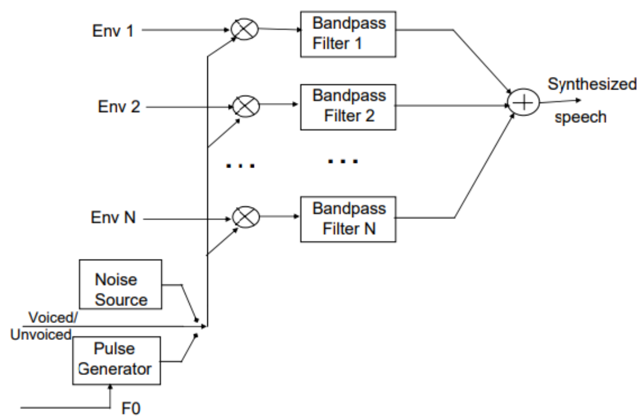
A. Vocoding as CI Simulation

Because speech perception in CI users is highly variable across individuals, it can be studied more easily using a more homogenous group of NH listeners presented stimuli that simulate some features of speech as heard through a CI. Through the use of a vocoder, speech can be processed in a manner similar to the speech processing algorithm of a CI. It can then be further manipulated to simulate an approximation of the effects of different factors that may affect speech perception in CI users.

The basic CI speech processing algorithm is sometimes called “vocoder-centric” processing (Loizou, 2006). This is because the acoustic signal is modified using a process similar to that used by Dudley in his seminal 1939 article discussing his use of a speech synthesis system to reduce the auditory information sent over telephone lines. This system was termed a “vocoder” as shorthand for the term “voice coder.” In vocoding, the acoustic signal is first separated into a number of spectral frequency bands from which the envelope of each band is later extracted (Rao et al., 2007).

Figure 1

The channel vocoder synthesizer (Loizou, 2006)



B. Sine vs. Noise Carriers

Following envelope extraction, the envelope must then be transmitted using a carrier. In the case of a CI, the carrier is a high-rate electrical pulse train for each electrode that follows the modulations in the envelope. For NH listeners, an acoustic carrier must be used to convey envelope information. One type of carrier is bandpass-filtered, Gaussian white noise in the frequency ranges of the vocoded stimuli. Another commonly used type of carrier is sine waves with center frequencies for each filter. The modulated signals of each carrier band are then added together to create the final sound output. This replicates the loss of temporal fine structure information typically faced by CI users (Loizou, 2006). Although studies indicate that it is almost equivalently difficult for listeners to understand speech via both noise and sine wave carriers, the sound outputs of these carriers are quite distinct from one another. This output is also dependent upon other possible variations, such as manipulating the number of channels used to alter the available amount of frequency information (e.g., Baskent & Shannon, 2001), varying the slopes of synthesis bands to alter the distortion caused by electrical spread between electrodes (e.g., Bingabr et al., 2008), and manipulating tonotopic shift to alter the frequency range available in the stimuli (e.g., Siciliano et al., 2009).

1.6. Variability in Vocoded Speech Perception

A. Individual Differences in Training

Although experiments are often conducted using NH participants to avoid the variability potentially caused by biological, surgical, and/or device factors often found among individuals with CIs (Litovsky *et al.*, 2012), in many vocoder studies, a great deal of variability is still found within participants. This is found in individual data from training studies (Davis et al., 2005; Rosen et al., 1999; Waked et al., 2017) as well as acute listening studies where listeners provide responses to stimuli without training (e.g., Eisenberg et al., 2000). These results have been found across both child and adult age groups. In training studies in particular, when individual data are presented, as well as group averages, individuals can be seen to progress at differing rates. Participants showing higher or lower acute scores did not necessarily progress at respectively higher or lower rates (Davis et al., 2005; Rosen et al., 1999; Waked et al., 2017). This variability is not typically a focus of these studies; however, there are a number of factors that may lead to these observed individual differences. Among these are linguistic and cognitive factors.

B. Linguistic Factors

There are a number of linguistic factors that impact typical speech perception. These include vocabulary knowledge (e.g., Geers et al., 2003) and lexical retrieval (Vitevitch et al., 2014). Vocabulary knowledge has been shown to potentially operate as a compensatory mechanism for resolving lexical ambiguity in adverse listening conditions (e.g., Roman et al., 2017; Chiappe et al., 2001; Chiappe et al., 2004). As sentence context and lexical predictability have also been shown to impact speech perception, this may indicate that a larger vocabulary gives listeners a larger set from which to select predictions for upcoming items. As such, a larger vocabulary may aid in lexical retrieval, the ability to quickly and accurately identify words in real time during a continuous stream of speech.

Various models of speech perception suggest different potential roles of lexical retrieval in speech perception. These models can be broadly broken down into top-down and bottom-up models of speech perception. In bottom-up models, such as the motor theory of speech perception, speech is perceived solely from the auditory signal with no input from context or lexical knowledge (Liberman & Mattingly, 1985). In top-down models, such as the cohort or TRACE theories of speech perception, higher-level linguistic knowledge can be used to more efficiently narrow the range of possible options given the phonemes present in the acoustic signal (Marslen-Wilson & Welsh, 1978; McClealland & Elman, 1986). Evidence for top-down models comes from studies investigating phonemic restoration, in which listeners have been shown to able to perceive a word despite the removal or masking of one phoneme. Additionally, listeners are also often unaware of when the order phonemes within a word are switched when presented in a string of speech (Dufour & Grainger, 2019). This indicates that semantic and syntactic knowledge are prioritized in situations of auditory and phonemic degradation.

While these two types of models differ in the role of lexical and contextual access, both categories of speech perception theories prioritize the role of acoustic, bottom-up information. However, only top-down theories explicitly account for our ability to perceive speech in adverse listening conditions where this bottom-up information may be degraded and some acoustic information may be made inaccessible. While evidence supports our ability to use lexical access and context to perceive distorted or deleted phonemes, it remains unclear whether it is truly necessary for listeners to have access to these levels of linguistic processing to perceive degraded speech at the phonemic level.

C. Inhibitory Processing and Age

As previously mentioned, bi-multilingual individuals generally show stronger inhibitory responses when compared to their monolingual peers (e.g., Anderson et al., 2017; Bialystok et al., 2005; Calabria et al., 2012, Calabria et al., 2018; Filippi, et.al., 2015; Martin-Rhee & Bialystok, 2008). Decreased inhibition has been shown to negatively impact monolingual listeners within age groups in difficult listening situations. Such situations include speech in noise (Knight & Heinrich, 2017) and in individuals with tinnitus (Araneda et al., 2015). Additionally, inhibitory control appears to improve with age. Cragg (2016) found that at both 7 and 10 years of age, children had longer reaction times and reduced accuracy relative to 20-year-old adults on measures of inhibitory control. Thus, while increased inhibitory control is likely related to perception of speech in difficult listening environments, this factor also quite likely intersects with age (Zhao et al., 2016). The inherent differences found between bi/multilingual individuals and their monolingual peers on measures of inhibitory control may intersect with age-related factors to further increase variability of vocoded speech perception.

1.7. Comparison of Spanish and English Languages

One means by which it is possible to examine the role of the bilingualism on perception of vocoded speech, is to compare bilingual speakers of two languages with monolingual speakers of one of these languages. One possible pairing is bilingual speakers of Spanish and English and monolingual speakers of English. These two languages share many similarities. Both are intonation languages whose consonant sounds share the same places of articulation. Additionally, as shown in Figure 2, both languages have a similar number of consonant sounds that fall within the same frequency range. Figure 3 shows that, while English contains a greater number of separate vowel phonemes as compared to Spanish, all vowels, both monothongs and diphthongs, fall within the same frequency ranges as their closest equivalent in both languages (Delattre, 1964). However, differences between the phonemic inventories of these two languages do exist. One difference is manner of articulation, particularly as found in the incidence of the alveolar trilled /r/ found in Spanish, which differs from the alveolar retroflex liquid /ɹ/ found in English (Brice et al., 2019; Martínez-Celdrán et al., 2004).

Figure 2

Representation of the first two formants of vowels in Spanish and English as represented in frequency (Hz or cycles per second, cps) (Delattre, 1964).

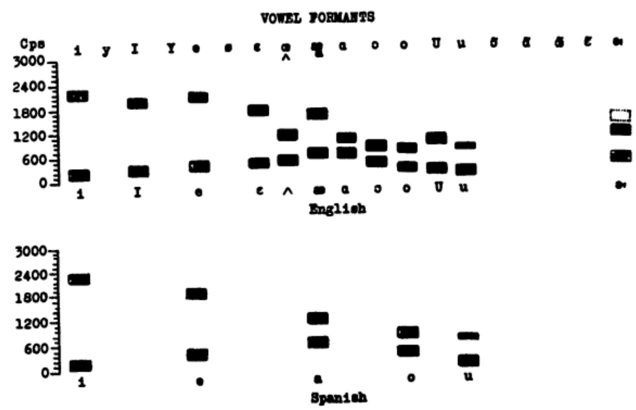
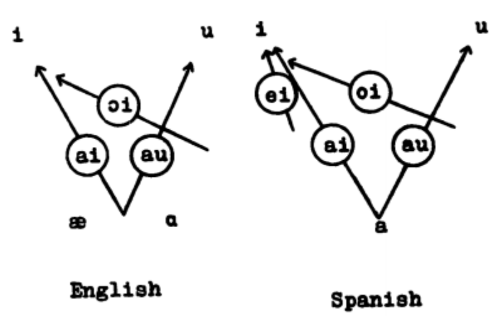


Figure 3

Representation of the most commonly used diphthong vowels in Spanish and English (Delattre, 1964).



1.8. Summary and Aims

This dissertation includes two experiments that aim to examine the impact of bilingualism, linguistic skill, verbal inhibitory skill, age of L2 acquisition, and age at testing on perception of vocoded speech. The primary motivation behind the approaches implemented in these studies is to isolate the factors of both age of acquisition and age at the time of testing in bilingual Spanish-English populations as compared to their monolingual, English-speaking peers. Studies were carried out using vocoded speech to simulate what is heard through a CI. By studying these factors in both language populations, we will be able to better identify the ways in which these factors differ both between groups as well as within each of the seven total groups studied. Measurement of verbal inhibition and language skills will also allow us to better examine possible causes of variability both within and across groups.

Chapter Two focuses on the role of age at the time of testing on perception and learning of vocoded speech at differing degrees of tonotopic shift. I examine prior literature comparing perception and training of vocoded speech in children and adults. The chapter also examines literature comparing perception of vocoded speech between monolingual and bilingual individuals. I will examine the role of cognitive skill and linguistic experience on speech perception in both children and adults. To further examine potential factors that may contribute to variation both within and across groups, linguistic skill will be examined using measures of vocabulary and cognitive skill will be investigated using a measure of verbal inhibition. To control the potentially confounding factor of age of acquisition, all bilingual participants will have been exposed to their L2 of English by the age of four years. To control the potentially confounding factor of differences across participants' native languages, bilingual participants will all be native speakers of Spanish. To better examine the role of bilingualism, each age group will be paired with monolingual, age-matched peers.

In Chapter Three, I focus on the role of age of L2 acquisition in acute perception of target words that differ in factors impacting lexical retrieval difficulty. To manipulate contextual support for word recognition, words will either be presented alone or at the ends of sentences. Words presented in isolation will differ in frequency and neighborhood density. Sentences will either provide high or low context for sentence-final target words. To further examine potential factors that may contribute to variation both within and across groups, linguistic skill will be examined using measures of reading comprehension and cognitive skill will be investigated using a measure of verbal inhibition. To control the potentially confounding factor of age at testing, all bilingual participants will be between the ages of 18 and 25 years. To control the potentially confounding factor of differences across participants' native languages, bilingual participants will all be native speakers of Spanish. To better examine the role of bilingualism, participants will be paired with monolingual, gender-matched peers.

In the final chapter, I combine and compare the overall findings of this dissertation. I also discuss the role of the linguistic measures examined and verbal inhibition on performance both within and across groups on vocoded speech perception. I will then discuss theoretical and clinical implications, general conclusions, and possible future directions.

Chapter 2: The role of age, bilingualism, and individual differences on perception of vocoded speech

2.1 Overview

As discussed in the previous chapter, while the majority of studies on vocoded speech perception have been conducted on monolingual individuals, the majority of the world's population is bi/multilingual. As such, it is important to investigate the role that bi/multilingualism plays in perceiving speech when using a CI. A number of factors may contribute to differences in speech perception with a CI in bi/multilingual listeners as compared to their NH peers. These may include bilingual cognitive advantages in verbal inhibition as well as bilingual linguistic disadvantages in both total lexical capacity and potential lexical gapage in each language of use. Another factor that may impact one's ability to understand speech with a CI is age at the time of testing. Lexical knowledge grows over the lifespan. Children are just beginning to develop their vocabulary and have less overall experience with language use than adults. Children are also still developing cognitive skills that may assist in speech perception.

In this chapter, I discuss existing literature that has examined ways that listeners of different ages and language profiles learn to understand vocoded speech, the benefits and disadvantages of bilingualism on speech perception, and the role of verbal inhibition on speech perception. Additionally, I discuss an experiment conducted with the aim of expanding our understanding of the roles of age and bilingualism on the ability to learn to understand vocoded speech. This experiment used a task that employed alternating testing and training sessions of vocoded speech perception. Measures of English and Spanish receptive vocabulary and verbal inhibition were examined as possible predictors of speech perception scores. Participants in this study were NH individuals listening to vocoded speech simulating what is heard through a CI. NH listeners were studied to better avoid the potential heterogeneity in CI users discussed in the previous chapter.

2.2 Age at Testing

There are fewer studies examining the way that children, rather than adults, understand vocoded speech. Existing studies show that from the very young age of 27 months, children are able to recognize words in 8-channel noise vocoded speech (Newman & Chatterjee, 2013). Studies comparing this ability between children and adults, such as Eisenberg et al. (2000) and Nittrouer et al. (2009), show that young children, ranging in age from 5-7 years, are able to understand noise-vocoded speech, but not as proficiently as adult listeners. Eisenberg et al. (2000) also included an older child age group, ranging from 10 to 12 years. These older children performed on par with the adult participants in this study. Thus, we can see a potential influence of cognitive and linguistic developmental factors in speech recognition even at relatively young ages.

One aspect of cognitive ability is executive function. Executive function is comprised of numerous skills that may be related to speech perception. Some of these skills appear to be fully developed by the age of six years, such as working memory (Gathercole et al., 2004). Others, such as cognitive flexibility, the mental ability to switch between thinking about two different concepts and to think about multiple concepts simultaneously (Scott, 1962), continue to develop throughout adolescence (Anderson, 2002). Verbal inhibition is one aspect of cognitive flexibility. This skill is particularly important for adaptation to unfamiliar forms of speech, such as accents or speech perceived through a vocoder or CI (Bradlow & Bent, 2008).

2.3 Bi/Multilingualism

Age is not the only factor that impacts the highly variable development of executive function skills. Bi/multilingualism also has been shown to facilitate earlier development of some cognitive skills. This may be because bi/multilingual listeners necessarily engage in more tasks of selective attention and cognitive flexibility in their everyday life by virtue of the fact that they must switch between their known languages in different social situations. Differences between monolingual and bilingual children's performance on the Stroop task (Stroop, 1935) can be seen as early as 24 months of age (Poulin-Dubois, 2011). In this study, the task was modified such that stimuli measured verbal inhibition by having children identify smaller images of fruits superimposed onto larger images of either the same or different fruits. As originally produced for adult and older child participants, this measure requires participants to report the color of text that is either printed in the same or different color as the text itself. Responses to discongruent stimuli (e.g., the word "red" printed in green ink in the case of older children and adults) require participants to inhibit their presumed automatic response of reading.

However, bi/multilingual children have been found to experience linguistic disadvantages when compared to their monolingual peers on a variety of tasks. This is particularly noticeable when comparing lexical capacity in bi/multilingual individuals and their monolingual peers. In each of their known languages, bi/multilinguals tend to have smaller lexicons than monolinguals of these same languages. Bi/multilinguals also have greater difficulty in lexical access as compared to their monolingual peers (Sullivan et al., 2018; Bialystok et al., 2010). While some studies indicate that this disadvantage is greatly reduced by the age of seven years (e.g., Yan & Nicoladis, 2009), others suggest that a meaningful difference in vocabulary size can be found throughout the lifespan (e.g., Gasquoine, 2016). It has been hypothesized that some difficulties faced by bi/multilinguals come from the need to process both known languages simultaneously and the need to continually work to inhibit the language not currently in use (e.g., Gasquoine, 2016; Bialystok, 2008). This may explain the longer response times seen in bilingual individuals in lexical retrieval tasks, as well as lower accuracy and increased number of tip-of-the-tongue events (e.g., Sullivan et al., 2018).

2.4 CI Insertion Depth

Even in optimal circumstances, it is difficult to insert an electrode array into the most apical portion of a cochlea. The most apical electrode is often placed near the portion of the basilar membrane with best frequencies of 500 Hz (Landsberger et al., 2016). This means that there will be at least some degree of frequency-to-tonotopic place mismatch. Auditory stimuli will be delivered to fibers of the auditory nerve that are tuned to frequencies higher than those present in the original signal.

Potential etiological variability may further complicate the physical insertion of a CI. Some causes of deafness, such as meningitis, can lead to ossification, which may make it impossible to fully insert the electrode array (Lassig et al., 2005). Shallow electrode array insertion is also performed in a relatively shorter time period than a standard operation for a deep electrode array insertion. In situations where it is preferable for a future CI user to remain under anesthesia for a shorter duration of time, a shallower insertion depth may be implemented as well. Shallower electrode array insertion depths may also allow individuals with some residual hearing to maintain their normal perception of the lower frequencies located at the more apical portion of the cochlea, as implantation destroys any normal residual hearing in a hard of hearing (HoH) individual at the points of implantation (Nordfalk et al., 2016).

This may also make it more difficult to position electrodes near the modiolus. This in turn can increase stimulation sensitivity due to its proximity to the spiral ganglia, which are attached to the auditory nerve (Balkany et al., 2009). In cases where CIs are inserted at relatively shallow depths, tonotopic mismatch is more pronounced (Landsberger et al., 2016).

The effects of age at testing, bi/multilingualism, and CI insertion depth on speech perception were examined in the following study. NH mono- and bilingual children and adults listened to CI simulations of both shallow and deep insertion depths. This allowed us to examine the role that these factors may play on the learning trajectories of perceiving these two kinds of altered speech. Participants were also tested on vocabulary knowledge and verbal inhibition to examine what role these factors may have played in the ability to learn to perceive these two forms of distorted speech.

2.5 Experiment 1

In this study, monolingual and bilingual children (8-10 years), and adults (19-52 years) were trained to understand vocoded speech that simulated either a deep (0-mm) or shallow (6-mm) insertion depth. These conditions were chosen to allow us to examine speech as perceived through an ideal CI implantation (0-mm shift) in which there are no impediments to full insertion of the electrode array as well as speech as perceived through a more complex implantation where the electrode array cannot be fully inserted into the most accessible apical position in the cochlea.

To appraise the potential roles of cognitive and linguistic factors in speech perception, participants in all four groups were tested on measures of verbal inhibition and receptive vocabulary in English. Bilingual speakers of English and Spanish were also tested on receptive vocabulary in Spanish.

Research Questions

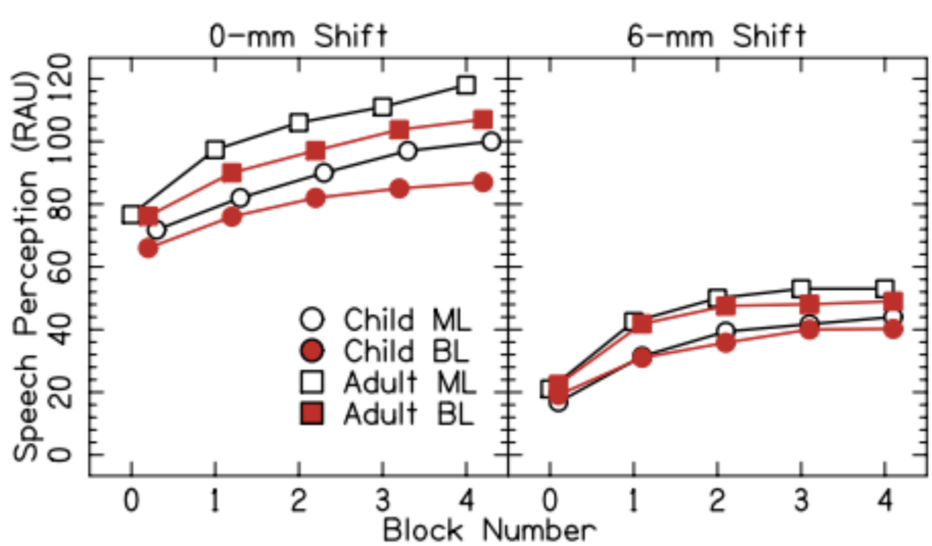
1. Does age (e.g., children and adults) impact learning outcomes of perception of speech vocoded at 0- and 6-mm degrees of shift?
2. Does language status (e.g., mono-, bilingualism) impact learning outcomes of perception of speech vocoded at 0- and 6-mm degrees of shift?
3. Does lexical capacity impact learning outcomes in perception of speech vocoded at 0- and 6-mm degrees of shift in different age and language groups?
4. Does verbal inhibition impact learning outcomes in perception of speech vocoded at 0- and 6-mm degrees of shift in different age and language groups?

Hypotheses

It is hypothesized that improved perception of vocoded speech is unlikely to be solely due to developmental differences between children and adults given the results of Waked et al. (2017), in which monolingual adults only outperformed children in simulations of deep electrode array insertion. As such, it is hypothesized that in conditions of minor distortion, adults are able to use cognitive and linguistic skills that may not have fully developed in children in the 8-10 year age range. However, as shown in Waked et al. (2017), in conditions of more severe distortion, as in the simulation of a shallow electrode array insertion, there will be no distinction between the learning outcomes of child and adult participants. As such, it is hypothesized that these factors are no longer available to compensate for perception of degraded speech. As such, they no longer provide adult listeners with a significant advantage over the speech perception of their child counterparts.

For the same reason, it is hypothesized that monolinguals will outperform bilinguals within their age group. As bilingual speakers may find themselves using different languages or combinations of languages in different settings throughout their lifespans, they are likely to have less experience in either known language as compared to their monolingual peers.

Figure 4
Hypothesized results of training data over the course of the study



It is hypothesized that larger English lexicons and greater verbal inhibition will assist in outcomes in vocoded speech perception of English target words in this task. Larger Spanish lexicons will impede outcomes in vocoded speech perception of the English target words in this task. Lexical capacity has been shown to be a predictor of speech perception (e.g., Geers et al., 2003). As such, it is hypothesized that a larger English language lexicon, the language of testing, will lead to improved speech perception. It is also hypothesized that a larger Spanish language lexicon may hinder bilingual participants' success in this study. Lexical capacity in each known language in bilingual individuals tend to be smaller than that of monolingual speakers of the same language. This is due to the fact that bilingual speakers are exposed to fewer lexical tokens in each language as compared to their monolingual peers. They may, however, have a similar total number of lexical tokens when known languages are combined (e.g., Anaya et al., 2018). As discussed in Chapter 1, some researchers believe that this difference is only found in childhood (e.g., Yan & Nicoladis, 2009), others, such as Gasquoine (2016), believe that this difference is likely to persist throughout the lifetime as different lexical tokens are consistently associated with different environments and situations. This decreases listeners' ability to access a semantically equivalent token in one language when it is more commonly used in their other language. As such, a higher number of Spanish language lexical tokens may be associated with decreased efficiency of lexical retrieval of English target words. Target words in the task used in this study are presented within a sentence. The reduced efficiency of lexical retrieval in bilingual individuals may hinder access to the full syntactic context of each sentence, thus leading to greater difficulty in perception of speech as presented in this study.

Verbal inhibition also plays a role in successful language learning and use. When L2 learners are most successful, they are often shown to experience a temporary decline in assessments of their first language. This may reflect the fact that they are successfully inhibiting interference from their first language in order to effectively use an L2 (Linck et al., 2009). Similarly, the increased ability to inhibit existing representations of speech relative to their monolingual peers may assist in bilinguals' ability to perceive vocoded speech. This is assumed to be due to the fact that vocoded speech will likely be perceived as a new representation for known lexical items that will need to be quickly assimilated into a new form of lexical representation. As such, it is hypothesized that greater verbal inhibition skill will improve performance on the speech perception task.

Method

Participants: Participants included children (ages 8-10 years) and adults (ages 19-52 years). The age range for children in this study was selected in order to more closely replicate Waked et al. (2017). In this study, the age range was selected to target the crucial fourth-grade age range in which students transition from learning to read to reading to learn (Chall & Jacobs, 2003). Monolingual groups included native speakers of English who self-reported exposure to English during at least eighty percent of their day. Bilingual groups included native speakers of Spanish who had not been exposed to languages other than English. To avoid issues that may be caused by late exposure to an L2, parents of children participating in this study reported that their child had been exposed to both English and Spanish from birth. Additionally, due to evidence supporting the possibility of a critical period for second language acquisition (e.g., DeKeyser, 2012), all adult participants self-reported regular exposure to their second language in one or more primary areas of their childhood environments by the age of four years. Members of bilingual groups self-reported exposure to English between 30% and 70% of their day.

Child participants were recruited using the University of Maryland Infant Database. Many adult participants were also recruited through this database as parents of child participants. The remaining adult participants were recruited through the University of Maryland Department of Psychology research recruitment system. All child participants were financially compensated for their time and received small toys and prizes throughout the duration of testing. Adult participants received either financial compensation or course credit as compensation for participating in this study.

Vocoded speech testing: Prior to engaging in this study, all participants received a hearing screening to ensure that their hearing thresholds were at 20 dB-A or lower for frequencies ranging from 250-8,000 Hz. The procedure for the first session took place over a two-hour period and consisted of five testing blocks.

During testing blocks, participants were asked to identify vocoded speech simulating both 0- and 6-mm of tonotopic shift. The 0-mm condition simulated a deep insertion depth of a CI electrode array (less distortion) and a 6-mm shift simulated a shallow insertion depth of a CI electrode array (greater distortion). Following each of the first four testing sessions, participants were trained on stimuli simulating a 6-mm shift. No training took place following the final fifth test.

Figure 5
Computer interface for the speech perception portion of the experiment

Training included simultaneous visual and auditory feedback. Accurately perceived targets words were highlighted in green and inaccurately perceived target words were highlighted in red. Inaccurately selected words were highlighted in blue. Simultaneous to this visual feedback, participants also received auditory feedback. Each target sentence was first played in the unprocessed condition, followed by repetition of the same sentence in the 6-mm shifted condition (Davis et al., 2005; Stacey & Summerfield, 2007, Waked et al., 2017). Participants heard each of the two conditions 20 times for a total of 40 randomized repetitions.

The study began with a baseline testing session with vocoded conditions at both 0- and 6-mm of shift. For child participants, three trials of unaltered speech were administered prior to the testing condition to ensure that participants understood the basic requirements of the study. Stimuli were delivered via Sennheiser, HD650, circumaural headphones. All testing took place in a double-walled, sound-attenuated booth. Child participants were accompanied by an experimenter to ensure proper control of the computer interface and to keep participants on task. Trials were participant-led and both began and ended with a button press.

Vocoded speech testing generally followed the procedure of Waked et al. (2017). Stimuli in both experiments consisted of a phonetically balanced matrix of words (Kidd et al., 2008), shown in Figure 4. This closed set of words was presented in an 8×5 matrix where one word from each column was heard during each trial. This matrix included five columns of words in English. Each of these columns contained eight words. The first column consisted of proper names, the second of verbs, the third of numbers, the fourth of adjectives, and the last of nouns. These five words were presented together as simple sentences, such as 'Jane gave two red bags.' This corpus was selected because it consists of elementary-level words as determined by Kidd et al. (2008) in order to ensure that reading comprehension was unlikely to be a factor in the assessment of speech perception of child participants. Words were spoken by a single female speaker. All stimuli in this portion of the experiment was presented via computer interface.

In the vocoding process, fourth-order Butterworth filters were used to band-pass filter stimuli into eight channels. The corner frequencies were logarithmically spaced and covered a 200 to 5000 Hz frequency range. This range was chosen to prevent the central frequencies of the shifted condition from exceeding the upper range of human hearing.

Table 1
0- and 6-mm shifted center frequencies

Unshifted Center Frequency (Hz)	Shifted Center Frequency (Hz)
244.57	748.16
365.72	1025.69
546.87	1440.70
817.77	2061.28
1222.84	2989.26
1828.58	4376.92
2734.36	6451.95
4088.83	9554.85

Speech envelopes were extracted using a 2nd-order low-pass filter with a 32-Hz cutoff frequency. These were used to modulate sine-tone carriers. A relatively low envelope cutoff was used to prevent sidebands generated by the modulations from being spectrally resolved (e.g., within a single auditory filter) as resolved sidebands greatly improve vocoded speech perception (Souza & Rosen, 2009) and would have introduced a potential confound for the shifted stimuli. Carrier frequencies were linearly shifted by 0 or 6 mm using the Greenwood (1990) formula. A loudness correction was used for the shifted conditions to diminish differences in performance across the conditions based on level or audibility of the speech information. The loudness compensation adjusted the level by 50% between the threshold for the unshifted and shifted carrier frequencies. Threshold was based on the minimum audible field curve (Faulkner et al., 2003). Stimuli were synthesized by summing the channels into the acoustic waveform and then normalized to have equal root-mean-square energy as the unprocessed speech. Because a previous study found no difference in perception between simulations of the medium array insertion of 3-mm and the short array insertion of 6-mm (Waked et al., 2017), only the 0- and 6-mm conditions were used in this study. We chose to use the 6-mm condition for both training and testing conditions as it has previously been used in other existing literature (e.g., Rosen et al., 1999).

Linguistic and cognitive testing: During the second visit, tasks consisted of receptive vocabulary measures in English and/or Spanish and a measure of verbal inhibition. The goal of these measures was to examine possible effects of these factors on overall performance in the speech perception portion of the experiment across groups.

Receptive vocabulary in English was measured using the *Peabody Picture Vocabulary T*est-*Revised (PPVT-R)* (Dunn, 1981). Bilingual participants also completed the *Test de Vocabulario en Imagenes Peabody* (*TVIP*) (Dunn et al, 2010), the approximate Spanish language equivalent to the *PPVT-R.* To improve consistency, tests were administered using stimuli prerecorded by a male native speaker of either Spanish or English. Rather than using the typical method of scoring using either standard scores or percentiles, raw scores were used to assess each of these measures. As this method of scoring differs from that of the normed, standardized scoring measures, this may potentially weaken the reliability of these measures used in our study. This presents a potential weakness of our study in which the reported scores do not necessarily accurately reflect the receptive vocabulary skill of the participants of this study (Williams, 1999).

The Stroop Test was used to assess verbal inhibition as another possible source of variability. This task was presented on an iPad and required participants to select the color in which a word was written while ignoring the written name of a color. This task included both congruent and discongruent stimuli. Because of the automatization of the reading process and the strength of the association between colors and their names, participants were required to inhibit their inclination to respond with the text of the word rather than the color of the font in which it was written (Stroop, 1935). As preliminary testing indicated that only the accuracy of discongruent stimuli in this test significantly impacted speech perception outcomes, the percentage of correctly identified discongruent stimuli was used as the measure of inhibition in this study. This method was used rather than the typical scoring method of calculating the difference in reaction time between correct responses of congruent and discongruent stimuli. As this is not the standardized, normed method of scoring, this may also reduce the reliability of our testing, potentially inaccurately assessing participants' verbal inhibition skill (Jensen, 1965).

Results

Results for this study were calculated using mixed-effect modeling with all predictor variables centered and standardized to improve convergence. This form of modeling allowed us to account for both random and fixed effects (Walker et al., 2019). All models were run using the software R Studio.

<u>Main Effects:</u>

Figure 6

Average responses for adult and child listeners as a function of block number. Error bars represent ±1 standard error. Standard error values under 1.5 are not visible in this figure. Error bars are not visible in the case of bilingual child participant results in 0-mm shift and in all participant results in 6-mm shift.

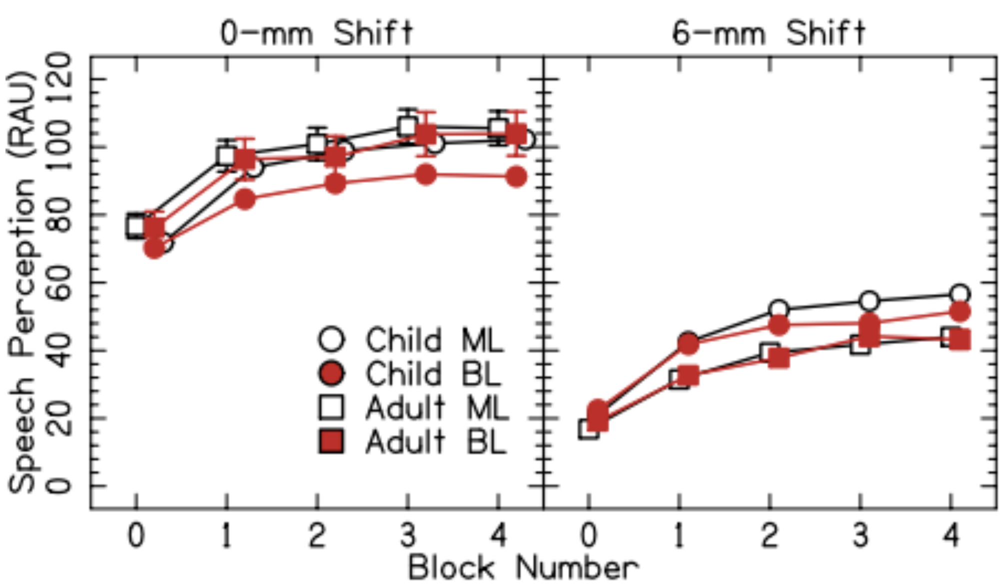


Table 2

Descriptive statistics of child and adult data at 0-mm at post-test in RAU

	Monolingual Child	Bilingual Child	Monolingual Adult	Bilingual Adult
Number of Participants	21	20	21	19
Mean	102.19	91.29	105.52	103.90
Standard Deviation	11.92	18.73	8.37	5.27

Table 3

Descriptive statistics of child and adult data at 6-mm at post-test in RAU

	Monolingual Child	Bilingual Child	Monolingual Adult	Bilingual Adult
Number of Participants	21	20	21	19
Mean	56.58	51.54	44.01	43.21
Standard Deviation	20.63	20.82	24.71	26.12

Two models were built to examine whether main effects of age or language group could be found in each of the two conditions of shift. Prior to constructing these models, all factors, including predictor variables added in the following section, were tested for possible correlations. No correlations were found between any variables. In these models, both age and language group were used as fixed effects. The block number (pre-test and post-test) and degree of shift (0- and 6-mm) were also used as fixed effects in each model. These models were built using the dependent variable, "test score," which included the scores of the first and final runs of testing in the two conditions of shift. Due to the high number of tests run in both the analysis of main effects and predictor variables, only scores at $p < 0.0001$ were considered to be significant.

In the first model, monolingual adults were used as the reference group. As such, all results pertain specifically to this group, but were extrapolated to the other three groups.

Table 4

Fixed effects of age and language group with monolingual adults as the reference group

	Estimate	Std. Error	df	t-value	P (>|t|)
(Intercept)	1.77	3.78	9.45	18.98	< 2e-16 *
Language Group	-1.54	5.34	219.45	-0.28	0.77
Age Group	4.92	5.218	9.45	0.94	0.34
Post Test	30.42	4.43	213.00	6.86 `	7.19e-11 *
6-mm Shift	-50.70	4.43	213.00	-11.44	< 2e-16 *
Language Group x Age Group	1.03	7.6493	219.45	0.136	0.89
Language Group x Post-Test	-9.35	6.26	213.00	-1.49	0.13
Age Group x Post-Test	-1.59	6.11	213.00	-0.26	0.79
Language Group x 6-mm Shift	2.97	6.26	213.00	0.47	0.63
Age Group x 6-mm Shift	-9.14	6.11	213.00	-1.49	0.13
Post Test x 6-mm Shift	5.10	6.26	213.00	0.81	0.41
Language Group x Age Group Post-Test	8.24	8.96	213.00	0.91	0.35
Language Group x Age Group x 6-mm shift	-0.19	8.96	213.00	-0.02	0.98
Language Group x Post Test x 6-mm Shift	2.88	8.86	213.00	0.32	0.74
Age Group x Post-Test x 6-mm Shift	-6.75.	8.65.	213.00	-0.78	0.44
Language1 x Age Group x Post-Test x 6-mm Shift	-4.839.	4.12.67	1 3.00	-0.382.	0.70

As shown in Figure 6 above, participants were found to significantly improve over the course of the study and the 6-mm shifted task was found to have significantly lower scores than the 0-mm shifted task. These results were both significant at $p < 0.0001$. No significant main effects of language or age were found through this model.

As there were no significant interactions in the above model, it could be assumed that these results extended to all other groups included in this study. However, to confirm this, a second model was constructed using bilingual children as the reference group.

Table 5

Fixed effects of age and language group with bilingual children as the reference group

	Estimate	Std. Error	df	t-value	Pr(>|t|)
(Intercept)	76.18	4.12	219.45	18.48	< 2e-16 *
Language Group	0.50	5.46	219.45	0.09	0.92
Age Group	-5.95	5.59	219.45	-1.06	0.28
Post-Test	27.71	4.82	213.00	5.73	3.27e-08 *
6-mm Shift	-57.07	4.82	213.00	-11.81	< 2e-16 *
Language Group x Age Group	1.03	7.64	213.00	0.13	0.89
Language Group x Post-Test	1.11	6.41	213.00	0.17	0.86
Age Group x Post-Test	-6.64	6.55	213.00	-1.0	0.31
Language Group x Post-Test	-2.78	6.41	213.00	-0.43	0.60
Age Group x 6-mm Shift	9.33	6.55	213.00	1.42	0.15
Post-Test x 6-mm Shift	-3.61	6.83	213.00	-0.52	0.59
Language Group x Age Group x Post-Test	8.24	8.96	213.00	0.91	0.35
Language Group x Age Group x 6-mm Shift	-0.19	8.96	213.00	-0.02	0.98
Language Group x Post-Test x 6-mm Shift	1.96	9.06	213.00	0.216	0.82
Age Group x Post-Test x 6-mm Shift	11.59	9.27	213.00	1.25	0.21
Language Group x Age Group x Post-Test x 6-mm Shift	-4.83	12.67	213.00	-0.38	0.70

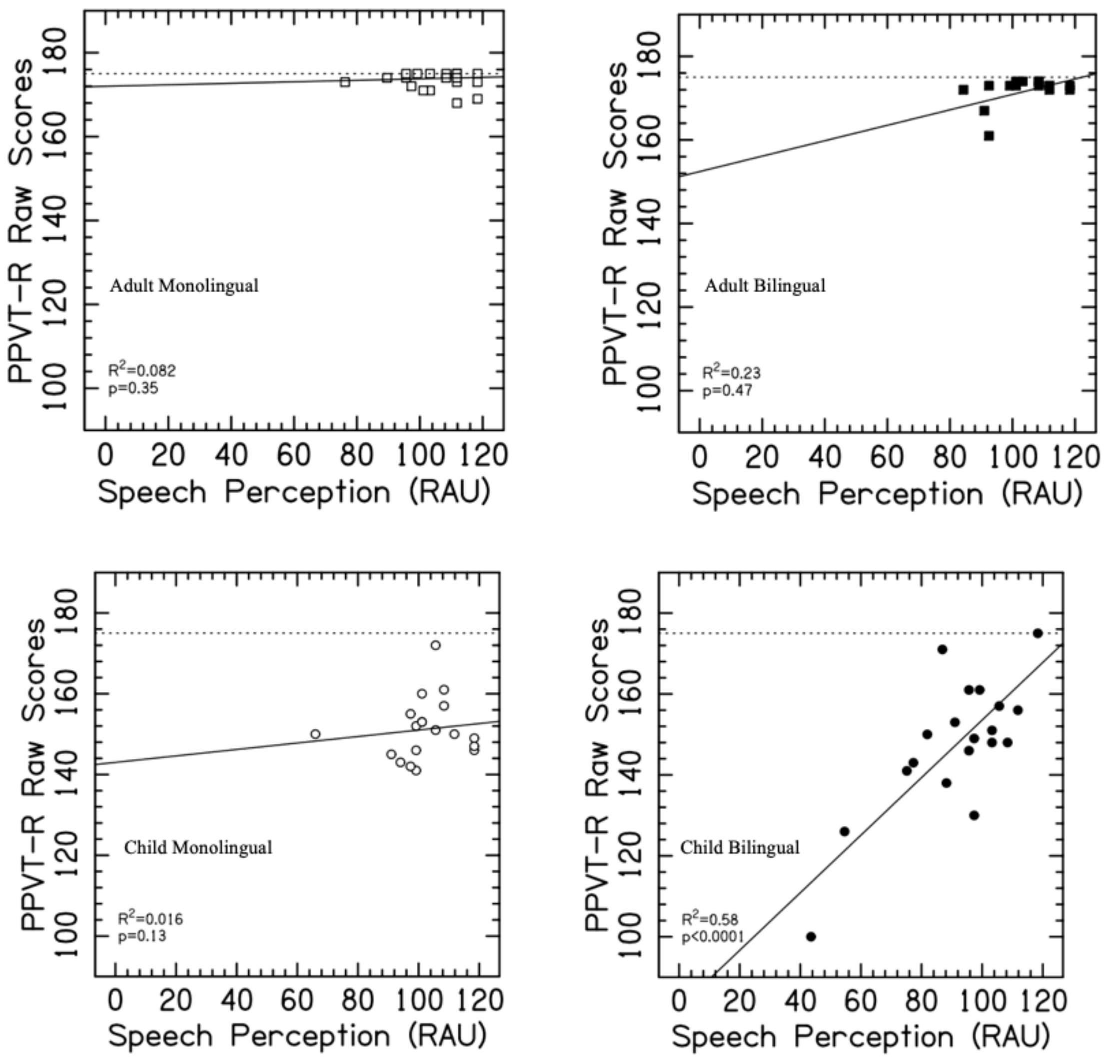
As was found with the previous model, bilingual children are found to improve over the course of testing and to score higher in the 0-mm condition relative to the 6-mm condition.

<u>Predictor Variables:</u> In this study, three variables were considered as possible predictors of test scores. These included the independent variables of English vocabulary, Spanish vocabulary, and verbal

inhibition. English vocabulary was tested through the *PPVT-R,* Spanish was tested through the *TVIP,* and verbal inhibition was tested through the Stroop Test. Variables were added one at a time to each of the two models above. English vocabulary was first added, and was not found to improve model fit. As such, this variable was not included in the construction of further models. The variable Spanish Vocabulary was also not found to improve model fit, and as such was also excluded from further models. The final variable added was Stroop test score. This variable also was not found to improve model fit for either of the models constructed. As such, it can be determined that none of these variables significantly impacted speech perception in this study.

Following model testing, Pearson r correlations were conducted to determine whether any correlational relationships existed between speech perception scores and the three predictor variables for each of the four groups tested. Only one significant correlation was found. As shown in Figure 7, raw scores of the *PPVT-R* were found to significantly correlate with speech perception scores in the 0-mm shift condition at $p < 0.0001$. Raw scores were used in this measure as no standard scores or percentiles were available.

Figure 7
Correlations of scores on the *PPVT-R* and post-test scores in the 0-mm shifted condition. Dashed line indicates ceiling of *PPVT-R* scores



Follow-up analysis: As the findings of the main effects of this study do not replicate what has been found in previous literature comparing vocoded speech learning by monolingual adults and children (Eisenberg et al., 2001; Nittrouer et al., 2009; Waked et al., 2017), a brief follow-up analysis was performed to account for a possible effect of age at the time of testing. Adults in the primary study ranged in age from 19-52 years, whereas adults in previous studies have ranged in age from approximately 18-25 years. A repeated measures ANOVA showed that scores at both 0- and 6-mm of shift in adults age 25 years or lower was not significantly different than those above the age of 25 years at p = 0.47 for the 0-mm shift condition and p = 0.43 for the 6-mm shift conclusion; however, a follow-up study was conducted to more accurately replicate previous work.

In the follow-up study, the monolingual children from the primary study were compared to a group of twenty-one monolingual, young adult participants. This group was comprised of twelve participants of the primary experiment between the ages of 18 and 25 years and an additional nine monolingual participants in this age range who were tested after the initial period of data collection. In the following model, age, shift, and run number were used as fixed variables. Test score was used as the dependent variable, and adults were used as the reference group.

Figure 8

Average responses for monolingual young adult and child listeners as a function of block number. Error bars represent ±1 standard error. Standard error scores below 1.5 are not visible in this figure. Error bars are not visible in the final two blocks of 0-mm shift in adult participant results.

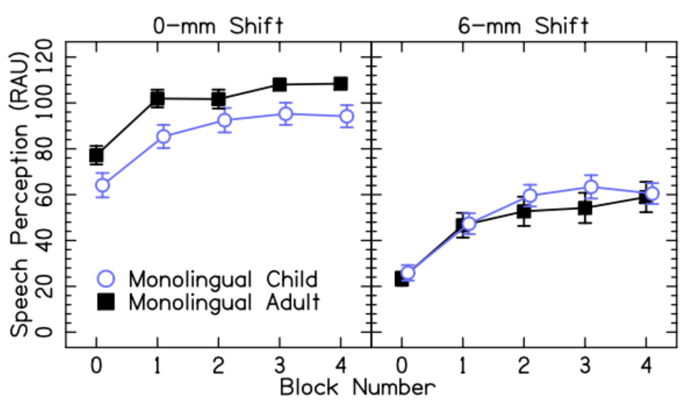


Table 6

Descriptive statistics of monolingual child and young monolingual adult post-test scores at 0-mm in RAU

	Monolingual Child	Monolingual Adult
Number of Participants	21	21
Mean	102.19	108.41
Standard Deviation	11.92	10.01

Table 7

Descriptive statistics of monolingual child and young monolingual adult post-test scores at 6-mm in RAU

	Monolingual Child	Monolingual Adult
Number of Participants	21	21
Mean	56.58	58.94
Standard Deviation	20.63	30.31

Table 8

Fixed effects of age and language group with monolingual children and young monolingual adults

	Estimate	Std. Error	df	t-value	Pr(>|t|)
(Intercept)	71.71	4.23	129.10	16.94	< 2e-16*
Age Group	6.324	5.84	129.10	1.08	0.28
Post-Test	30.42	4.38	342.00	6.94	1.95e-11 *
6-mm Shift	-50.70	4.38	342. 00	-11.57	< 2e-16 *
Age Group x 6-mm Shift	-4.07	6.04	342.00	-0.67	0.500
Post Test x 6-mm Shift	5.10	6.19	342.00	0.82	0.41
Age Group x Post-Test x 6-mm Shift	0.21	8.55	342.00	0.02	0.97

As with the original group of monolingual adults from a wider age range, no significant differences were found between child and young adult participants in the either condition of vocoded speech, despite the visible difference in the 0-mm condition shown in Figure 8. This is inconsistent with the results found in Eisenberg et al. (2000) as well as Waked et al. (2017). Because the current experiment replicated the methods of Waked et al. (2017) an ANOVA was conducted in order to replicate the method of calculation used in that study. Results remained insignificant at both degrees of shift with a 0-mm shift x age group interaction at $p = 0.67$ and a 6-mm shift x age group interaction at $p = 0.69$.

Despite using similar methods, these results do not replicate those of Waked et al. (2017). In the 2017 study, these measures were used to examine differences between monolingual young adults and 8-10 year old children at 0-, 3-, and 6-mm of shift, as shown in Figure 9. In this study, adults were found to significantly outperform children at 0-mm of shift. No such difference was found in the current study. While there is no significant difference between child and adult participants at 6-mm of shift in the current study, there is also no significant difference between the scores of child and adult participants at 0-mm shift in these two studies as measured by a repeated measures ANOVA, where p is insignificant at 0.83. This overlap is reflected in Figure 10, comparing the results of these two experiments.

Figure 9

Average responses for monolingual young adult and child listeners as a function of block number. Error bars represent ±1 standard deviation (Waked et al., 2017)

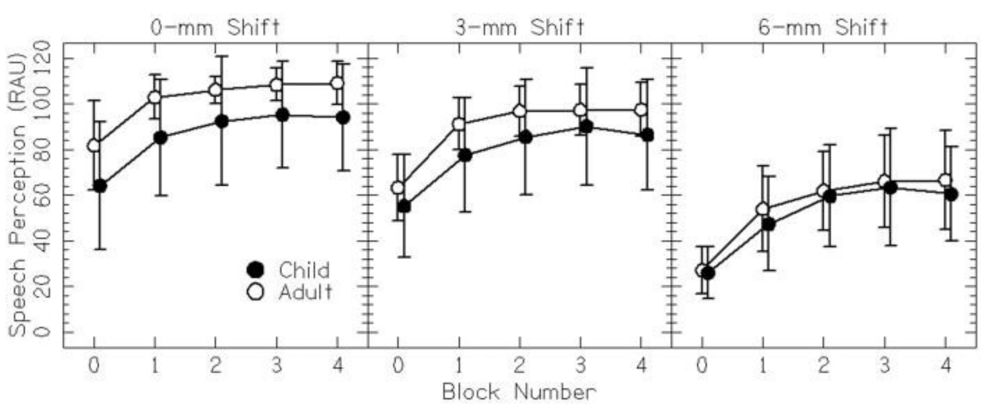
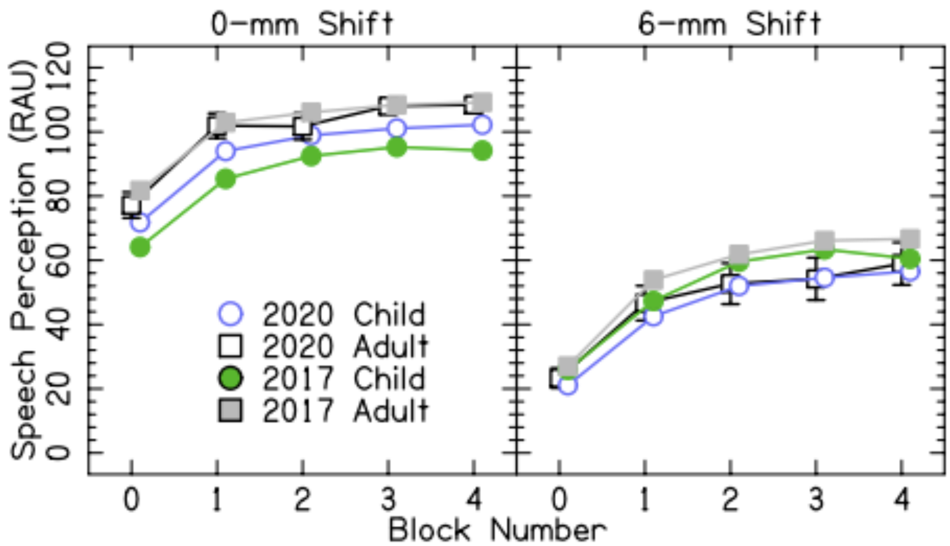


Figure 10

Average responses for monolingual young adult and child listeners as a function of block number in both the 2017 and current study. Error bars represent ±1 standard error. Standard error scores below 1.5 are not visible in this figure.



2.6 Discussion

This study aimed to investigate the roles of bilingualism and age on perception of vocoded speech simulating both a deep (0-mm) and shallow (6-mm) CI electrode array insertion in NH children and adults. The task alternated testing and training sessions of vocoded speech perception. This study also investigated factors thought to play a possible role in perception of these forms of vocoded speech, including lexical capacity in English and/or Spanish as well as scores of verbal inhibition. These variables probe the potential role of cognitive and linguistic systems of bilingual individuals, which include improved executive function of bilingual individuals relative to their monolingual peers (e.g., Bialystok, 1987, Weiseheart et al., 2016) and of adults relative to their child counterparts (Cragg, 2016). These variables also include the bilingual linguistic disadvantage, as shown through reduced numbers of lexical tokens in each known language, potential lexical gapage, and greater difficulty of lexical access of bilingual individuals relative to their monolingual peers (e.g., Sullivan et al., 2018; Bialystok et al., 2010).

One aim of this study was to discover if age and language groups impact the learning trajectory of perceiving speech vocoded at 0- and 6-mm degrees of shift. In this study, no significant age effects were found. Based on the results of Waked et al. (2017), we hypothesized that adults would outperform children within their language group wherever they were able to use their greater linguistic knowledge and experience to better perceive distorted speech. In this earlier study, adults significantly outperformed children in conditions of 0-mm shifted vocoded speech. This result was not found in conditions of 3- and 6-mm speech. As such, it was concluded that in conditions of minor distortion, adults are able to use cognitive and linguistic skills that may not have fully developed in children in the 8-10 year age range. This study concluded that this greater linguistic knowledge and experience was only available to adults in conditions of minor distortion, as found in the 0-mm shifted condition. In conditions of more severe distortion, as in the simulation of medial (3-mm) and shallow (6-mm) electrode array insertion, these factors were presumed to no longer be available to assist in the perception of degraded speech. As such, they no longer provided adult listeners with a significant advantage over the speech perception of their child counterparts.

The current experiment failed to find the significant difference between young adult and child participants found in Waked et al. (2017). This indicates that there may be some slight differences between the two child groups in these studies. One key difference between these two studies is the presence of the 3-mm shift condition, which was not included in the current study. It is possible that the presence of greater diversity in testing conditions may have led to greater fatigue and distraction in children relative to their adult counterparts in Waked et al. (2017). Children in the tested age group have been shown to perform less successfully when asked to focus on a greater number of stimuli as compared to their adult counterparts (Chavual et al., 2017). It is possible that reducing the number of conditions removed a portion of the cognitive load placed on children in Waked et al. (2017) in the current study. As such, although the same number of trials were included in the current study under both testing and training conditions and the same number of trials were used in both studies, the actual outcome of the studies may have differed due to the decreased cognitive load in the current study. This may suggest that the conclusions of Waked et al. (2017) were incomplete. The conclusion of the previous study may also have been under-informed due to the fact that stimuli were comprised of syntactically correct sentences that were essentially devoid of meaning. Had context cues been included, the role of linguistic knowledge and experience in children and adults may have been better examined.

Another factor that may have led to the null results found in this study is the fact that it was likely underpowered. A post-hoc power analysis indicated that in order to avoid type two errors at 80% probability, 77 participants would have been required in each of the four groups tested. However, in this study, groups ranged between 19 and 21 participants. As such, it is very likely that had more participants been tested, effects of age and language group would have a greater likelihood to be found.

Age at the time of testing may also have impacted the results of this study in ways not evaluated by previous literature, such as Eisenberg et al. (2000), Nittrouer et al. (2009) and Waked et al. (2017). In Nittrouer et al. (2009), seven-year-old monolingual children were shown to perform more poorly than adult monolingual participants in conditions of 4-channel noise-vocoded speech. In Eisenberg et al. (2000), two groups of children were studied. These groups consisted of one group of 5-7 year olds and another group of 10-12 year olds. In this study, only younger children were found to perform more poorly on measures of more severely degraded conditions of vocoded speech perception than both adult and older child participants. As the current study was in part intended to test the replicability of Waked et al. (2017), ten-year-old children were included in the tested age group. Had only younger children been tested, age differences might have been found.

Age effects and lack of context in stimuli, as well as the failure to examine word frequency and neighborhood effects, may also account for the lack of any significant difference found between monolingual and bilingual participants (Massingham, 2018). It was hypothesized that as bilingual speakers often find themselves using different languages or combinations of languages in different settings, this would lead participants to have less experience in either known language as compared to their monolingual peers. Had stimuli in this study examined context and word frequency rather than semantically empty sentences, potential differences between monolingual and bilingual groups may have been found. Including sentences with greater semantic context may have allowed us to better understand the role of top-down processing, by which participants may have been better able to construct a conceptual representation of the stimulus. This context might improve speech perception outcomes by allowing participants to fill in any perceptual gaps caused by misheard words. The role of semantic context might also be examined by varying the availability of syntactic context, which would better isolate the role of semantic context in speech perception.

Another factor that may have impacted this study is the fact that all bilingual participants were exposed to both English and Spanish at an early age. All bilingual children were regularly exposed to both Spanish and English at birth and all bilingual adults were exposed to both languages by the age of four years. Tabri et al. (2010) found no significant difference between monolingual and early bilingual adult speakers in conditions of speech perception in noise. Differences were, however, found between these two groups and late L2 learners. It is possible that monolingual and early bilingual listeners respond similarly to other forms of difficult speech perception, including vocoding. As such, we cannot conclude that the factor of bilingualism alone can predict differences in vocoded speech perception between monolingual and bilingual individuals.

In addition to examining how age and bilingualism impact the learning trajectory of perceiving speech vocoded at 0- and 6-mm degrees of shift, we also sought to examine ways that English and/or Spanish lexical capacity and verbal inhibition might have impacted this learning. It was hypothesized that increased English lexical capacity and verbal inhibition would assist in outcomes of vocoded speech perception. It was also hypothesized that increased scores of Spanish lexical capacity would impede speech perception outcomes of the English-language stimuli used due to the act that this would indicate greater overall lexical capacity in Spanish. No significant effects of either vocabulary knowledge in either language or verbal inhibition were found on the post-test scores of any of the four groups tested at either degree of shift.

Verbal inhibition was measured by the Stroop test. In this study, verbal inhibition showed no significant effect on speech perception scores for any group. This test was measured using accuracy scores of discongruent trials on the Stroop test, as preliminary testing showed no significant effect of accuracy or reaction time of congruent trials, the reaction time of either congruent or discongruent trials, or the time difference between these two types of trials. As such, it was determined that these other measures should be removed from calculation in this study to reduce potential variance. However, to accurately calculate the Stroop effect, the difference in reaction time between congruent and discongruent stimuli should have been examined. Accuracy is a binary measurement. Subtler differences may have been found between groups had reaction time been used. Reaction time allows for the observation of greater variability than the use of accuracy alone. Without reaction time, the measure does not present the actual Stroop effect. As such, verbal inhibition as examined in this study does not actually use the Stroop test as it was intended. Reliability of this measure may have been reduced and potentially miscalculated the verbal inhibitory skill of participants. Had a different decision been made regarding how to best assess verbal inhibition while reducing potential variance, different results may have been found.

This measure of verbal inhibition, the Stroop test, was chosen due to the fact that stimuli in this study consist of auditorily presented verbal stimuli. However, it is possible that using a verbal measure of inhibition may have acted as a confounding factor in determining the effect of inhibition on speech perception. This is due to the fact that using two measures of the same type of processing may have led the measure testing inhibitory skill to account for variance in scores in the speech perception portion of this study. As such, it may have been more prudent to use a different measure of inhibition, such as the go, go-no measure of motor inhibition, in which participants are instructed to physically react to all stimuli presented on a screen aside from one particular image. When presented with this image, participants must inhibit themselves from the automatic physical response they have been instructed to give when presented with any other stimuli. By testing a different type of stimuli, this potential confound could have been avoided.

In addition to null effects of verbal inhibition in relation to speech perception outcomes, no significant effects of lexical capacity in either Spanish or English were found to effect speech perception in any age or language group in this study. Previous research indicates that lexical capacity significantly improves speech perception (e.g., Geers et al, 2003). In this study the *PPVT-R* and the *TVIP* were used to measure receptive vocabulary in English and Spanish respectively. These tests measure decreasingly frequent lexical tokens where target words are presented auditorily and must be matched to one of four visually presented images. Following presentation, participants are required to select an image that semantically relates to the auditory stimulus. These tests were chosen as they can be used to study both child and adult populations and are equivalent to one another in methodology across both English and Spanish. However, it is important to note that all measures were scored atypically. For the *PPVT-R/TVIP*, either standard scores or percentiles are typically used to assess performance. However, in this study, only raw scores were used. As such, these scores are not normed to the appropriate ages of individual participants relative to their peers of the same age, decreasing the reliability of this measure. It is possible that, had traditional scoring methods been used, an effect of lexical capacity might have been found.

In post-hoc correlations, scores on the *PPVT-R* were found to significantly positively correlate with post-test scores of only bilingual children in the 0-mm condition. Greater exposure to English in the home environment has been linked to greater scores of speech perception in bilingual speakers exposed to English at a young age (Tao & Taft, 2017). It is possible that bilingual child participants with larger English lexical capacities may also have greater exposure to English in their home environment than those with smaller English lexical capacities. Greater amounts of exposure may also lead to greater comfort and familiarity with perception of speech in English. Bilingual participants in this study were reported to experience English exposure between thirty and seventy percent of their daily linguistic interactions.

It is possible that participants who are exposed to English for a greater percentage of their day have improved speech perception in English relative to other members of the bilingual groups tested. This increased exposure may have helped some bilingual children to outperform group members with lower levels of English language exposure. As such, future analyses of this potential relationship should include a regression of the degree of exposure to English and perception of speech vocoded at 0-mm of shift. It may also be prudent to examine the role of other, non-verbal linguistic factors on bilingual children's perception of vocoded speech. The current experiment effectively examined syntactic context as sentences used were devoid of meaning. In addition to examining the role of syntactic context, it may also be worthwhile to investigate the role of intonation and other linguistic cues in perception of vocoded speech in bilingual children.

The fact that an effect of receptive vocabulary in English was found on perception of vocoded speech may indicate a potential area of concern for bilingual children who are CI users. In order to improve speech perception scores in English, greater lexical capacity in this language is needed. However, in order to improve this lexical capacity, participants must both be exposed to English lexical tokens as well as have the auditory ability to accurately perceive these words. Yet to better auditorily perceive these lexical tokens, participants may require greater lexical capacity. This leads to a circular effect in which speech perception impacts lexical knowledge while lexical knowledge impacts speech perception.

In NH monolingual children, perception of sounds present in their target language during infancy has predicted later vocabulary growth. These early phonological representations appear to form the basis of later speech perception, which in turn allow for later lexical acquisition. In NH bilingual infants, the ability to differentiate between the sounds of their two native languages becomes apparent by the age of 4 months (Werker, 2012). For NH bilingual children exposed to both Spanish and English from birth, the ratio of early English to Spanish exposure predicts later vocabulary size in each language (Kuhl, 2009, Silven et al, 2014). The majority of studies of bilingual language acquisition in CI users does not include exposure to two oral/aural languages; however, in studying bilingual Spanish-English bilingual CI users implanted by the age of 36 months, Yim (2012) found that scores on the *PPVT-IV* (Dunn, 1988) improved with age, duration of implantation, and the amount of home exposure to the target language, English. These results indicate that early exposure to the phonemic components of an L2 improve later receptive vocabulary knowledge in bilingual children who use CIs. Future studies may be used to investigate the role of early phonological perception in bilingual CI users on later lexical capacity in both expressive and receptive vocabulary as well as the role of phonological perception following implantation on speech perception at later ages.

The current study similarly used a version of the *PPVT* to examine receptive vocabulary in both bilingual and monolingual participants in all four age x language groups. As testing with this measure begins with more frequent words of English followed by progressively less frequent words, scores in bilingual participants of both age groups may have been impacted by knowledge of the lexical tokens more frequently used in monolingual English home environments. As discussed in Chapter 1, Cummins (2008) specified two different types of lexical categories likely to be encountered by bilinguals. BICS is used to describe conversational fluency of bilingual students in a language, and CALP is used to describe bilingual student's ability to use concepts in their L2 related to educational success. For bilingual listeners with less exposure to English in the home, terms that are likely to influence BICS are more likely to belong to the lexicon of their heritage language. Without a solid foundation of BICS in English, L2 learners of English are at a greater disadvantage of acquiring terminology related to CALP. For child participants, both the *PPVT-R* and *TVIP* begin at an earlier point in the task, where words more frequently found in in the BICS category of lexical items are used. Adult participants begin testing at a later stage of the task, where words more frequently found in the CALP category of lexical items are used. This may partially explain why no effect of *PPVT-R* scores on perception of 0-mm shifted speech were found in the NH bilingual adults tested in the current study. This may have caused the test to be a less appropriate measure of the total English lexical capacity of bilingual adults as compared to their child counterparts.

As adults in both language groups were predominately at ceiling in the assessment of the *PPVT-R*, it is quite likely that this task may also have simply been too easy to adequately measure vocabulary in this age group. For adult participants, there are other measures that may have more accurately assessed participants' lexical knowledge in English. One such type of task measures verbal fluency and is often measured using the Controlled Oral Vocabulary Test (COVT). In this measure, participants are given one minute to produce lexical items corresponding to a given phonemic item (e.g. /f/) (Tarlow and Sellers, 2001). This task is most frequently scored using the total number of items produced, but can also be scored using the number and length of clusters of word from the same semantic category (e.g., types of food), as well as the number of semantic categories of lexical items produced (Moscovitch et al., 1998). Another potential vocabulary assessment is a yes-no vocabulary test in which participants are auditorily presented a series of words and phonemically permissible non-words. Participants are asked to verbally respond to auditorily presented stimuli by indicating if they believe the stimulus to be a real word by responding with either yes or no. This task uses signal detection theory, meant to correct for falsely selected guesses and participant response style. Response style includes both phonetic and semantic clustering (Huibregtse et al., 2002).

It is also possible that vocabulary was not sufficient to measure speech perception of English in this study, as a closed selection of target responses was used in the task. These words were intended to be accessible to children at an elementary school level (Kidd, et al., 2008). As such, the size of participants' lexicons may not have been entirely relevant to this task. A more accurate measure might have included one of listening comprehension, such as the Test of English as a *Foreign Language (TOFEL) and TOFEL Junior Listening Tests*. These tests measure listening comprehension by playing a short, pre-recorded paragraph at an age appropriate level, following which participants are asked to answer a series of questions related to the auditorily presented material. This may have assessed a linguistic skill that is more related to the task. Although there is minimal need for semantic comprehension in the generally semantically nonsense sentences presented, a listening test in clear, unprocessed speech may have provided better insight into participants' ability to listen and retain auditory information in English, as was required in the speech perception measure used.

From this study, it is not possible to conclude whether early bilinguals and monolinguals perform differently in learning to perceive 0- and 6-mm vocoded speech or whether the two adult groups perform significantly differently to their child counterparts in the 8-10 year age range. Future research with child participants of a younger demographic and bilingual participants exposed to their L2 at a range of ages may show differences that are not apparent in the present study. Supplementing the *PPVT/TVIP* with either more effective vocabulary measures or a listening comprehension task may also show both overall and group impacts that were not discovered in this study. Use of the recommended means of calculating verbal inhibition via the Stroop task may provide more accurate insight into the role of verbal inhibition on perception of vocoded speech perception. Using different stimuli more adequately suited to assessing vocabulary in adult participants as well as a measure of inhibition examining non-verbal stimuli may also have provided a clearer result pertaining to the effect of these factors on vocoded speech perception, as using this verbal measure may have accounted for some variance in the speech perception measure used. By incorporating these changes, a more nuanced and accurate account of possible impacts of age, bilingualism, linguistic knowledge, and verbal inhibition on perception of speech simulating deep and shallow CI array insertion may potentially be found.

Chapter 3: Facilitating Lexical Access in Degraded Speech Perception

3.1. Overview

As discussed in Chapter One, in adverse listening conditions, external factors such as background noise (Tabri et al., 2010) and reverberation (Rogers et al., 2006) cause bilingual individuals to experience more difficulty in speech perception than their monolingual peers. Although this difference was not found among participants in the experiment discussed in Chapter Two, this may be due to the fact that all bilingual participants were exposed to their L2 early in their lives. Tabri et al. (2010) found differences in speech perception in noise to be worse for bilinguals who were exposed to their L2 later in life.

In this chapter, I discuss existing literature examining the role of age of acquisition for L2 learners, models of bilingual lexical access, and lexical neighborhood effects. Additionally, I conduct an experiment that aims to expand our understanding of the role of age of acquisition in bilingual individuals on the ability to learn to understand vocoded speech. This experiment consisted of a task in which target words were presented either in isolation or at the end of sentences. Words in isolation were classified as either "easy" or "hard" based on their phonological and semantic neighborhood density. Target words at the ends of sentences were classified as either high-context or low-context based on the semantic predictability of the preceding sentence content. Participants were tested on a vocoded simulation of what is heard through the implantation of a CI electrode array, similar to what was discussed in Chapter 2 in the 0-mm shift condition. As in Chapter 2, participants were tested on language skill; however, a reading comprehension task was used to better represent the influences of context and neighborhood effects (Van Assche et al., 2016). As described in Chapter 2, participants were also tested on verbal inhibition ability in order to assess the potential role of this purported bilingual advantage on the speech perception tasks.

3.2. Effects of word frequency and lexical neighborhoods on speech perception

The ability to quickly and accurately identify words in real time during a continuous stream of speech is critical to conversational speech perception. Even for NH monolingual listeners, this task becomes more difficult for words that appear less often in both spoken and written language (e.g., Chee et al., 2003; Rudell & Hu, 2000). These words are referred to as lower in *frequency*. Speech perception also becomes more difficult for words that share phonological and/or semantic properties with a greater number of words (e.g., Garlock et al. 2001; Laszlo et al., 2009; Prabhakran et al., 2006). These words are referred to as greater in *neighborhood density*. For the purposes of this study, words that are higher in frequency while also lower in neighborhood density will be referred to as *easy words.* Words that are lower in frequency while greater in neighborhood density will be referred to as *hard words* (Kirk et al. 1995).

In NH bilingual individuals, some studies on neighborhood effects have been orthographic, and used visually presented written words (e.g., Van Heuven et al., 1998). Others have examined the tip of the tongue phenomenon (TOT), in which an individual fails to retrieve a word, but is able to retrieve some parts of either its semantic or phonetic form [e.g., responding "It rhymes with 'can'" when the target word is "ban" (Yan & Nicoladis, 2009)]. Other studies of bilingual lexical access have examined various forms of responses to *cognates*, words from differing languages that share both phonological form and meaning (e.g., the English word, "abrupt", and the Spanish word, "abrupto"), and interlingual homographs, words from differing languages that share phonological form but have different meanings (such as the English word, "exit", and the Spanish word, "exito", translating to the English word, "success") (e.g., Dijkstra et al., 1999). When studying cognates and interlingual homographs, it is impossible to compare lexical retrieval in bilingual individuals with those of monolinguals, as one must know two or more languages to recognize the phonological form and/or semantic meaning of words across languages.

The roles of neighborhood density and frequency on lexical retrieval have been studied in monolingual child CI users. In these studies, participants have had greater accuracy in easy words as compared to hard words (Eisenberg et al., 2002; Kirk et al., 1995; Kirk et al., 1998; Kirk et al., 1999). Similar results have been found in adult CI users (e.g., Meyer et al., 2003). However, the impact of these features has not been studied in bilingual CI users of any age group. Prior to conducting studies exclusively tailored to studying lexical retrieval in bilingual CI users, it may be prudent to conduct a study comparing bilingual and monolingual CI users and/or vocoded simulations using stimuli that have been normed on monolingual CI users in order to determine what differences, if any, might exist between the two groups.

3.3. Models of bilingual lexical access

For bilingual individuals, there are several unique theories to accommodate the fact that an individual's lexical items belong to two or more languages. These primarily focus on whether language is stored in overlapping lexicons as concepts common across all known languages (e.g., Kroll & Stewart, 1994), or if they are stored as individual lexicons, each exclusively consisting of one known language (e.g., Lambert et al., 1968).

The Separate Storage Model is one which hypothesizes that there are separate representational systems for each language. In this model, the language not in use is considered to be completely deactivated in situations in which the other language is activated for use (Hamers & Lambert, 1972). Support for this model has come from early work using questionnaires, recall, and word association tasks. For example, Lambert et al. (1968) studied two groups of bilinguals, one French-English and the other Russian-English, who were presented various lists for free recall. Some lists were constructed such that all words presented across languages were semantically related, while others had lists in which all words presented across languages were semantically unrelated. Lists either contained items in only one of the participant's known languages or items from both known languages administered simultaneously within one task. Because participants showed semantic benefit in the mixed-language condition, even with lexical items from their other known language potentially interfering with one another, researchers concluded that participants' lexicons are able to switch rapidly between their active and inactive state. According to the conclusion of this study, had a reduction in accuracy occurred in conditions in which semantic foils had been presented across target languages, this would have presented evidence that lexical items across languages are connected at the conceptual level. As this was not found to be the case, researchers concluded that bilingual individuals store lexical information in two separate, language-specific lexicons.

Conversely, some models propose that the two lexicons known by bilingual individuals overlap completely. The Concept-Mediation Hypothesis purports that lexical items in a bilingual's L2 are linked to their L1 at the conceptual level. In this model, the conceptual level contains both linguistic and non-linguistic concepts that are common between the two words. Potter et al. (1984) studied two groups of individuals. These included proficient Chinese-English bilinguals, proficient in both known languages, and native English speakers learning French in high school, who were not proficient in their L2. Participants were asked to identify either line drawings or written words. Half of the written stimuli were presented in participants' native language and the other half in their L2. Both groups named images in their L2 more quickly than it was assumed was necessary to translate an L1 word into the corresponding L2 word. This was taken as support for the Concept-Mediation Hypothesis and evidence against the assumption of independent storage. Despite the fact that this outcome is very similar to that found in Lambert et al. (1968), these results were interpreted as showing unification of lexical items across all known languages rather than a rapid switch of language activation and deactivation as is assumed in the Separate Storage Model.

Unlike the Concept-Mediation Hypothesis, there are other models and theories that propose that L1 and L2 lexicons only partially overlap. Some also hypothesize that sometimes this overlap is asymmetrical. Among these is the Distributed Model, which hypothesizes that some word types have relatively separate storage, whereas others generally overlap in what are termed "conceptual nodes."

Concrete words (e.g., nouns) and cognates are assumed to share more features than grammatical items (e.g., pronouns) and abstract items (e.g., feelings). Because of these differences, this model predicts an asymmetrical overlap in which some types of words have shared representation while other types do not (de Groot et al., 1994). All three types of models of bilingual lexical access will be considered in our study of the role of the identification of words presented in isolation.

Connectionist models, such as the Bilingual Interactive Activation Model (BIA+), are currently viewed as the most likely representation of lexical organization in bilingual individuals. The BIA+ model includes the role of sentence context in lexical retrieval and word identification, as well as non-linguistic information, such as an individual's expectations or test-taking strategies (Dijkstra & van Heuven, 2002). In this model, items are integrated across languages and are selected in a language non-selective way. This means that whichever lexical item is best supported by the associated context will receive the greatest amount of activation (Lam & Dijkstra, 2010). It is this model that will be considered in our study of the role of context on target words presented at the ends of sentences.

3.4. Lexical neighborhood effects in bilinguals

One way these models have been tested is by examining lexical neighborhood effects in bilinguals, often studied by investigating TOTs in word production tasks. Generally, bilinguals have more TOTs than monolinguals, unless they are asked to produce a cognate. For both cognates (Gollan & Acenas, 2004) and proper names (Gollan et al., 2005), bilinguals produce TOTs at the same rate as monolinguals. This has been taken as evidence that both lexical systems are always active and perhaps the mental lexicon(/s) of a bilingual individual at least partially overlap. However, this has also been taken as evidence that bilinguals only have one lexicon in which all the words known in all their languages are stored (Gollan et al., 2005). When asked to produce a non-cognate target, bilinguals tend to have longer reaction times (Gollan et al., 2004). This may suggest that they may have a much larger neighborhood to search than their monolingual peers. This also provides evidence for a partial overlap in the mental lexicon(s). Others have proposed that this ease of access for cognates does not indicate one representation across all known languages. It may be that because representations in each language are so similar, the target word will receive activation from both languages due to the overlapping phonological form and meaning, allowing bilingual individuals to more quickly and accurately retrieve the target word than would be seen with non-cognates (Yan & Nicoladis, 2009).

In summary, the ease with which bilingual individuals can retrieve cognates and proper nouns has been used as support for the argument that bilingual individuals' lexical networks in both known languages are active at all times (Gollan et al., 2005; Gollan & Acenas, 2004). TOT experiments have been used to argue that for non-cognates, bilingual individuals may have significantly larger lexical neighborhoods, as shown by their higher error rate relative to monolinguals (Gollan et al., 2005; Gollan & Acenas, 2004; Yan & Nicoladis, 2009). In this study, the effect of lexical neighborhoods in the participants' L2 will be examined via the correct identification of target words belonging to the "hard" classification, consisting of words with relatively higher neighborhood density and lower frequency.

3.5. Age of Acquisition Effects in Bilinguals

Although TOTs have been used to effectively study neighborhood density in bilingual populations, they have not been used to study age of acquisition effects of an L2. As such, one area that has not been examined is the extent to which someone exposed to an L2 later in life is able to learn/acquire the lexical system of their second language (van Heuven et al., 2011). This is an issue for those exposed to their L2 in an unnatural setting, such as a classroom, where rote memorization of formulaic statements or lists of vocabulary terms are likely to occur. This can be contrasted with more naturalistic settings in which learners acquire their L2 in organic listening and/or conversational environments. Early L2 learners are more likely to have acquired this language naturally from the home environment, whereas late L2 learners are more likely to have acquired this language in the classroom setting (Ely, 1986). As such, it is likely that early L2 learners have more robust representations of this language relative to their later L2 peers. This may impact the ease with which bilingual individuals access the phonological contrasts of their L2, with early learners more accurately identifying words containing phonemes not found in their L1 relative to their later exposed peers. This may indicate that L1 learners have larger phonological neighborhoods due to their increased proficiency in their L2 (Ferre et al., 2006).

Assuming that earlier L2 learners have greater experience and efficiency navigating their comparatively larger lexical capacity and the resulting increased phonological neighborhood density, it may be less difficult for early L2 learners to accurately perceive distorted speech in their L2. From the results of the study conducted in Chapter 2, early bilinguals were shown to perform as well as their monolingual counterparts on vocoded speech perception, as measured in that particular study. As stated in Chapter 1, vocoded speech simulates some aspects of speech as would be presented through a CI (Loizou, 2006). This allows us to hold constant factors that contribute to the large variability in performance in CI users, referenced in Chapter 1. As in a CI, vocoded speech reduces the availability of temporal and spectral cues that assist in speech perception. As such, vocoded speech will serve to distort the phonological information available, potentially increasing neighborhood density of target words. Early exposure to an L2 may allow bilingual listeners to more effectively use the available cues found in vocoded speech to accurately identify target words relative to their later exposed bilingual peers.

In this study, I will examine whether reducing the amount of information available for phoneme recognition via vocoding will increase neighborhood density as a function of age of L2 acquisition. This may cause words with greater neighborhood density to become even more difficult to identify, particularly for bilingual individuals exposed to their L2 later in life. I will also examine the effect of vocoding on participants' ability to use semantic context to accurately identify words at the end of high- and low-context vocoded sentences as a function of age of L2 acquisition. The results of these experiments will be discussed in the context of the models of bilingual lexical storage discussed in section 3.3.

3.6. Experiment 2

Research Questions

1. Do bilingual listeners have differentially lower accuracy compared to monolingual listeners for vocoded vs. unprocessed stimuli?
2. Do bilingual listeners have differentially lower accuracy compared to monolingual listeners for different types of stimuli (e.g., easy vs. hard words and high- vs. low-context sentences)?
3. Does age of L2 acquisition impact the influence of context and frequency/neighborhood density in the L2 as measured by accuracy?
4. Does L1 and/or L2 proficiency impact the use of context and frequency/neighborhood density in speech perception as measured by accuracy?
5. Does verbal inhibition impact the use of context and frequency/neighborhood density in speech perception as measured by accuracy?

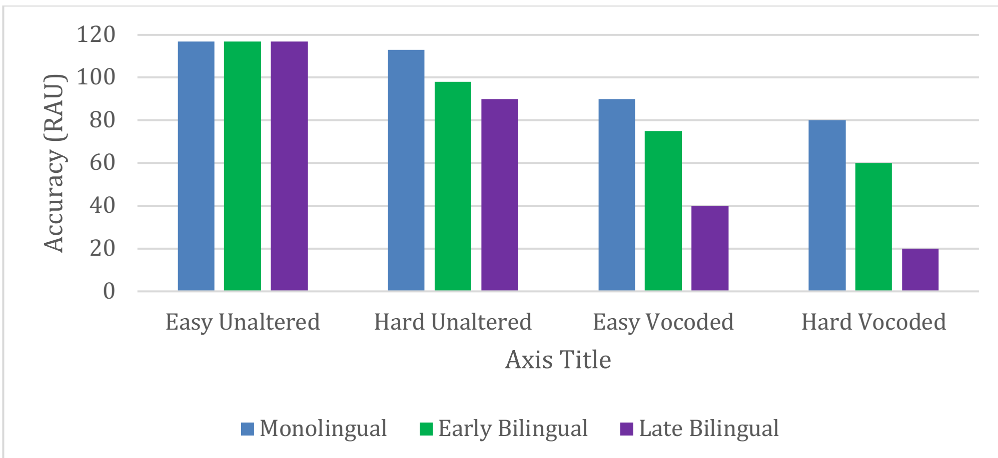
Hypotheses

Because vocoding reduces both spectral and temporal properties (Fu et al., 2004), it is hypothesized that vocoding will increase neighborhood density. This is due to the fact that possible phonemes comprising target words will be broadened with more feature overlap and thus will be less easily identified. It is also hypothesized that bilingualism will increase neighborhood density. Increased neighborhood density will be shown through reduced accuracy. It is hypothesized that late bilinguals will show significantly lower accuracy in the vocoded speech conditions compared to monolinguals and early bilinguals because their lexical representations in their L2 are likely less robust (Yan & Nicoladis, 2009).

It is also hypothesized that context in sentences will provide greater help to monolinguals and early bilinguals, but not to late bilinguals. This is due to both monolinguals' and early bilinguals' abilities to more efficiently access the meanings of the words presented in real time as compared to late L2 learners (Skoe & Karayanidi, 2019). These hypotheses are presented in graphic form in Figure 11.

Figure 11

Hypothesized accuracy responses for monolingual, early bilingual, and late bilingual participants measured in Rationalized Arcsine Units (RAU)



Proficiency in English, the language of testing, is hypothesized to positively impact the extent to which bilingualism impacts performance (Ferre et al., 2006). Proficiency in Spanish may be negatively correlated with English language proficiency, and higher scores of Spanish proficiency will negatively impact the extent to which bilingualism impacts performance. This will be reflected in reading comprehension scores, particularly in English, for later L2 learners. It is also hypothesized that verbal inhibition scores will be highest in early L2 learners relative to the monolingual and late L2 learning groups, as they will have a greater length of practice in suppressing competing lexical items. This greater inhibition will also assist them in perception of vocoded speech.

Methods

Participants: Participants included twenty Spanish-English bilingual and twenty monolingual English speakers. Participants were gender matched across the two groups such that each group consisted of fifteen females and five males. All participants were between the ages of 18 and 25 years and had audiometric thresholds of 20 dB HL or lower between the frequencies of 250 and 8,000 Hz. Age of L2 acquisition for bilingual participants ranged between birth and 12 years. Participants were recruited through the University of Maryland Department of Psychology research recruitment system. Participants received either financial compensation or course credit as compensation for participating in this study.

Stimuli: Speech perception stimuli included single words from the Lexical Neighborhood Task (*LNT*) and Multisyllabic Lexical Neighborhood Task (*MLNT*) created by Kirk et al. (1995), as well as the Revised Speech Perception in Noise (*R-SPIN*) sentences created by Bilger et al. (1984). The *LNT* and *MLNT* were created to take into account both lexical frequency and neighborhood density in English. Words were divided by the authors into "hard" and "easy" words based on both the frequency and neighborhood sizes of each stimulus item. These measures were intended for use with children with CIs and as such were created using words that these children would likely know. Kirk et al. (1995) used words compiled by Logan (1992), who tabulated lexical entries in the Child Language Data Exchange System (CHILDES; www.childes.talkbank.org). This database contains transcripts from published studies of child language development. These corpora have been validated against several similar lists (Kirk et al., 1999). These words have also been used in studies that have shown that children with CIs organize and access words within phonological neighborhoods similarly to NH children (Eisenberg et al., 2002; Kirk et al., 1998).

The *R-SPIN* sentence corpus has also been used repeatedly with CI users (e.g., Blamey et al., 1984; Turner et al., 2004; Wilson et al., 1991), and allows for the examination of the role of context on lexical access. The *R-SPIN* consists of eight sentence sets, each comprised of fifty total sentences. Twenty-five sentences do not provide biasing context for the final word (e.g., "The old man discussed the drive.") and twenty-five do provide biasing context for the final word (e.g., "She made the bed with clean sheets.") (Bilger et al., 1984). Participants were asked to repeat only the final word of each sentence.

Participants responded to two sentence sets. One was presented as unprocessed and the other as vocoded. Individual words from the *LNT* and *MNLT* were also presented in two sets, one of which was unprocessed and the other vocoded. Vocoding was accomplished using the same methodology outlined in Chapter Two to produce stimuli simulating an 8-channel CI insertion array at 0-mm shift.

Participants were also tested on reading comprehension tasks in English and, in the case of bilingual participants, Spanish. These measures included the reading comprehension portion of the *Test of English as a Foreign Language (TOEFL)* to assess reading comprehension in English and the reading comprehension portion of the advanced placement (AP) Spanish test. Participants were also tested on the Stroop test to examine verbal inhibitory skills.

Procedure: Prior to participating, bilingual participants were asked if they were comfortable completing a reading comprehension task in Spanish. All participants were screened for audiometric thresholds of 20 dB HL or lower at 250, 500, 1000, 2000, 4000, and 8000 Hz. Participants in each group began by hearing and responding to one combined set of *LNT/MLNT* single words in the unprocessed condition followed by one set of *R-SPIN* sentences in the unprocessed condition. Following this, participants were presented with ten vocoded sentences from the IEEE sentence corpus (Rothauser, 1969) to familiarize them with vocoded speech. Participants first heard these sentences processed with 8-band, 0-mm shift vocoding and were asked to respond. They then received auditory feedback similar to what was used in Chapter Two. Stimuli were replayed in unprocessed speech followed by another repetition using vocoded speech. Following this brief exposure period, participants were presented with a set of vocoded single words followed by a set of vocoded sentences.

All listening took place in a double-walled, sound-attenuating booth. Participants were accompanied by a researcher and were asked to verbally repeat target words. The researcher recorded accuracy of each target stimuli. Participants were then tested on the *TOEFL* and Stroop task, used to examine verbal inhibitory skill. Bilingual participants were also examined using the AP Spanish test.

Results

Main effects: Prior to carrying out any calculations, accuracy scores were first converted from percent correct to rationalized arcsine units (RAUs) in order to improve normality of score distribution. Following this transformation, Pearson r correlations were carried out to assess whether there was an effect of age of acquisition on age of acquisition in bilingual participants in the eight conditions tested. Age of acquisition ranged from birth to 12 years; however, no correlation with age was found in any condition.

For all unaltered conditions, scores were at ceiling for all participants, as predicted. In these conditions, scores for easy words were not significantly correlated with age of acquisition at $p = 0.39$ ($R^2 = 0.05$), hard words at $p = 0.27$ ($R^2 = 0.08$), high-context sentences at $p = 0.64$ ($R^2 = 0.01$), and low-context sentences at $p = 0.28$ ($R^2 = 0.07$). This is most likely due to ceiling effects.

In the vocoded conditions, accuracy scores for both hard and easy words were randomly distributed. Accuracy scores of sentence context were distributed around the mean. In both the hard and easy sentence conditions as well as the hard and easy sentence conditions, no significant correlations between scores and age of acquisition were found. Scores for easy words were not significantly correlated with age of acquisition at $p = 0.54$ ($R^2 = 0.02$), for hard words at $p = 0.65$ ($R^2 = 0.01$), for high-context sentences at $p = 0.71$ ($R^2 = 0.01$), and for low-context sentences at $p = 0.73$ ($R^2 = 0.01$).

As there was no effect of age of acquisition on any scores in the bilingual group of participants, the following models were carried out with all bilingual participants, whether early or late L2, considered as a single group. In order to assess the main effects of bilingualism, vocoding, word difficulty, and sentence context, two models were constructed. Both models had the fixed effects of vocoding and either word difficulty or sentence context level. Accuracy was used as the dependent variable. In both models, monolinguals served as the reference group. The first model examined differences in accuracy of word identification based on lexical neighborhood and frequency in conditions of both vocoded and unaltered speech. Model output is shown in Table 10. Due to the high number of calculations in this study, results were considered significant at $p < 0.0001$.

Table 9
Descriptive statistics of bi- and monolingual participants for vocoded words in isolation in RAU

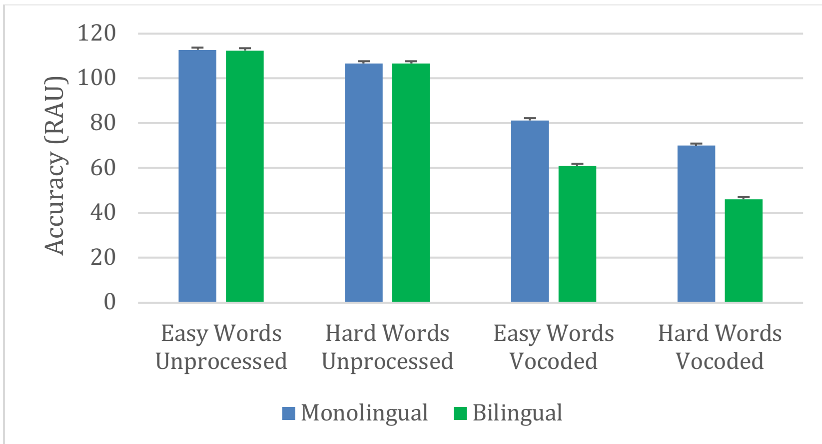
	Monolingual Easy	Monolingual Hard	Bilingual Easy	Bilingual Hard
Mean	69.12	53.78	61.03	46.14
Standard Deviation	20.92	19.83	16.00	15.30

Table 10
Fixed effects of word difficulty and vocoding in monolinguals and bilinguals

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	110.859	3.482	135.810	31.836	< 2e-16 *
Language Group	1.976	4.859	135.810	0.407	0.684
Vocoding	-27.649	4.668	105.000	-5.923	4.05e-08 *
Word Difficulty	-8.718	4.668	105.000	-1.867	0.064
Language Group x Vocoding	-23.572	6.515	105.000	-3.618	2.4e-72*
Language Group x Word Difficulty	2.585	6.515	105.000	0.397	0.692
Vocoding x Word Difficulty	-3.931	6.602	105.000	-0.595	0.552
Language Group x Vocoding x Word Difficulty	-4.607	9.213	105.000	-0.500	0.618

Results indicate no effect of word difficulty for monolingual or bilingual participants in either the vocoded or unaltered conditions. Results do, however, indicate that both groups had more difficulty accurately identifying target words in the vocoded speech conditions as compared to unaltered speech conditions at $p < 0.0001$. Although both groups showed more difficulty in understanding the vocoded speech conditions, the significant interaction between language group and vocoding indicates that bilingual participants experienced even more difficulty in the vocoded conditions relative to their monolingual peers at $p < 0.0001$. This interaction is shown in Figure 12 through the visibly lower scores of bilingual participants relative to their monolingual peers in vocoded conditions.

Figure 12
Average group results for word accuracy in rationalized arcsine units (RAU). Error bars represent + 1 standard error.



The second model in this study examined differences in accuracy of final word identification in high- or low-context sentences in conditions of vocoded and unaltered speech. Model output is shown in Table 12.

Table 11

Descriptive statistics of bi- and monolingual participants for vocoded words at the end of sentences in RAU

	Monolingual High Context	Monolingual Low Context	Bilingual High Context	Bilingual Low Context
Mean	95.27	80.40	89.77	78.59
Standard Deviation	15.87	20.59	10.28	16.00

Table 12

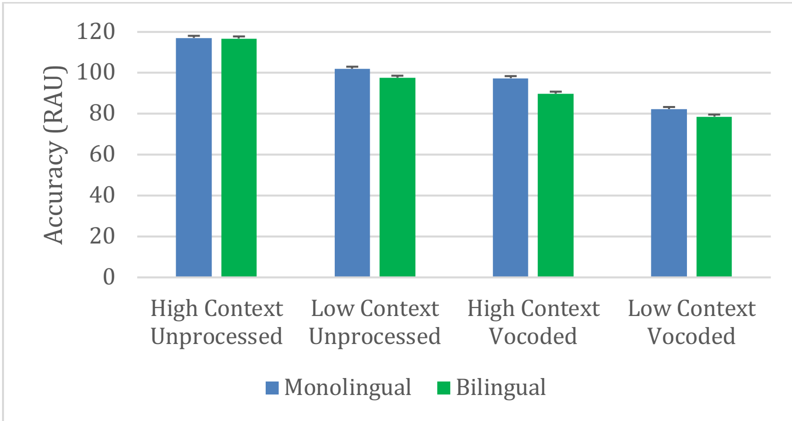
Fixed effects of vocoding and sentence context level in monolinguals and bilinguals

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	101.182	2.725	131.640	37.130	< 2e-16 *
Language Group	-2.599	3.802	131.640	-0.684	0.495
Vocoding	-10.712	3.579	104.190	-2.993	2.67e-27 *
Context Level	15.086	3.579	104.190	4.215	5.33e-05 *
Language Group x Vocoding	-8.668	4.994	104.190	-1.735	0.085
Language Group x Context Level	3.186	4.994	104.190	0.638	0.524
Vocoding x Context Level	0.884	5.102	104.750	0.173	0.862
Language Group x Vocoding x Context Level	-8.650	7.093	104.480	-1.220	0.225

Results indicate that there are no significant differences between monolinguals and bilinguals on perception of either vocoded or unaltered speech. There are also no significant differences between these groups on perception of words presented at the end of sentences that provide either high or low levels of sentence context. However, all participants had significantly more difficulty understanding sentence-final words in vocoded conditions than they did in unaltered condition at $p < 0.0001$. All participants also had more difficulty identifying sentence-final words in conditions of lower context level at $p < 0.0001$. Unlike the single word condition, bilingual participants do not experience more difficulty than their monolingual peers in identifying target words in vocoded conditions. The negative impact of reduced context and vocoding on both groups is shown in Figure 13.

Figure 13

Average group results for target word accuracy in sentences in rationalized arcsine units (RAU). Error bars represent + 1 standard error.



<u>Predictor variables:</u> Predictor variables in this study consisted of reading comprehension measures in English and/or Spanish and verbal inhibition as measured by the accuracy of discongruent stimuli in the Stroop task. As in Chapter 2, as this method of scoring is not standardized or normalized, reliability of this measure may have been reduced. This may have potentially caused an inaccurate assessment of participants' verbal inhibition skill. Reading comprehension in English was measured using the reading comprehension portion of the TOEFL exam. Reading comprehension in Spanish was measured using the reading comprehension portion of the Spanish AP exam. These measures were chosen as they are of approximately the same length and are intended for the same age group, high school senior students.

Models were first constructed by adding the variable of English language scores to first the model described in Tables 10 above, used to analyze accuracy of single word identification, and then by adding this variable to the model described in Table 12 above, used to analyze accuracy of target words presented at the end of sentences. As this variable was not found to alter the fit of either of these models, it was discarded from these models for the remainder of the study. The same process was repeated for the variable Spanish language score, which was also not found to alter the fit of either model and was removed from further calculations. This process was finally carried out using the accuracy scores of discongruent stimuli in the Stroop task. As this variable also did not alter the fit of the model, it was determined that no predictor variable, as measured in this study, impacted speech perception scores.

3.7. Discussion

This study sought to determine whether there is an effect of age of acquisition on perception of speech that is unaltered or vocoded at 8-channels with 0-mm of shift. This study also examined the impact of frequency and neighborhood effects on the identification of single words as well as the effect of context on the identification of target words presented in sentences. Additionally, this study examined whether reading comprehension in English and/or Spanish, as well as verbal inhibition, as measured by the accuracy of discongruent stimuli in the Stroop task, impacted speech perception scores.

Results of this study indicate that there is no significant correlation between age of acquisition (early vs late L2) and scores on either unaltered or vocoded stimuli in both the single word and sentence conditions. These results do not support the hypotheses of this study. It was hypothesized that because vocoding reduces both spectral and temporal properties available in the auditory signal (Fu et al., 2004), vocoding would increase neighborhood density across all participants, with particular difficulty found among later L2 learners. It was also hypothesized that later L2 learners would have more difficulty correctly identifying target words in low-context sentences. Because age of acquisition effects were not found among bilingual participants, this variable was not considered in further analyses.

In the identification of single words, it was hypothesized that neighborhood density would be higher in bilingual participants relative to their monolingual peers due to the lexical capacity across their two known languages. Because of this greater neighborhood density, it was hypothesized that the reduced phonetic information available following the vocoding process would more severely impact bilingual individuals, as this effectively increases phonological neighborhood size. Given that bilingual individuals are already presumed to have greater lexical neighborhood density, further increasing phonological density through vocoding was presumed to cause a decrease in accuracy relative to monolingual participants. It was hypothesized that this effect would be most prominent for words in the “hard” condition, which are relatively lower in frequency and higher in neighborhood density as compared to those in the “easy” condition.

As shown in Figure 12, vocoding did not interact with difficulty level in the single-word identification task. This result does not provide support for the hypothesis that decreased frequency and increased neighborhoods leads to more difficulty in correct identification of target words. Both bilingual and monolingual individuals were found to show significantly greater difficulty accurately identifying target words in the vocoded condition relative to the unaltered condition; however, the interaction of language group and vocoding shown in Table 11 indicates that bilingual participants experienced greater difficulty in this condition when compared to their monolingual peers. This finding supports the hypothesis that bilingual participants are more significantly impacted by vocoding than monolingual participants. The reduced and distorted phonetic information available in vocoded stimuli may make it more difficult for bilingual listeners to accurately identify target words due to the fact that their lexicons may include more phonological neighbors to the distorted target as compared to their monolingual peers.

It was also hypothesized that context in sentences would provide greater help to monolinguals and early bilinguals than to late bilinguals. It was assumed that both monolinguals and early bilinguals would have the ability to more efficiently access the meanings of the words presented in real time as compared to late L2 learners (Skoe & Karayanidi, 2019). However, as stated above, no effects of age of acquisition were found in any condition tested. As shown in Figure 13, no effect of language group was found on correct identification of target words in sentences. As early and late bilingual participants were examined as a single group, this result can be viewed as supporting the hypothesis that early bilinguals and monolinguals benefit from access to greater context. As with single words, both groups had significantly lower accuracy scores in vocoded conditions relative to unaltered conditions. However, unlike the single word conditions, there was no significant interaction between language group and vocoding, meaning that both groups were similarly impacted by the presence of vocoding. This again supports the hypothesis that bilinguals, as included in this study, and monolinguals are similarly assisted when they are able to use context to assist in identifying target words. Although there was no interaction of vocoding and context level, the degraded phonemic input available in the vocoded condition likely reduced listeners' access to semantic content that was otherwise available in high-context sentence stimuli.

As in Chapter 2, one factor that may have led to the null results found in this study is the fact that it was likely underpowered. A post-hoc power analysis indicated that in order to avoid type two errors at 80% probability, 84 participants would have been required in each group. However, in this study, groups consisted of 20 participants each. As such, it is possible that, had more participants been tested, effects of age and language group may have been found.

3.7.1 Models of bilingual lexical storage

This difference in perception of words with reduced phonological information provides support for theories that assume at least partial overlap in bilingual lexical storage. Models in this category often presume that at least some types of words, such as the concrete nouns used in this study, overlap at the contextual level. However, these models also assume that some features of cross-linguistic lexical items are not shared, such as language-specific phonemes. These features are stored independent of items in the other known lexicon. As bilingual listeners display greater difficulty correctly identifying target lexical items presented in isolation in vocoded conditions, this may provide support for the hypothesis that, in cases of words with larger phonological neighborhoods, bilingual participants have greater difficulty identifying target words through the features available in items found in both the overlapping and individual features in their multiple lexicons. In isolation, bilingual participants may be unable to immediately identify the language of the target stimuli, leading to larger neighborhood effects. This same phenomenon is not found in target words presented at the ends of sentences. Even in low-context sentence conditions, lexical and syntactic information prime bilingual listeners to predict a target stimulus in English at the end of an English-language sentence. The fact that the *R-SPIN* stimuli provide English-language context may account for the fact that correct identification of target words in low- and high-context sentence conditions is consistent across all participants, as shown in Figure 6. These results provide support for the BIA+ theory, which assumes that bilingual listeners use context to better identify lexical items.

3.7.2 Weaknesses and future suggestions

Although this study superficially touched upon models of lexical storage in bilingual individuals, further work could be conducted to more effectively examine lexical storage in bilingual CI users. It is important to note that as all stimuli in this study were presented exclusively in English, bilingual participants' L2, this study does not specifically evaluate the models discussed in section 3.3. Participants may have used strategies as suggested in the Separate Storage Model where the unused language is effectively deactivated for the duration of the study. The current study could have more thoroughly examined models of lexical storage in bilingual individuals had a test with stimuli other than concrete nouns, such as function words, been used. Function words are primarily a grammatical feature of language and are less likely to be joined at a conceptual level across languages. This may be especially true in the current study given the fact that the semantic equivalent of many function words in English are affixes, commonly suffixes, in Spanish. Model assessment in this study would also have been improved had bilingual participants been tested on an additional measure identifying concrete nouns in Spanish in conjunction with the *LNT/MLNT*. This would have allowed us to examine differences between correct identification in the two languages. Similar identification across cross-linguistic equivalent tasks would have provided stronger evidence for overlapping models of bilingual language storage.

In this study, results indicated that bilingual listeners show greater difficulty understanding of vocoded lexical items presented in isolation relative to their monolingual peers. Future studies may use this as a starting point to more thoroughly examine the research questions of this study. In particular, it might be of use to increase the difficulty of the speech perception tasks to include simulations of a shallow CI insertion depth, as was used in Chapter Two. By including a more difficult listening condition, it is possible that an age of acquisition effect may have been found in perception of distorted speech, particularly in the case of isolated lexical items where context cannot be used.

In the single word condition, the fact that no difference was found between easy and hard words, as shown in Figure 12, may have been due to the stimuli used in this study. While the *LNT/MLNT* have been shown to be appropriate for use with CI users, those users have all been children. As with the *PPVT-R* in Chapter 2, this measure was likely too easy to show a difference in hard vs easy words in adults. Had a more age-appropriate task been used, differences may have been seen both between early and late bilinguals and between bilinguals and monolinguals in the identification of similarly differentiated target words. A more age-appropriate corpus may also have exposed age of acquisition differences that were not apparent when using the *LNT/MLNT*. This condition is of particular importance given the interaction between bilingualism and vocoding seen in the single word condition. It is possible that with a more difficult lexical corpus, differences in the vocoded condition could be made more readily apparent.

As in Chapter 2, the fit of models examining speech perception scores did not improve with the addition of any of the linguistic or cognitive predictive variables. Although different language assessments were used, reading comprehension tasks may not have been the most appropriate measure to best assess listening skills in either English or Spanish. As suggested in Chapter 2, it may have been more prudent to use listening comprehension measures to assess language ability in a medium similar to that used in the study. Although a more age-appropriate measure was used, reading comprehension does not measure linguistic skill in real time. Reading comprehension measures allow participants to complete the task non-linearly and to make notations on the test passage both during and after their initial reading. Had more appropriate measures been used, an effect of language skill in both participants L1 and L2 might have been found. As is also found in Chapter 2, this study used only the accuracy scores of discongruent stimuli in the Stroop task to measure verbal inhibition. The typical method by which to assess the results of this measure is to compare the reaction times of participants' responses to discongruent and congruent stimuli. This non-standardized and non-normed method of calculating scores may have reduced the reliability of testing causing inaccurate assessment of participants' verbal inhibitory skill. Additionally, as is also discussed in Chapter 2, use of a verbal measure of inhibition may have acted as a confounding factor in this experiment as the verbal stimuli may have accounted for some of the variance in the speech perception scores examined. Had the results of this task been calculated differently or a different measure of inhibition used, it is possible that both differences between language groups and an effect on speech perception scores may have been found.

It is important to note the finding that, without context, bilingual listeners perform more poorly than their monolingual peers on correct identification of vocoded lexical items. However, there are numerous ways that this study could have been altered to better assess the research questions and explore evidence supporting models of lexical storage in bilinguals. Altering the method used to evaluate linguistic skills and correctly calculating the Stroop task might also have more accurately answered the research question regarding the predictive value of these variables. Increasing the difficulty of the single-word identification task, both by using a more difficult corpus and by adding a simulation of a shallow CI insertion depth, may have allowed better examination of potential age of acquisition effects and allowed for a more nuanced exploration of differences between language groups. The addition of tasks designed specifically to test bilingual listeners may have provided evidence for how models of bilingual lexical storage relate to perception of vocoded as compared to unaltered speech. This would have allowed for greater evidence to be produced regarding the impact of a CI on lexical storage in bilingual individuals, particularly as compared to their NH peers. By implementing these changes, a more thorough examination of the research questions of this study may transpire, as well as an examination of models of bilingual lexical storage in CI users.

Chapter 4: General Discussion and Conclusions

This dissertation aimed to examine the role of bilingualism and age on perception of vocoded speech. It also aimed to examine the potential role of individual differences in language skill and verbal inhibition on perception of vocoded speech. In order to explore these issues, two experiments were conducted using monolingual speakers of English and bilingual, native speakers of Spanish whose L2 was English. The role of bilingualism was explored through the use of these two language groups in each study. Bilingual listeners were exclusively native speakers of Spanish. Inclusion was restricted to one language group in order to avoid possible confounding variables that may have occurred through the inclusion of native speakers of other languages that varied from one another in phonological, syntactic, and morphological structure.

The primary motivation behind the approaches implemented in these studies was to isolate the factors of both age of acquisition and age at the time of testing in bilingual Spanish-English populations as compared to their monolingual, English-speaking peers. Stimuli examining vocoded speech perception was used in both studies to simulate what is heard through a CI. Through the measures used in both studies, it was hoped that greater insight would be gained into the ways that bilingualism and age impact perception of speech in different conditions of CI simulations.

4.1 Vocoded conditions

Vocoded conditions in this study simulated speech as perceived through an 8-channel CI. In the first study, two conditions of shift were considered. These consisted of simulations of both deep (0-mm shift) and shallow (6-mm) insertion of a CI electrode array. These conditions were chosen to allow us to examine speech as perceived through an ideal CI implantation (0-mm shift) in which there are no impediments to full insertion of the electrode array as well as speech as perceived through a more complex implantation where the electrode array cannot be fully inserted into the most accessible apical position in the cochlea (Helmstaedtar et al., 2018).

These conditions were examined through alternating testing and training conditions presented over a period of 2 hours. Testing conditions included both conditions of shift and required participants to identify auditory-presented semantically empty sentences from a word matrix presented via computer interface, shown in Figure 4 (Kidd et al., 2008). Training conditions were used between all testing blocks with both auditory and visual feedback. In these conditions, only the more difficult 6-mm shift condition was used. Auditory feedback consisted of replaying the stimulus first in unaltered speech followed by the 6-mm speech originally heard in the stimulus. Visual feedback was also provided by highlighting both correctly and incorrectly selected words, as well as intended target words. As shown in Tables 11 and 12 results showed that all participants had lower post-test scores in the more difficult 6-mm condition as compared to the less difficult 0-mm testing condition. From this result, we can conclude that, even with explicit training on the more difficult 6-mm condition, participants have lower speech perception scores relative to the less difficult 0-mm shift condition relative to the trained condition (e.g., El Boghdady et al., 2018; Waked et al., 2017). It can be presumed that CI users whose electrode arrays with shallower insertions will have greater difficulty adapting to perceiving speech through their CI than those whose electrode arrays have been inserted closer to the most apical position in the cochlea. As such, individuals who have been implanted at more shallow insertion depths may require more assistance in learning to adapt to speech perception than those who have been implanted at deeper insertion depths.

In the second experiment, only the 0-mm shift condition was used. This condition was compared to performance in unaltered speech conditions. Participants were required to identify target words which were either presented in isolation or at the end of sentences. Single words were classified as either “easy” or “hard” based on both frequency and neighborhood density (Kirk et al., 1995; Kirk et al, 1999). In sentence conditions, target words were presented at the end of either high-context sentences (e.g., She made the bed with clean sheets) or low-context sentences (e.g., The old man heard about the yell) using the *R-SPIN* corpus (Bilger et al., 1984). In this experiment, as shown in Tables 11 and 12, all vocoded conditions were found to be significantly more difficult than unaltered conditions. From this result, we can conclude that the 0-mm condition of vocoding is more difficult to accurately perceive than the unaltered condition (e.g., Smith et al., 2018). It may be that even CI users who have been implanted under ideal circumstances will need time and assistance to adapt to speech as perceived through their CI.

4.2 Impact of age and bilingualism on vocoded speech perception

These studies both examined the effects of age and bilingualism on perception of vocoded speech as described in section 4.1. These factors were chosen due to the fact that the majority of individuals worldwide speak two or more languages, and the fact that both adults and children, as well as bilingual individuals who learned their L2 at a variety of ages, are regularly implanted with CIs. English language stimuli were selected as it is one of the most commonly used languages worldwide (Lyons, 2017). Bilingual individuals in the current studies were native speakers of Spanish whose L2 was English. These participants were compared to monolingual speakers of English. It was hypothesized that both these factors would interact with perception of vocoded speech.

The first study consisted of four groups: Monolingual adults, monolingual children, bilingual adults, and bilingual children. In this study, all bilingual children were reported by their parents to have been exposed to both English and Spanish at birth, and all bilingual adults self-reported that they had been exposed to their L2 of English by the age of 4 years. By ensuring that all participants were exposed to their L2 early in life, we were able to test only the impact of age at the time of testing on perception of speech vocoded to simulate either a deep (0-mm) or shallow (6-mm) insertion of a CI electrode array. As shown in Figure 4, no significant differences were found between these four groups on speech perception in either the 0-mm or 6-mm vocoded speech condition.

A brief follow-up study was conducted to examine the effects of age on monolingual young adults and the monolingual children included in the main study on perception of vocoded speech. This was conducted because age at testing in the adult population range from 19 to 52 years. Most studies comparing speech perception through a vocoder in monolingual adults and children have found that adults significantly outperform their child counterparts (e.g., Eisenberg et al., 2000; Nitrouer et al., 2009; Waked et al. 2017). However, in these studies, only young adults were studied in comparison to child participants. As shown in Figure 8, no significant effects of vocoding were found in either condition. In Figure 8, we see that both child and adult participants follow the same general trajectories as found in Waked et al. (2017), which was replicated by this follow-up study, despite their differing results overall. From these data, we cannot conclude that members of either age or language group is likely to require greater assistance relative to one another in adapting to speech perceived through a CI.

In the second study, participants also included monolingual speakers of English and bilingual native speakers of Spanish whose L2 was English. However, rather than studying age at the time of testing, this study examined age of L2 acquisition in native speakers of Spanish. Age of English language acquisition ranged from 0-12 years. All participants were between 18 and 25 years of age at the time of testing. It was predicted that those exposed to their L2 at earlier ages would outperform those exposed to their L2 at later ages in tasks of vocoded speech perception in their L2 of English (Mayo et al., 1997, Regalado et al., 2019, Skoe & Karayanidi, 2019; Tabri et al., 2015). However, no effect of age of acquisition was found. From these results we can presume that there is no impact of age of L2 acquisition on either vocoded or unprocessed speech perception as measured in this study. As no effect of age was found, further calculations in this study were carried out with bilingual participants considered as one group rather than the originally intended two groups of early and late L2 learners.

This study required participants to identify both lexical items presented in isolation as well as target words presented at the ends of sentences in condition of both unaltered and 8-channel, 0-mm shifted vocoded speech. Single words were considered either “hard” or “easy” based on both their neighborhood density and frequency of use (Kirk et al., 1995; Kirk et al, 1999). Target words presented at the end of sentences were considered either high- or low-context based on preceding semantic information (Bilger et al., 1984). As shown in Tables 10 and 11 and Figures 12 and 13, in both the single word and sentence-final lexical identification tasks, vocoded conditions were significantly more difficult than unprocessed conditions for all participants. From these results, we can presume that both bilingual and monolingual adult CI users require assistance in learning to understand speech as perceived under ideal conditions of electrode array insertion.

As shown in Table 10, in the single word condition, no difference was found between hard and easy words for either group. However, as shown by the interaction of vocoding and language group, bilingual individuals experienced greater difficulty identifying lexical items presented in isolation as compared to their monolingual peers. No such difference was found in the sentence condition, as shown in Table 11, although both groups had significantly more difficulty identifying target lexical items in low-context sentence conditions than in high-context sentence conditions. From these results, we can presume that both bilingual and monolingual participants rely on context in predicting words within sentences in conditions of vocoding. However, bilingual participants may be more dependent on context than their monolingual peers as they showed greater difficulty identifying vocoded isolated lexical items relative to their monolingual counterparts. As such, we can presume that bilingual adult CI users may rely more heavily on context in perceiving speech under ideal conditions of electrode array insertion relative to their monolingual peers.

4.3 Impact of linguistic skill and verbal inhibition on vocoded conditions

In both studies, linguistic skill and verbal inhibition were examined as potential predictors of vocoded speech. In the first study, linguistic skill was measured using the *PPVT-R* to measure receptive vocabulary skill in English and the *TVIP* was used to assess receptive vocabulary skill in Spanish for bilingual participants. In the second study, the reading comprehend portion of the *TOEFL* was used to assess reading comprehension in English and the reading comprehension portion of the AP Spanish exam was used to assess reading comprehension in Spanish for bilingual speakers. Accuracy of discongruent stimuli in the Stroop test was used to assess verbal inhibition in both studies.

Following calculations of main effects, these factors were added one at a time to the models examining main effects to determine if their inclusion improved model fit. None of these factors were found to do so in either study. However, as shown in Figure 7, in the first study, a correlation between post-test performance on the 0-mm vocoded speech condition and raw scores on the *PPVT-R* was found to be significant at $p < 0.0001$ for bilingual child participants. For all other age x language groups, the correlation between these factors was insignificant with nearly all adults and several monolingual children performing at or near ceiling. As discussed in Chapter Two, the *PPVT-R* begins with more frequent words for children than it does for adults. Many of these are considered BICS words (Cummings, 2008), which are typically learned in early childhood from the home environment. As such, monolingual children may be more likely to have been exposed to these words than their bilingual peers, resulting in their overall higher scores. Testing material for adults begins with less frequent words, many of which belong to the CALP domain (Cummings, 2008). CALP words are primarily geared towards academic success and may be both more explicitly taught and generally used in the English as a Second Language educational environments. As such, adult bilingual participants may have been tested on material less relevant to overall speech perception outcomes relative to their child counterparts. From this result, we can presume that greater exposure to English in early childhood may lead to greater familiarity with the words presented at the child age-appropriate portion of the *PPVT-R*. This greater exposure to more frequent words of English may assist bilingual child CI users in their perception of speech in ideal conditions of electrode array insertion.

4.4 Power

In these studies, approximately 20 participants were included in each group. However, post-hoc power analyses found that in order to reach an 80% confidence level, 77 participants would have been required in the four age and language groups tested in Experiment 1 and 84 participants would have been required in each of the three predicted groups of early bilinguals, late bilinguals, and monolinguals. As such, these studies were quite underpowered.

Null results were found for the majority of the hypotheses in this dissertation, which may have been due to the fact that only approximately one quarter of the appropriate number of participants were tested in each group. As such, it is possible that these results are incomplete. Had a larger number of participants been tested, this dissertation may have produced more nuanced results.

4.5 Bilingual language learning

There are numerous research gaps in bilingual language acquisition/learning. This is in part due to the fact that many studies have focused on lexical acquisition rather than suprasegmental features that also facilitate linguistic development. Bilingual individuals have been shown to have different language learning strategies and trajectories relative to their monolingual peers. For bilingual individuals exposed to their first language in infancy, this differences are apparent by the first year of life. These strategies allow bilingual infants to develop two separate linguistic systems while achieving the same linguistic milestones as their monolingual peers at similar ages. These include identification of phonemes of their language(s) of exposure as well as the ability to discern between languages belonging to differing rhythmic classes (Werker & Byers-Heinlein, 2008).

However, as bilingual individuals are exposed to fewer lexical tokens in each of their languages of use, this frequently leads to a disadvantage in which bilingual individuals have smaller lexical capacities in each of their known language relative to monolingual speakers of these languages. Some researchers believe that this difference lasts throughout the lifespan (e.g., Bialystok, 2010) while others believe that this difference resolves by adulthood (e.g., Yan & Nicoladis, 2009). This may also lead to instances in a delay of recognition of frequent words in either known language relative to their monolingual peers (Vihman et al., 2007) in early childhood.

Yet despite these possible lexical disadvantages, it is generally in the best interest of an individual belonging to a bilingual family or community to learn both languages of use. Due to the relatively greater variations of phonological, lexical, and syntactic tokens in the total linguistic items to which they are exposed, bilingual individuals may be employing different language learning strategies relative to their monolingual peers (Yayla et al., 2016). These strategies may lead to the cognitive advantages found among bilingual individuals as compared to their monolingual peers. Using these strategies, may play a role in the fact that many of the early linguistic disadvantage, particularly with regards to total vocabulary size resolves either completely or to the point of communicative competence by adulthood. This indicates that ultimately a bilingual child will actually grow to have a larger overall lexical capacity relative to their monolingual peers due to the increased capacity in each known language (e.g., Yan & Nicoladis, 2009). Additionally, the ability to communicate in all relevant languages in an individual's environment is extremely important for social development and interaction (Ren & Wyver, 2016).

4.6 Practical applications for CI users

The results of these studies have several practical applications for CI users. One key finding is that after only two hours of training in the setting of Experiment 1, participants of both the child and adult age group showed improvement between pre- and post-tests. This was true in the case of both the deep (0-mm) and shallow (6-mm) insertion depth. This indicates that, with both exposure and training, individuals are able to adapt to speech simulating what is heard through a CI. As such, it can be presumed that with appropriate clinical intervention, both child and adult CI users can learn to better understand speech as perceived through their CI. However, it is important to note that, while this improvement is found at both degrees of insertion, speech perception of vocoded speech simulating a shallow insertion depth remains significantly lower at post-test relative to scores in the deep insertion condition. As such, it is reasonable to conclude that CI users with shallow electrode array insertion may require greater intervention relative to CI users with deep electrode array insertion.

For deaf infants and infants with severe-to-profound hearing loss, one way to improve lexical and speech perception outcomes is to implant these children at the earliest possible age. In doing so, infants are better able to develop their auditory cortex through earlier exposure to sound (Polonenko et al., 2017). Early implantation may also improve children's speech perception and communication outcomes through earlier clinical intervention. This may allow children to better develop their vocabulary beginning at earlier ages (Connor et al., 2006), as well as better learn to use context cues to understand speech (e.g., Holt et al., 2016). This may have positive effects on future educational outcomes as well, particularly if child CI users are integrated into mainstream classrooms (Dettman et al., 2013).

Morini and Newman (2020) have found that, with both bilingual and monolingual infants, novel words can be learned with relatively comparable results in conditions of background noise. While this difficult listening condition differs to that of speech perception through a CI, it nevertheless indicates lexical acquisition of bilingual infants at a similar level to their monolingual peers is possible in difficult listening conditions. It is important to note that these items were learned from exposure rather than explicit instruction. While explicit instruction may lead to improved lexical outcomes, acquisition through social interaction and ambient exposure has been shown to yield greater results (Atkinson et al., 2018). As such, it is important to directly interact with child CI users in both the home and clinical environment.

4.4 Future directions

The results of the studies conducted in this dissertation lead to several potential areas of future exploration. In the first study, it was shown that young monolingual adults visibly, though not significantly, outperform monolingual children on speech perception in conditions of 0-mm of shift. It may be prudent to examine the same factors in bilingual individuals. As bilingual children visibly, though insignificantly, performed less successfully on the speech perception task, it would be interesting to explore weather a significant difference can be found between young bilingual adults and bilingual children. Additionally, it may be worthwhile to replicate the entire study using only young adults in order to determine if significant differences in vocoded speech perception can be found between the four age x language groups.

In previous studies, a bilingual advantage has been found in verbal inhibition; however, this advantage is larger in younger adults as compared to both child and older adult listeners (Incera & McLennan, 2018, Knight & Heinrich, 2017; Bialystok et al., 2005). This may indicate a possible role of both cognitive development and decline that may itself interfere with the verbal inhibition necessary to effectively and efficiently understand multiple languages. Although no difference was found in the speech perception results of older and younger monolingual adults, future studies might possibly explore the role of age and verbal inhibition by using the intended measurement of the Stroop task on groups of children, younger adults, and older adults. It is possible that individual differences in verbal inhibition could provide extra benefit to vocoded speech perception in young bilingual adults relative to monolingual participants and bilingual participants of both older and younger age groups.

It may also be worthwhile to also replicate both studies using more difficult lexical stimuli. Both the lexical items in the word matrix, used in Chapter 2 (Kidd et al., 2008) and the LNT/LMNT, used in Chapter 3 (Kirk et al., 1995) were created for use with child participants. As such, these measures may not have been appropriate for use with adult participants. It would be worthwhile to replicate both studies using lexical corpuses designed for use with adult participants, such as the Revised Consonant-Nucleus-Consonant (R-CNC) List (Peterson & Lehiste, 1962). For the second study examining the role of age of acquisition, it may also be worthwhile to add a more difficult listening condition, such as the 6-mm shift condition used in the first experiment. By increasing the difficulty of the lexical items presented in isolation, it is possible that a difference in the effect of age of acquisition may be found in conditions devoid of semantic and syntactic context, such as the single word condition. An effect of age of acquisition on target words presented at the ends of sentences may also show an effect of age of L2 acquisition in conditions where semantic context is available if later-exposed bilingual individuals experience more difficulty accessing speech distorted to a greater degree than their early-exposed bilingual and monolingual peers.

In exploring models of bilingual lexical storage, there are several additions that could have been made to the second experiment. One possible addition would be including a lexically equivalent task in Spanish to that used to evaluate perception of lexical items presented in isolation in English. The LNT/LMNT use only concrete nouns. Either adding a separate measure of concrete nouns for bilingual Spanish speakers or testing bilingual speakers using a corpus containing both English and Spanish lexical items would provide better evidence for models that show either overlapping or separate storage. These tasks could be presented in both conditions where stimuli are presented in one language at a time as well as conditions where stimuli from both languages are presented, requiring participants to quickly switch between their lexicons. Presumably, if participants have lower accuracy in a task of switching between languages than they do in tasks where languages are presented separately, this would provide evidence for models that suggest overlapping lexicons. Additionally, it may be prudent to add a test that includes function words/affixes rather than concrete nouns alone, as these words/affixes as these are primarily grammatical rather than lexical items. If there is decreased accuracy in identification of function words in English/conjugated words in Spanish relative to concrete nouns, this would allow us to explore which items are shared in potentially overlapping lexicons.

The method by which predictor variables are measured can also potentially provide more information if altered in future studies. In this dissertation, verbal inhibition was measured by accuracy of discongruent stimuli in the Stroop task. The use of latency scores would have allowed the examination of subtler group differences than the use of the binary measure of accuracy alone. Had the recommended method of calculating the difference in reaction time for congruent and discongruent stimuli been used instead, this may have provided greater insight into the role of verbal inhibition on vocoded speech perception. Additionally, use of a different stimulus type to assess inhibitory skill may have been more appropriate in tasks measuring speech perception. Similarly, receptive vocabulary and reading comprehension may not have been the best measures of linguistic skill to predict performance on speech perception tasks. Had listening measures, such as the *TOEFL* and *TOEFL Junior Listening Tasks* been used instead, these may have provided better insight into linguistic skill relevant to predicting speech perception tasks. It is also important to note that, while vocabulary is a predictor of speech perception (Geers et al., 2003), the *PPVT-R* may have simply been too easy a measure for the majority of participants, as all but the bilingual children group performed at or near ceiling.

The fact that, in the first experiment, bilingual children's scores on the *PPVT-R* were found to significantly correlate with speech perception scores in the 0-mm shift condition raises several interesting avenues of future exploration. As the earlier items from which child participants began the *PPVT-R* primarily contain BICS words, it may be worthwhile to retest adult bilingual participants by having them begin at the same point in the test as their child counterparts. If adult bilingual participants also show a correlation between receptive vocabulary skill beginning at this level of lexical knowledge and speech perception scores, it would provide evidence that the types of words typically learned by monolingual children from an early age in their home environment are essential for speech perception in bilingual CI users, and possibly all bilingual learners. It would also be interesting to explore whether there is a correlation between knowledge of BICS, rather than simply CALP words, and academic outcomes at different points in bilingual students' academic careers. It would be of particular interest to compare these factors between NH and CI using bilingual students, as bilingual CI users are at the unique disadvantage that in order to acquire a word, they must first be able to hear it, and in order to perceive a word, they must have both acquired and heard the word in its appropriate context. Such a study could provide evidence for providing a greater focus on BICS words in both English as a Second Language (ESL) classes as well as in clinical settings for bilingual CI users (Cummings, 2008).

More importantly, it would be of great use to study means by which individuals with CIs are able to improve earlier speech perception. Acquisition from ambient speech is a much more effective way of learning and retaining vocabulary than explicit instruction, and is most effective when begun at an earlier age. Wang et al. (2017) showed that infants who had been implanted with CIs react to infant directed speech (IDS), but, unlike their NH peers, showed no reaction to adult directed speech (ADS). Infant directed speech is characterized by a distinctive pattern of acoustic-phonetic and lexical properties that have been shown to attract greater infant attention. Dilly et al. (2020) found that increased use of IDS in infancy predicted improved speech perception at 2 years of age. All infants reacted significantly more to IDS than ADS, a phenomenon that is well documented, and has been found to be more useful for mapping phonetic form to meaning in both monolingual and bilingual infants (Ma et al., 2020). However, NH infants and young children also acquire speech from the ADS that is more prominent in home environments (e.g., Bergson et al., 2018). It is of great importance to determine ways that families and clinicians can improve young CI user's attention to speech in order to help them to better acquire the vocabulary that will lead to improved speech perception skills later in life.

4.5 Conclusions

Main effects of age as studied in these experiments, either at the time of testing or at the age of L2 acquisition, were not found to be significant in either study conducted in this dissertation. However, insignificant trends were observed indicating that child listeners, particularly bilingual child listeners, experienced greater difficulty in learning to perceive vocoded speech simulating a deep CI electrode array insertion (0-mm) relative to their adult counterparts. This effect is of particular importance as scores of English receptive vocabulary were found to significantly correlate with speech perception scores at post-test for bilingual child participants in the 0-mm shift condition. It is possible that this indicates that knowledge of lexical items belonging to the BICS category of words may be of particular importance in an individual's potential ability to learn to perceive speech through a CI. This poses a unique situation for both clinicians and ESL educators in which these words, which are typically acquired in childhood via the home environment, may need to be explicitly taught to bilingual CI users in order to improve speech perception outcomes.

Main effects of vocoding were found to significantly impact speech perception for all seven participant groups examined. From this we can extrapolate that vocoding replicating speech as perceived through a CI negatively impacts listeners' abilities to accurately perceive speech. Even with explicit training on a difficult condition replicating shallow electrode array insertion (6-mm), participants showed significantly more benefit in the condition replicating a deep electrode array insertion (0-mm) relative to the trained condition. From this we can conclude that individuals who are unable to receive implantation at deeper depths may require greater clinical intervention relative to their peers implanted in more optimal conditions, as replicated by the 0-mm shift condition.

In conditions where context was unavailable, bilingual participants showed significantly greater difficulty identifying target lexical items presented in isolation relative to their monolingual peers. This was examined in the 0-mm shifted condition, simulating optimal CI insertion depth. From this it can be concluded that bilingual CI users may be reliant on access to semantic context in order to predict, and as such, accurately perceive, sentence-final target words. This again poses the difficult issue in which bilingual CI users must first be able to perceive lexical items in order to learn their semantic properties, despite the greater difficulty they experience identifying these words when presented in isolation relative to their monolingual peers. Greater lexical capacity is likely to improve CI users' abilities to use semantic cues. It is perhaps only after greater exposure to language, explicit lexical instruction, and/or explicit training on the perception of individual lexical items that bilingual CI users may acquire the ability to use these items to perceive the context facilitating improved lexical perception.

The fact that vocoding simulating both shallow (0-mm) and deep (6-mm) CI electrode array insertion depths significantly negatively impacted both monolingual and bilingual listeners of all ages studied and across a wide range of L2 age of acquisition indicates that CI users face unique difficulty perceiving speech relative to their NH peers. It is only with explicit training and the availability of context that listeners show significant improvement in the least distorted (0-mm) simulation of speech perception through a CI. Trends in these studies indicate that particular attention must be paid to both bilingual and child CI users, and most predominantly to bilingual children. In Chapter 2, it was found that even a brief training period led to improvement in speech perception in both conditions of shift for all groups tested. This highlights the importance of clinical intervention and the significant role it may play in speech perception outcomes of CI users. It is only with time and assistance that CI users will develop the ability to better perceive speech and communicate more easily in a world designed to accommodate their NH peers.

Appendix A: *LNT/MLNT* Stimuli of Experiment 2

Table 13

Words presented in the unaltered condition

Easy	Hard
Juice	Thumb
Good	Pie
Drive	Wet
Time	Fight
Hard	Toe
Gray	Cut
Foot	Pink
Orange	Hi
Count	Song
Brown	Fun
Home	Use
Old	Mine
Watch	Ball
Need	Kick
Food	Tea
Dance	Book
Live	Bone
Stand	Work
Six	Dad
Cold	Game
Push	Lost
Stop	Cook
Girl	Gum

Hurt	Cap
Cow	Meet
Children	Butter
Animal	Lion
Monkey	Money
Finger	Jelly
Pocket	Yellow
Apple	Purple
Morning	Hello
Sugar	Carry
Alright	Corner
About	Heaven
Because	Measles
Crazy	Ocean

Table 14

Words presented in the vocoded condition

Easy	Hard
Down	Ear
Truck	Hand
Mouth	Dry
Pig	Zoo
Give	Goat
School	Toy
Boy	Call
Put	Sing
Three	Cut
Farm	Wrong
Fish	Bed
Green	Fat
Catch	Man
Break	Run
House	Hot
Sit	Read
Friend	Grow
Jump	Bag
Bird	Cake
Swim	Seat
Hold	Nine
Want	Sun
Snake	Bath
More	Ten
White	Ride

Water	Puppy
Banana	Pickle
Glasses	Button
Airplane	Summer
Window	Bottom
Tiger	Finish
Cookie	Bunny
Again	Belly
Another	Couple
Almost	Under
Broken	Naughty
China	Really

Appendix B: *R-SPIN* Stimuli of Experiment 2

Table 15

Sentences presented in the unaltered condition

Low Context	High Context
The old man discussed the dive.	The watchdog gave a warning growl.
Bob heard Paul called about the strips.	She made the bed with clean sheets.
I should have considered the map.	The old train was powered by the stream.
Miss Brown shouldn't discuss the sand.	He caught the fish in his net.
They might have considered the hive.	Close the window to stop the draft.
David has discussed the dent.	My T.V. has a twelve-inch screen.
He can't consider the crib.	The sandal has a broken strap.
I am thinking about the knife.	The boat sailed along the coast.
David does not discuss the hug.	Crocodiles live in muddy swamps.
We've been discussing the crates.	The farmer harvested his crop.
Miss Black knew about the doll.	All the flowers were in bloom.
She couldn't discuss the pine.	She wore a feather in her cap.
Miss Black thought about the lap.	The Admiral commands the fleet.
Mr. Black knew about the pad.	The beer drinkers raised their mugs.
You heard Jane called about the van.	He was hit by a poisoned dart.
Tom wants to know about the cake.	The bread was made from whole wheat.
She's spoken about the bomb.	I made the phone call from a booth.
We hear you called about the lock.	The cut on his knee formed a scab.
The old man discussed the yell.	His boss made him work like a slave.
They're glad we heard about the track.	The farmer baled the hay.
Sue was interested in the bruise.	A termite looks like an ant.
Ruth will consider the herd.	Air mail requires a special stamp.
The girl talked about the gin.	Football is a dangerous sport.
Paul can't discuss the wax.	We saw a flock of wild geese.
I hope Paul asked about the mate.	Drop the coin through the slot.

Table 16
Sentences presented in the vocoded condition

Low Context	High Context
You're glad they heard about the slave.	Hold the baby on your lap.
The girl knows about the swamps.	For your birthday I baked a cake.
They did not discuss the screen.	The railroad train ran off the track.
They were interested in the strap.	Tear off some paper from the pad.
I had a problem with the bloom.	The fruit was shipped in wooden crates.
Peter should speak about the mugs.	The rancher rounded up his heard.
She wants to speak about the ant.	The lonely bird searches for its mate.
We're discussing the sheets.	They drank a whole bottle of gin.
They boy would discuss the scab.	On the beach we play in the sand.
Tom could have thought about the sport.	The airplane went into a dive.
You'd been considering the geese.	We're lost so let's look at the map.
Mr. Black considered the fleet.	Household goods are moved in a van.
I want to know about the crop.	The honeybees swarmed round the hive.
Betty has talked about the draft.	The airplane dropped a bomb.
Tom discussed the hay.	Cut the bacon into strips.
Jane was interested in the stamp.	The drowning man let out a yell.
I had not thought about the growl.	I gave her a kiss and a hug.
Paul should know about the net.	I cut my finger with a knife.
Tom heard Jane called about the booth.	the candle flame melted the wax.
We can't consider the wheat.	This key won't fit in the lock.
We have not discussed the steam.	The little girl cuddled her doll.
Miss Brown might consider the coast.	Tom fell down and got a bad bruise.
Mr. Brown can't discuss the slot.	The furniture was made of pine.
He hasn't considered the dart.	How did your car get that dent?
Mr. smith thinks about the cap.	The baby slept in his crib.

References

Abrahamsson, N., & Hyltenstam, K. (2009). Age of onset and nativelikeness in a second language: Listener perception versus linguistic scrutiny. *Language Learning, 59*(2), 249-306.

Altman, C., Goldstein, T., & Armon-Lotem, S. (2018). Vocabulary, metalinguistic awareness, and language dominance among bilingual preschool children. *Frontiers in Psychology.*

American Speech Language and Hearing Association (2004). Scope of practice in audiology.

American Speech Language and Hearing Association. (2016). Cochlear implant quick facts.

Anaya, J. B., Peña, E. D., & Bedore, L. M. (2018). Conceptual Scoring and Classification Accuracy of Vocabulary Testing in Bilingual Children. *Language, speech, and hearing services in schools*, 49(1), 85–97.

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology. 8*(2), 71-82.

Anderson, J. A., Saleemi, S., & Bialystok, E. (2017). Neuropsychological Assessments of Cognitive Aging in Monolingual and Bilingual Older Adults. *Journal of neurolinguistics*, *43*(A), 17–27.

Ardila, A.; Ostrosky-solís, F.; Bernal, B. (2006). "Cognitive testing toward the future: The example of Semantic Verbal Fluency (ANIMALS)". *International Journal of Psychology*. *41(5)*. 324–332

Atkinson, D., Churchill, E., Nishino, T., & Okada, H. (2018). Language learning great and small: Environmental support structures and learning opportunities in a sociocognitive approach to second language acquisition/teaching. *The Modern Language Journal. 102*(3). 471-493.

Balkany, T., Whitley, M., Shapira, Y., Angeli, S., Brown, K., Eter, E., Van De Water, T., Telischi, F., Eshrahgi, A., & Treaba, C. (2009). The temporalis pocket technique for cochlear implantation: An anatomic and clinical study. *Otology and Neurotology. 30*(7), 903-907.

Başkent, D., & Shannon, R. V. (2005). Interactions between cochlear implant electrode insertion depth and frequency-place mapping. *The Journal of the Acoustical Society of America*, 117(3), 1405-1416.

Bergelson, E., Casillas, M., Soderstrom, M., Seidl, A., Warlaumont, A., & Amatuni, A. (2018). What do North American babies hear? A large-scale cross-corpus analysis. *Developmental Psychology. 22(1). e12724.*

Bent, T., Loebach, J. L., Phillips, L., & Pisoni, D. B. (2011). Perceptual adaptation to sinewave-vocoded speech across languages. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(5), 1607.

Bialystok, E. (1987). Influences of bilingualism on metalinguistic development. *Interlanguage Studies Bulletin. 3*(2). 154-166.

Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. *Developmental science*, *7*(3), 325-339.

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan: The rise and fall of inhibitory control. *International Journal of Bilingualism*, *9*(1), 103–119.

Bialystok, E. (2008). Bilingualism: The good the bad and the indifferent. *Bilingualism: Language and Cognition,* 12(1), 3-11.

Bialystok, E., Luk, G., Peets, K. & Yang, S. (2010). Receptive vocabulary differences in monolingual and bilingual children. *Biling (Camb Engl). 13*(4), 525-531.

Bialystok, E., & Luk, G. (2012). Receptive vocabulary differences in monolingual and bilingual adults. *Bilingualism: Language and Cognition*,15(02), 397-401.

Bingabr, M., Espinoza-Varas, B., & Loizou, P. (2008). Simulating the effect of spread of excitation in cochlear implants. *Hearing Research. 241*(1-2), 73-79.

Birdsong, D. (2001). Age and second language acquisition and processing: A selective overview. *Language Learning. 56*(1),9-49.

Blamey, P., Artieres, F., Başkent, D., Bergeron, F., Beynon, A., Burke, E., Dillier, N., Dowell, R., Fraysse, B., Gallégo, S., Govaerts, P. J., Green, K., Huber, A. M., KleinePunte, A., Maat, B., Marx, M., Mawman, D., Mosnier, I., O'Connor, A. F., O'Leary, S., Rousset, A., Schauwers, K., Skarzynski, H., Skarzynski, P. H., Sterkers, O., Terranti, A., Truy, E., Van de Heyning, P., Venail, F., Vincent, C., & Lazard, D. S. (2013). Factors affecting auditory performance of postlinguistically deaf adults using cochlear implants: An update with 2251 patients. *Audiology Neurootology, 18*(1), 36-47.

Bovo, R., Lovo, E., Astolfi, L., Montino, S., Franchella, S., Gallo, S., Prodi, N., Borsetto, D., & Trevisi, P. (2018). Speech perception in noise by young sequential bilingual children. *Acta Otorhinolaryngologica Italica : organo ufficiale della Societa italiana di otorinolaringologia e chirurgia cervico-facciale*, *38*(6), 536–543.

Bradlow, A., & Bent, T. (2008) Perceptual adaptation to non-native speech. *Cognition. 106*(2), 707-729.

Brice, A., Salnaitis, C., & Porzig, R. (2019). Recognition of code-mixed gated words: Phonotactic features of Spanish and English. *Rivista de Logopedia, Foniatria y Audiologia.*

Briscoe, J., Bishop, D. V., & Norbury, C. F. (2001). Phonological processing, language, and literacy: A comparison of children with mild-to-moderate sensorineural hearing loss and those with specific language impairment. *Journal of Child Psychology and Psychiatry*, *42*(03), 329-340.

Brunetti, R, Del Gatto, C., & Delogu, F. (2014). eCorsi: Implementation and testing of the Corsi block-tapping task for digital tablets. *Frontiers in Psychology. 5.*

Bunta, F., Douglas, M., Dickson, H., Cantu, A., Wickesberg, J., & Gifford, R. H. (2016). Dual language versus English-only support for bilingual children with hearing loss who use cochlear implants and hearing aids. *International Journal of Language & Communication Disorders*.

Burkholder, R. A., & Pisoni, D. B. (2003). Speech timing and working memory in profoundly deaf children after cochlear implantation. *Journal of experimental child psychology*, *85*(1), 63-88.

Bybee, J. L., & Hopper, P. J. (Eds.). (2001). *Frequency and the emergence of linguistic structure* (Vol. 45). John Benjamins Publishing.

Calabria, M., Hernandez, M., Branzi, F., & Costa, A. (2012). Qualitative differences between bilingual language control and executive control: Evidence from task-switching. *Frontiers in Psychology. 13.*

Carlozzi, N. E., Tulsky, D. S., Chiaravalloti, N. D., Beaumont, J. L., Weintraub, S., Conway, K., & Gershon, R. C. (2014). NIH Toolbox Cognitive Battery (NIHTB-CB): the NIHTB pattern comparison processing speed test. *Journal of the International Neuropsychological Society*, *20*(06), 630-641.

Carlson, M., Goldrick, M., Blasingame, M., & Fink, A. Navigating conflicting phonotactic constraints in bilingual speech perception. *Bilingualism: Language and Cognition. 19(5).* 939-954.

Casaponsa, A., Sohoglu, E., Moore, D., Fullgrabe, C., Molloy, K., & Amitay, S. (2019). Does training with amplitude modulated tones affect tone-vocoded speech perception? *PLOS ONE.*

Central Intelligence Agency (2016). Field Listing: Languages. The World Factbook.

Cervera, T., & González-Alvarez, J. (2011). Test of Spanish sentences to measure speech intelligibility in noise conditions. *Behavior research methods*, *43*(2), 459-467.

Cesur, S., & Ufuk, D. (2020). Temporal processing and speech perception performance of postlingual adult users of cochlear implants. *Journal of the American Academy of Audiology. 31(2),* 129-136.

Chall, J. & Jacobs, V. (2003) The classic study on poor children's fourth-grade slump. *American Educator.*

Chauvel, G., Palluel, E., Brandao, A., Barbiberi, G., Nougier, V., & Olivier, I. (2017). Attentional load of walking in children aged 7-12 and in adults. *Gait and Posture. 56,* 95-99.

Chiappe, P., Chiappe, D. L., & Siegel, L. S. (2001). Speech perception, lexicality, and reading skill. *Journal of experimental child psychology*, *80*(1), 58-74.

Chiappe, P., Chiappe, D. L., & Gottardo, A. (2004). Vocabulary, context, and speech perception among good and poor readers. *Educational Psychology*, *24*(6), 825-843.

Cleary, M., Pisoni, D. B., & Geers, A. E. (2001). Some measures of verbal and spatial working memory in eight-and nine-year-old hearing-impaired children with cochlear implants. *Ear and hearing*, *22*(5), 395.

Coco, A., Epp, S., Fallon, J., Millard, R., Sheperd., R. Does cochlear implantation and electrical stimulation affect residual hair cells and spiral ganglion neurons? *Hearing Res. 225*(1-2), 60-70.

Cole, R. (1973). Listening for mispronunciations: A measure of what we hear during speech. *Perception and Psychophysics. 1,*153-156.

Connor, C., Craig, H., Raudenbush, S., Heavner, K., & Zwolan, T. (2006). The Age at Which Young Deaf Children Receive Cochlear Implants and Their Vocabulary and Speech-Production Growth: Is There an Added Value for Early Implantation? *Ear and Hearing 27*(6). 628-644.

Conrad, L. (1989). The Effects of Time-Compressed Speech on Native and ESL Listening Comprehension. *Studies in Second Language Acquisition. 11*(1), 1-116.

Conrad, S., & Mauranen, A. (2003). The corpus of English as lingua franca in academic settings. *Tesol Quarterly*, 37(3), 513-527.

Corsi, P. (1972). Human memory and the medial temporal region of the brain. Dissertation Abstracts International, 34 (02), 819B. (University Microfilms No. AAI05-77717).

Costa, A., Hernandez, M., Costa-Faidella., & Sebastian-Galles., N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition. 113*. 135-149.

Cragg, L. (2015). The development of stimulus and response interference control in midchildhood. *Developmental Psychology. 52*(2). 242-252.

Cummins, J. (2008). BICS and CALP: Empirical and Theoretical Status of the Distinction. In: Street, B. & Hornberger, N. H. (Eds.). *Encyclopedia of Language and Education, 2nd Edition, Volume 2: Literacy.* (pp. 71-83). New York: Springer Science + Business Media LLC

Crystal, David (November 19, 2004). "Subcontinent Raises Its Voice". *The Guardian*.

Davis, M. H., Johnsrude, I. S., Hervais-Adelman, A., Taylor, K., & McGettigan, C. (2005). Lexical information drives perceptual learning of distorted speech: evidence from the comprehension of noise-vocoded sentences. *Journal of Experimental Psychology: General*, 134(2), 222

Dettman, S., Wall, E., Constantinescu, G., & Dowell, R. (2013). Communication outcomes for groups of children using cochlear implants enrolled in auditory-verbal, aural-oral, and bilingual-bicultural early intervention programs. *Otology and Neurotology. 34.* 451-459.

de Bruin, A., Treccani, B., & Sala, S. (2015). Cognitive advantage in bilingualism: An example of publication bias? *Psychological Science. 26*(1). 99-107.

de Groot, A., Dannenburg, L., & van Hell, J. (1994). Forward and backward word translation by bilinguals. *Journal of Memory and Language. 33*, 600-629.

de Jong, P. F., Seveke, M. J., & van Veen, M. (2000). Phonological sensitivity and the acquisition of new words in children. *Journal of Experimental Child Psychology*, *76*(4), 275-301.

DeKeyser, R. M. (2000). The robustness of critical period effects in second language acquisition. *Studies in Second Language Acquisition, 22*(4), 499-533.

DeKeyser, R. M., Alfi-Shabtay, I., & Ravid, D. (2010). Cross-linguistic evidence for the nature of age effects in second language acquisition. *Applied Psycholinguistics, 31*(3), 413-438.

DeKeyser, R. M. (2012). Age effects in second language learning. In S. Gass & A. Mackey (Eds.), *Handbook of Second Language Acquisition* (pp. 442-460). London: Routledge.

DeKeyser, R. (2018). Age in learning and teaching grammar. In: *The TESOL Encyclopedia of English Language Teaching.* Ed. J. Liontas, M. DelliCarpini, & H. Nassaji. John Wiley and Sons, Inc.

Delattre, P. (1964). Comparing the vocalic features of English, German, Spanish and French. *IRAL-International Review of Applied Linguistics in Language Teaching*, 2(1), 71-98.

Diamond, A., & Taylor, C. (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to "Do as I say, not as I do." *Developmental Psychology. 29*(4), 315-334.

Dickinson, D. K., McCabe, A., Clark–Chiarelli, N., & Wolf, A. (2004). Cross-language transfer of phonological awareness in low-income Spanish and English bilingual preschool children. *Applied Psycholinguistics*, *25*(03), 323-347.

Dijkstra, T., Grainger, J., & van Heuven, W. (1999) Recognition of cognates and interlingual homographs: The neglected role of phonology. *Journal of Memory and Language. 41*, 496-518.

Dijkstra, T., & van Heuven, W. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition. 5*(3), 175-197.

Dikmen, S. S., Bauer, P. J., Weintraub, S., Mungas, D., Slotkin, J., Beaumont, J. L., & Heaton, R. K. (2014). Measuring Episodic Memory Across the Lifespan: NIH Toolbox Picture Sequence Memory Test. *Journal of the International Neuropsychological Society*, *20*(06), 611-619.

Dilley, L., Lehet, M., Wieland, E., Argmondi, M., Kondaurova, M., Wang, Y., Reed, J., Svirsky, M., Houston, D., Bergeson, T. (2020). Individual differences in mothers' infant-directed speech predict language attainments in children with cochlear implants. *Journal of Speech, Language, and Hearing Research. 63.* 2453-2467.

Donaldson, G., & Nelson, D. (2000). Place-pitch sensitivity and its relation to consonant recognition by cochlear implant listeners using the MPEAK and SPEAK speech processing strategies. Journal of the Acoustical Society of America. 107(3).1645-1658

Dudley, H. (1939). Remaking speech. The Journal of the Acoustical Society of America. 11(2). 169-177.

Dufour, S., Grainger, J. (2019). Phoneme-order encoding during spoken word recognition: A priming investigation. *Cognitive Science. 43,* e12785.

Eisenberg, L. S., Johnson, K. C., Martinez, A. S., Cokely, C. G., Tobey, E. A., Quittner, A. L., & Niparko, J. K. (2006). Speech recognition at 1-year follow-up in the childhood development after cochlear implantation study: methods and preliminary findings. *Audiology and Neurotology*, *11*(4), 259-268.

Eisenberg, L. S., Shannon, R. V., Martinez, A. S., Wygonski, J., and Boothroyd, A. (2000). "Speech recognition with reduced spectral cues as a function of age," J. Acoust. Soc. Am. 107, 2704-2710.

Eisenberg, L., Martinez, A., Holowecky, S., & Pogorelsky, S. (2002). Recognition of lexically controlled words and sentences by children with normal hearing and children with cochlear implants. *Ear and Hearing. 23*(5), 450-462.

El Boghdady, N, Baskent, & Gaudrain, E. (2018). Effect of frequency mismatch and band partitioning on vocal tract length perception in vocoder simulations of cochlear implant processing. *The Journal of the Acoustical Society of America, 143(6).*

Ely, C. (1986). An analysis of discomfort, risk taking, sociability, and motivation in the L2 classroom. *Language Learning. 36*, 238-244.

Erard, M. (January 15, 2012). Are we really monolingual? *The New York Times.* pp-SR12

Fagan, M. K., Pisoni, D. B., Horn, D. L., & Dillon, C. M. (2007). Neuropsychological correlates of vocabulary, reading, and working memory in deaf children with cochlear implants. *Journal of deaf studies and deaf education*, *12*(4), 461-471.

Faulkner, A., Rosen, S., & Stanton, D. (2003). Simulations of tonotopically mapped speech processors for cochlear implant electrodes varying in insertion depth. *The Journal of the Acoustical Society of America. 120*(6), 1073-1080.

Ferre, P., Sanchez-Casas, & Guasch, M. (2006). Can a horse be a donkey? Semantic and form interference effects in translational recognition in early and late proficient and nonproficient Spanish-Catalan bilinguals. *Language Learning. 56*(4), 571-608.

Filippi, R., Morris, J., Richardson, F. M., Bright, P., Thomas, M. S., Karmiloff-Smith, A., & Marian, V. (2015). Bilingual children show an advantage in controlling verbal interference during spoken language comprehension. *Bilingualism (Cambridge, England)*, *18*(3), 490–501.

Finley, C. C., & Skinner, M. W. (2008). Role of electrode placement as a contributor to variability in cochlear implant outcomes. Otology & neurotology: official publication of the American Ontological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 29(7), 920.

Fitzgibbons, P., & Gordon-Salant, S. (2001). Age and temporal discrimination in auditory sequences. *Journal of the Acoustical Society of America. 109*(6), 2955-2963.

Flege, J. E. (1987). A critical period for learning to pronounce foreign languages? *Applied*

Linguistics, *8*(2), 162-177.

Flege, J. E. (1991). Age of learning affects the authenticity of voice-onset time (VOT) in stop consonants produced in a second language. *The Journal of the Acoustical Society of America*, 89(1), 395-411.

Friesen, D., Luo, L., Luk, G., & Bialystok, E. (2014). Proficiency and control in verbal fluency performance across the lifespan for monolinguals and bilinguals. *Language, Cognition and Neuroscience. 30(3),* 238-250.

Friesen, L., Shannon, R., & Baskent., D. (2001). Speech recognition in noise as a function of the number of spectral channels: Comparison of acoustic hearing and cochlear implants. *Journal of the Acoustical Society of America. 110*(2), 1150-1163.

Fontenot, T., Giradina, C., Dillon, M., Rooth, M., Teagle, H., Park, L., Brown, K., Adunka, O., Buchman, C., Fitzpatrick, H., & Dougles, F. (2019). Residual cochlear function in adults and children receiving cochlear implants: Correlations with speech perception outcomes. *Ear and Hearing. 40(3),* 577-5 91.

Foulke, E., Sticht, T. (1969). Review of research on the intelligibility and comprehension of accelerated speech. *Psychological Bulletin. 72*(1), 50-62.

Füllgrabe, C., Moore, B. C., & Stone, M. A. (2015). Age-group differences in speech identification despite matched audiometrically normal hearing: contributions from auditory temporal processing and cognition. *Frontiers in aging neuroscience*, *6*, 347.

Füllgrabe, C., & Rosen, S. (2016). Investigating the role of working memory in speech-in-noise identification for listeners with normal hearing. In *Physiology, Psychoacoustics and Cognition in Normal and Impaired Hearing* (pp. 29-36). Springer International Publishing.

Fu, Q., & Galvin, J. (2001). Recognition of spectrally asynchronous speech by normal-hearing listeners and Nucleus-22 cochlear implant users. *The Journal of the Acoustical Society of America. 109*(3), 1166-1172.

Fu, Q. (2002). Temporal processing and speech recognition in cochlear implant users. *NeuroReport. 13*(13), 1635-1639.

Fu, Q., Chinchilla, S., & Galvin, J. (2004). The role of spectral and temporal cues in voice gender discrimination by normal-hearing listeners and cochlear implant users. *Journal of the Association for Research in Otolaryngology. 5*(3), 253-260.

Fu, Q. J., & Nogaki, G. (2005). Noise susceptibility of cochlear implant users: the role of spectral resolution and smearing. *Journal of the Association for Research in Otolaryngology*, 6(1), 19-27.

Fujiki,N., Naito, Y., Hirano, S., Kojima, H., Shiomi, Y., Nishizawa, S., Konishi, J., Honjo., I. (2000). Cortical activity and speech perception performance in cochlear implant users. Adv. Otorhinolaryngol, 57 (2000), pp. 32–35

Gasquoine, P. (2016). Effects of bilingualism on vocabulary, executive functions, age of dementia onset, and regional brain structure. *Neuropsychology, 30(8)*, 988–997.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of memory and language*, *29*(3), 336-360.

Gathercole, S., Pickering, S., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology. 40*(2), 177-190.

Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics*, *27*(04), 513-543.

Garcia Lecumberri, M. L., Cooke, M. & Cutler, A. (2010) Non-native speech perception in adverse conditions: A review. *Speech Communication*, 52, 864-886.

Garlock, V., Walley, A., Metsala, J. (2001). Age-of-acquisition, word frequency, and neighborhood density effects on spoken word recognition by adults and children. *Journal of Memory and Language. 45*(3), 468-492.

Gogate, L., & Maganti, M. (2017). The origins of verb learning: Preverbal and postverbal infants learning of word-action relations. *Journal of Speech, Language, and Hearing Research. 60,* 3538-3550.

Gomaa, N. A., Rubinstein, J. T., Lowder, M. W., Tyler, R. S., & Gantz, B. J. (2003). Residual speech perception and cochlear implant performance in postlingually deafened adults. *Ear and hearing*, *24*(6), 539-544.

Gomez,R., & Gerken, L. (2000). Infant artificial language learning and language acquisition. *Trends in Cognitive Science. 4*(5), 178-187.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and cognition*, *1*(02), 67-81

Green, K. M., Julyan, P. J., Hastings, D. L., & Ramsden, R. T. (2005). Auditory cortical activation and speech perception in cochlear implant users: effects of implant experience and duration of deafness. *Hearing research*, *205*(1), 184-192.

Green, K., Julyan, P., Hastings, D., & Ramsden, R. (2005). Auditory cortical activation and speech perception in cochlear implant users: Effects of implant experience and duration of deafness. *Hearing Research. 205*(1-2), 184-192.

Greenwood, D. (1990). A cochlear frequency-position function for several species-29 years later. *The Journal of the Acoustical Society of America. 87*(6), 2592-2605.

Goldinger, S., Luce, P., & Pisoni, D. (1989). Priming lexical neighbors of spoken words: Effects of competition and inhibition. *Journal of Memory and Language. 28*(5), 501-518.

Gollan, T., & Acenas, L. (2004). What is a TOT? Cognate and translation effects on tip-of-the-tongue states in Spanish-English and Tagalog-English bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition. 30*(1), 246-269.

Gollan, T., Montoya, R., Fennema-Notestine, C., & Morris. (2005). *Memory and Cognition. 33*(7), 1220-1234.

Grosjean, F. (2020). The amazing rise of bilingualism in the United States. *Psychology Today.*

Guiberson, M. M. (2005). Children with cochlear implants from bilingual families: Considerations for intervention and a case study. *The Volta Review*, 105(1), 29.

Guiberson, M. (2013). Survey of Spanish parents of children who are Deaf or hard of hearing: Decision-making factors associated with communication modality and bilingualism. *American Journal of Audiology,* 22, 105-119.

Hartshorne, J. K., Tenenbaum, J. B., & Pinker, S. (2018). A critical period for second language acquisition: Evidence from 2/3 million English speakers. *Cognition*, *177*, 263–277.

Harrison, X., Donaldson, L., Correa-Cano, M., Evans, J., Fisher, D., Goodwin, C., Robinson, B., Hodgson, D., & Inger, R. (2018). A brief introduction to mixed effects modeling and multi-level inference in ecology *.PeerJ.6*, e4794.

Hattori, K., & Iverson, P. (2009). English /r/-/l/ category assimilation by Japanese adults: Individual differences and the link to identification accuracy. *The Journal of the Acoustical Society of America. 125*(1), 469-479.

Hayes, E. A., Warrier, C. M., Nicol, T. G., Zecker, S. G., & Kraus, N. (2003). Neural plasticity following auditory training in children with learning problems. *Clinical neurophysiology*, 114(4), 673-684.

Helmstaedter, V., Beuchner, A., Stolle, S., Goetz, F., Lenarz, T., & Durisin, M. (2018). *International Journal of Pediatric Ortholaryngology. 113,* 102-109.

Hinde, E. (1962). Increase of the corticosterone level in ducklings during the sensitive period of the following response. *Developmental Psychobiology.* 10(1), 59-64.

Holt, C., Demuth, K.; Yuen, I. (2016). The Use of Prosodic Cues in Sentence Processing by Prelingually Deaf Users of Cochlear Implants. *Ear and Hearing 37*(4). e256-e262.

Huibregtse, I., Admiraal, W., & Meara, P. (2002). Scores on a yes-no vocabulary test: Correction for guessing and response style. *Language Testing.19(3)*, 227-245.

Hurtado, N., Marchman, V. A., & Fernald, A. (2008). Does input influence uptake? Links between maternal talk, processing speed and vocabulary size in Spanish-learning children. *Developmental science*, *11*(6), F31-F39.

Incera, S., & McLennan, C. (2018). Bilingual and age are continuous variables that influence executive function. *Aging, Neuropsychology, and Cognition. 25(3),* 443-463.

Israel Central Bureau of Statistics. (2016). Selected data from the 2011 social survey on mastery of the Hebrew language and usage of languages (Hebrew only).

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2011). Short-and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences*, 108(25), 10081-10086.

Jenkins, J. (2006). Current perspectives on teaching world Englishes and English as a lingua franca. *Tesol Quarterly*, 40(1), 157-181.

Jensen, R. (1965). Scoring the Stroop Test. *Acta Psychologica. 24.* 398-408.

Johnson, J. S., & Newport, E. L. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognitive psychology*, 21(1), 60-99.

Jusczyk, P. W., Luce, P. A., & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory and Language*, 33(5), 630.

Kalikow, D. N., Stevens, K. N., & Elliott, L. L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *The Journal of the Acoustical Society of America*, *61*(5), 1337-1351.

Kidd, G., Jr., Best, V., and Mason, C. R. (2008). "Listening to every other word: Examining the strength of linkage variables in forming streams of speech," J. Acoust. Soc. Am. *124*, 3793-3802.

Kirk, K., Pisoni, D., & Osberger, M. (1995). Lexical effects on spoken word recognition by pediatric cochlear implant users. *Ear and Hearing. 16*(5), 470-481.

Knight, S., & Heinrich, A. (2017). Different measures of auditory and visual Stroop interference and their relationship to speech intelligibility in noise. *Frontiers in Psychology. 8,* 230-237.

Knoors, H. & Marschark, M. (2012). Language planning for the 21st century: Revisiting bilingual language policy for deaf children. *The Journal of Deaf Studies and Deaf Education. 18*(4), 291-305.

Kochunov, P., Fox, P., Lancaster, J., Tan, L. H., Amunts, K., Zilles, K., & Gao, J. H. (2003). Localized morphological brain differences between English-speaking Caucasians and Chinese-speaking Asians: new evidence of anatomical plasticity. *Neuroreport*, 14(7), 961-964.

Kopp, B., Rist, F., & Mattler, U. W. E. (1996). N200 in the flanker task as a neurobehavioral tool for investigating executive control. *Psychophysiology*, *33*(3), 282-294.

Kormi-Nouri, R., Moniri, S., & Nilsson, L. G. (2003). Episodic and semantic memory in bilingual and monolingual children. *Scandinavian Journal of Psychology*, *44*(1), 47-54.

Krashen., S. (1973). Lateralization, language learning, and the critical period: Some new evidence. *Language Learning.23*(1).

Krashen, S., & Harshman, R. (1972). Lateralization and the critical period. *The Journal of the Acoustical Society of America. 52*(174).

Krashen, S. D., Long, M. A., & Scarcella, R. C. (1979). Age, rate and eventual attainment in second language acquisition. *Tesol Quarterly*, 573-582.

Kroll, J., & Stewart, E. (1994). Category interference in translational and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language. 33*, 149-174.

Kroll, J., van Hell, J., Tokowicz, N., & Green, D. (2010). The revised hierarchical model: A critical review and assessment. *Biling (Camb Engl). 13*(3), 373-381.

Lachs, L., Pisoni, D. B., & Kirk, K. I. (2001). Use of audiovisual information in speech perception by prelingually deaf children with cochlear implants: A first report. *Ear and hearing*, *22*(3), 236.

Rogers, C. L., Lister, J. J., Febo, D. M., Besing, J. M., & Abrams, H. B. (2006). Effects of bilingualism, noise, and reverberation on speech perception by listeners with normal hearing. *Applied Psycholinguistics, 27*, 465-485.

Lam, K., & Dijkstra, T. (2010). Word repetition, masked orthographic priming, and language switching: Bilingual studies and BIA+ simulations. *International Journal of Bilingual Education and Bilingualism. 13*(5), 487-503.

Lambert, W. E., Ignatow, M., & Krauthammer, M. (1968). Bilingual organization in free recall. *Journal* *of Verbal Learning and Verbal Behavior. 7*, 207-214

Landsberger, D., Vermeire, K., Claes, A., Van Rompaey, V., & Van de Heyning, P. (2016). Qualities of single electrode stimulation as a function of rate and place of stimulation with a cochlear implant. *Ear and Hearing. 37*(3), e149-e159.

Lassig, A. A. D., Zwolan, T. A., & Telian, S. A. (2005). Cochlear implant failures and revision. *Otology & Neurotology*, 26(4), 624-634.

Laszlo, S., & Federmeier, K. (2009).A beautiful day in the neighborhood: An event-related potential study of lexical relationships and prediction in context. *Journal of Memory and Language. 61*(3), 326-338

Leake, P., Hradek, G., & Snyder, R. (1999). Chronic electrical stimulation by a cochlear implant promotes survival of spiral ganglion neurons after neonatal deafness. *The Journal of Comparitive Neurology. 412*(4), 543-562.

Lee, S., Shim, Y.J., Han, J. Song, J., Koo, J., Oh, S., & Choi, B. (2020). The molecular etiology of deafness and auditory performance in the postlingually deafened cochlear implantees. *Sci Rep 10,* 5768.

Lenneberg (1967). The biological foundations of language.

Li, T., & Fu, Q. (2007). Perceptual adaptation to spectrally shifted vowels: Training with nonlexical labels. Journal for the Association for Research in Otolaryngology.

Liberman, A., & Mattingly, I. (1985). The motor theory of speech perception revised. *Cognition. 21,*1-36.

Lillo-Martin, D., Goodwin, C. (2019). Morphological accuracy in the speech of bimodal bilingual children with CIs. *The Journal of Deaf Studies and Deaf Education, 24(4),* 435-447.

Linck, J. A., Kroll, J. F., & Sunderman, G. (2009). Losing Access to the Native Language While Immersed in a Second Language: Evidence for the Role of Inhibition in Second-Language Learning. *Psychological Science*, *20*(12), 1507–1515.

Litovsky, R., Goupell, M., Godar, S., Grieco-Calub, T., Jones, G., Geradat, S., Agrawal, S., Kan, A., Todd, A., Hess, C., & Misurelli, S. (2012). Studies on bilateral cochlear implants at the University of Wisconsin's Binaural Hearing and Speech Lab. *Journal of the American Academy of Audiology. 23*(6), 476-494.

Loebach, J. L., & Pisoni, D. B. (2007). Perceptual learning under a cochlear implant simulation. *Research on Spoken Language Processing Progress Report. No*, *28*.

Loizou, P. (2006). Speech processing in vocoder-centric cochlear implants. Advanced Otorhinolaryngology. 64. 109-143.

Luce, P. A., Feustel, T. C., & Pisoni, D. B. (1983). Capacity demands in short-term memory for synthetic and. natural speech. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *25*(1), 17-32.

Lyons, D. (2017). How many people speak English and where is it spoken? *Babbel Magazine.*

Ma, W., Fiveash, A., Margulis, E., Behrend, D., & Thompson, W. (2020). Song and infant-directed speech facilitate word learning. *Quarterly Journal of Experimental Psychology. 73(7).* 1036-1054.

Maccagno, Laura M., "Effectiveness of Semantic Mapping in Increasing Reading Comprehension for English Language Learners" (2019). Capstone Projects and Masters Theses. 640.

Marslen-Wilson, W., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology. 10*(1), 29-63.

Martin-Rhee, M., & Bialystok, E. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition. 11(1)*, 81-93.

Martínez-Celdrán, E., Fernández-Planas A., & Carrera-Sabaté, J. (2003). Castilian Spanish. *Journal of the International Phonetic Association, 33*(2), 255–259.

Massingham, D. (2012). Sentence-in-noise perception in monolinguals and multilinguals: The effect of contextual meaning, and linguistic and cognitive load. Durham University.

McKinney, S. (2017). Cochlear implantation in children under 12 months of age. *Current Opinion in Otolaryngology & Head and Neck Surgery. 25(5).* 400-404.

Madsen, S., Marschall, M., Dau, T., & Oxenham, A. (2019). Speech perception is similar for musicians and non-musicians across a wide range of conditions. *Scientific Reports. 9,* 10404.

Mayo, L. (1997). Age of second-language acquisition and perception of speech in noise. *Journal of Speech, Language and Hearing Research. 40*(3), 686.

McClelland, J. & Elman, J. (1986). The TRACE model of speech perception. *Cognitive Psychology. 18,* 1-86.

McClelland, J., Mirman, D., & Holt, L. (2006). Are there interactive processes in speech perception? *Trends in Cognitive Science. 10*(8), 363-369.

McDonald, J. (2000). Grammaticality judgments in a second language: Influences of age of acquisition and native language. *Applied Psycholinguistics. 21*(3), 395-423.

McElree, B., Jia, G., & Litvak, A. (2000). The time course of conceptual processing in three bilingual populations. *Journal of Memory and Language*, *42*(2), 229-254.

McQueen, J. & Cutler, A. (2010). Cognitive Processes in Speech Perception. In *The Handbook of Phonetic Sciences.* Eds. W. Hardcastle, J. Laver, & F. Gibbon.

Mendel, L., & Widner, H. (2016). Speech perception in noise for bilingual listeners with normal hearing. *International Journal of Audiology. 55(2),* 126-134.

Meyer, T., Frisch, S., Pisoni, D., Miyamato, R., & Svirsky, M. (2003). Modeling open-set spoken word recognition in post-lingually deafened adults following cochlear implantation: Some preliminary results with the neighborhood activation model. *Otol Neurology, 24(4)*, 612-620.

Miller, M., Calandruccio, L., Buss, E., McCreery, R., Oleson, J., Rodriguez, B., & Leibold, L. (2019). Masked English speech recognition performance in younger and older Spanish-English bilingual and English monolingual children. *Journal of Speech, Language, and Hearing Research, 62,* 4578-4592.

Morales, J., Calvo, A., & Bialystok, E. (2013). Working memory development in monolingual and bilingual children. *Journal of experimental child psychology*, *114*(2), 187-202.

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S. L., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old children: more evidence for brain plasticity. *Cerebral Cortex*, 19(3), 712-723.

Morini, G., & Newman, R. (2020). Monolingual and bilingual word recognition and word learning in background noise. *Language and Speech. 63*(2). 381-403.

Morton, J. & Harper, S. (2007). What did Simon say? Revisiting the bilingual advantage. *Developmental Science. 10*(6), 719-726.

Muise-Hennessey, A., Tremblay, A., White, N., McWhinney, S., Zaini, W., Maessan, H., Comeau-Grandy, A., Bance, M., & Newman, A. (2019). Age of onset and duration of deafness drive brain organization for biological motion perception in non-signers. Halifax, Canada.

National Institute of Deafness and Other Communication Disorders. (2017). Cochlear Implants.

Nayagam, B. A., Muniak, M. A., & Ryugo, D. K. (2011). The spiral ganglion: connecting the peripheral and central auditory systems. *Hearing research*, *278*(1), 2-20.

Newman, R., & Chatterjee, M. (2013). Toddlers' recognition of noise-vocoded speech. *The Journal of the Acoustical Society of America. 133*(483), 483-494.

Nicholas, J. G., & Geers, A. E. (2007). Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss. *Journal of Speech, Language, and Hearing Research*, 50(4), 1048-1062.

Nittrouer, S., Lowenstein, J. H., and Packer, R. R. (2009). "Children discover the spectral skeletons in their native language before the amplitude envelopes," J. Exp. Psychol. Hum. Percept. Perform. 35, 1245-1253.

Nordfalk, K., Fredrik, R., Kjell, H., Einar, B.,T., Jablonski, E., (2016). Insertion Depth in Cochlear Implantation and Outcome in Residual Hearing and Vestibular Function, *Ear and Hearing, 37*(2) e129-e137.

Ortega, L., & Iberri-Shea., G. (2005). Longitudinal research in second language acquisition: Recent trends and future directions. *Annual Review of Applied Linguistics. 25*. 26-45.

Padilla, A. & Liebman, E. (1975). Language acquisition in the bilingual child. *Bilingual Review 2*(1/2), 34-55.

Pallier, C., Colome, A., & Sebastian-Galles, N. (2001). The influence of native-language phonology on lexical access: Exemplar-based vs. abstract lexical entries. *Psychological Sciences. 12,* 445-449.

Pasquarella, A., Chen, X., Lam, K., Luo, Y. C., & Ramirez, G. (2011). Cross-language transfer of morphological awareness in Chinese–English bilinguals. *Journal of Research in Reading*, *34*(1), 23-42.

Paula, J., Paiva, G., & Costa, D. (2015). Use of a modified version of the switching verbal fluency test for the assessment of cognitive flexibility. *Dementia and Neuropsychologia. 9*(3), 258-264.

Peterson, G., & Lehiste, I., (1962). Revised CNC lists for auditory tasks. *Journal of Speech and Hearing Disorders. 27(1),*62-70.

Peterson, N. R., Pisoni, D. B., & Miyamoto, R. T. (2010). Cochlear implants and spoken language processing abilities: Review and assessment of the literature. *Restorative neurology and neuroscience*, 28(2), 237-250.

Pichora-Fuller, M. (2003). Processing speed and timing in aging adults: Psychoacoustics, speech perception and comprehension. *International Journal of Audiology. 42*(sup1), 59-67.

Pisoni, D. B., & Cleary, M. (2003). Measures of working memory span and verbal rehearsal speed in deaf children after cochlear implantation. *Ear and hearing*, *24*(1 Suppl), 106S.

Pisoni, D. D., & Geers, A. E. (2000). Working memory in deaf children with cochlear implants: Correlations between digit span and measures of spoken language processing. *The Annals of otology, rhinology & laryngology. Supplement*, *185*, 92.

Pisoni, D. B., Nusbaum, H. C., Luce, P. A., & Slowiaczek, L. M. (1985). Speech perception, word recognition and the structure of the lexicon. *Speech communication*, *4*(1), 75-95.

Pisoni, D. B. (2000). Cognitive factors and cochlear implants: Some thoughts on perception, learning, and memory in speech perception. *Ear and hearing*, *21*(1), 70.

Polonenko, M., Gordon, K., Cushing, S., & Papsin, B. (2017). Cortical organization restored by cochlear implantation in young children with single sided deafness. *Sci Rep, 7*. 16900.

Popova, D., Varbanova, S., Todorov, S., Stancheva, I. (2019). *International Bulletin of Ortholaryngology.*

Potter, C. E., & Lew-Williams, C. (2019). Infants' selective use of reliable cues in multidimensional language input. *Developmental psychology*, *55*(1), 1–8.

Potter, M., So, K., Von Eckardt, B., & Feldman, L. (1984). Lexical and conceptual representation in beginning and proficient bilinguals. *Journal of Verbal Learning and Verbal Behavior. 23*, 23-38.

Poulin-Dubois, D., Blaye, A., Coutya, J., & Bialystok, E. (2011). The effects of bilingualism on toddlers' executive functioning. *Journal of Experimental Child Psychology. 108*(3), 567-579.

Prabhakaran, R., Blumstein, S., Myers, E., Hutchison, E., & Britton, B. (2006). An event-related fMRI investigation of phonological-lexical competition. *Neuropsychologia. 44*(12), 2209-2221.

Proctor, C. P., August, D., Carlo, M. S., & Snow, C. (2006). The intriguing role of Spanish language vocabulary knowledge in predicting English reading comprehension. *Journal of Educational Psychology*, *98*(1), 159.

Ramanujan K, Weekes BS (2019). Predictors of lexical retrieval in Hindi– English bilingual speakers. *Bilingualism: Language and Cognition* 1–9.

Rao, K. S., Prasanna, S. M., & Yegnanarayana, B. (2007). Determination of instants of significant excitation in speech using Hilbert envelope and group delay function. *IEEE Signal Process. Lett.*, 14(10), 762-765.

Regalado, D., Kong, J., Buss, E., & Calandruccio, L. (2019). Effects of language history on sentence recognition in noise or two talker speech: Monolingual, early bilingual, and late bilingual speakers of English. *American Journal of Audiology. 28,* 935-946.

Rejali, D., Lee, V. A., Abrashkin, K. A., Humayun, N., Swiderski, D. L., & Raphael, Y. (2007). Cochlear implants and ex vivo BDNF gene therapy protect spiral ganglion neurons. *Hearing research*, *228*(1), 180-187.

Ren, Y., & Wyver, S. (2016). Social competence, cultural orientations and gender differences: A study of Mandarin-English bilingual preschoolers. *International Journal of Early Years Education. 24*(2). 143-156.

Robbins, A. M., Green, J. E., & Waltzman, S. B. (2004). Bilingual oral language proficiency in children with cochlear implants. *Archives of Otolaryngology–Head & Neck Surgery*, 130(5), 644-647.

Rogers, C. L., Lister, J. J., Febo, D. M., Besing, J. M., & Abrams, H. B. (2006). Effects of bilingualism, noise, and reverberation on speech perception by listeners with normal hearing. *Applied Psycholinguistics*,27(03), 465-485.

Roman, A. S., Pisoni, D. B., Kronenberger, W. G., & Faulkner, K. F. (2017). Some Neurocognitive Correlates of Noise-Vocoded Speech Perception in Children With Normal Hearing). *Ear and hearing*, *38*(3), 344–356.

Ronnberg, J., Rudner, M., Lunner, T., & Zekveld, A. (2010). When cognition kicks in: Working memory and speech understanding in noise. *Speech Perception and Understanding. 12*(49), 263-269.

Rosen, S., Faulkner, A., and Wilkinson, L. (1999). "Adaptation by normal listeners to upward spectral shifts of speech: Implications for cochlear implants," J. Acoust. Soc. Am. 106, 3629-3636.

Rothauser, E. (1969). IEEE recommended practice for speech quality measurements. *IEEE Transactions on Audio and Electriacoustics. 17*(3), 225-246.

Rudell, A., & Hu, B. (2000). Behavioral and brain wave evidence for automatic processing of orthographically regular letter strings. *Brain and Language. 75*(2), 137-152.

Rvachew, S., & Grawburg, M. (2006). Correlates of phonological awareness in preschoolers with speech sound disorders. *Journal of Speech, Language, and Hearing Research*, *49*(1), 74-87.

Sandoval, T., Gollan, T., Ferreira, V., & Salmon, D. (2010). What causes the bilingual disadvantage in verbal fluency? The dual-task analogy. *Bilingualism: Language and Cognition. 13*(2), 231-252.

Sarant, J. Z., Blamey, P. J., Dowell, R. C., Clark, G. M., & Gibson, W. P. R. (2001). Variation in speech perception scores among children with cochlear implants. *Ear and hearing*, *22*(1), 18-28.

Schmidtke, J. (2016). The bilingual disadvantage in speech understanding in noise is likely a frequency effect related to reduced language exposure. *Frontiers in Psychology*, 7 (678), 1-15.

Schroeder, S. R., & Marian, V. (2012). A bilingual advantage for episodic memory in older adults. *Journal of Cognitive Psychology*, *24*(5), 591-601.

Schvartz, K., Chatterjee, M., & Gordon-Salant, S. (2008). Recognition of spectrally degraded phonemes by younger, middle-aged, and older normal-hearing listeners. *The Journal of the Acoustical Society of America. 124*(6), 3972-3988.

Senan, T., Jelfs, S., & Kohlrausch, A. (2018). Cognitive disruption by noise-vocoded speech stimuli: Effects of spectral variation. *The Journal of the Acoustical Society of America. 143(3),* 1407-1418.

Shannon, R., Zeng, F., Kamath, V., Wygonski, J., & Ekelid, M. (1995). Speech recognition with primarily temporal cues. *Science. 270*(5234), 303-304.

Siciliano, C., Faulkner, A., Rosen, S., & Mair, K. (2010). Resistance to learning binaurally mismatched frequency-to-place maps: Implications for bilateral stimulation with cochlear implants. *Journal of the Acoustical Society of America. 127*(3), 1645-1660.

Singleton, D. M., & Ryan, L. (2004). *Language acquisition: The age factor* (Vol. 9). Multilingual Matters.

Skoe, E., & Karayanidi, K. (2019). Bilingualism and speech understanding in noise: Auditory and linguistic factors. *Journal of the American Academy of Audiology. 30(2)*, 115-130.

Smith, Z. (2018). Effect of vocoding on dialect and gender perception. *The Ohio State University.*

Snow, C. E., & Hoefnagel-Höhle, M. (1978). The critical period for language acquisition: Evidence from second language learning. *Child development*, 1114-1128.

Souza, P., & Rosen, S. (2009). Effects of envelope bandwidth on the intelligibility of sine- and noise-vocoded speech. *The Journal of the Acoustical Society of America. 126*(2), 792-805.

Stacey, P. C., Raine, C. H., O'Donoghue, G. M., Tapper, L., Twomey, T., & Summerfield, A. Q. (2010). Effectiveness of computer-based auditory training for adult users of cochlear implants. *International Journal of Audiology*, *49*(5), 347-356.

Stacey, P. C., & Summerfield, A. Q. (2007). Effectiveness of computer-based auditory training in improving the perception of noise-vocoded speech. *The Journal of the Acoustical Society of America*, 121(5), 2923-2935.

Stritikus, T. (2002). *Immigrant Children and the Politics of English-Only: Views from the Classroom. The New Americans: Recent Immigration and American Society*. LFB Scholarly Publishing, 2472 Broadway, Suite 251, New York, NY 10025.

Stroop, J. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology. 18*(6), 643-662.

Sullivan, M., Porach, G., Bialystok, E. (2018). Why is lexical retreival slower for bilinguals? Evidence from picture naming. *(Cambridge, England)*, *21*(3), 479–488.

Svirsky, M., Silveria, A., Suarez, H., Neuburger, H., Lai, T., & Simmons, P. (2001). Auditory learning and adaptation after cochlear implantation: A preliminary study of discrimination and labeling of vowel sounds by cochlear mplant users. *Research on Spoken Language Processing. 24.*

Svirsky, M., Teoh, S., & Neuburger, H. (2004). Development of language and speech perception in congenitally, profoundly deaf children as a function of age at cochlear implantation. *Audiology and Neuro Otology. 9.* 224-233.

Tabri, D., Abou Chacra, K., & Pring, T. (2010). Speech perception in noise by monolingual, bilingual and trilingual listeners. *International Journal of Language and Communication Disorders.*

Tao, L., & Taft, M. (2017). Effects of early home language environment on perception and production of speech. *Bilingualism: Language and Cognition. 20(5)*, 1030-1044.

Tembe, J. (2008). Developing literacy in second-language learners: Report of the National Literacy Panel on Language-Minority Children and Youth. *Studies in Second Language Acquisition,* 30(1), 116-118.

Teoh, S., Pisoni., D., Miamoto, R. (2004). Cochlear implantation in adults with prelingual deafness. Part II. Underlying constraints that affect audiological outcomes. *Laryngoscope. 114*(10), 1714-1719.

Thomas, E., El-Kashlan, H., & Zwolan, T. A. (2008). Children with cochlear implants who live in monolingual and bilingual homes. *Otology & Neurotology*, 29(2), 230-234.

Thomas-Sunesson, D., Hakuta, K., & Bialystok, E. (2018). Degree of bilingualism modifies executive control in Hispanic children in the USA. *International journal of bilingual education and bilingualism*, *21*(2), 197–206.

Tulsky, D. S., Carlozzi, N., Chiaravalloti, N. D., Beaumont, J. L., Kisala, P. A., Mungas, D., & Gershon, R. (2014). NIH Toolbox Cognition Battery (NIHTB-CB): List sorting test to measure working memory. *Journal of the International Neuropsychological Society*, *20*(06), 599-610.

Uccelli, P., & Páez, M. M. (2007). Narrative and vocabulary development of bilingual children from kindergarten to first grade: Developmental changes and associations among English and Spanish skills. *Language, Speech, and Hearing Services in Schools*, 38(3), 225-236.

Valente, J. (2019). A Deaf Lens: Adapting video-cued multivocal ethnography for the “Kindergartens for the Deaf in Three Countries” project. *Anthropology and Education Quarterly, 50(3),* 340-347.

Van Assche, E., Duyck, W., & Hartsuiker, R. (2016). In: R.R. Heredia et al. (eds.), *Methods in Bilingual Reading Comprehension Research*, The Bilingual Mind and Brain Book Series 1. Springer Science + Business Media: New York van Hoesel, R., Ramsden, R., and O'Driscoll, M. (2002). 'Sound-direction identification, interaural time delay discrimination and speech intelligibility advantages in noise for a bilateral cochlear implant user. Ear and Hearing. 23(2), 137-149.

Van Heuven, W., Dijkstra, T., & Grainger, J. (1998). Orthographic neighborhood effects in bilingual word recognition. *Journal of Memory and Language. 39*, 458-483.

Van Rooij, J. C. G. M., & Plomp, R. (1990). Auditive and cognitive factors in speech perception by elderly listeners. II: Multivariate analyses. *The Journal of the Acoustical Society of America*, *88*(6), 2611-2624.

Verhoeven, L. (2007). Early bilingualism, language transfer, and phonological awareness. *Applied Psycholinguistics*, *28*(03), 425-439.

Vitevitch, M. S., Chan, K. Y., & Goldstein, R. (2014). Insights into failed lexical retrieval from network science. *Cognitive Psychology*, *68*, 1–32.

Waked, A., Dougherty, S., & Goupell, M. (2017). Vocoded speech perception with simulated shallow insertion depths in adults and children. *The Journal of the Acoustic Society of America, 141*, EL45.

Wang, Y., Bergeson, T, & Houston, D. (2017). Infant directed speech enhances attention to speech in deaf infants with cochlear implants. *Journal of Speech, Language, and Hearing Research. 60,* 3321-3333.

Waltzman, S. B., Robbins, A. M., Green, J. E., & Cohen, N. L. (2003). Second oral language capabilities in children with cochlear implants. *Otology & Neurotology*, 24(5), 757-763.

Warrier, C. M., Johnson, K. L., Hayes, E. A., Nicol, T., & Kraus, N. (2004). Learning impaired children exhibit timing deficits and training-related improvements in auditory cortical responses to speech in noise. *Experimental Brain Research*, 157(4), 431-441.

Wei, W., Wong, R., Hui, Y., Au, D., & Wong, B. (2000) Chinese tonal language rehabilitation following cochlear implantation in children. *Acta Oto-Laryngologica, 120*(2). 218-212

Weintraub, S., Dikmen, S., Heaton, R., Tulsky, D., Zelazo, P., Bauer, P., Carlozzi, N., Slotkin, J., Blitz, D., Wallner-Allen, K., Fox, N., Beaumont, J., Mungas, D., Nowinski, C., Richler, J., Deocampo, J., Anderson, J., Manly, J., Borosh, B., Havlik, R., Conway, K., Edwards, E., Freund, L., King, J., Moy, C., Witt, E., & Gershon, R. (2013). Cognitive assessment using the NIH toolbox. *Neurology. 11*(sup. 3), S54-S64.

Werker, J., & Byers-Heinlein. (2008). Bilingualism in infancy: First steps in perception and comprehension. *Trends in Cognitive Sciences, 12*(4). 144-151.

Werker, J., & Tees, R. (1984). Cross language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7.* 49-63

Werker, J. F., & Tees, R. C. (2005). Speech perception as a window for understanding plasticity and commitment in language systems of the brain. *Developmental psychobiology*, 46(3), 233-251.

Westerhausan, R., Bless, J., Passow, S., Kompus, K, & Hugdahl, K. (2015, March 30). Cognitive Control of Speech Perception Across the Lifespan: A Large-Scale Cross-Sectional Dichotic Listening Study. *Developmental Psychology*.

Whitmal, N., Poissant, S., Freyman, R., & Helfer, K. S. (2007). Speech intelligibility in cochlear implant simulations: Effects of carrier type, interfering noise, and subject experience. The Journal of the Acoustical Society of America. 122(4). 2376-2388.

Williams, J. (1999). Test review: Peabody Picture Vocabulary Test-Third Edition. *Canadian Journal of School Psychology. 14*(2). 67-73.

Wiseheart, M., Viswanathon, M., & Bialystok, E. (2016). Flexibility in task switching by monolinguals and bilinguals. *Biling (Cog Engl). 19(1)*, 141-146.

Woodward, A., Markman, E., Fitzsimmons, C. (1994). *Developmental Psychology. 30*(4), 553-566.

Wooi Teoh, S., Pisoni, D. B., & Miyamoto, R. T. (2004). Cochlear implantation in adults with prelingual deafness. Part I. Clinical results. *The Laryngoscope*, *114*(9), 1536-1540.

World Health Organization. (2013). Millions of people in the world have hearing loss that can be treated or prevented.

Wurm, L. H., & Samuel, A. G. (1997). Lexical inhibition and attentional allocation during speech perception: Evidence from phoneme monitoring. *Journal of Memory and Language*, *36*(2), 165-187.

Yan, S., & Nicoladis, E. (2009). Finding le mot juste: Differences between bilingual and monolingual children's lexical access in comprehension and production. *Bilingualism: Language and Cognition. 12*(3), 323-335.

Yang, S., Yang, H., & Lust, B. (2011). Early childhood bilingualism leads to advances in executive attention: Dissociating culture and language. *Bilingualism: Language and Cognition*, *14*(03), 412-422.

Yayla, A., Kozikoglu, I., & Celik, S. (2016). A comparative study of language learning strategies used by monolingual and bilingual learners. *European Scientific Journal. 12*(26). 1857-1863.

Yim, D., (2012). Spanish and English language performance in bilingual children with cochlear implants. *Otology & Neurotology. 33(1)*, 20-25.

Zhao, X., Chen, L., & Maes, H. (2016). Training and transfer effects of response inhibition training in children and adults. *The Journal of Analytical Psychology. 21(1)*, e12511.

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