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Word learning processes in children with cochlear implants

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WORD LEARNING PROCESSES IN CHILDREN WITH COCHLEAR IMPLANTS

by

Elizabeth Ann Walker

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Speech and Hearing Science
in the Graduate College of
The University of Iowa

May 2010

Thesis Supervisor: Professor Karla K. McGregor

ABSTRACT

Children with cochlear implants (CIs) typically have smaller lexicons in relation to their same-age hearing peers. There is also evidence that children with CIs show slower rates of vocabulary growth compared to hearing children. To understand why children with CIs have smaller vocabularies, we proposed to investigate their word learning process and determine how it compares to children with normal hearing. The present study explores multiple aspects of word learning – acquisition, extension, and retention – to better inform us about the real-world process of lexical acquisition in children with CIs.

We evaluated 24 children with cochlear implants, 24 children with normal hearing matched by chronological age, and 23 children with normal hearing who were matched by vocabulary size. Participants were trained and tested on a word learning task that incorporated fast mapping, word extension, and word retention over two days. We also administered a battery of tests that include measures of receptive vocabulary and speech perception skills to determine which variables might be significant predictors of fast mapping and word retention.

Children with CIs performed more poorly on word learning measures compared to their age-mates, but similarly to their vocabulary-mates. These findings indicate that children with CIs experience a reduced ability to initially form word-referent pairs, as well as extend and retain these pairs over time, in relation to their same-age hearing peers. Additionally, hearing age-mates and vocabulary-mates showed enhancement in their production of novel words over time, while the CI group maintained performance. Thus, children with CIs may not take the same route in learning new words as typically-developing children. These results could help explain, in part, why this population consistently demonstrates slower rates of vocabulary learning over time. Furthermore, we expected that speech perception and vocabulary size would relate to variations in fast mapping, as well as word retention. Neither of these variables proved to be significant predictors of fast mapping, but they were highly significant for word retention. Based on these findings, we may conclude that the factors that account for acquiring that first link between a word and its referent are not the same as those that are important for storing in a word in long-term memory.

Abstract Approved: ______________________________
Thesis Supervisor

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Title and Department

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Date

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

Elizabeth Ann Walker

has been approved by the Examining Committee
for the thesis requirement for the Doctor of Philosophy
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To Mary Fisher, Freda Collison, and Grace Walker

“Always and never are two words you should always remember never to say.”
Wendell Johnson

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CHAPTER 1

BACKGROUND AND REVIEW OF LITERATURE

Introduction

Children with cochlear implants (CIs) typically have smaller lexicons in relation to their same-age hearing peers. There is also evidence that children with CIs show slower rates of vocabulary growth compared to hearing children (Connor et al., 2000). This vocabulary delay occurs even in children who receive their CIs at young ages and are successful in terms of their auditory capacity and speech perception skills (Hayes, Geers, Treiman, & Moog, 2009). Unfortunately, these delays in vocabulary have a cascading effect on overall language achievement as well as reading and academic outcomes. To understand why children with CIs have smaller vocabularies, we need to study their word learning process and determine how it compares to children with normal hearing. By only documenting that these children exhibit deficient lexicons, and not exploring the path that children with hearing loss take to learn words, we limit our ability to treat these deficits. The present dissertation explores multiple aspects of the word learning process – acquisition, extension, and retention – to better inform us about the real-world process of lexical acquisition in both typical and atypical populations.

A secondary goal of this dissertation relates to the large variation in outcomes for children with CIs (Carney & Moeller, 1998). Given this variability, it is critical to identify which children will succeed and which will struggle following the CI surgery and initial stimulation, specifically with regards to learning words. We can make assumptions regarding the variables that may account for variation in word learning ability, based on past findings with children who are hard of hearing, but children with CIs possess unique characteristics that limit generalizations from other populations. Therefore, we will examine variables such as vocabulary size, speech perception ability, and age at implantation, to determine which factors contribute to the variance in word acquisition and retention.

A tertiary goal is to investigate one strategy for facilitating word learning in children with CIs. Caregivers and clinicians often use gesture cues to highlight novel words for infants and preschoolers with hearing loss (Farran, Lederberg, & Jackson, 2009; Lederberg & Spencer, 2009). It is not clear if certain gestures such as touching or manipulating an object provide more scaffolding for word learning (specifically the learning of object names) than non-contact gestures such as pointing or looking at an object. On the other hand, typically-developing children demonstrate a hierarchy or saliency for different gesture cues in relation to word learning (Booth et al., 2008). This hierarchy is mediated in part by vocabulary size, in that children with smaller vocabularies need more salient gesture cues to support word learning than do their age-mates with larger vocabularies (Booth, McGregor, & Rohfling, 2005). Therefore, our objective is to determine whether children with CIs use their communication partner's gesture cues for word learning in a manner that is similar to their same-age peers with normal hearing, or alternatively, whether they demonstrate patterns of gesture cue usage that are more consistent with their reduced vocabulary size.

Theories of Word Learning

Not surprisingly, there are numerous theories to explain the process of lexical development in young children with normal hearing. Each perspective differs in the degree of importance attributed to factors internal to the child and factors related to the environment. For our purposes, we will describe three models: associationist theories (Landau, Smith, & Jones, 1992; Samuelson & Smith, 2005), social-pragmatic theories (Bloom, Margulis, Tinker, & Fujita, 1996; Tomasello et al., 2005), and a hybrid theory referred to as the Emergentist Coalition Model (ECM) (Golinkoff & Hirsh-Pasek, 2006; Golinkoff et al., 2000; Hollich et al., 2000).

Associationist Theories

Proponents of associationist theories focus on domain-general attention and memory processes in young children and dispute the idea that children possess innate constraints for determining word-referent mappings (Houston-Price, Plunkett, & Duffy, 2006; Landau et al., 1992; Samuelson & Smith, 2000, 2005). The role of social cues and the environment in scaffolding lexical acquisition is limited. Instead, children use simple associative mechanisms for learning words. These mechanisms take the form of biases in word learning, particularly as children are acquiring object labels. These biases develop over time through trial and error, as children learn to recognize that certain linguistic cues co-occur with perceptual properties of objects. Once they form these associations, presentation of the linguistic cues draw attention to the perceptual properties of a given object (Golinkoff et al., 2000).

Associationist theories have often been used to frame investigations of extension of novel-word objects pairings to other exemplars. The shape features of objects is perhaps one of the most frequently studied extensions. Children reliably generalize novel names to objects that have the same shape (Landau, Smith, & Jones, 1988). Moreover, the substance of an object influences how children extend unnamed, but not named objects (Samuelson and Smith, 2000). Samuelson and Smith (2000) presented 3-year-olds with rigid (e.g., wood) and nonrigid (e.g., clay) objects and reported that children grouped unnamed novel objects based on their shape if they were rigid and their material if they were nonrigid. In a second experiment children saw the same set of stimuli, but the novel objects were paired with novel labels. Children relied on shape cues for both rigid and nonrigid objects, suggesting that the act of naming an object draws attention to shape regardless of the object's substance.

One question that arises is the source of the shape bias: is it an innate ability that children are born with, or an association that develops through the observation of statistical regularities between nouns and objects? Parental checklists on the first words of their children offers insight into this question (Samuelson & Smith, 1999). The first 312 nouns in the children's lexicons consisted primarily of count nouns (nouns like "ball" that can take a plural form and are preceded by indefinite or definite articles), rather than proper nouns like "Kathy" or mass nouns like "water". A group of adults then determined if the count nouns could be categorized in terms of their shape, color, size, or material. Count nouns were highly correlated with shape-based properties. These findings suggest that the statistical regularities between the syntactical cues and perceptual properties of words in early vocabularies may help to build a bias towards shape. This bias then becomes apparent in word learning studies with 2- and 3-year-olds, in which children consistently generalize names of objects based on their shape.

Associationist theories are closely linked to connectionism, in which knowledge is described as a series of interconnected nodes in the brain (Thelen & Bates, 2003). Learning takes place when these connections are repeatedly activated together (hence, the oft-repeated phrase "neurons that fire together, wire together"). Connectionist computer simulations have been utilized as support for associationist theories. For example, Samuelson (2002) used a simulation to demonstrate how statistical regularities in early vocabularies lead to the formation of the shape bias.

Social-Pragmatics Theories

The social-pragmatics theory of word learning constitutes a different view of the underlying mechanisms for acquiring a lexicon, focusing on the social nature of communication and language. The work of Jerome Bruner forms the foundation of social-pragmatics theories (Carpenter, Nagell, & Tomasello, 1998). Bruner's theoretical approach emerged in response to the strong nativist views of Chomsky and other linguists, in which it was assumed that children possess adult-like linguistic skills from birth. Bruner argued that children do not have sophisticated language capacities at early ages. Instead, they learn words by interacting in a shared referential framework with their communication partners. The significance of words are redundant with the social environment in which infants participate, making word learning less of an induction problem than others might propose. These social interactions and routines are presented in a playful and engaging context; as a result, infants are motivated to learn words in order to communicate with their partners.

Proponents of social-pragmatic views focus on when children start to attend to social cues in their environment, namely point following and eye gaze. Both cues are utilized for word learning in typically-developing children by 12 to 15 months (Carpenter et al., 1998). These three developmental milestones – pointing, eye gaze and word learning – are intercorrelated (Golinkoff et al., 2000). Word learning is dependent upon the ability to engage in joint attention; therefore, it is observed in infants around the same time as the joint attention behaviors of pointing and eye gaze.

Hybrid Theories: The Emergentist Coalition Model

The two theories discussed above posit different origins of the word learning process in young children. In a recent hybrid theory, the emergentist coalition model (ECM; Hollich et al., 2000), these origins are viewed as complementary rather than mutually exclusive. The ECM proposes that the processes underlying lexical acquisition change with development, as infants use different strategies over time. More specifically, infants start off relying primarily on associationist mechanisms to pair words with their referents (Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006). Perceptual salience has a major influence on early word learning, as infants around 10 to 12 months of age will effectively ignore social cues from their communication partners in the presence of highly perceptually salient stimuli (e.g., a brightly colored toy). At around 12 months of age, infants begin to attend to social cues in the environment, such as pointing or eye gaze, although they may not utilize these cues for word learning. When children are 18 to 24 months, there is a shift in the relative importance of perceptual and social cues.

They will depend on social cues to determine word-object mappings and ignore the perceptual salience of objects (Golinkoff & Hirsh-Pasek, 2006). Word learning is therefore thought to be an emergent product of several factors, including social influences and general perceptual-attentional mechanisms (Hollich et al., 2000).

Each of these theoretical perspectives takes a different approach in explaining the underlying mechanisms that are necessary for learning words. The associationist model posits that language is a learning problem and focuses on how domain-general attention and memory processes help children learn. The social-pragmatics theory emphasizes the social environment as a scaffold to word learning. The ECM attempts to merge aspects of both perspectives into one cohesive theory. Our current objective is not to test the validity of these divergent word learning models. Taking a lead from the structure of the ECM, we intend to incorporate elements of both associationism and social-pragmatics theories into the framework of our study. This allows us to develop a word learning paradigm that builds upon robust empirical findings from each perspective into one task.

Word Learning Processes in Typically-Developing Children

During the first year of life, vocabulary acquisition is initially slow, particularly in terms of productive vocabulary (Hoff, 2001). Children will typically add 8 to 11 words to their vocabularies each month after they begin producing first words (Benedict, 1979). The rate of vocabulary acquisition increases once children average around 50 to 150 words in their expressive lexicons (Bates et al., 1994). Carey estimated that by 18 months of age, children will learn around 9 new words per day, or about one per waking hour (Carey, 1978), but Reznick and Goldfield (1992) offered the more conservative estimate of 22 to 37 words per month. By 30 months, the median lexicon in typically-developing children contains 573 words. At the same time, there is considerable variability in the size of individual children’s lexicons, with the 10th and 90th percentiles falling at 348 words and 658 words for girls and 251 words and 647 words for boys (Fenson et al., 1994).

Once children have acquired around 50 words in their expressive vocabulary, they become rapid word learners, capable of acquiring words even after minimal exposure to the word and its referent (Lederberg, 2003). The ability to map a word to its referent after only a few exposures has been termed fast mapping (Carey, 1978). Fast mapping can be thought of as the first stage in learning a word. It involves the early connections between words and referents in memory and is characterized by limited semantic knowledge (McGregor, Friedman, Reilly, & Newman, 2002). Fast mapping occurs when a child uses linguistic and non-linguistic information in the environment to pair a novel label with its referent (Heibeck & Markman, 1987).

Typically-developing children clearly demonstrate that they are capable of fast mapping at an early age (Dollaghan, 1985; 1987; Mervis & Bertrand, 1994). In the original paradigm (Carey, 1978), an experimenter showed 3- and 4-year-olds an identically-shaped blue tray and a green tray and an identically-shaped red cup and green cup. The experimenter instructed the child to “bring me the chromium tray, not the blue one, the chromium one” and “bring me the chromium cup, not the red one, the chromium one.” Children consistently selected the green tray and cup, without knowing the meaning of “chromium.” Heibeck and Markman (1987) extended these findings by including 2-year-olds in their sample and introducing shape and texture terms in addition to color terms. Furthermore, children as young as 13 to 15 months of age display fast mapping when the set size is reduced or the number of exposures is increased (Woodward, Markman, & Fitzsimmons, 1994).

In Carey’s (1978) original inception, fast mapping was considered only the first phase in lexical acquisition. The second phase was referred to as slow mapping or word retention. It has received far less attention, perhaps because fast mapping is often equated with word learning (Horst & Samuelson, 2008) or perhaps because it is easier to study. This tendency to focus on fast mapping and not the retention phase has possibly led to an overestimation of toddlers' word learning abilities. Recently, Horst and Samuelson found that young children have far more difficulty with the slow mapping phase of word learning, specifically with the retention and extension processes, than with the fast mapping process. They conducted four experiments with 2-year-olds, in which the children were first presented with a fast mapping paradigm, followed by a 5-minute delay and then presentation of a retention/extension paradigm. In all four experiments, participants had no difficulty formulating word-object pairings in the fast mapping paradigm. On the other hand, they could not retain or extend novel names at above chance levels unless the novel objects were manipulated and ostensively named by the experimenter prior to the retention test. Based on these results, Horst and Samuelson concluded that fast mapping should not be conflated with word learning in young children.

Horst and Samuelson's work highlights the importance of memory load and perceptual salience in retaining a word-referent link over time. There is additional evidence that word retention is heavily influenced by memory, specifically memory consolidation. Consolidation is the process in the brain by which a memory (in this case, the formulation of a word-referent pair) strengthens over time, without additional experience with that memory. In particular, learning is enhanced over time through sleep-dependent processes. Word-learning consolidation has been documented in adult learners (Dumay & Gaskell, 2007) and in child learners (McGregor, Rohlfing, Bean and Marschner, 2009). In the latter study, 40 two-year-olds received training for the spatial term "under." Some of the children received additional scaffolding in the form of a gesture cue during training. Other children viewed a still photograph demonstrating "under" and the remaining children received no additional support in learning "under," aside from verbal training. Children who received the gestural support performed better on untrained examples of "under" than the other two groups, but only after a delay of two to three days (not immediately after training). McGregor and colleagues interpreted these findings as an example of the gesture-enhanced memory consolidating over time.

A third process of word learning is word extension, or the process of generalizing a target object to other exemplars of that object. The ability to extend words is an important step in language learning because it allows us to form category boundaries for different properties and objects in the environment. By approximately 12 months of age, children have a basic understanding that words can refer to categories rather than just the original object and can extend to multiple exemplars based on that understanding (Hirsh-Pasek, Golinkoff, and Hollich, 1999). Two-year-olds will extend novel names to novel objects that differ from the original exemplar in size or color (Behrend, Scofield, and Kleinknecht; 2001).

Word Learning Processes in Children who are Deaf or Hard of Hearing

It has been suggested that the word learning process described above differs in children with hearing loss (Jerger et al., 2006), but there is little research to support this hypothesis. Most studies on children with hearing loss have documented delays in receptive and expressive vocabulary (Mayne, Yoshinaga-Itano, & Sedey, 1998; Mayne, Yoshinaga-Itano, Sedey, & Carey, 1998), and have not examined the actual process of word learning in this population. This is a critical point because merely documenting delays does not get at the underlying reasons for how and why these children are falling behind; it only shows that they are behind. For those few studies that have looked at the word learning process in children with hearing loss, the focus has been on the fast mapping stage, to the exclusion of word retention and word extension (Gilbertson & Kamhi, 1995: Pittman, Lewis, Hoover, & Stelmachowicz, 2005; Stelmachowicz, Pittman, Hoover, & Lewis, 2004). As previously mentioned, however, fast mapping does not equal word learning (Horst & Samuelson, 2008). The underlying assumption of studies that only look at this single phase is that if children with hearing loss perform more poorly than their peers on the fast mapping task, they will also perform more poorly on word retention and extension. If this indeed the case, then we need to document it and provide additional support for these other two aspects of word learning. If it is shown to be not the case, then perhaps we can capitalize on relative strengths in therapy and at home.

The first study to examine fast mapping in children who were hard of hearing involved a group of children with mild-to-moderate hearing loss (Gilbertson & Kamhi, 1995). Half of the children with hearing loss performed equivalently to a group of normal-hearing children matched by receptive vocabulary size. The other half of the children showed significant impairments in their fast mapping abilities. Language level, but not degree of hearing loss, mediated differences between the two groups. In particular, receptive vocabulary skills accounted for approximately 53% of the variance on the fast mapping task. The exclusion of children with more severe degrees of hearing loss limited the findings of the study, however.

Another study looked at fast mapping in 11 children with mild-to-moderate hearing loss and 20 children with normal hearing (Stelmachowicz et al., 2004). Both groups included children 6 to 9 years of age. The investigators manipulated several variables, including lexical form (noun versus verb), stimulus level (50 dB SPL versus 60 dB SPL), and number of repetitions (4 versus 6). They also evaluated the effects of chronological age, speech perception skills, vocabulary size, and audibility of speech on fast mapping ability. Participants viewed a brief animated video in which 8 novel words were embedded in a story context. Following two presentations of the video, the participants identified novel words. Experimenters used a four-alternative forced-choice task to evaluate fast mapping. As a group, the children with normal hearing outperformed the children with hearing loss (60% correct and 41% correct, respectively). They also found that vocabulary size, stimulus level, and number of repetitions significantly influenced performance. Unfortunately, it is difficult to make any definitive conclusions from the study because statistical power was low due to a small sample size.

In a follow-up study, Pittman et al. (2005) included a larger sample size and wider age range (5 to 14 years). Sixty normal-hearing children and 37 children with moderate hearing loss participated. They used the same fast mapping task as in Stelmachowicz et al. (2004), although stimulus level and number of repetitions remained constant. Pittman et al. were specifically interested in looking at the influence of vocabulary size and chronological age on fast mapping. Results replicated the findings from Stelmachowicz et al., in that children with normal hearing consistently outperformed children with hearing loss. In addition, vocabulary size was related to performance because children with lower receptive vocabulary sizes identified fewer novel words than children with larger vocabularies.

Investigators have also examined word learning skills in children with moderate-to-profound hearing loss (Lederberg, Prezbindowski, and Spencer, 2000). Participants used simultaneous communication in their preschools, which was defined as American Sign Language (ASL) signs in English word order, produced in combination with spoken English. The stimuli consisted of novel words and signs paired with novel objects. Both sets of stimuli followed the phonological rules of spoken English and ASL, respectively. Novel words and signs were presented simultaneously to the participants. The experimenters used two different tasks. In the first task, children had to infer that a novel word refers to a novel item through inductive reasoning (termed “novel mapping”). In the second task, the children learned words when the label for the referent was explicitly named during stimulus presentation (termed “rapid word learning”). This task was presumed to be easier than the novel mapping task because the children did not have to make inferences. Results supported this hypothesis, in that more of the children succeeded on the rapid word learning task than the novel mapping task. Consistent with the results of Gilbertson and Kamhi (1995), Pittman et al. (2005), and Stelmachowicz et al. (2004), vocabulary size mediated performance. The children who succeeded on both word learning tasks had significantly larger vocabularies than the children who succeed on the rapid word learning task only.

To summarize, children who are deaf or hard of hearing display deficits in fast mapping relative to their same-age peers with normal hearing. Vocabulary size is a strong mediator in their fast mapping performance. In addition, the primary focus in the above studies was on fast mapping. Another phase of word learning – word retention – was not addressed. We do not know whether word extension and retention are similarly affected. There is a clear need to understand how children with hearing loss perform on multiple processes of word learning, as all are integral to building a lexicon over time, and as building a lexicon is closely tied to linguistic and academic achievements.

There is an additional limitation in our understanding of children with hearing loss; specifically, most studies have been restricted to children who wear hearing aids. None of the previously discussed studies (Gilbertson & Kamhi, 1995; Lederberg, Prezbindowski, & Spencer, 2000; Pittman, Lewis, Hoover, & Stelmachowicz, 2005; Stelmachowicz, Pittman, Hoover, & Lewis, 2004) included children who use CIs. This is an interesting population to examine in relation to the other experiments, because they share characteristics with children with mild-moderate hearing loss and children with severe-profound hearing loss. Children with CIs typically present with auditory thresholds similar to children in the mild-to-moderate range, but may demonstrate language skills closer to that of children with more moderate-to-severe hearing losses (Blamey et al., 2001).

Cochlear Implants

A CI is a device that is designed to improve the auditory capacity of individuals with severe-to-profound sensorineural hearing loss. It consists of an electrode array that is surgically inserted into the cochlea. Acoustic signals are picked up by an external microphone and transformed into electrical signals, which are then sent to the electrode array. The array stimulates the neural fibers in the cochlea, in effect replacing damaged hair cells on the basilar membrane. Most individuals with CIs have some awareness of sound and usually demonstrate audiometric thresholds in the mild hearing loss range (20 to 40 dB HL).

Researchers first began investigating the viability of electrical stimulation of the cochlea in the 1950s (Niparko, 2000). Since then, technology has rapidly progressed to the point at which CIs are now considered a standard treatment option for people with severe to profound hearing loss. As a result, the criteria for CI candidacy have evolved over the years. It was initially designated only for adults with profound bilateral hearing loss. Candidacy was then expanded to include children. For adults, the current criteria require candidates to have a severe-to-profound bilateral sensorineural hearing loss. They must receive little to no benefit from hearing aids and score 50% or less on a sentence recognition test in the ear that is to be implanted. For children ages 2 to 17 years, the criteria are similar, but with the additional requirement that they must demonstrate a lack of progress in the development of auditory skills. The criteria for children between the ages of 12 to 24 months are more conservative. Children in this age range must have a profound hearing loss and their families must be motivated to participate in the aural habilitation process following implantation. However, physicians can perform the surgery at younger ages when it is deemed necessary (usually in cases of cochlear ossification following meningitis).

In the past two decades, the benefits of CIs have been well established (Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth, 1997; Waltzman et al., 1997). Much of the early research on CIs in children focused on speech perception (Boothroyd & Eran, 1994; Carney et al., 1993; Ching et al., 2005; Dawson et al., 1992; Dettman et al., 2004; Dorman, Loizou, Kemp, & Kirk, 2000; Dowell et al., 2002; Gantz et al., 2000; Geers & Brenner, 1994; Houston, Pisoni, Kirk, Ying, & Miyamoto, 2003; Kirk, Hay-McCutcheon, Sehgal, & Miyamoto, 2000). This empirical focus is logical because the CI device was developed to improve speech perception (Chute & Nevins, 2006). The most consistent finding has been the enormous variability in speech perception scores across children (Miyamoto et al., 1994; O'Donoghue, Nikolopoulos, Archbold, & Tait, 1998). For example, in a group of 77 children with CIs, auditory-only speech perception scores ranged from 0 to 85% on a monosyllabic word list and 0 to 100% on a sentence test (Blamey et al., 2001). Another group of 181 children ranging in age from 8 to 9 years, with 4 to 6 years of CI experience, achieved scores between 0 and 92% on a closed-set word recognition measure and 0 to 76% on a closed-set sentence recognition measure (Geers, Brenner, and Davidson, 2003). Furthermore, they achieved scores between 0 and 100% on open-set word and sentence recognition tests.

Early studies were aimed at determining which variables predict speech perception abilities. More recently, speech perception itself has been tested as a predictor variable. Speech perception ability is a significant predictor of grammatical morphology use (Spencer, Tye-Murray, and Tomblin, 1998), as well as reading ability (Spencer & Oleson, 2008) in school-age children with CIs. To date, no studies have considered speech perception as a predictor of word learning ability in children with CIs. The only study to investigate the relationship between speech perception ability and word learning performance in children who are hard of hearing indicated no relationship between the two (Stelmachowicz et al., 2003), but this study was limited by a small sample size (n = 11). Therefore, one important goal is to determine if variations in speech perception account for differences in word learning for children with CIs. If some children with CIs do more poorly on a word learning task than others, the reason may be as simple as variations in their ability to perceive speech.

In conjunction with the plethora of research on speech perception, there has been increased interest in investigating language (Geers, Nicholas, & Sedey, 2003; Miyamoto, Houston, Kirk, Perdew, & Svirsky, 2003; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999), speech production (Blamey et al., 2001; Ertmer & Mellon, 2001), and literacy (Connor & Zwolan, 2004; Spencer, Barker, & Tomblin, 2003) in children with CIs, particularly those children who are deaf from birth. The impetus for research in speech and language outcomes is due to the success of the device in transmitting a viable auditory signal, which infants with prelingual deafness can then utilize to develop spoken language skills.

Pisoni (2000) observed that most investigators studying the effects of CI technology on speech perception and language abilities use a clinical assessment approach to predict outcomes. As a result, research protocols concentrate primarily on performance on standardized test measures, to the exclusion of psychological processing variables such as learning, attention, and memory or components of social interaction, such as joint attention and caregiver scaffolding. This assessment approach makes sense in that many people involved in CI research are clinicians interested in understanding the clinical applications of CIs. From a developmental standpoint, however, it limits us from looking at the broader picture of how the CI influences underlying cognitive and linguistic mechanisms in young children.

The use of a clinical assessment approach has also influenced our views on lexical development in children with CIs. There are many studies documenting receptive and expressive vocabulary skills in this population, but nearly all of them discuss performance on parent report or standardized language measures. For example, Dawson et al. (1995) looked at the rate of vocabulary acquisition at pre- and post-implant intervals, using the Peabody Picture Vocabulary Test, and found that growth rates were steeper at post-implant intervals then pre-implant intervals. Also, children implanted at younger ages show steeper vocabulary growth rates than children implanted at older ages (Hayes, Geers, Treiman, & Moog, 2009). These findings are integral to our knowledge base because they justify the use of CIs with young children. On the other hand, relying entirely on standardized assessment tools in research does not allow us to understand the process of word learning in these children. If we can learn more about why these children are delayed relative to their peers, instead of just acknowledging that they are, perhaps we can develop more effective, evidence-based practice for facilitating vocabulary growth over time.

Thus far, there are three published studies that experimentally test word learning in children with CIs. Tomblin, Barker, and Hubbs (2007) replicated the experimental design used in Gilbertson and Kamhi (1995). Fourteen children with CIs and 14 children with normal hearing participated. All participants were between the ages of 2 and 5. The children were trained and tested on three novel word-object combinations via five different tasks related to fast mapping. In the first task, the children were exposed to the novel label and object. The experimenter displayed three objects, two of which were familiar and one of which was novel. The experimenter also displayed three hiding locations (e.g., an upside-down bowl, a paper, an upside-down box). The child was instructed to hide one of the familiar objects in one location, and then the second familiar object in another location. At this point, only the novel object was visible to the child. The experimenter then instructed the child to hide the novel object by saying "Hide the koob under the box." The experimenter only used the novel word once; if the child required further instructions gestures and tactile cues were provided. Following the exposure task, a comprehension task was administered. The experimenter displayed the three original objects, along with two new novel objects. The child attempted to identify the previously named novel object (e.g., the koob), along with the two familiar objects. The third task involved production of the novel name. The experimenter held up the named novel object and the two familiar objects and asked the child to label them. If the child was unable to produce a recognizable label for the novel word, they performed a recognition task. The experimenter provided the child with three labels: the correct label, a phonetically similar foil, and a phonetically dissimilar foil. In the fifth and final task, the experimenter asked the child to identify the original hiding location of the novel object. The goal of this measure was to assess the child’s nonverbal knowledge of the entire task.

For data analysis purposes, each child received a “fast-mapping” score, which was a composite score for correct performance on the comprehension, production, and recognition measures. Using this composite score, children with normal hearing performed significantly better than children with CIs. Chronological age was significantly correlated with fast mapping performance in the CI and NH groups. After they controlled for chronological age in the fast mapping scores in the CI group, the investigators found a significant negative correlation between age at implantation and fast mapping; that is, children who had received their CIs at younger ages had higher fast mapping composite scores than those who received CIs at older ages.

Houston et al. (2005) examined both fast mapping and word retention in 2- to 5-year-olds with CIs, compared to an age-matched group of normal-hearing children. An experimenter presented a series of word-object pairs to participants. The referent objects were 16 Beanie Baby animals. The experimenter labeled the stuffed animals with real words according to salient perceptual attributes (e.g., a goat named “Horns”). No novel labels were used to name the objects. The younger group of participants (2- to 3-year-olds) was trained on 8 animals, while the older group (4- to 5-year-olds) was trained on 16 animals. After training on the name-object pairings, the children were tested for comprehension and production (immediate condition). Following a two-hour delay, the children were retested on their ability to identify and produce labels (delay condition). While the children participated in the experiment, the primary caregiver filled out a questionnaire regarding their child’s prior knowledge and familiarity with the target names.

Children in the normal-hearing group performed significantly better than the children with CIs, regardless of task (comprehension and production) or testing interval. Prior familiarity with the target words was a confound in the CI group. Children with CIs performed better on comprehension and production tasks when they were presented with known words. This trend was not seen in the normal-hearing group due to their familiarity with all of the words. Data were re-analyzed using only known words for children in the CI group, but the normal-hearing children still consistently outperformed the children with CIs. In contrast to the significant main effect for group, there was no significant effect for testing interval. Average performance on the delayed task did not differ compared to the immediate task for the CI or NH group. Correlational analyses with demographic factors in the CI group (age at implantation, chronological age, and length of CI use) indicated a significant negative relationship between age at implantation and fast mapping comprehension performance (immediate test interval), but no other correlations achieved significance. Houston et al. suggested that the reason the children with CIs had more difficulty forming word-object pairings was because of atypical memory skills, specifically phonological working memory, although phonological processing was not assessed in the experiment. They proposed that using novel words might provide more insight into this issue. They also posited that differences in language level might account for some of the differences between groups. Language skills were not assessed, but it is likely children with CIs had delayed language compared to their age-matched controls. The authors proposed including a language-matched normal-hearing control group in the future, to more clearly delineate the effects of chronological age and language ability. Additionally, the investigators did not collect data on speech perception in the CI users. Given what we know about the wide variability in speech perception abilities in children with CIs, it is possible that this variable could also account for a significant proportion of the variance in word learning. In the current study, we will include a vocabulary-matched control group and we will measure speech perception abilities as well.

One puzzling result of the study was the similar performance on fast mapping and word retention probes. There is evidence to suggest that children with CIs have a more limited phonological working memory capacity than their same-age peers with normal hearing (Burkholder & Pisoni, 2003; Cleary, Pisoni, & Geers, 2001; Pisoni & Cleary, 2003). As a result, it might be expected that performance would decrease after a delay, particularly in the CI group. The use of familiar objects and words could explain this null result. It is plausible that the stimulus materials and labels did not create enough of a working memory load to affect performance over time. In the current study, we use novel objects and novel labels to increase the memory load of the task and circumvent the confound of word familiarity in Houston et al.

In addition, the design in the Houston et al. study (2005) did not permit examination of the effects of memory consolidation on word learning. Perhaps if the children had been exposed to a *longer* delay between the immediate post-test and the delayed post-test, they would have shown improvement in their word learning performance. The two-hour delay may not have allowed for sufficient memory consolidation in both the CI group and the normal-hearing group, as this appears to be dependent upon an intervening period of sleep (Dumay & Gaskell, 2007; McGregor, Rohlfing, Bean and Marschner, 2009). Therefore, we will investigate word retention when there is at least a 24-hour delay between training, immediate post-test, and delayed post-test. Given our current lack of knowledge about word retention in this population, it is not at all clear if children with CIs would display consolidation effects in word learning, as typically-developing children and adults have done, or if they would show no effect in the long delay in initial learning and testing. It is even possible that they would show a decline in performance following a delay of one or more days between training and testing.

In the third study on word learning in children with CIs, 15 school-age Swedish children participated in a fast mapping and word retention task (Willstedt-Svensson et al., 2004). They ranged in age from 5 years, 4 months to 11 years, 5 months. The authors explored the influence of time factors (chronological age, length of device use, and age at implantation) and working memory on novel word learning. The novel word learning paradigm was identical to the task used in Tomblin, Barker, and Hubbs (2007), with the exception that they also included a word retention measure, which was administered 30 minutes after training. The investigators measured fast mapping and word retention based on a three-point scale. Children received three points if they could accurately name the word-referent pair, two points if they could produce a label that was close to the target label (only one or two phonemes altered), and one point if they could recognize the target label from a set of three verbal alternatives. They assessed novel word comprehension, but did not report on the results in the data analysis. Working memory was measured through a non-word repetition task, with the non-words being constructed according to Swedish phonotactic rules. In the non-word repetition task, the percentage correct for consonants and vowels were scored separately.

The authors reported that CI participants performed better on the fast mapping task (45.8% correct) than on the word retention task (28% correct), but they did not perform t-tests to determine if this difference was significant. In the simple correlations, there was a positive correlation between age at implantation and fast mapping/word retention. This would indicate that children who had received their implants at older ages did better on the word learning measures, although the authors inexplicably do not address this counter-intuitive finding. Length of device use and chronological age were not significantly correlated. Phonological working memory, as measured by the non-word repetition task (consonants correct), correlated with performance on the word retention task. The vowel-correct score on the non-word repetition task was significantly correlated with both the fast mapping and word retention tasks. When the variables were entered into a stepwise multiple regression analysis, age at implantation no longer contributed any predictive power to the analysis. Only the vowel-correct score on the non-word repetition task contributed a significant proportion to the variance, and that was only for the word retention score. None of the variables contributed a significant proportion to the variance in the fast mapping score.

Willstedt-Svensson et al. (2004) stated that phonological working memory is predictive of novel word learning in children with CIs, a finding that is consistent with SLI literature (Gathercole & Baddeley, 1990; 1993). The report also raises additional questions, however. None of the variables accounted for a significant proportion of the variance in the fast mapping measure when the data were analyzed in a multiple regression analysis. It is important to determine what variables are predictive of fast mapping because we can then identify what influences success and failure in this phase of word learning. Willstedt-Svensson and colleagues did not assess the relationship between receptive vocabulary size and word learning, so it is not clear if this factor may have played a role in fast mapping or word retention. Vocabulary size accounts for a significant proportion of the variance in word learning for children who are hard of hearing (Pittman et al., 2005); therefore, it may be an accurate predictor of word learning performance in children with CIs. Additionally, speech perception measures were not assessed; therefore, we cannot be certain if performance did not vary as a result of differences in that factor.

As in Houston et al. (2005), this study examined word retention, but only with a brief delay between immediate post-test and delayed post-test (30 minutes). Such a short delay would not allow for examination of possible memory consolidation. Consolidation results in enhanced memory for newly learned words in children with normal language (McGregor et al., 2009). Short delays in word retention are only an intermediary step in the word learning process (Horst & Samuelson, 2008); therefore, it is critical to look beyond this to more long-term measures. Only in this manner can we verify the similarities and differences in lexical development between children with CIs and children with normal hearing.

Finally, Willstedt-Svensson et al. did not include a word extension task in their paradigm. In fact, there is no research comparing word extensions in children with CIs and normal-hearing peers. Young children with normal hearing reliably extend novel labels to unfamiliar objects based on their shape (Samuelson, 2002; Smith et al., 2002). Therefore, in this dissertation we will systematically evaluate the ability of children with CIs to extend novel labels to additional exemplars of the same shape.

Facilitating Lexical Acquisition: The Role of Gesture Cues in Word Learning

As described in social-pragmatics models of word learning, young children learn words during moments of communication with another person (Carpenter, Nagell, & Tomasello, 1998). They come to make use of their communication partner when inferring new word referents. One fairly reliable cue provided by the partner is gesture. Presumably, children with hearing loss can make good use of such cues as they tap their stronger modality, vision in comparison to audition. In fact, it is recommended that caregivers use gesture cues when labeling objects during conversation (Farran, Lederberg, & Jackson, 2009), in order to scaffold word learning. Farran and colleagues reported that mothers of children with hearing loss were more likely to use contact gestures such as pointing to, touching, or manipulating an object when the label was novel rather than familiar. They did not, however, determine whether specific gestures facilitated novel word learning more than others.

Normal-hearing children benefit from the contribution of specific gesture cues to lexical acquisition, such as eye gaze, pointing, touching, and manipulating objects (Booth et al., 2008). Booth and colleagues were interested in whether or not children weight various gesture cues differently in word learning. All gesture cues (eye gaze, pointing, touching, and manipulating) facilitated lexical acquisition. When cues were categorized as contact versus non-contact, however, those cues that involved physical contact (touching and manipulating) were found to be more effective at facilitating word learning than cues that did not (pointing and eye gaze). In addition, pointing also seemed to facilitate word learning better than eye gaze.

One factor that may be mediating individual differences in this hierarchy of gesture cues is vocabulary size. As children expand their vocabulary knowledge, they become more aware of the importance of gesture cues for word learning. Conversely, children who show slow vocabulary growth may be more immature in their understanding of gesture cues. Booth et al. (2005) provide support for these contentions. They hypothesized that the influence of gesture cues on fast mapping and word extension might vary as a function of the participants' vocabulary sizes. Participants include 80 30-month-olds (range 28 to 31 months). Children who scored between the 15th and 50th percentile on the MacArthur-Bates Communicative Development Inventory were considered to be less skilled word learners. Those children with the smaller vocabulary sizes formed more word-referent extensions when novel words were accompanied by contact cues (touching and manipulating) than non-contact cues (pointing and eye gaze). For the children with larger vocabularies (i.e., between the 51st and 99th percentile), there was a strong effect of manual gestures over eye gaze cues. Pointing, touching, and manipulating were equally effective in facilitating mapping and extension for the stronger word learners. The results must be interpreted with caution due to small cell sizes, but it does imply that vocabulary knowledge influences the relative importance of gesture cues in word learning.

The findings raise additional questions; specifically, are children with significant delays in vocabulary acquisition also more reliant on contact gesture cues for word learning? In other words, would a child with a language delay learn more words when they are labeled with a contact gesture cue than a non-contact gesture cue compared to typically-developing, age-matched peers? The children in the Booth et al. study (2005) were divided into two groups based on CDI scores, but all participants were typically developing and did not demonstrate language delays.

Because vocabulary delays among young children with CIs are well documented (Carney & Moeller, 1998), we posit that children with CIs will gain more benefit from contact gesture cues than non-contact gesture cues, as seen in typically-developing children (Booth et al., 2005). Scaffolding from adult communication partners can augment word learning in children. This investigation is a preliminary step in determining which gesture cues may act as a scaffold to word learning in children with CIs.

Summary and Hypotheses

It has been suggested that the word learning process differs in children who are deaf/hard of hearing, compared to normal-hearing children (Jerger et al., 2006). However, this process has not been thoroughly examined in children with CIs, particularly with respect to word retention and word extension. There is evidence that fast mapping is problematic in this population (Tomblin, Barker, & Hubbs, 2007). We do not know if children with CIs will also have difficulty with retention and extension. As these additional aspects give us a more complete picture of the word learning process, it is critical to examine all three components of lexical development.

The present dissertation will examine three aspects of word learning: fast mapping, word retention, and word extension. Related to this objective, our first hypothesis is that vocabulary size mediates the acquisition, extension, and retention of novel words. This hypothesis is based on studies demonstrating that vocabulary size influences word learning in children who are deaf or hard of hearing (Gilbertson & Kamhi, 1995; Pittman et al., 2005; Tomblin, Barker, & Hubbs, 2008), although no one has directly compared children with CIs to their vocabulary-mates on a word-learning measure. In doing so, we can more fully separate the effects of chronological age from language level. Based on this hypothesis, we predict that children with cochlear implants will perform similarly to their vocabulary-matched hearing peers on different processes of spoken novel word learning, including fast mapping, word extension, and word retention, but will demonstrate lower performance than their same-age hearing peers.

It has also been proposed that word retention should be more difficult than fast mapping because it entails more memory demands (Houston et al., 2005; Willstedt-Svensson et al., 2004), but no studies on word retention in children with CIs have had more than a two-hour delay between training and retention testing. Previous studies with typically-developing children and adults that include longer delays, especially those involving sleep (i.e., more than one day) have shown that word retention can improve due to the process of memory consolidation (Dumay & Gaskell, 2007; McGregor, Rohlfing, Bean and Marschner, 2009). Our second hypothesis is that memory for newly learned words can improve due to memory consolidation over time. We predict that hearing children will show an increase in performance following a delay of one to three days. We are unsure whether the children with CIs will show a similar increase, maintain performance, or show a decline, as no previous studies have explored word retention following a period of sleep in children with CIs.

Fast mapping performance is related to vocabulary size and age at implantation, although the direction of this latter relationship is not clear (Houston et al., 2005; Tomblin, Barker, & Hubbs, 2007; Willstedt-Svensson et al., 2004). We do not know about the relationship between speech perception skills and word learning ability in children with CIs, although it has been documented that speech perception varies widely in this population (Miyamoto et al., 1994; O’Donoghue, Nikolopoulos, Archbold, & Tait, 1998). Therefore, our third hypothesis is that novel word learning abilities are multiply determined. We predict that children with CIs who have larger vocabularies, better speech perception skills, and receive their CIs at earlier ages will perform better on both fast mapping and word retention than children with smaller vocabularies, poorer speech perception skills, and older ages at implantation, when the word learning paradigm is presented in a controlled experiment.

With typically-developing children, gesture cues have been examined as a possible scaffold for word learning (Booth et al., 2008). Although a similar recommendation has been made in the aural habilitation literature (Farran, Lederberg, & Jackson, 2009), there is no evidence to support this practice. It is possible that children with hearing loss might be more reliant on contact gesture cues for word learning (i.e., touching an object) in relation to their same-age peers with normal hearing. The rationale behind this hypothesis is that children with CIs need increased gestural support, in the form of contact cues like touching, to map a novel word-referent pair. The need for more gestural support could be due to limited vocabulary skills. Preliminary research suggests an interaction between vocabulary size and the type of gesture cue used to facilitate word learning in normal-hearing children (Booth et al., 2005). Therefore, our fourth hypothesis is that gesture cues scaffold word learning, but the utility of one gesture cue over another varies with vocabulary knowledge. We predict that children with CIs and their vocabulary-mates will be more reliant on a speaker using contact cues (touching and looking at an object while naming it) for learning novel words than non-contact cues (looking at an object while naming it). In other words, children with CIs and their vocabulary-matched hearing peers will perform better at identifying and naming novel objects during fast mapping and word retention that have been labeled with a touch+eye gaze cue than an eye gaze-only cue. Chronological-age matched hearing peers will show no difference in identifying or naming novel objects that are labeled with a touch+eye gaze cue or eye gaze-only cue.

Significance

It is beneficial to augment our knowledge of word learning processes among children with CIs because this information can be incorporated into diagnostic and therapeutic contexts. Based on previous studies, it seems likely that children with CIs will have more difficulty forming initial word-referent maps than their same-age hearing peers. At this point, we do not know how they do in terms of extending novel words to similar exemplars, however. It is possible that they also struggle with this component of word learning, which would have a large impact on further vocabulary growth. It would also indicate additional need for treatment that focuses on generalizing word knowledge, rather than just training on single exemplars. We also know nothing about their ability to retain a newly-learned word after a lengthy delay (e.g., 24 hours or more), although one previous study has shown a decline in performance after a 30-minute delay (Willstedt-Svensson et al., 2005) and another has shown no difference after a two-hour delay (Houston et al., 2005). If children with CIs show a different pattern of memory consolidation and enhancement that what we have seen in children with normal hearing (McGregor et al., 2009) and adults (Dumay & Gaskell, 2007), we may need to concentrate efforts on the retention of newly learned words.

It is also relevant to identify factors that predict successful word learners. If certain variables, such as vocabulary size or speech perception skills, predict word learning success or difficulty, children with CIs who are limited in these abilities can be identified. It may be necessary to provide these children with increased support at home, school, and in therapy, in order to enhance their vocabulary growth. Furthermore, if a relationship between age at implantation and word learning ability can be established, such that children who receive CIs at younger ages do better at a word learning task compared to children receiving CIs at older ages, this provides further support for the argument that earlier implantation leads to more successful outcomes.

Whereas it is important to examine the word learning process in children with CIs, it is also crucial to determine if there are means to facilitate lexical development. Examining the influence of a speaker’s gesture cues on word learning is an initial step in determining which cues may serve as a scaffold for lexical development. It might be useful to determine the relative importance of gestural cues in word learning for children with hearing loss because vocabulary acquisition is often delayed in this population. If it is established that children with CIs need increased gestural support to form word-referent pairs, as has been recommended (Farran, Lederberg, & Jackson, 2009), the use of gestures can be integrated into therapy sessions and into natural language-learning contexts. Efforts to increase vocabulary can be supplemented by the use of contact cues. Over time, therapists can decrease the amount of contact cues needed to facilitate lexical acquisition.

CHAPTER 2

METHODS

Participants

Cochlear Implant Users

Twenty-five children with CIs (15 males, 9 females) participated. We excluded one children from data analysis due to clinically low performance (standard score = 50) on the nonverbal cognitive measure, the matrices subtest of the *Kaufman Brief Intelligence Test-2* (KBIT-2; Kaufman & Kaufman, 2004). Out of the 24 remaining children, 20 children completed testing for both visits. Four children completed testing for only the first visit, due to illness or scheduling conflicts. All participants had a prelingual onset of deafness (prior to 12 months of age), bilateral severe-to-profound sensorineural hearing loss and no diagnosed cognitive or learning disabilities.

All participants received a CI prior to 36 months of age, and had a minimum of 12 months of experience with their CI. The average age at initial stimulation was 1.68 months (*SD* = 0.50) and the average length of CI use was 3.16 years (*SD* = 1.07). Thirteen participants had sequential bilateral CIs, 9 had one CI only, and 3 utilized one CI and a hearing aid on the unimplanted ear. Participants used spoken English as their primary language, although some were also exposed to a second language.

We recruited participants from private deaf oral education schools in the Midwest. Testing took place at the children's schools, with the exception of one child who participated at a hospital following CI programming. Prior to participation in the study, teachers or audiologists checked the devices of the children to ensure that they were working correctly. All children were between the ages of 3 years, 6 months and 6 years, 9 months at their time of participation (mean age = 4.86 years, *SD* = 1.04 years). Table 1 displays demographic information for the CI group, including age at implantation, length of device use, and device type.

Participants CI 008 through CI 025 attended Child's Voice School in Chicago, IL. Participants CI 026 through CI 030 attended St. Joseph Institute for the Deaf in Chesterfield, MO. Participants CI 031 through CI 033 attended St. Joseph Institute for the Deaf in Indianapolis, IN. CI 034 attended a regular-education classroom in the state of Iowa. Because the testing sites varied across participants, we were only able to obtain recent audiograms (within one year of testing) for a subset of participants (6/24). Of the six participants, all demonstrated flat audiometric responses between 250 to 4000 Hz, with thresholds ranging from 10 dBHL to 35 dBHL, which is consistent with the expected range for cochlear implant users.

Normal-Hearing Control Participants

We recruited 46 children with normal hearing from the local community. All completed both visits. NH participants had normal (corrected) vision and cognitive abilities. Twenty-four children (15 males, 9 females) served as age-matched (AM) control participants (mean age = 4.88 years, *SD* = 1.02 years). An additional 23 children (12 males, 11 females) served as vocabulary-matched (VM) control participants (mean age = 3.74 years, *SD* = 1.02 years). The VM group contained one less participant than the CI and AM groups because we did not complete vocabulary testing for one CI participant (CI 008) due to behavioral issues at the time of testing. Table 2 displays demographic information for the AM group and Table 3 displays demographic information for the VM group.

Table 1. CI participant characteristics (N = 24)

Participant ID	Age at test (years)	Age at CI (years)	Length of CI use (years)	PPVT-III standard score	Highest level of maternal ed	Device Type	Languages spoken in home
CI 008	3.67	1.92	1.75	CNT	16	Nucleus Freedom	English
CI 009	4.33	0.75	3.58	99	16	Nucleus Freedom	English
CI 010	4.42	1.42	3.00	70	6	Auria Harmony	English, Spanish
CI 011	4.42	1.42	3.00	74	6	Auria Harmony	English, Spanish
CI 012	5.5	1.33	4.17	106	16	Nucleus Freedom	English
CI 013	4.5	1.17	3.25	106	16	Nucleus Freedom	English
CI 014	3.17	0.75	2.33	93	18	Nucleus Freedom	English, ASL
CI 015	3.33	1.67	1.67	94	18	Nucleus Freedom	English
CI 016	4.00	2.00	1.92	68	14	Nucleus Freedom	English
CI 017	6.42	2.92	3.42	73	15	Nucleus Freedom	English
CI 018	4.08	1.42	2.67	99	18	Nucleus Freedom	English, Russian
CI 019	5.58	1.58	4.00	82	18	Nucleus Freedom	English
CI 020	4.42	1.33	3.08	116	No response	Nucleus Freedom	English, Romanian
CI 024	5.00	1.83	3.08	99	12	Auria Harmony	English
CI 025	5.92	1.00	5.92	92	16	Nucleus Freedom	English
CI 026	6.75	1.58	5.17	55	16	Nucleus Freedom	English
CI 027	3.25	1.50	2.33	93	16	Auria Harmony	English
CI 028	4.58	1.92	2.58	93	14	Nucleus Freedom	English

Table 1. Continued.

CI 029	4.83	1.50	2.42	81	14	Nucleus Freedom	English, Spanish
CI 030	5.33	1.92	3.42	101	16	Nucleus Freedom	English
CI 031	5.42	2.25	3.08	108	16	Nucleus Freedom	English
CI 032	5.00	1.75	3.25	84	12	Nucleus Freedom	English
CI 033	6.42	2.83	3.42	93	16	Nucleus Freedom	English
CI 034	6.33	1.33	4.92	96	16	Nucleus Freedom	English
Mean	4.86	1.68	3.16	90.22	14.87		
Range	3.33-6.75	0.75-2.92	1.67-5.92	55-116	6-18		
SD	1.04	0.5	1.07	14.8	1.25		

Table 2. AM participant characteristics (N = 24)

Participant ID	Age at test (years)	PPVT-III standard score	Highest level of maternal ed	Languages spoken in home
AM 022	3.58	133	16	English
AM 019	4.33	118	16	English
AM 016	4.42	121	20	English
AM 017	4.42	112	20	English
AM 041	5.42	120	16	English
AM 042	4.58	124	18	English
AM 026	3.08	112	16	English
AM 069	3.42	104	18	English
AM 025	3.92	112	16	English
AM 043	6.67	96	12	English
AM 049	4.08	130	14	English
AM 064	5.58	115	18	English
AM 053	4.50	123	18	English
AM 045	5.00	100	12	English
AM 033	5.92	137	19	English
AM 066	6.75	120	18	English
AM 036	3.83	117	18	English
AM 065	4.75	129	16	English
AM 030	4.75	98	14	English
AM 054	5.33	108	18	English
AM 060	5.33	107	18	English
AM 029	4.92	115	13	English
AM 061	6.50	116	16	English, Spanish
AM 059	6.08	116	18	English
Mean	4.88	116.0	16.35	
Range	3.08-6.75	96-137	12-20	
SD	1.02	10.6	2.17	

Table 3. VM participant characteristics (N = 23)

Participant ID	Age at test (years)	PPVT-III standard score	Highest level of maternal ed	Languages spoken in home
VM 044	5.00	96	12	English
VM 018	2.50	101	19	English
VM 024	3.33	93	16	English
VM 028	5.75	104	18	English, Romanian
VM 038	3.42	121	18	English
VM 023	3.00	106	18	English
VM 062	3.00	104	16	English
VM 048	2.08	No SS*	18	English
VM 058	3.17	102	18	English
VM 046	3.75	103	16	English
VM 020	3.17	105	18	English
VM 037	4.92	115	18	English
VM 063	3.83	109	18	English
VM 052	4.08	108	16	English
VM 032	3.25	100	14	English
VM 040	3.42	97	16	English
VM 027	3.33	99	14	English
VM 015	2.67	107	16	English
VM 021	3.25	129	18	English
VM 031	5.58	109	18	English
VM 051	3.25	100	16	English
VM 050	5.33	105	16	English
VM 035	5.00	110	18	English
Mean	3.74	106.1	16.25	
Range	2.08-5.58	93-129	12-19	
SD	1.02	8.2	1.7	

*VM 048 was too young to determine standardized test scores for the PPVT-III.

Test Measures

Standardized Tests

Nonverbal Cognition

Kaufmann Brief Intelligence Test-2nd edition (KBIT-2)

The KBIT-2 (Kaufman & Kaufman, 2004) is a standardized, norm-referenced measure of cognitive ability. It is appropriate for children ages 4;0 to adulthood; therefore, most of the children in the VM group did not receive this measure. Because most CI participants demonstrated a significant language delay, we only administered the non-verbal “Matrices” subtest to children 4 years and older. In the Matrices subject, the examiner points to a target picture and the child is expected to identify a corresponding picture at the bottom of the page (from a set of 4 or 5 pictures) that “goes with” the target. The test is designed to be administered in 10 to 15 minutes.

Minnesota Child Development Inventory (MCDI)

The MCDI (Ireton & Thwing, 1974) is a norm-referenced parent-report measure that evaluates many areas of development, including motor, nonverbal cognition, language comprehension and language production. Parents indicate if behaviors do or do not apply to their child by circling “yes” or “no” on designated forms. It is appropriate for children birth to 6 years of age; therefore, children older than 6;0 did not receive this measure. Although the MCDI contains six separate subtests, we only administered the Situation-Comprehension subtest, which measures nonverbal cognitive skills, to parents in the current study.

The MCDI yields age-equivalent scores. We calculated Situation-Comprehension quotient (SCQ) scores by dividing the age-equivalent scores by the child’s chronological age to control for non-verbal cognitive differences across participants as a function of age. SCQ scores that equal 1.0 indicate language performance consistent with what is expected for an individual’s chronological age. SCQ scores below 1.0 indicate delayed language performance, relative to chronological age, and SCQ scores above 1.0 indicate language performance that is advanced relative to chronological age.

Language

Peabody Picture Vocabulary Test-3rd edition (PPVT-III)

The PPVT-III (Dunn & Dunn, 1997) is a standardized, norm-referenced measure of receptive vocabulary skills. It is appropriate for children ages 2 years, 6 months to adulthood. It includes two parallel forms; Form III-A was used in the present study. The test is a multiple-choice measure consisting of sets of four black and white line drawings. The examiner names one of the pictures and the test recipient is expected to indicate which picture has been labeled, either verbally or through pointing. The test is designed to be administered in 10 to 15 minutes.

Articulation

Goldman-Fristoe Test of Articulation-2 (GFTA-2)

The GFTA-2 (Goldman & Fristoe, 2000) is a standardized, norm-based articulation measure that samples spontaneous sound production. Children are asked to respond to picture plates and verbal cues from the examiner with single words that test consonant accuracy in initial, medial, and final positions. The test is designed to be administered in 5 to 15 minutes. All CI participants received the GFTA-2. NH participants who demonstrated articulation difficulties also received this measure. For those participants who took the test, we used their performance to judge consistent articulatory error patterns that children demonstrated.

Speech Perception

Multisyllabic Lexical Neighborhood Test (MLNT)

The purpose of speech perception or spoken word recognition measures is to assess CI users' abilities to understand speech in the absence of any visual cues. We administered the present speech perception measure through live voice, given the young ages of some of the CI participants. During actual test administration, the examiner eliminated any speechreading cues by covering her lower face with an acoustic hoop consisting of an 8" embroidery hoop and acoustic speaker cloth. The acoustic hoop allowed the examiner to transmit an auditory signal without distortion.

We included the *Multisyllabic Lexical Neighborhood Test* (MLNT; Kirk, Pisoni, & Osberger, 1995) as our speech perception measure. Researchers at Indiana University developed this measure for the purpose of assessing speech perception skills of pediatric CI users (Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2000) and it is considered to be appropriate for preschool-age children. In the MLNT, the experimenter read a list of 24 multisyllabic words and the participants repeated the word after each presentation. The MLNT consists of two parallel lists. Lists were counterbalanced across participants. If the child was not attending, target words were repeated. Performance was scored as percent correct out of 24 at the whole-word level.

Analysis of Demographic Variables

We analyzed differences in demographic variables and outcome measures using independent-sample t-tests. The CI and AM groups showed no significant difference in chronological age, $t(45) = .285$, $p = .78$. The CI group was significantly older than the VM group, $t(44) = -3.51$, $p = .001$. For raw scores on the PPVT-III, the AM group demonstrated significantly higher scores than the CI group, $t(45) = 5.31$, $p < .000$. The CI and VM groups showed no significant difference, $t(44) = .27$, $p = .79$. We also analyzed standard scores on the PPVT-III. The AM group had significantly higher standard scores than the CI group, *t*(45) = 6.88, *p* < .000. The VM group also had significantly higher standard scores than the CI group, *t*(43) = 4.46, *p* < .000. Although the AM and VM groups both had significantly higher standard scores on the PPVT-III compared to the CI participants, it should be noted that on average, the CI group demonstrated scores within the average range of performance (*M* = 90.22; range 55-116; *SD* = 14.8).

We compared performance across groups on the non-verbal cognitive measures. The CI group showed no significant difference in KBIT-2 standard scores compared to the AM group, *t*(37) = .102, *p* = .92, or the VM group, *t*(24) = .59, *p* = .56. We also analyzed quotient scores on the MCDI Situation-Comprehension subtest. The CI group showed no significant different MCDI quotient scores with the AM group, *t*(34) = -.76, *p* = .46, or the VM group, *t*(37), .69, *p* = .50.

We attempted to control for maternal education level by including AM and VM participants with similar levels of maternal education compared to the CI group. Maternal education was calculated as a continuous variable, in which we determined the number of years of education for each participant. We analyzed data in an independent-sample t-test. Results approached significance between the CI and AM groups, *t*(45) = 2.008, *p* = .051. They were statistically significant between the CI and VM groups, *t*(44) = 2.331, *p* = .024. These data indicate that the children in the NH groups tended to have mothers with higher education levels compared to the CI group. We calculated Pearson correlations to determine the influence of maternal education level on comprehension and production scores. The correlation for comprehension at Visit 1 was marginally significant (r = .22, p = .07) and at Visit 2 it was significant (*r* = .35, *p* = .004). Correlations were significant for production at Visit 1 (*r* = .32, *p* = .007) and marginally significant at Visit 2 (*r* = .22, *p* = .08). Table 4 displays mean scores and standard deviations for age and cognitive, language, and speech perception measures across the three groups.

Table 4. Mean scores and standard deviations on demographic variables.

Test measures	CI *M (SD)*	AM *M (SD)*	VM *M (SD)*
Chronological age	4.86 (1.04)	4.88 (1.02)	3.74 (1.02)
PPVT raw score	52.5 (19.9)	82.8 (19.2)	54 (18.3)
PPVT standard score	90.2 (14.8)	116.0 (10.6)	106.1 (8.2)
MLNT word correct	0.77 (0.2)	1.0 (0.02)	0.99 (0.03)
KBIT standard score	99.8 (12.9)	100.2 (12.4)	102.9 (8.03)
MCDI quotient score	1.34 (0.24)	1.28 (0.22)	1.41 (0.37)
Maternal education level	14.87 (3.25)	16.35 (2.17)	16.65 (1.7)

Word Learning Tasks

The word learning experiment spanned two visits. For all CI participants, visits were one day apart. For NH hearing participants, visits were one to three days apart (m = 1.53, SD = 0.55). The stimuli and experimental protocol followed Horst and Samuelson's (2008) and Booth et al.'s (2008) designs.

Stimuli

The stimuli consisted of 16 novel objects (Figure 1). Eight of the novel objects were targets, while the other eight were foils. Each novel object (both targets and foils) had an extension that differed in size or color, but not shape. We selected novel objects that would be unfamiliar to children and different from one another in shape. Prior to testing, parents saw photographs of the novel objects. If the parent indicated that the child would know the name of one of the novel objects, we replaced that object and its extension with back-up objects. In addition, familiar objects were used in warm-up trials and in one control trial. The familiar object in the warm-up included small books, cups, and cookies. The familiar objects in the control trial were small plastic dogs. We selected familiar objects selected from the most frequent objects in the typical productive vocabulary of a 16-month-old (Dale & Fenson, 1996).

Figure 1. Novel target objects, foils, and extensions

The novel words followed the phonological constraints of English. We also atempted to control for phonotactic probability (Storkel, 2001; Vitevitch & Luce, 2004). Novel words consisted of consonant-vowel-consonant-vowel combinations with high segmental and biphone phonotactic probabilities (e.g., “modi”) based on Storkel’s (2001) criteria. Segmental and biphone phonotactic probabilities were calculated using Vitevitch and Luce’s (2004) phonotactic probability calculator. These criteria were meant to maximize the likelihood of word learning. Table 5 displays the list of novel words.

Table 5. List of novel word stimuli and sums of segmental and biphone phonotactic probability.

Novel word	Sum of Segmental Probability	Sum of Biphone Probability
kaetah	0.2555	0.0190
foluh	0.2493	0.0201
dihbo	0.1950	0.0183
modi	0.1876	0.0094
haekay	0.1867	0.0119
poboo	0.1709	0.0063
gahmay	0.1503	0.0087
nehpay	0.1483	0.0057

Procedure and Design

Children sat across from an experimenter at a table. If parents were present, they observed from behind the child's chair or on a closed-circuit television. None of the CI participants used sign language to communicate; therefore, we provided all directions in spoken English.

Warm-Up Trials

We first presented children with three warm-up trials, to establish rapport with the experimenter and understand what was expected of them during the task. For each warm-up trial, the experimenter placed a familiar object (cup, cookie, or book) with extensions (a different cup, cookie, or book) and a novel object on a tray. After setting the tray with the objects on the table, the experimenter first asked the child to identify the familiar object (e.g., *Is there a cup here?*). If the child accurately identified the familiar object, the experimenter asked the child to identify extensions of the familiar object (e.g., *Is there another one?*). The experimenter continued asking this question until the child indicated that there were no more extensions or they identified all of the objects on the tray. If the child could not identify the familiar object or identified objects on the tray that were not extensions of the familiar object, the experimenter corrected the child. After the child had identified the familiar object and extensions (with or without assistance), the experimenter asked the child to identify the novel object on the tray (e.g., *Is there a toma?*). The experimenter then asked the child to name the familiar object and then the novel object. If the child could not name the novel object, the experimenter prompted the child by producing the first two phonemes of the word (e.g., *It's a to*___). This procedure was identical to the procedure used in the cued production trials during the experiment.

For the first warm-up trial, the experimenter presented the child with three cups and a novel object labeled *toma*. For the second warm-up trial, the experimenter presented the child with one book and a novel object labeled *waytoo*. For the third warm-up trial, the experimenter presented the child with two cookies and a novel object labeled *boono*. The number of familiar object extensions varied across trials so as to give the impression that the number of extensions could vary. We randomized the position of the objects across the three warm-up trials. We did not use these same objects again in the experimental trials. Following each warm-up trial, we praised children effusively for their performance.

Novel Word Learning Paradigm

We exposed children to eight training trials and one control trial. The experimenter first labeled four of the novel objects and then tested the child on production, preference, comprehension, and extension. The control trial followed the first four training and testing trials, and then training and testing took place with the other four novel objects. Within the novel word training trials, gesture cues were manipulated during labeling. The testing had three to five phases, depending on the child's performance: uncued production, cued production (not administered if the child accurately named the object), preference, comprehension, and extension (not administered if the child was not accurate on the comprehension phase).

Training Trials

The experimenter placed the target novel object and the foil novel object 60 mm apart on the table. The experimenter labeled the object three times by stating: “There is a [target word]. I see the [target word]. Wow, that’s a [target word]!” For four of the novel word trials, eye gaze cues accompanied labeling, in which the experimenter turned her head and looked at the target object. For the other four trials, touch+eye gaze cues accompanied labeling, in which the experimenter turned her head and touched the target object three times with her index finger (once for each label). Care was taken to ensure that the training for the eye gaze trials and touch trials took approximately the same length of time and were presented in the same prosody, in order to prevent the participant from benefiting from temporal or speech differences across trials. For 20% of the participants, an independent observer timed all eight training trials. The observer selected 19 participants’ videotapes at random (10 NH and 9 CI) and determined the amount of time that elapsed between the beginning of labeling to the end. For eye gaze trials, the average time was 9.22 seconds (*SD* = 1.01). For touch + eye gaze trials, the average time was 9.59 (SD = 1.53). On a paired sample t-test, this difference was marginally statistically significant, *t*(75) = -1.93, *p* = .06, indicating that there was a trend for the touch+eye gaze training trials to be longer than the eye gaze trials. If the results demonstrate a significant advantage for touch+eye gaze cues, this could be due to the slightly longer time interval in the touch+eye gaze training and we will need to take this confound into account.

Location of gesture cues and positions of the objects on the table were pseudo-randomized. To avoid order effects, four versions of the training trials were administered, in which the same words and objects were used but presented in a different pre-determined order. The first trials of Version 1A and 1B started with an eye gaze cue, while the first trials of Version 2A and 2B started with a touch+eye gaze cue. The remainder of the trials had the gesture cues randomized, with the same gesture or location (left or right) never presented on more than two trials in a row. Versions 1 and 2 also presented novel words in different random orders. We administered the four versions through random assignment. Pilot testing indicated that initiating trials with a particular gesture cue (eye gaze or touch+eye gaze) did not influence performance on subsequent trials.

Uncued and Cued Production Testing

After labeling the first four targets, the experimenter administered the uncued and cued production tests. Target objects were presented in the order in which they were trained. The experimenter looked at the child, held up the target object and asked, "What is this called?" If the child correctly named the object, the experimenter said, "Yes, you're right!" and praised the child. If the child said "I don't know" or gave an incorrect response, the experimenter moved on to the cued production test. The experimenter said, "Let me give you a clue. It's a mo__," providing the first two phonemes of the novel word. If the child provided a correct response for the cued production, the experimenter said, "Yes, you're right!" If the child was still unable to provide a response after five seconds or provided an inaccurate response, the experimenter held up the target object and said, "I know, it's a modi!" This was done to ensure that all children had the same number of exposures to the correct object-label pairing, prior to administering the comprehension and extension tests.

For children in the CI group, we compared productions to performance on the GFTA-2. If any error patterns appeared to be consistent (e.g., /t/ for /s/ substitutions), performance was scored taking the child's substitutions into account. We performed this same procedure with any children in the NH groups who showed consistent articulation difficulties. We scored production performance using two different measures. For the first measure, children received two points for accurately naming the target word during the uncued production trial. All four phonemes had to be produced accurately (taking into account phonological error patterns), as well as be produced in the correct sequence. Children received one point for accurately naming the target word during the cued production trial. Credit was given if they produced all four phonemes accurately, in the correct sequence, or the final two phonemes of the target word. In addition, we scored uncued production using a "lax" criteria, in which children received credit for producing any of the target phonemes in the target word. This scoring method is described in more detail in the results section. An additional coder transcribed 20% of the participants' uncued productions for reliability purposes. We measured reliability by calculating the number of agreements by phoneme divided by the number of agreements plus disagreements. Using this method, the transcription reliability was 80%.

Preference Testing

After the production testing was completed for the first four targets, the experimenter administered the preference testing. In the preference phase, the experimenter presented three objects to the child on a tray. These objects consisted of a target, its foil from the training trial, and a target from another trial. The examiner asked the child, "Which one is your favorite?" If children selected two objects, the examiner asked, "Which one do you like the best?" In all cases, children eventually indicated preference for one object. The preference phase served several purposes. First, it allowed us to determine if children understood what was being asked of them during the comprehension/extension testing, or if they were merely choosing their favorite object. It also had the unintended benefit of maintaining the children's interest in the task, because they appeared to be very enthusiastic about showing the experimenter their favorite object.

Comprehension and Extension Testing

Comprehension and extension testing immediately followed each preference trial. In this phase, the experimenter presented six objects in random order to the child on a tray. These objects consisted of a target and its extension, its foil from the training trial and the foil's extension, and another target from a different training trial and its extension (see Figure 2). The order and pairings of objects remained consistent across all participants. In other words, the first comprehension/extension test trial included Target Object #1 (and extension), Unnamed Foil #1 (and extension), and Named Foil #2 (and extension). The unnamed foil was the distractor object during the training trial. The named foil was the target object from the second training trial.

Figure 2. Sample tray of novel target object, unnamed foil, named foil, and extensions.

Participants were instructed to identify Target Object #1 from the set (e.g., "Give me the *modi*"). If the child accurately identified the target, the experimenter then asked, “Is there another one?” The experimenter continued asking this question until the child indicated no or there were no more objects on the tray. If the child did not accurately identify the target object, the experimenter held up the target and said, “Here it is!” and moved on to the next test trial. We did not administer extension trials in situations in which the child was unable to identify the target. We judged performance on the extension task to be accurate if the child correctly identified the extension object after the comprehension task and answered “no” when the examiner asked, “Is there another one?” after that point.

This same procedure continued for the second comprehension/extension test trial, which included Target Object #3 (and extension), Unnamed Foil #3 (and extension), and Named Foil #4 (and extension). In the second trial, the experimenter requested Target Object #3. The third comprehension/extension test trial included Target Object #4 (and extension), Unnamed Foil #4 (and extension), and Named Foil #1 (and extension). In the third trial, the experimenter requested Target Object #4. In the fourth comprehension/extension test trial, the experimenter presented Target Object #2 (and extension), Unnamed Foil #2 (and extension), and Named Foil #3 (and extension). Children had to identify and extend Target Object #2.

After the child had completed production, preference, comprehension, and extension testing for the first four trials, the experimenter administered a control trial. In the control trial, the experimenter presented three toy dogs and four novel objects (two different objects with extensions) on the tray. The experimenter asked the child, “Are there any dogs here? Give me a dog.” When the child indicated the dog to the experimenter, the experimenter then asked, “Is there another one?” until the child indicated no or there were no more objects on the tray. After the comprehension/extension control trial, the experimenter held up one of the dogs and asked, “What is this called?” The purpose of the control trial was to ensure that the children understood and were attending to the task. Unlike test trials, we tested comprehension and extension before production in the control trial because all of the children could easily name the dogs.

Following the control trial, the experimenter trained and tested participants on Target Objects 5 through 8. The presentation order for comprehension/extension testing was identical to Objects 1-4: Trial 1 consisted of Target Object #5, Unnamed Foil #5, and Named Foil #6; Trial 2 consisted of Target Object #7, Unnamed Foil #7, and Named Foil #8; Trial 3 consisted of consisted of Target Object #8, Unnamed Foil #8, and Named Foil #5; and Trial 4 consisted of Target Object #6, Unnamed Foil #6, and Named Foil #7. Table 6 displays the sequence of events for the entire word learning paradigm.

Follow-up Visit

CI participants participated in the second visit one day after initial testing. Testing intervals varied from one to three days apart for the AM and VM groups. As a result, the NH control groups, on average, had a longer retention interval than the CI group. This difference should work in favor of the CI group, providing a more stringent test of word retention between the experimental group and control groups. Word training procedures were identical from Visit 1 to Visit 2, with the exception that there were no training trials at Visit 2.

The word learning task took approximately 25 minutes (5 minutes for warm-up, 10 minutes for training, and 10 minutes for testing). We videotaped all sessions for later scoring. The complete test battery took approximately 60 minutes at the first visit and 30 minutes during the second visit. During the first visit, the experimenter administered the word learning experiment first, followed by the GFTA-2, MLNT, and the KBIT-2 (if time permitted). During the second visit, we again administered the word learning experiment first, followed by the PPVT-III and the KBIT-2 if needed.

Table 6. Sample sequence for testing paradigm using *modi* as the target word.

Task	Examiner's statement	Child's response
Uncued production	*"What's this called?"*	C names object.
If the child does not produce a label, the experimenter provides a scaffolded cue.		
Cued production	*"It's called a "mo_. What's this called?"*	C names object.
If the child does not produce an accurate labeling after cueing, the experimenter holds up the object and says, "I know, it's a *modi*."		
Preference	*"Which one is your favorite?"*	C points to favorite
Comprehension	*"Show me the modi."*	C points to object.
If the child does not accurately identify the target object, the experimenter holds up the target and says, "No, that's not it. Here it is!" and moves on to the next trial. If the child accurately identifies the target object, the experimenter administers the extension phase.		
Extension	*"Is there another one?"*	C points to object or indicates no.
If the child accurately identifies the target extension, the experimenter repeats the extension until the child indicates there are no more extensions or there are no more objects left on the tray.		

Statistical Analysis

We analyzed production and comprehension separately using a three-way mixed-model analysis of variance (ANOVA), with session (Visit 1 vs. Visit 2) and gesture cue (eye gaze vs. touch + eye gaze) as the within-subject factors and group (CI vs. AM vs. VM) as the between-subject factors. We utilized Tukey's HSD for all post-hoc testing, except in situations in which there was unequal variance across the groups. In this situation, we used the Dunnett T3 post-hoc test. For all ANOVAs and correlations, we report significant findings as p-values equal or less than 0.05 and marginally significant findings as p-values equal or less than 0.10. Effect sizes were reported in the form of partial eta squared (partial η^2) with all significant and non-significant findings for ANOVAs. We utilize Kittler, Menard, and Phillips' (2007) guidelines for the strength of effect sizes, with a small effect size being equal to 0.01 or greater, a medium effect size equal to 0.06 or greater, and a large effect size being equal to 0.14 or greater.

We also examined performance as a composite word learning score in which comprehension and production were considered together (Tomblin, Barker, & Hubbs, 2008). The composite score involved a three-point scale for each novel word trial. Children received two points if they accurately named the target word in the uncued production task (all three phonemes correct, taking into account consistent articulatory error patterns), one point if they accurately named the target word in the cued production task, and one point if they accurately identified the target object. The maximum number of possible points was 24 (3 points per trial x 8 trials). We analyzed data in terms of a percent correct out of the maximum number of points. Composite scores were entered for Visit 1 and Visit 2 into multiple regression analyses with outcome measures and demographic variables as the independent measures.

CHAPTER 3

RESULTS

In the section below, results from the mixed-model ANOVAs for comprehension and production data are presented first, followed by a description of the extension data. The section concludes with the multiple regression analyses.

Comprehension

We analyzed the influence of gesture cues on comprehension in a three-way mixed-model ANOVA, with session (Visit 1 vs. Visit 2) and gesture cue (eye gaze vs. touch+eye gaze) as the within-subject factors and group (CI vs. AM vs. VM) as the between-subject factors. The comprehension scores from the word learning task served as the dependent variable. As shown in Table 7 and Figure 3, the ANOVA revealed a main effect for session, with scores at Visit 2 being higher than at Visit 1, $F(1, 64) = 6.887$, $p = .011$, partial $\eta^2 = .097$. This was consistent with our prediction that word learning scores would improve over time. There was also a significant main effect for group, $F(2, 64) = 8.39$, $p = .001$, partial $\eta^2 = .208$. Using Tukey's HSD, we conducted a post-hoc test for the group factor. Consistent with predictions, it indicated that the AM group performed significantly better than the CI group ($p = .005$) and the VM group ($p = .001$). There was no significant difference between the CI and VM groups ($p = .945$). Finally, there was a marginally significant three-way interaction between session, gesture cue, and group, $F(2, 64) = 2.974$, $p = 0.058$, partial $\eta^2 = .085$. At Visit 2 only, the VM group only performed better when given touch+eye gaze cues than eye gaze cues alone. Contrary to predictions, there was no significant main effect for gesture cue, $F(1, 64) = .98$, $p = .326$, partial $\eta^2 = .015$. There were also no significant two-way interactions between visit and group, $F(2, 64) = 1.124$, $p = .331$, partial $\eta^2 = .034$, gesture cue and group, $F(2, 64) = 1.906$, $p = .157$, partial $\eta^2 = .056$, or session and gesture cue, $F(1, 64) = .553$, $p = .46$, partial $\eta^2 = .009$.

As stated in the Method section, there was a significant difference in maternal education level between children in the CI group and children in the NH groups. Therefore, we re-analyzed the mixed-model ANOVA including highest level of maternal education as a covariate. Using this more conservative approach, we found a significant between-subject main effect for group, $F(2,62) = 8.595$, $p = .001$, partial $\eta^2 = .217$. Inconsistent with the previous ANOVA, we did not find a significant within-subject main effect for session, $F(1 ,62) = .015$, $p = .903$, partial $\eta^2 = .000$.

Table 7. Descriptive statistics for comprehension scores (all subjects)

Condition	Group	Mean (SD)
Eye gaze Visit 1	AM	2.63 (0.92)
	VM	1.65 (1.03)
	CI	2.35 (1.18)
	Total	2.21 (1.11)
Touch + Eye gaze Visit 1	AM	2.83 (1.05)
	VM	2.09 (1.24)
	CI	1.90 (1.02)
	Total	2.30 (1.17)
Eye gaze Visit 2	AM	3.17 (1.09)
	VM	2.00 (0.85)
	CI	2.05 (1.10)
	Total	2.43 (1.14)
Touch + Eye gaze Visit 2	AM	2.96 (1.16)
	VM	2.57 (1.34)
	CI	2.30 (0.98)
	Total	2.63 (1.19)

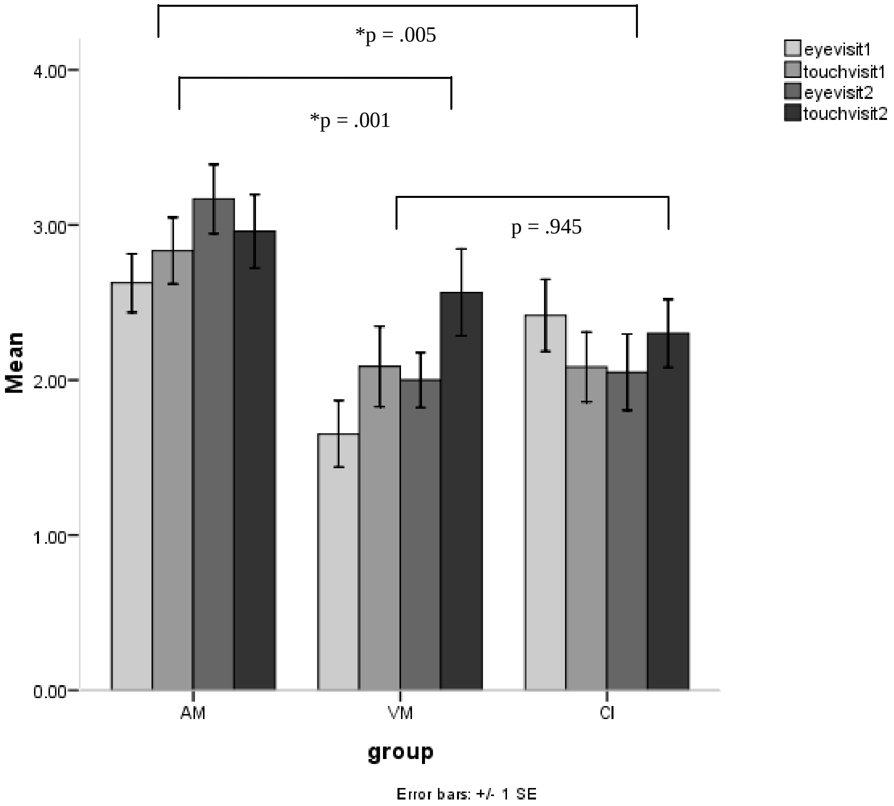

Figure 3. Mean comprehension scores separated by gesture cue, group, and visit.

As shown in Tables 1, 2, and 3 in the Method section, six children in the CI group had exposure to other languages in addition to English in the home. One child in the AM group and one child in the VM group also had exposure to additional languages. As a result, we re-analyzed the mixed-model ANOVA, excluding all children who were exposed to multiple languages (Figure 4). There were few changes in the statistical significance of the results when we analyzed data in this manner. Consistent with the analysis for all subjects, there was a significant main effect for session, *F*(1, 56) = 8.579, *p* = .005, partial η^2 = .133, and a significant main effect for group, *F*(2, 56) = 6.248, *p* = .004, partial η^2 = .182. The sole exception was the gesture cue by group interaction;

with the exclusion of subjects, this interaction became marginally significant, *F*(2, 56) = 2.364, *p* = .10, partial η^2 = .078, such that the VM group showed significantly higher scores with touch+eye gaze cues than eye gaze alone when performance was collapsed across visits.

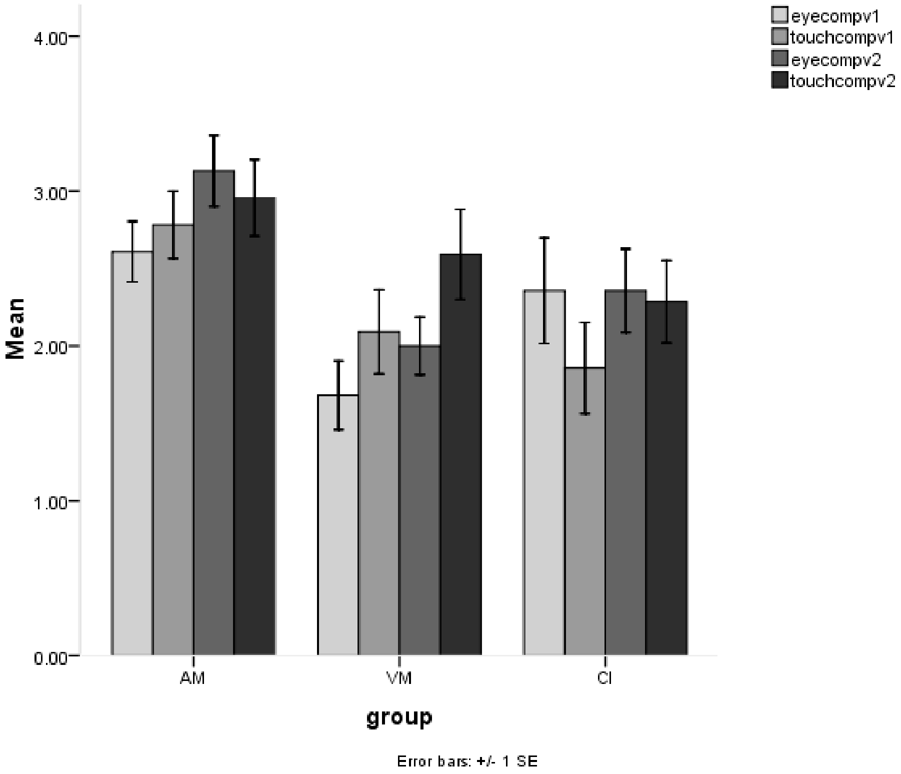

Figure 4. Mean comprehension scores separated by gesture cue, group, and visit, English speaking-only subjects.

Recall that all of the CI participants completed the second visit the day after the first visit. In contrast, the amount of time between the first and second visits in the NH groups varied from one to three days (*m* = 1.53 days), with 11 children in the AM group completing the second visit the next day and 12 children in the VM group completing the second visit the next day. To control for the length of time between the first and second visit, we re-analyzed the data, only including the NH children who were tested two days in a row (Figure 5). Because of the decrease in subjects and resulting loss of power, we combined gesture cues in the statistical analysis. The mixed-model ANOVA indicated a marginally significant main effect for session, $F(1, 40) = 3.659$, $p = .06$, partial $\eta^2 = .084$, favoring the second visit, and a significant main effect for group, $F(2, 40) = 5.552$, $p = .007$, partial $\eta^2 = .217$. Post-hoc tests confirmed that the AM group scored higher than the CI group ($p = .011$) and the VM group ($p = .017$) and there was no significant difference between the CI and VM groups ($p = .985$). There was no significant interaction between group and session, $F(2, 40) = .805$, $p = .454$, partial $\eta^2 = .039$. Overall, data that only included children who were seen two days in a row were consistent with data from the whole group.

Because there were no significant differences in comprehension based on gesture cue for the groups, we combined eye gaze and touch+eye gaze scores for further analyses. First, we analyzed preference testing by calculating the number of times the child selected the target object on the preference task and dividing by the number of trials. We compared these scores to chance using a one-sample t-test with chance set at 33%. Chance was set at 33% because there was one out of three opportunities to randomly select the target object. All three groups demonstrated preference scores significantly below chance at Visit 1 [CI: $t(23) = -4.96$, $p < .001$: AM: $t(23) = -1.96$, $p = .06$, VM: $t(22) = -2.59$, $p = .02$] and Visit 2 [CI: $t(19) = -2.52$, $p < .02$: AM: $t(22) = -2.39$, $p = .03$, VM: $t(22) = -2.33$, $p = .03$]. The below chance performance was likely due to a novelty effect. All three groups chose the unnamed foil more often than the target object or named foil. When the proportion of objects selected were collapsed across groups and visits, participants chose the unnamed foil 50% of the time, the target object 24% and the named foil 26%. This 1:2:1 ratio was maintained when groups and visits were separated.

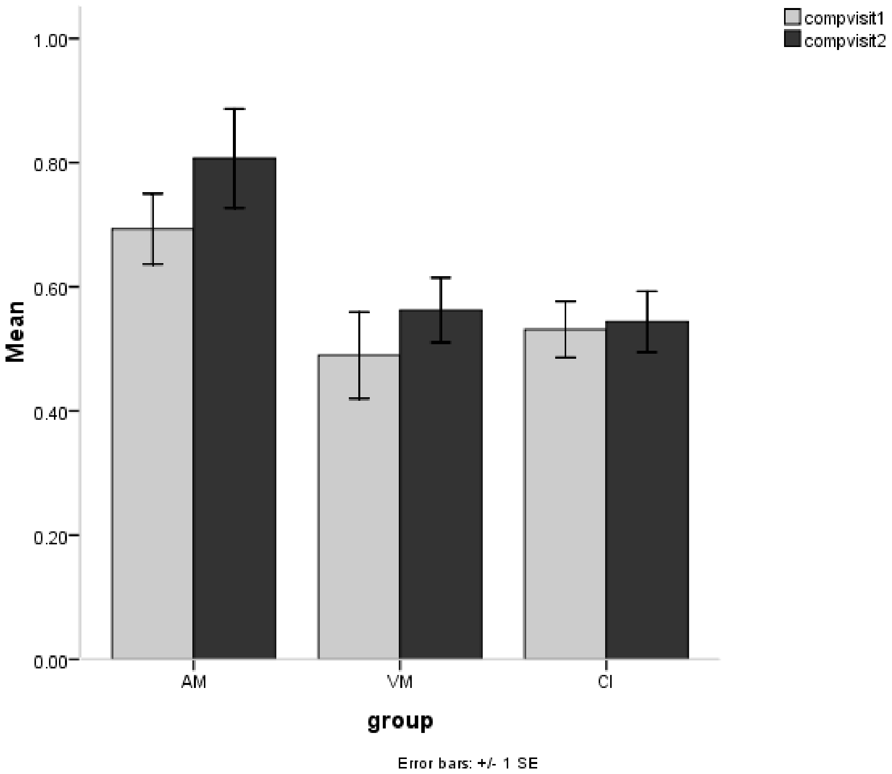

Figure 5. Mean comprehension scores for participants who were tested two days in a row.

To determine how children performed on the comprehension task compared to chance, scores were analyzed within each group using a one-sample t-test with the test value set at chance (0.33). Chance remained set at 0.33 even though the participants saw six objects (the target and its extension, the foil and its extension, and a target from another training trial and its extension) in the comprehension task. We scored performance as correct if the participant selected the target or its extension; therefore, chance performance was two out of six. The AM, VM, and CI groups all scored significantly higher than chance at Visit 1 [$t(23) = 9.767$, $p < .001$; $t(22) = 2.905$, $p = .008$; $t(23) = 5.457$, $p < .001$, respectively]. The AM, VM, and CI groups also scored

Table 8. Descriptive statistics for comprehension scores, gestures combined.

Condition	Group	Mean (SD)
Comprehension Visit 1	AM	0.68 (0.18)
	VM	0.47 (0.23)
	CI	0.53 (0.20)
	Total	0.56 (0.22)
Comprehension Visit 2	AM	0.77 (0.25)
	VM	0.57 (0.21)
	CI	0.54 (0.22)
	Total	0.63 (0.25)

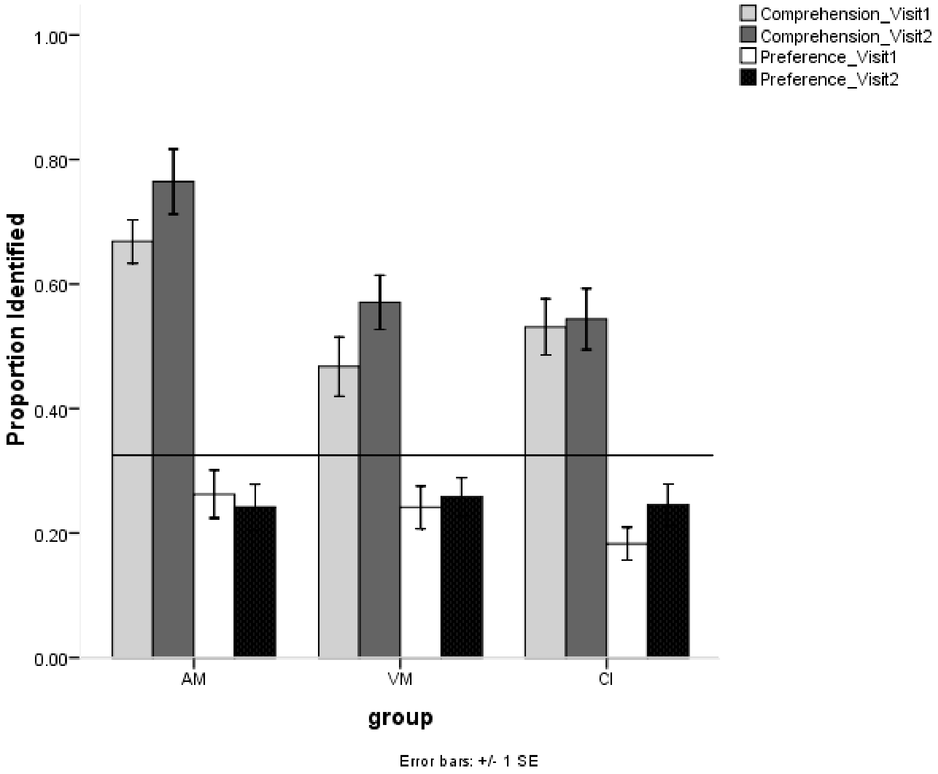

Figure 6. Mean comprehension and preference scores for AM, VM, and CI groups at both visits (solid line representing chance, set at 33%).

significantly higher than chance at Visit 2 [$t(23) = 8.723$, $p < .001$; $t(22) = 5.515$, $p < .001$; $t(19) = 4.356$, $p < .001$, respectively]. When compared with the data from the preference testing, these results suggest that children were not selecting their favorite item on the comprehension task, but instead understood that they were expected to choose the target object. Table 8 and Figure 6 display data for comprehension and preference scores compared to chance.

We also analyzed the comprehension errors to determine any patterns in erred object selections (Table 9 and Figure 7).

Table 9. Proportion of trials in which participants selected named or unnamed foils instead of target object.

Error selection	Group	Mean (SD)
Target object Visit 1	AM	0.69 (0.18)
	VM	0.47 (0.23)
	CI	0.57 (0.21)
Named foil Visit 1	AM	0.19 (0.12)
	VM	0.33 (0.18)
	CI	0.21 (0.17)
Unnamed foil Visit 1	AM	0.13 (0.12)
	VM	0.21 (0.18)
	CI	0.23 (0.19)
Target object Visit 2	AM	0.77 (0.25)
	VM	0.57 (0.21)
	CI	0.56 (0.24)
Named foil Visit 2	AM	0.13 (0.17)
	VM	0.27 (0.15)
	CI	0.18 (0.15)
Unnamed foil Visit 2	AM	0.10 (0.13)
	VM	0.17 (0.13)
	CI	0.26 (0.19)

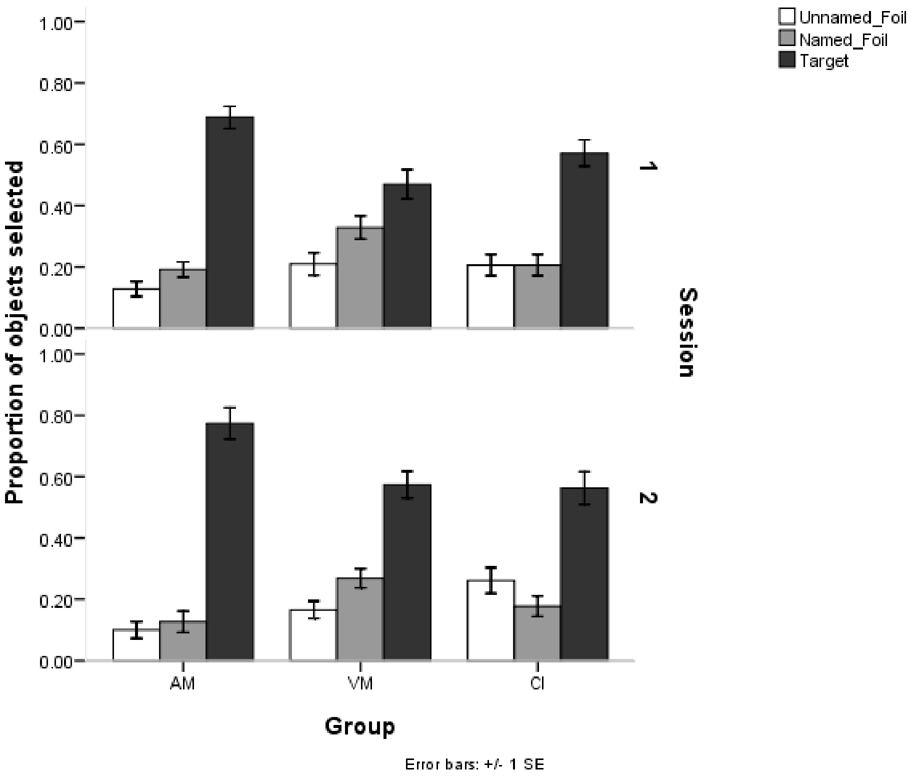

Figure 7. Comparison of proportion of trials in which participants selected target object, unnamed foil, and named foil at sessions 1 and 2.

The possibilities consisted of one novel object which the participants had seen during training but had not been named by the experimenter (the unnamed foil), and a novel object from another training trial, which had been named by the experimenter on a different trial (the named foil). Paired sample t-tests with a Bonferroni correction (α = .0167) indicated a marginally significant difference within the VM group, *t*(22) = -2.083, *p* = .05, and the AM group, *t*(23) = -1.923, *p* = .067, at Visit 1. Both groups tended to choose the named foil more frequently than the unnamed foil, suggesting that, in these cases, they may have recalled which objects had been named but they did not correctly recall the exact name to object link. There was no significant difference within the CI group, *t*(23) = .408, *p* = .687. At Visit 2, the VM group showed a significant effect for selecting the named foil more often than the unnamed foil,

$t(22) = -2.615$, $p = .016$. There was no significant difference for the AM group, $t(23) = -.762$, $p = .45$ or the CI group, $t(19) = 1.584$, $p = .13$.

Production

We analyzed production scores as a weighted score, in which participants received two points for naming objects without a verbal cue from the examiner and one point for naming objects when provided with a verbal cue. We conducted a three-way mixed-model ANOVA for the weighted production scores, with session (Visit 1 vs. Visit 2) and gesture cue (eye gaze vs. touch+eye gaze) as within-subject factors and group (AM vs. VM vs. CI) as the between-subject factor. The ANOVA indicated a significant main effect for session, with significantly higher scores at Visit 2 than Visit 1, $F(1, 64) = 11.40$, $p = .001$, partial $\eta^2 = .151$. Again, this was consistent with our prediction that there would be improvement over time. As predicted, there was also a main effect for group, $F(2, 64) = 7.13$, $p = .002$, partial $\eta^2 = .182$. The test of homogeneity of variances indicated that variances were unequal across groups; therefore, we used the Dunnett T3, which does not require equal variances, as a post-hoc measure. Post-hoc tests with a correction indicated that the AM group performed significantly better than the CI group ($p = .003$). The difference between the AM and VM groups was marginally significant ($p = .052$). There was no significant difference between the VM and CI groups ($p = .528$). Contrary to predictions, there was no significant main effect for gesture cue, $F(1, 64) = 2.298$, $p = .134$, partial $\eta^2 = .035$. There were also no significant interactions between gesture cue by group, $F(2, 64) = .546$, $p = .582$, partial $\eta^2 = .017$ or gesture cue by session, $F(1, 64) = 1.131$, $p = .292$, partial $\eta^2 = .017$.

There was a marginally significant three-way interaction between session, group, and gesture cue, $F(2, 64) = 2.80$, $p = .068$, partial $\eta^2 = .08$. Each group showed a different pattern for gesture cue across visits (Table 10 and Figure 8). The AM group showed no difference when naming words labeled with eye gaze alone or touch+eye gaze at either visits. The CI group tended to name more items labeled with touch+eye gaze cues than eye gaze cues alone at Visit 1. The VM group showed same pattern, but only at Visit 2 (touch+eye gaze scores better than eye gaze alone). There was also a significant interaction between session and group, *F*(2,64) = 4.02, *p* = .02, partial $\eta^2 = .112$. We conducted tests of simple main effects to further analyze this interaction, which included two one-way ANOVAs (Table 11 and Figure 9). In the first ANOVA, we compared production scores for Visit 1 across the three groups, resulting in no significant effect for group, *F* (2, 68) = 1.89, *p* = .16. In the second ANOVA, we analyzed production scores across groups at Visit 2, resulting in a significant effect for group, *F*(2, 64) = 8.38, *p* = .001. Post-hoc tests with the Dunnett T3 indicated a significant difference in production scores at Visit 2 between the AM and CI groups, with the AM group outperforming the CI group ($p < .000$). There was a marginally significant difference between the AM and VM groups, with the AM outperforming the VM group (*p* = .085). There was no significant difference between the VM and CI groups (*p* = .136). We also performed a series of paired sample t-tests to examine the differences in performance from Visit 1 to Visit 2 within each group. The AM group showed significant improvement in production from Visit 1 to Visit 2, *t*(23) = -3.358, *p* = .003. The VM also showed a significant improvement between Visit 1 and Visit 2, *t*(19) = -2.152, *p* = .04. In contrast, the CI group showed no change in production across the two visits, *t*(19) = .000, *p* = 1.000.

We re-analyzed the data including highest level of maternal education as a covariate. This analysis showed a significant between-subject main effect for group, F(2, 62) = 5.733, p = .005, partial $\eta^2 = .156$, a significant two-way interaction between session and group, F(2, 62) = 3.932, p = .025, partial $\eta^2 = .017$, and a marginally significant three-way interaction between session, gesture, and group, F(2, 62) = 3.086, p = .053, partial $\eta^2 = .017$. Inconsistent with our original ANOVA, but consistent with the results of the comprehension ANOVA that included maternal education as a covariate, we did not find a significant within-subject main effect for session, F(1, 62) = .878, $p = .353$, partial $\eta^2 = .014$.

Table 10. Descriptive statistics for production scores.

Condition	Group	Mean (SD)
Eye gaze Visit 1	AM	0.50 (0.88)
	VM	0.39 (0.66)
	CI	0.10 (0.31)
	Total	0.34 (0.69)
Touch + Eye gaze Visit 1	AM	0.54 (0.83)
	VM	0.17 (0.39)
	CI	0.40 (0.60)
	Total	0.37 (0.65)
Eye gaze Visit 2	AM	1.00 (0.98)
	VM	0.35 (0.65)
	CI	0.15 (0.37)
	Total	0.52 (0.80)
Touch + Eye gaze Visit 2	AM	1.00 (0.98)
	VM	0.65 (0.78)
	CI	0.35 (0.59)
	Total	0.69 (0.84)

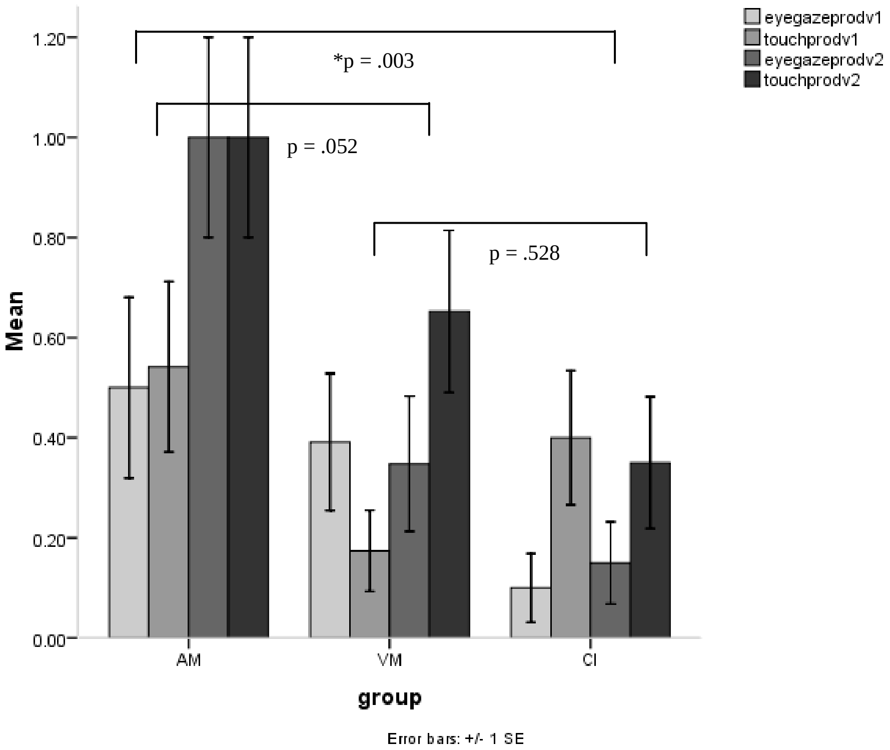

Figure 8. Mean scores for production separated by gesture cue, group, and visit.

Table 11. Descriptive statistics for production scores with gesture cues combined.

Condition	Group	Mean (SD)
Production	AM	1.04 (1.12)
Visit 1	VM	0.56 (0.84)
	CI	0.50 (0.76)
	Total	0.72 (0.95)
Production	AM	2.00 (1.59)
Visit 2	VM	1.09 (1.16)
	CI	0.50 (0.69)
	Total	1.24 (1.36)

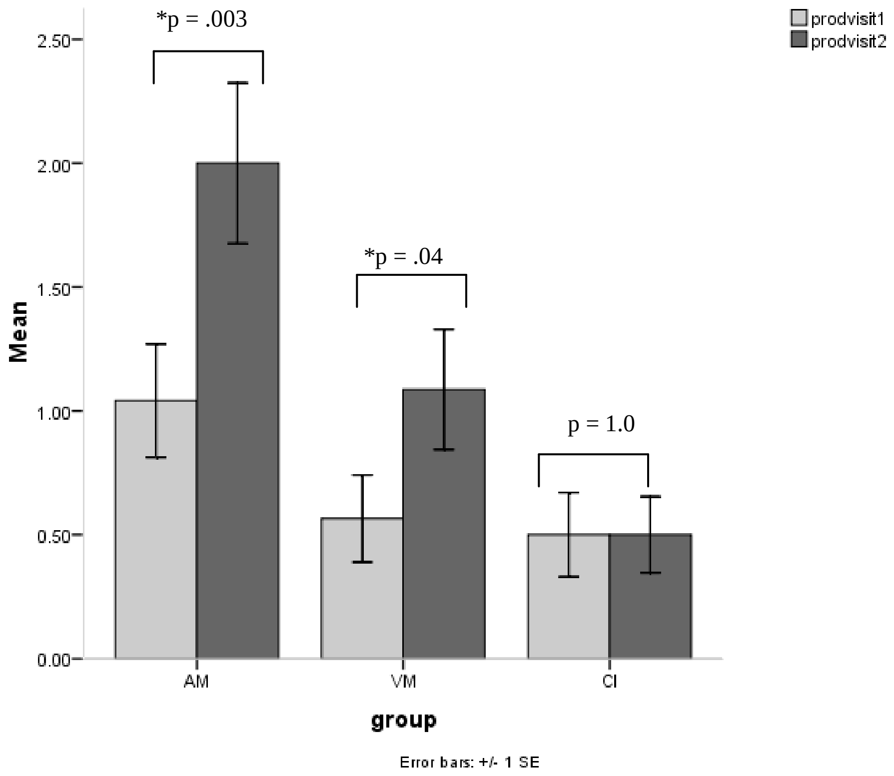

Figure 9. Mean production scores for AM, VM, and CI groups across visits.

We re-analyzed the mixed-model ANOVA excluding all children who were exposed to another language in addition to English (Figure 10). Results were consistent with data including all subjects. The main effect for session remained significant, $F(1, 56) = 10.432$, $p = .002$, partial $\eta^2 = .157$, as did the main effect for group, $F(2, 56) = 4.181$, $p = .012$, partial $\eta^2 = .147$, and the interaction between group and session, $F(2, 56) = 3.733$, $p = .03$, partial $\eta^2 = .118$.

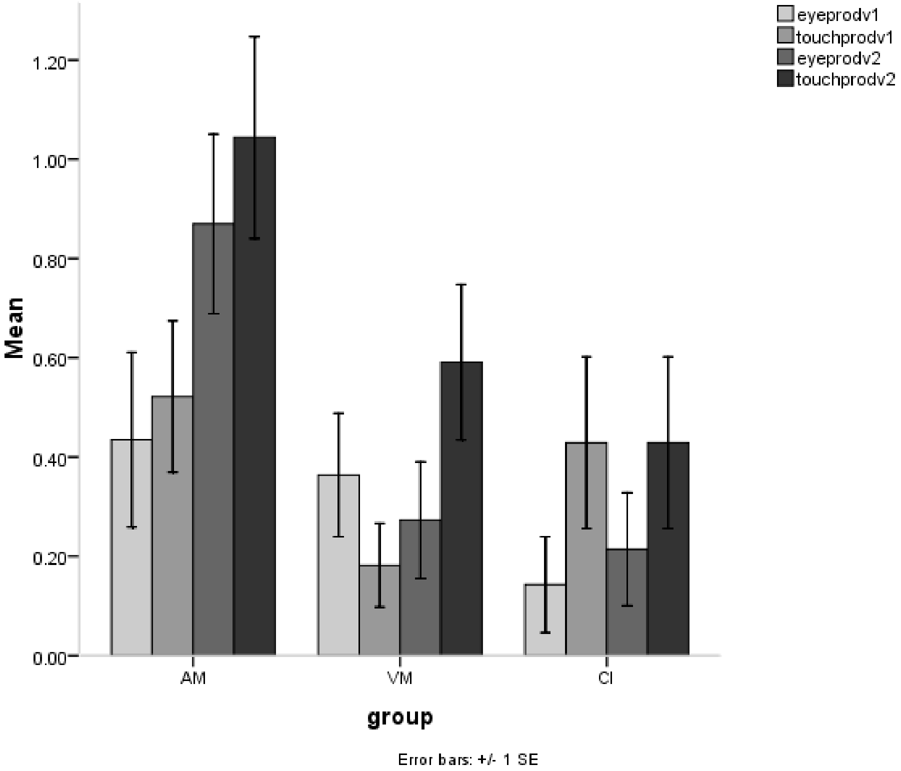

Figure 10. Mean production scores separated by gesture cue, group, and visit, English speaking-only subjects.

Data were re-analyzed to only include the NH children who were tested two days in a row (Figure 11). Again due to the decrease in subjects, we combined gesture cues in the statistical analysis. Results were consistent with previous analyses. The mixed-model ANOVA indicated a significant main effect for session, $F(1, 40) = 6.176$, $p = .017$, partial $\eta^2 = .134$, and a significant main effect for group, $F(2, 40) = 17.1$, $p < .001$, partial $\eta^2 = .37$. Post-hoc tests confirmed that the AM group scored higher than the CI group ($p < .001$) and the VM group ($p = .008$) and there was no significant difference between the CI and VM groups ($p = .555$). There was a marginally significant interaction between group and session, $F(2, 40) = 3.009$, $p = .06$, partial $\eta^2 = .131$, such that the AM group showed marginally significant improvements from Visit 1 to Visit 2, *t*(10) = -2.02, *p* = .07. There was no significant difference for the VM group, *t*(11) = -.842, *p* = .417, or the CI group, *t*(19) = .000, *p* = 1.00. These findings are inconsistent with the larger group data, but this is likely the result of the small number of subjects in the NH groups. Visual inspection of the graph in Figure 3.8 shows non-overlapping standard error bars for the AM group, and the same pattern for the VM group, suggesting that there is a difference between Visit 1 and Visit 2 for NH participants, although there is insufficient power to demonstrate this statistically.

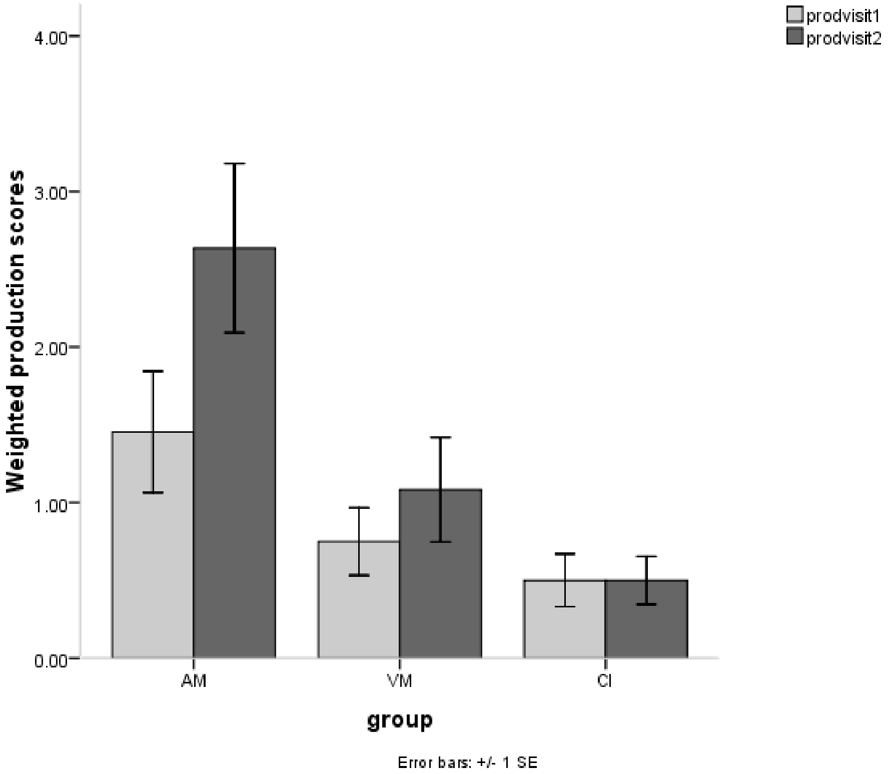

Figure 11. Weighted production means for participants who were tested two days in a row.

During administration of the production task, children could make an attempt to produce the novel word, or they could refuse to attempt the task. Therefore, the possibility existed that children in the AM group received higher scores because they were more willing to attempt to name the novel objects. To investigate this possibility, we determined the number of times children attempted to name the object, regardless of accuracy. We coded attempts as any intentional production made by the child after the experimenter initiated the uncued production trial, but prior to the initiation of the cued production trial. Refusals (e.g., “I don’t know”) or reflexive vocalizations were not considered attempts. We scored attempts as a proportion of the total number of production trials. Descriptively, the CI group had the highest mean proportion of attempts with 43% (*SD* = .37), followed by the VM group with 38% (*SD* = .31), and then the AM group with 25% (*SD* = .31). We analyzed data in an independent sample t-test (two-tailed). There was no significant difference in the number of attempts between the CI group and the VM group, *t*(45) = -.529, *p* = .60. There was a marginally significant effect between the CI and AM groups, *t*(46) = -1.804, *p* = .078. Based on these data, we can conclude that the significant difference in production scores between the CI and AM groups is not due to failure of the CI group to attempt naming, as they showed marginally more attempts than the AM group.

The criteria we used to determine production accuracy was strict, in that participants had to produce all four phonemes for a novel word accurately (taking into account consistent phonological error patterns). As a result, uncued production scores were uniformly low across all participants. We reanalyzed the data using more lax criteria, to determine if production scores differed within and across groups. Participants received credit if they produced any correct phonemes in the target word prior to the cued production trial. Each production trial was scored as a proportion, with four being the denominator in the equation (four possible phonemes). If the child accurately produced one of the phonemes in the target word, he/she received a score of 0.25 for that trial. If the child produced two phonemes, he/she received a score of 0.50. Three phonemes correct equaled a score of 0.75 and four phonemes correct equaled a score of 1. In this context, productions were deemed accurate regardless of position. For example, if a child labeled an object as "domi" and the target was "modi", the production was scored as a 1. Even using this lax criterion, uncued production scores were still extremely low for all three groups. Results using the lax criteria are displayed in Figure 12.

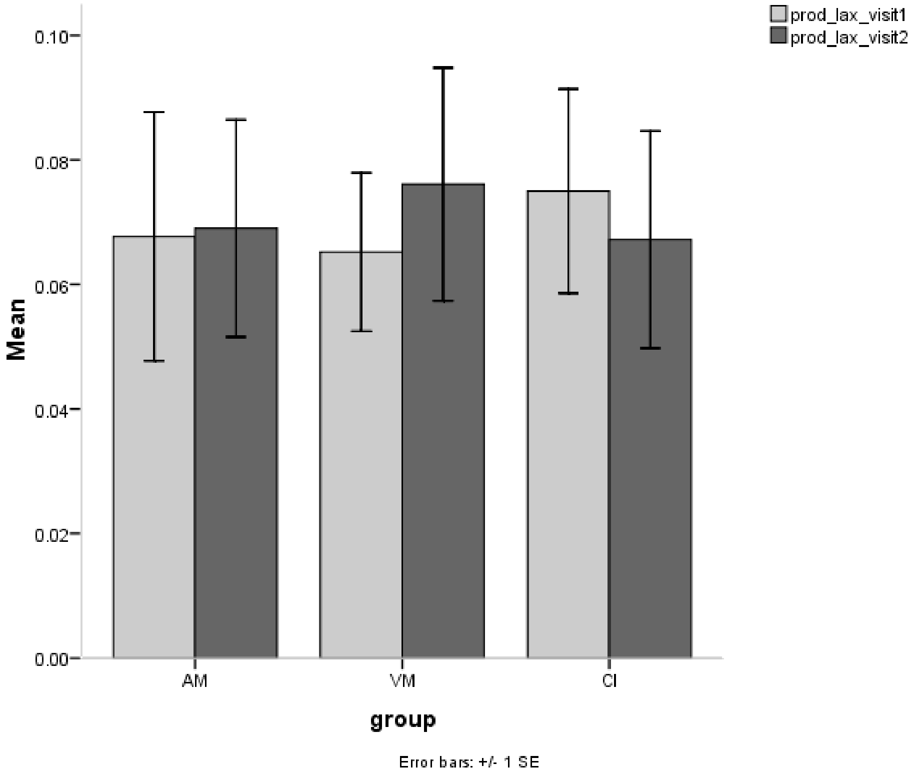

Figure 12. Mean production scores using "lax" criteria scoring.

Children in the CI group demonstrated a mean proportion of 6.9% phonemes correct at Visit 1 (*SD* = .08) and 6.7% at Visit 2 (*SD* = .08). Children in the AM group showed a mean proportion of 6.8% phonemes correct at Visit 1 (*SD* = .10) and 6.9% at Visit 2 (*SD* = .09). Children in the VM group showed a mean proportion of 6.5% phonemes correct at Visit 1 (*SD* = .06) and 7.6% at Visit 2 (*SD* = .09). We analyzed performance in a mixed-model ANOVA, with session as the within-subject variable and group as the between-subject variable. The gesture cue category was combined. Using this "lax" criteria, the ANOVA indicated no significant differences between session, $F(1, 64) = .024$, $p = .877$, partial $\eta^2 = .000$ or group, $F(2, 64) = .009$, $p = .991$, partial $\eta^2 = .000$. There was also no significant group by session interaction, $F(2, 64) = .323$, $p = .725$, partial $\eta^2 = .010$. This analysis indicates that all children found it extremely difficult to name the target objects without some form of scaffolding, even when we utilized a favorable scoring method.

We also compared the results for uncued versus cued production to determine the degree to which the inclusion of a phonological cue facilitated novel word retrieval. To calculate this, we divided the number of words produced with and without cueing by the total number of novel words. Figure 13 displays how phonological cues affected production across the three groups and across visits. The striped bars indicate the proportion of novel words participants named without a phonological cue, whereas the white bars indicate the proportion of novel words that children could name when the experimenter provided a phonological cue. Across all three groups, these scores are uniformly low regardless of visit. At Visit 1, the AM group named 1% of the novel words without a cue, the VM group named .6% and the CI group named .5%. At Visit 2, the AM named 2% and the VM group named 1%. The CI group was unable to name any words without cues. Results for cued production vary across groups and visits. When provided with a phonological cue, the AM group named 11% of the words at Visit 1 and

22% at Visit 2. The VM group named 6% of the words at Visit 1 and 12% at Visit 2. The CI group named 6% of the words at both Visit 1 and Visit 2.

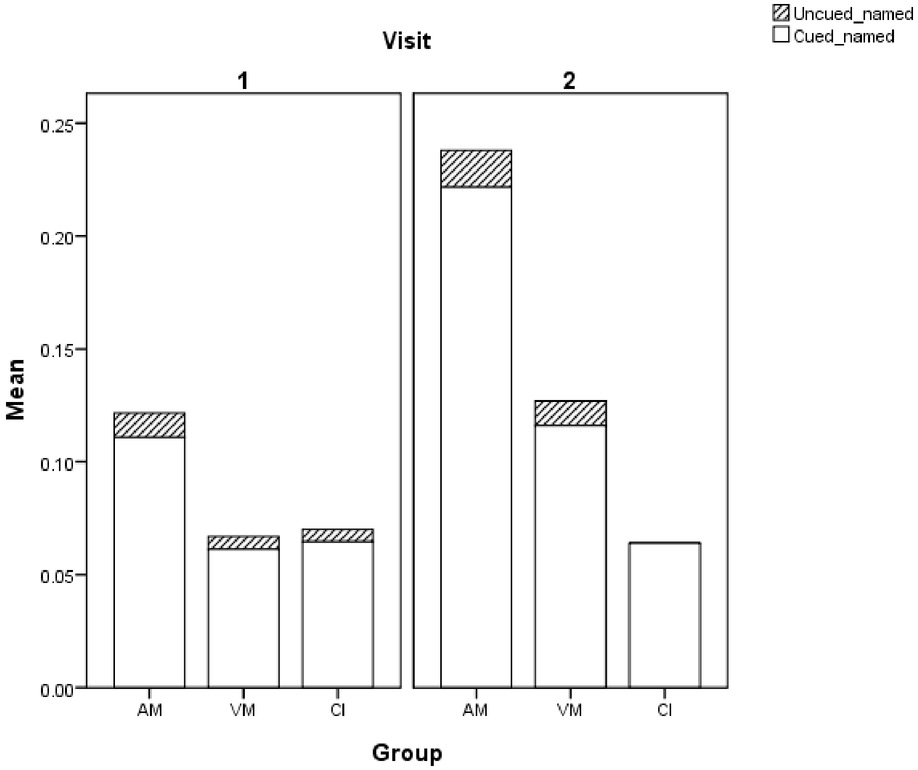

Figure 13. Proportion of uncued versus cued production separated by visit.

To determine if these differences were significant, we conducted a mixed-model three-way ANOVA, with session (Visit 1 vs. Visit 2) and phonological cues (uncued production vs. cued production) as the within-subject variables and group (AM vs. VM. vs. CI) as the between-subject variable. There was a significant main effect for phonological cues, *F*(1, 64) = 48.57, *p* < .000, partial η^2 = .43, indicating that participants named more novel objects with a cue than without a cue. Consistent with previous data, there was a main effect for session, *F*(1, 64) = 13.60, *p* < .000, partial η^2 = .18, in which production scores at Visit 2 were better than at Visit 1, and a main effect for group, *F*(2, 64) = 6.43, *p* = .003, partial η^2 = .17, in which the AM group was significant better at production than the CI group (*p* = .005). The difference between the AM and VM group was marginally significant (*p* = .07) and there was no significant difference between the VM and CI groups.

There was a significant interaction for session by group, *F*(2, 64) = 4.43, *p* = .02, partial η^2 = .12. The three-way interaction between phonological cues, session, and group was marginally significant, *F*(2, 64) = .2.92, *p* = .06, partial η^2 = .06. Finally, the interaction between phonological cues and session was also significant, *F*(1, 64) = 8.36, *p* = .005, partial η^2 = .12.

We conducted tests of simple main effects to further analyze the significant interactions between session and group, phonological cues and session, and the marginal three-way interaction. We performed a series of paired sample t-tests to examine the differences in performance from Visit 1 to Visit 2 within each group. No groups showed any significant improvement in uncued production between Visit 1 and Visit 2. The AM group showed significant improvement in cued production from Visit 1 to Visit 2, *t*(23) = -3.438, *p* = .002. The VM showed a marginally significant improvement in cued production between Visit 1 and Visit 2, *t*(22) = -2.002, *p* = .058. In contrast, the CI group showed no change in cued production across the two visits, *t*(19) = .027, *p* = .979.

In sum, although novel word production was difficult for all groups, all groups benefitted from the experimenter providing a phonological cue during word retrieval. Furthermore, we can see that the facilitating effects of the cueing grew over time, as the proportion of words that the NH children could name with a cue increased from Visit 1 to Visit 2. The CI group did better with scaffolding than with no cues, but they did not show any changes from fast mapping to word retention.

Extension

In order for participants to receive the extension task, they had to accurately identify the target object on the comprehension task. All of the children in the CI and AM groups accurately identified at least one target object during the comprehension trials, and therefore moved on to an extension trial. One child in the VM group did not identify any targets during the comprehension trials at Visit 1, and therefore did not receive any extension trials. At Visit 2, all of the children in the VM group identified at least one target during comprehension and completed at least one extension trial. We calculated extension scores as a proportion of the total number of objects accurately extended divided by the total number of objects accurately identified in the comprehension test. Extensions were accurate if a participant identified the extension of the target and replied “no” when the examiner repeated the question “Is there another one?” An ANOVA could not be performed because of the lack of variance in the AM group. Therefore, we analyzed the data with the non-parametric Wilcoxon signed-ranks test. The AM group showed significantly higher extension scores than the CI group at Visit 1 ($Z = -2.214$, $p = .03$) and Visit 2 ($Z = -2.06$, $p = 0.04$). There were no significant differences between the AM and VM groups at Visit 1 ($Z = -1.633$, $p = .102$) or Visit 2 ($Z = -1.633$, $p = .102$) or the VM and CI groups at Visit 1 ($Z = -.990$, $p = .322$) and Visit 2 ($Z = -9.47$, $p = .344$). Results can be seen in Table 12 and Figure 14.

It must be noted that in the VM group, all of the children extended the novel label to the extension object without exception. A small subset of children (4/23) continued to select objects that were not extension objects when the examiner asked for additional objects. In other words, these three children overextended the novel object label when prompted to “find another one.” In all three cases, the VM participants were accurate at extending on the control trial with familiar objects. This indicates that they understood the directions by the examiner when they were asked to extend (or not extend) familiar items (e.g, a dog), but they had difficulty defining the category boundaries of the newly learned word-referent pairs.

Table 12. Descriptive statistics for extension scores.

Condition	Group	Mean (SD)
Extension Visit 1	AM	1.00 (0.00)
	VM	0.89 (0.30)
	CI	0.82 (0.33)
	Total	0.91 (0.26)
Extension Visit 2	AM	1.00 (0.00)
	VM	0.90 (0.29)
	CI	0.78 (0.39)
	Total	0.90 (0.28)

The situation with the CI children was more complicated. Seven out of 24 CI participants were inaccurate on at least one extension trial. Two of these children were correct on the control trials, suggesting that they understood the task. Both of these children were “overextenders” like the VM children. Three other “overextenders” were incorrect on the control trials (even after training with familiar objects at the start of the experiment), suggesting that they did not understand the question put forth by the examiner. One of the CI participants (CI 032) underextended on two trials at Visit 1 (i.e., indicated that there were no extensions for the target item) and overextended for one trial. This child was incorrect on the control trial at Visit 1 and correct at Visit 2. The other CI participant (CI 016) underextended on two trials and did not overextend. This child was correct on the control trial at Visit 1 and incorrect at Visit 2. In summary, due to incorrect or inconsistently correct performance on the control trials, we must suspect that five children in the CI group did not understand the extension task. Two other subjects demonstrated overextension despite good comprehension of the task requirements.

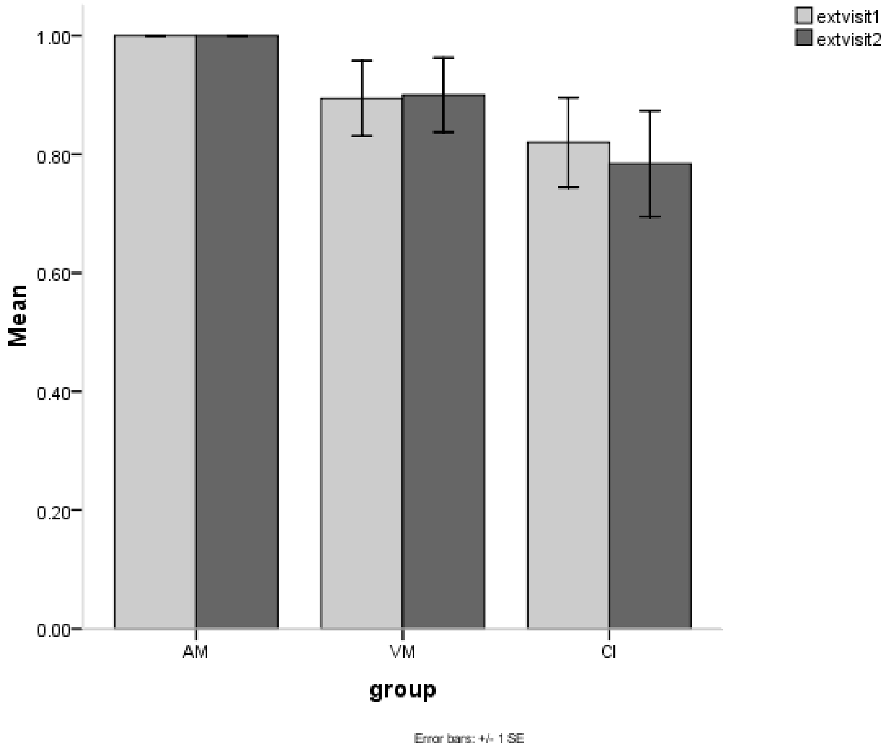

Figure 14. Mean extension scores for AM, VM, and CI groups across visits.

Multiple Regression Analyses

We conducted several multiple regression analyses to determine which variables accounted for the variance in fast mapping scores at Visit 1 and word retention scores at Visit 2. Composite word learning score were created by adding the production and comprehension scores together for each participant. These composite scores served as the dependent variables and will henceforth be referred to as composite fast mapping (for

Visit 1 scores) and composite word retention (for Visit 2 scores). Independent variables included PPVT-III raw scores as a measure of vocabulary size, MLNT whole-word correct scores as a measure of speech perception ability, chronological age, and age at implantation. PPVT-III raw scores were utilized because the normative sample for the PPVT-III did not include children with hearing loss; therefore, standard scores may not be accurate for this population.

We conducted two different multiple regression analyses for both fast mapping and word retention. This was done to isolate the contributions of two different constructs on word learning: lexical knowledge/perception (as measured by PPVT-III and MLNT) and time factors (as measured by age at implantation). We included chronological age in both of the regressions so we could separate the effects of this variable from the other independent variables. In the first regression, we analyzed two separate models in an attempt to differentiate the amount of unique variance that was being accounted for by vocabulary size and speech perception ability. In the first model, chronological age and PPVT-III raw scores were entered first, and then MLNT word-correct scores, and in the second model, chronological age and MLNT word-correct scores were entered first, then PPVT-III raw scores. For the second regression equation, chronological age and age at implantation were both entered into the regression as the independent variables.

For the CI group at Visit 1, none of the independent variables contributed significantly to the variance in fast mapping. There were some apparent trends that will be described, however. For model 1 (Table 13), in which we first entered chronological age and PPVT-III raw scores into the equation, followed by MLNT word-correct scores, chronological age and PPVT-III raw scores accounted for 14% of the variance. MLNT word-correct did not contribute any additional variance.

Table 13. Summary of regression analysis with composite fast mapping score as the dependent variable and chronological age and PPVT entered first.

	R	R^2	Sig.	Predictor variable	B	SE B	β	Partial r
Model 1	.37	.14	.23	Chron age	.248	.49	.12	.11
				PPVT-III	.031	.03	.29	.26
Model 2	.37	.14	.41	Chron age	.248	.51	.12	.11
				PPVT-III	.03	.03	.29	.21
				MLNT	.098	2.79	.01	.008

For model 2 (Table 14), chronological age and MLNT word-correct scores together accounted for 10% of the variance. When PPVT-III raw scores were added, this accounted for an additional 4% of the variance. We conclude that vocabulary size and speech perception ability are highly co-linear. Chronological age, vocabulary size, and MLNT do not account for a significant amount of variance in the fast mapping performance of children with CIs. In the second regression (Table 15), chronological age and age at implantation accounted for 8% of the variance, but this was not significant either.

Table 14. Summary of regression analysis with composite fast mapping score as the dependent variable and chronological age and MLNT entered first.

	R	R^2	Sig.	Predictor variable	B	SE B	β	Partial r
Model 1	.31	.10	.40	Chron age	.450	.46	.22	.21
				MLNT	1.575	2.32	.15	.15
Model 2	.37	.14	.41	Chron age	.248	.51	.12	.11
				MLNT	.098	2.79	.01	.008
				PPVT-III	.03	.03	.29	.21

Table 15. Summary of regression analysis with composite fast mapping score as the dependent variable and chronological age and age at implantation as the independent variables.

	R	R^2	Sig.	Predictor variable	B	SE B	β	Partial r
Model	.29	.08	.40	Chron age	.559	.45	.28	.26
				Age at CI	.077	.88	.02	.02

In contrast, all models accounted for a significant proportion of the variance in composite word retention scores. When we entered chronological age and PPVT-III raw scores first (Table 16), 39% of the variance was accounted for. MLNT word-correct scores contributed an additional 4% to the variance.

Table 16. Summary of regression analysis with composite word retention score as the dependent variable and chronological age and PPVT entered first.

	R	R^2	Sig.	Predictor variable	B	SE B	β	Partial r
Model 1	.62	.39	.02	Chron age	.171	.57	.07	.07
				PPVT-III	.065	.03	.57	.50
Model 2	.66	.43	.03	Chron age	.354	.58	.15	.15
				PPVT-III	.038	.04	.33	.25
				MLNT	3.137	2.72	.30	.28

When we entered chronological age and MLNT word-correct scores first (Table 17), 40% of the variance was accounted for. PPVT-III raw scores accounted for an additional 3% of the variance (R = .66, F(3, 16) = 4.01, p = .025). Again, this demonstrates the high degree of collinearity between speech perception and PPVT-III. At Visit 2, however, both variables are accounting for a small proportion of unique variance in word retention and their combination with chronological age accounts for 43% of the variance in retention scores.

Table 17. Summary of regression analysis with composite word retention score as the dependent variable and chronological age and MLNT entered first.

	R	R^2	Sig.	Predictor variable	B	SE B	β	Partial r
Model 1	.63	.40	.01	Chron age	.737	.45	.32	.37
				MLNT	4.994	2.05	.47	.51
Model 2	.66	.43	.03	Chron age	.354	.58	.15	.15
				MLNT	3.137	2.72	.30	.28
				PPVT-III	.038	.04	.33	.25

In the second regression model (Table 18), chronological age and age at implantation also accounted for a significant proportion of the variance. The majority of the contribution appeared to come from the age at implantation variable. Of the two variables, it was the only one to demonstrate significance (chronological age β = .15, *t* = .65, *p* = .52; age at implantation β = .501, *t* = 2.15, *p* = .047). It should also be noted that age at implantation and composite word retention had a stronger positive partial correlation (*r* = .46), than chronological age (*r* = .16).

Table 18. Summary of regression analysis with composite word retention score as the dependent variable and chronological age and age at implantation as the independent variables.

	R	R^2	Sig.	Predictor variable	B	SE B	β	Partial r
Model 1	.60	.40	.02	Chron age	.355	.54	.15	.16
				Age at CI	1.968	.92	.50	.46

The finding that there was a positive correlation between age at implantation and word retention was inconsistent with our predictions and with previous research on the influence of age at implantation. Therefore, we performed additional statistics to determine if there was a third variable mediating the relationship between age at implantation and word retention. One variable that could be a potential confound was vocabulary size. The correlation between age at implantation and PPVT-III raw scores was .13 (*p* = .55), however, making it unlikely that vocabulary size was mediating the relationship between age at implantation and word learning. Another variable that could be a potential confound was testing site. Of the 20 children who completed both visits, 13 of the subjects attended one private auditory-oral school (Child's Voice) and 7 attended a different auditory-oral school (St. Joseph's). Independent-sample t-tests were conducted to determine if there were disparities between the two programs in terms of independent and dependent variables. Some variables of interest, including chronological age, length of CI experience, PPVT-III standard scores, and maternal education, showed little or no difference between the two groups. There was a marginally significant difference between age at implantation, *t*(18) = -1.826, *p* = .08; children at Child's Voice, on average, received their CIs at younger ages. For the dependent variable, composite word retention scores, there was a statistically significant difference, *t*(18) = -2.35, p = .03, with children at St. Joseph's achieving higher scores. Results should be interpreted with caution given the small numbers of subjects, but it is does seem possible that testing site is a confounding variable that mediated the relationship between age at implantation and word retention. Therefore, it would appear that the positive relationship between the two variables is spurious.

To compare performance in CI group to the NH groups, we also conducted regression analyses in the AM and VM groups, with composite word learning scores at Visit 1 and Visit 2 as the dependent variable and chronological age and PPVT-III raw scores as the independent variables. For the VM group, the independent variables did not significantly predict word learning scores at Visit 1 or Visit 2 (Table 19). For the AM group, 52% of the variance in word learning at Visit 1 was accounted for by chronological age and vocabulary size, with the latter showing a higher partial correlation (r = .34) than the former (r = .07). At Visit 2, the model did not account for a significant proportion of the variance in composite word learning (Table 20).

Table 19. Summary of regression analysis for VM group with composite word retention scores at Visit 1 and 2 as the dependent variables and chronological age and PPVT-III raw scores as the independent variables.

	R	R^2	Sig.	Predictor variable	B	SE B	β	Partial r
Visit 1	.22	.05	.61	Chron age	.257	.86	.13	.07
				PPVT-III	.011	.05	.10	.05
Visit 2	.33	.11	.32	Chron age	.960	.97	.41	.22
				PPVT-III	-.013	.05	-.10	-.05

Table 20. Summary of regression analysis for AM group with composite word retention scores at Visit 1 and 2 as the dependent variables and chronological age and PPVT-III raw scores as the independent variables.

	R	R^2	Sig.	Predictor variable	B	SE B	β	Partial r
Visit 1	.52	.27	.04	Chron age	.215	.67	.09	.07
				PPVT-III	.059	.04	.45	.34
Visit 2	.39	.15	.18	Chron age	.707	.85	.25	.18
				PPVT-III	.027	.05	.17	.13

Summary of Results

In the above results, there were a large number of significant effects across Visit 1 and Visit 2, as well as comprehension and production. There were also a smaller number of effects that were marginally significant. A summary of the significant results appears below in Table 21. A summary of the marginally significant results appears below in Table 22.

Table 21. Summary table of significant and marginally signficant effects

Significant effects	Test interval	Test measure
	Visit 1 (fast mapping)	
		Comprehension
		AM > CI, CI = VM AM, VM, CI > chance
		Production
		Cued production > Uncued production
		Extension
		AM > CI
	Visit 2 (word retention)	
		Comprehension
		Retention > Fast mapping AM > CI, CI = VM AM, VM, CI > chance VM named foil > VM unnamed foil
		Production
		Retention > Fast mapping AM > CI AM retention > AM fast mapping VM retention > VM fast mapping Cued production > Uncued production AM retention cued production > AM fast mapping cued production
		Extension
		AM > CI
		Regressions
		Model 1 (chron. age, speech perception, vocabulary size, age at CI) Model 2 (chron. age, age at CI) AM (chron. age, vocabulary size)

Table 22. Summary table of marginally significant effects

Marginally significant effects	Test interval	Test measure
	Visit 1 (fast mapping)	
		Comprehension
		VM touch + eye gaze > VM eye gaze only AM named foil > AM unnamed foil VM named foil > VM unnamed foil
		Production
		AM > CI CI touch + eye gaze > CI eye gaze only
	Visit 2 (word retention)	
		Production
		AM > VM VM touch + eye > VM eye only AM cued production > VM cued production VM retention cued production > VM fast mapping cued production

CHAPTER 4

DISCUSSION

Group Differences on Word Learning Measures

We predicted that children with CIs would perform significantly worse on a novel word learning task relative to their same-age hearing peers, but would perform similarly to their vocabulary-matched hearing peers. The differences between the AM and CI groups would be significant in terms of comprehension and production across fast mapping and word retention, as well as word extension. The main effects from the mixed-model ANOVAs support the above predictions. We did find significant between-group differences between the AM and CI groups in both comprehension and production of novel words on the fast mapping and word retention measures. In addition, these differences remained significant even when we utilized a conservative approach and statistically controlled for maternal education level. The present findings are consistent with previous literature on children who are hard of hearing (Stelmachowicz et al., 2004), and children with CIs (Houston et al., 2005; Tomblin et al., 2007). It is also important to note that the participants in this study all received their CIs at young ages and were enrolled in intensive auditory-verbal programs. Furthermore, a majority of the subjects (14 out of 24) tested within the average range on the PPVT-III. Thus, even in the "best-case scenario," children with CIs will show delays compared to their age-mates in their ability to link a word to its referent and maintain that link over time. Professionals should be aware of the discrepancy in word learning skills when working with this population.

This is the first study to directly compare children with CIs to a group of vocabulary-matched hearing children. Previously, investigators relied entirely on correlations as support for a relationship between vocabulary size and word learning (Lederberg & Spencer, 2009; Pittman et al., 2005). We found no difference between children with CIs and their vocabulary matches; therefore, we have strong evidence that vocabulary size constrains word learning, both at the initial stage of mapping a word to its referent as well as retaining that word in memory after a delay.

With regards to the word extension testing, all participants in the AM group were successful at identifying the extension to the novel word/referent. The ability to extend a novel label to an exemplar is well-established by age 4 (Waxman & Booth, 2000). The average age for the AM group in the present study is 4 years, 10 months; therefore, it is not surprising that this group had no difficulty with the task.

Within the other two groups, three VM children (13%) and seven CI children (29%) were incorrect on at least one extension trial across the two visits. When the CI and VM groups were compared, some participants showed differences on the types of errors they made on the extension task. The three VM children can all be termed "overextenders." They were accurate at identifying the extension object when the examiner initially posed the question, "Is there another one?" When the examiner repeated the question, the VM children continued to hand over objects that were not extensions. It is possible and even likely, that the children did not understand the vague term "another one," however, in these three cases the participants did not overextend on the control trials at Visit 1 and Visit 2, which involved finding extensions for a familiar object (small toy dogs). This suggests that these typically-developing children did have some understanding of how to extend the label for a word, but this process may become disrupted when children are presented with novel objects.

Behrend, Scofield, and Kleinknecht (2001) examined the ability to extend novel words to additional exemplars in typically-developing 2, 3, and 4-year-olds. They tested 77 children, with a mean age of 3 years, 8 months, and found that the participants accurately extended the novel words to their appropriate exemplars on 71% of all trials. Similar to the Behrend et al. study, the VM group in the present study had an average age of 3 years, 8 months. They accurately extended the novel words on 91% of all trials, but the present study could also be considered easier because the children only had to extend the novel label to one exemplar (compared to four possible exemplars in Behrend et al.).

The CI children presented another pattern. Out of the seven CI children who had errors on the extension task, five children were unable to consistently demonstrate accurate extension for even familiar objects. Therefore, we must conclude that they did not understand the task. The other two children were accurate on the familiar items. In addition, they demonstrated overextensions like the VM children who made errors. It is interesting that all of the children who were accurate on the control trials had overextensions in the experimental trials, and none had underextensions. This appears to fit the trend for the emergence of under- and overextensions in language development. Dromi (2008) recorded all of the words that her daughter, Keren, produced from first words until two word combinations, with particular attention to extensions. She observed that underextensions tended to coincide with the acquisition of a new word and occurred at an infrequent but stable rate until a vocabulary burst, at which point they decreased. Overextensions for newly learned words emerged later in development, just prior to the vocabulary burst and the onset of word combinations. Data collection was discontinued when Keren was 17 months old and began combining words. At that point, use of underextensions had declined, and overextensions continued at a reduced level (approximately 10% of her vocabulary).

All of the children in the present study were well past the point of two-word combinations. However, the three VM children were among the youngest children in the study (ages 3;0, 2;8, and 3;3). One of the CI children was also very young (3;2) with vocabulary scores in the average range (PPVT-III standard score of 93). The other child with a CI was older (4;5), but presented with significant delays in vocabulary (standard score of 70). As none of these children demonstrated underextensions, they appear to be following the developmental trend seen in the longitudinal study by Dromi (2008), in which underextensions occurred early on and overextensions occurred later. Given the young ages of four of the participants (VM and CI combined), and the limited vocabulary size of the other, their use of overextensions is likely closely tied to their vocabulary size, highlighting yet again the importance of lexical knowledge to the word learning process.

Administration of the extension task was contingent on performance on the comprehension task. Participants only received the extension task if they were correct on the comprehension task. It was possible for one child to be tested on eight extension trials during a visit (if that child was accurate on all comprehension trials) and another child to only be tested on only one extension trial. Given that the CI and VM groups were lower overall on comprehension, they had fewer trials on which to demonstrate extension. Therefore, these scores are less sensitive measures of extension ability. Using a paradigm more like Experiment 2 in Behrend et al. (2001) could be useful. In this paradigm, the examiner labels the target object for the child ("My uncle gave me this koba"), leaves the target in full view along with four extensions and four foils, and then proceeds to ask ("Are there any other kobas here or not?"). This paradigm only measures children's ability to extend the novel label, not fast mapping or word retention, but would be a more accurate way to determine whether or not children with CIs have more difficulty with extending a novel name compared to AM or even VM peers.

Although a small number of the CI children displayed difficulty with the process of word extension, the majority of them (69%) performed perfectly on this index of word learning. Therefore, we may conclude that word extensions are a relative strength for this population compared to word acquisition and word retention. This tells us that these children are capable of forming links not just between a specific object and label, but also between a general category and label, which has important implications for real-world language usage. If children can generalize a word to additional exemplars, they can use that knowledge to form category boundaries for different objects. Attention to category boundaries in turn accelerates vocabulary development because as children become attuned to specific object properties, they utilize that knowledge to learn more words (Smith et al., 2002).

A relative weakness for the CI group in the present study was word retention. Although they did not perform significantly worse than the VM group at Visit 2, they did not show the same trend as the NH groups of improving over time. The next section will discuss performance on the word retention measures in depth, as it has important implications for vocabulary growth over time.

Word Retention Measures

The second prediction was that children with normal hearing would show an increase in performance between acquisition and word retention testing. This hypothesis was based on previous studies with adults (Dumay & Gaskell, 2007) and children (McGregor et al., 2008), in which word learning performance increased following a delay of one to three days. We were unsure if children with CIs would follow this pattern as no one had ever examined word retention in children with CIs (or even children with hearing loss) for more than a three-hour delay.

We must first point out that we did not see a significant main effect for session or a significant interaction when we utilized the lax criterion for production. This was likely due to the fact that the lax criterion only included performance on the uncued production task. Even when participants were given credit for producing any of the target phonemes of a novel word in any position, performance was extremely low. Therefore, we may conclude that the interaction in production scores was driven by performance on the cued production task.

We also did not see a significant main effect for session in comprehension or production scores when we included maternal education level as a covariate in the ANOVA. Changes in performance from Visit 1 to Visit 2 may be considered indicative of learning ability. Therefore, the lack of a significant within-subject main effect indicates that there are individual differences associated with parental education background that are present in children's learning skills, regardless of hearing status. By controlling for maternal education level, we may be, in effect, controlling for variations in learning that arise from differences in parental background. Regardless, even when we controlled for maternal education level, we continued to see a statistically significant interaction between session and group, which tells us that differences in learning ability across groups cannot be solely attributed to parental education level.

When we combined scores from the uncued and cued production tasks, children in the AM and VM groups showed significant improvement from Visit 1 to Visit 2. Children in the CI group showed no significant change in production scores between the two visits. This is consistent with the findings in Houston et al. (2005), in which CI participants maintained performance levels after a two-hour delay. With regards to comprehension, we did not see a significant interaction for session and group, although we did find a significant main effect for session. This suggests that we may have lacked sufficient power to show a significant interaction.

What accounts for this interaction when we combine uncued and cued production scores? First we must compare our task to previous research to determine why the hearing children did better at Visit 2 than Visit 1. There are several studies that show a similar trend in improving word-learning scores over time in both children and adults (Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; McGregor et al., 2009). McGregor and colleagues trained children on the spatial term "under," using various means of scaffolding to facilitate learning. Children demonstrated a better understanding of "under" following a two to three day delay in training than they did at a post-test immediately following training. Gaskell and Dumay trained adults on novel words that overlapped with real words (e.g., "cathedruke" instead of "cathedral"). Immediately after training using a pause detection task, participants showed no indication that they had integrated the novel words into their lexicon. When tested one week later, however, participants responded more slowly in the pause detection task, suggesting that the novel words had consolidated into memory. This was in spite of the fact that they had received no additional exposure to the novel words between initial training and testing.

These reports seem to share one point in common: additional learning took place following training in the absence of further exposure, but in the presence of a delay that included sleep. This leads us to a well-established line of research that investigates the process of memory consolidation across different perceptual and motor domains. In particular, this area focuses on the enhancement of learning over time through sleep-dependent processes. Walker (2005) describes this process in a model of sleep and memory consolidation. In this model, initial learning takes place during a period of acquisition. The acquisition period occurs during waking hours and involves forming the initial memory representations or traces. It can be measured by one’s performance level immediately after training. In word learning, this can be equated to the fast-mapping stage of lexical acquisition. Memory traces formed during acquisition are weak and prone to be disrupted by interference. The poor retention and extension performance of the children in the Horst and Samuelson (2008) study may be seen as an example of this.

Following the acquisition period, memory consolidation occurs. Consolidation may contribute to the slow-mapping phase of word learning, as described by Carey (1978), although slow mapping may be accomplished with repeated exposures to the word as well. Walker divides consolidation into two phases: stabilization and enhancement. Stabilization involves the process of maintenance. It occurs when the memory trace becomes resistant to interference. Like acquisition, stabilization appears to take place during periods of wakefulness and is not dependent on sleep.

The second phase of memory consolidation is enhancement. In this phase, additional learning takes place that is above and beyond what occurred during the acquisition and stabilization phases, but in the absence of any additional exposure to the stimulus material. Unlike acquisition and stabilization, research suggests that enhancement is sleep-dependent. It also appears to occur in both motor and perceptual domains on procedural memory tasks (i.e., long-term memory for how to do things, which involves automatic retrieval of procedures). For example, Walker et al. (2002; 2003) trained subjects on a sequential finger-tapping task. Investigators trained subjects at 10:00 pm or 10:00 am and retested them 12 hours later, and then another 12 hours after that. Those subjects who received training at night demonstrated significant improvement the next morning, but no change 12 hours later. Subjects trained at 10:00 am showed the opposite pattern; no significant change when tested at 10:00 pm, but significant improvement when tested the next morning. Karni et al. (1994) found similar results in the visual perception domain, as did Atienza and colleagues in terms of auditory perception (Atienza et al., 2002; 2003).

The model described by Walker (2005) relates to the findings in the present study. Participants in all three groups appeared to undergo an initial acquisition phase as a result of the word learning training because they all demonstrated performance levels on the comprehension task at Visit 1 that were significantly above chance performance. Children found the production task challenging at the first visit; in the AM group, they only labeled one out of eight items on average and in the CI and VM groups, only half a word. At the second visit, the AM group, and to a lesser extent, the VM group, showed signs of both phases of memory consolidation: stabilization and enhancement. Not only did their performance stabilize over time, but they also demonstrated enhancement by naming objects that they had not displayed knowledge of at Visit 1. Importantly, this enhancement took place in the absence of any additional training between Visit 1 and Visit 2. It also appears that it was the phonological word-form representation that showed the effects of consolidation, as opposed to the semantic representation. We can base this supposition on the finding that there was no significant interaction between session and visit for comprehension performance (a receptive/declarative learning task, in which the participant would have to identify the referent for a target word), but there was an interaction for the production performance using the strict criterion scoring (an expressive/procedural learning task, in which the participant would have to produce the target word form). These results are consistent with previous studies involving word learning and memory consolidation (Dumay & Gaskell; 2007; Gaskell & Dumay, 2003), which appears to relate to procedural memory (Gupta & Tisdale, 2009), as well as studies of memory consolidation and procedural memory in other sensory domains (Walker et al., 2002; 2003).

Although the CI group showed the same indicators of acquisition and stabilization, they did not show any enhancement of phonological word-form learning over time. Why would they not follow the same patterns as the NH children? This is particularly interesting when we compare the data from the VM group and CI groups, because it gives us an indication of what factors may be influencing memory consolidation. The two groups demonstrated similar levels of vocabulary knowledge, but only the VM group showed enhancement in word learning at Visit 2. The VM and CI groups also showed differences in which variables predicted word retention. Vocabulary size was a significant predictor of word retention in the CI group, but not the VM group. This suggests that another unknown variable was influencing performance for word retention for the VM children. One likely possibility could be working memory, specifically phonological short-term memory.

Working memory is the part of our memory system that temporarily stores and processes verbal and visuospatial input until it is transferred into long-term memory (Gathercole, 1999). One common framework of working memory describes it as a tripartite model (Baddeley & Hitch, 1974), with a central executive that controls attentional resources and information flow from temporary to long-term storage. There are also two modality-specific storage systems. The visuospatial sketchpad provides temporary storage for visual and spatial input. Phonological short-term memory (PSTM; also referred to as the phonological loop) is responsible for storage of speech. It has been argued that PTSM is an important mechanism for novel word learning. It permits one to store speech sound patterns and from there, individuals can develop stable, long-term representations of words in their lexicons (Briscoe & Rankin, 2009). Connectionist simulations have shown that both PSTM and vocabulary size are causally related to learning words at the phonological word-form level (Gupta & Tisdale, 2009). Therefore, when vocabulary size is controlled for, differences in PSTM could be directly affecting memory consolidation for expressive/procedural learning.

There is research to suggest that children with CIs show differences in PSTM compared to NH children, and it is possible that this could explain the discrepant findings. Researchers have posited that early auditory deprivation, in conjunction with the degraded electrical auditory signal presented through the cochlear implant, may result in neural reorganization in young children and differential developmental trajectories for phonological memory processing (Pisoni, 2008; Watson, Titterington, Henry, & Toner, 2007).

We can find evidence for developmental differences in PSTM for children with CIs based on their performances on nonword repetition, digit span, and sentence repetition tasks. Nonword repetition, in which individuals repeat back strings of novel words, is a frequently used measure of PSTM and is highly correlated with novel word learning up to age 5 (Bishop, North, & Donlan, 1996; Briscoe, Bishop, & Norbury, 2001; Gathercole, 1999). Several studies have found that children with CIs have significantly lower scores on nonword repetition tasks compared to their NH peers (Wass et al., 2008; Willstedt-Svensson et al., 2004). Auditory digit span is another measure of PSTM which involves repeating back numbers in correct serial order. Children with CIs show significantly shorter digit spans than AM peers (Pisoni & Cleary, 2003). They also exhibit longer interword pause durations during digit span recall, compared to hearing children (Burkholder & Pisoni, 2003). Longer interword pause durations are an indication of slower and less efficient retrieval of phonological information. This is turn reduces the memory span capacity, resulting in shorter digit recall. Speaking rate during sentence repetition is a third index of PSTM capacity. It is thought to be a measure of subvocal verbal rehearsal, which is how phonological stimuli can be maintained in working memory. Children with CIs demonstrate significantly longer sentence durations than hearing children. Burkholder and Pisoni interpreted results with digit span and sentence repetition as support for the hypothesis that children with CIs are less efficient at encoding and retrieving stimuli in PSTM, which may then have a cascading effect on higher-level cognitive processes such as learning and attention.

Watson et al. (2007) went a step further and examined the connection between early auditory processing and PSTM in CI users. From their perspective, early consistent exposure to a specific language drives automaticity for auditory processing cues, resulting in a child being able perceive incoming stimuli without having to allocate any higher-order attentional resources. Children with CIs experience early auditory deprivation, and once they do receive a CI, the input is degraded. As a result, they may not acquire the same degree of automatic processing of auditory signals that occurs in typical development. This leads to more attentional resources being allocated to perceiving the stimulus, which in turn leads to inefficiency in the working memory system. To test this theory, Watson and colleagues measured mismatched negativity (MMN) evoked potentials and PSTM in children with CIs and NH children. The MMN is a measure of automatic auditory sensory memory, unaffected by attention. If there is a link between lower level auditory processing, as measured by the MMN, and higher level working memory function, NH children with appropriate MMN activation should have good verbal working memory. Children with CIs would show disrupted performance on the MMN evoked potential and poor PSTM. Results supported this hypothesis. Children in the CI group did significantly worse on nonword repetition and digit span tasks. In the NH group, MMN activation strength was a significant predictor of nonword repetition, forward digit span, and backward digit span. There were no relationships between MMN activation and PSTM measures in the CI group. The authors concluded that there is a disruption in the connections between lower and higher level auditory memory processes in children with CIs, although given the small number of subjects, this null finding should be interpreted with caution.

To summarize, research indicates that children with CIs may have deficits in working memory ability compared to their NH peers, specifically with regards to PSTM. These deficits manifest themselves as reduced efficiency and speed for processing phonological input. If there is reduced efficiency in PSTM, this could possibly influence memory consolidation, the effects of which appear to occur at the level of phonological word-form representations (Gupta & Tisdale, 2009). Children with CIs may be able to form initial word-referent links at the same level as their NH peers, but their inefficiency in holding phonological word-form representations in temporary storage might disrupt their ability to engage in further enhancement of learning, as NH children do.

Furthermore, analysis of the error patterns in the three groups offers additional evidence for differences in the memory processes of the NH and CI groups. In the present study, we attempted to control for familiarity of objects during comprehension testing. Children saw a tray of six objects: the named target object and its exemplar, the unnamed foil from training and its exemplar, and a named target from another trial and its exemplar. Children had equal exposure to the named objects during training and comprehension testing, and slightly less exposure to the unnamed foils because these objects had not been presented during production testing, which preceded comprehension testing. At Visit 1, when in error, the NH groups both showed a preference for the named target from another trial in the comprehension array over the unnamed foil, suggesting that they retained some memory trace of which objects had been named, even when they could not recall which object was the target. The VM groups showed the same pattern of preference at Visit 2 (the AM group did not, but this is almost certainly due the limited number of errors they made at Visit 2). The CI children, in contrast, did not show any patterns in their error selections. These results suggest that the NH children might have retained some memory trace or connection of which objects had been labeled, even when they were incorrect on the comprehension task. The CI group, on the other hand, did not show any signs of recalling which foils were named or unnamed and therefore, do not seem to be forming the same connections. When they did not know the correct answer, they selected objects at random.

Of course, it is purely speculative to consider that underlying PSTM deficits could be leading to differences in memory consolidation for word learning in children with CIs. There is no evidence that children with CIs have poorer PSTM compared to their VM peers, as all the research to this point has only compared them to their AM peers. In addition, we did not collect data on traditional working memory measures such as nonword repetition or digit span, making it impossible to determine if there was a relationship between PSTM and word retention with these children. There is some evidence of such a link; Willstedt-Svensson et al. (2004) found a significant relationship between nonword repetition and word retention in a group of school-age children with CIs. Their retention task, which involved only testing production, was administered 30 minutes after training and acquisition testing. Within such a time frame, they may have been measuring the stabilization stage of consolidation. They could not have assessed any opportunities for enhancement, however, which is sleep-dependent (Walker, 2005).

There is also a simpler explanation for the results: the children with CIs may not have accurately perceived the novel words due to the degraded signal provided by the cochlear implant, resulting in differences in performance at Visit 2. Poor speech perception does not explain the results of the study overall, however. Test stimuli were presented in a quiet room at a conversational speech level with speechreading cues, which should have been more than adequate for the children with CIs to hear. If children in the CI group could not accurately perceive the novel word stimuli, then they would have done significantly worse than their VM peers in addition to the AM peers at the first visit. Instead, they achieved similar levels of performance compared to the VM peers. They also did significantly better than chance on comprehension, which indicates that they could perceive at least some of the novel words. Of course, the possibility still remains that the CI participants did not perceive all of the novel words or they perceived them well enough to match the word spoken by the examiner to their sparse representation, but not well enough to support consolidation and its manifestation as improved production at Visit 2. Additional research is needed to address the confound of accurately hearing the novel words during training. We also need to look more closely at the relationship between PSTM and long-term word retention in children with CIs.

Clinically, these findings have important implications for understanding lexical development in this population. If children with CIs do not show consolidation-based enhancement, this would partially explain why they show long-term delays in vocabulary size compared to their same-age NH peers, even after receiving the cochlear implants (Hayes, Geers, Treiman, & Moog, 2009). It would also explain their slower rate of vocabulary acquisition (Blamey et al., 2001; Connor et al., 2000). Children with NH not only maintain but also enhance memory for what they have already learned. Children with CIs, in contrast, can maintain what they have learned, but will need additional training on words that they were exposed to but did not form a stable word-referent map. It is important for clinicians working with these children to be aware that they may have difficulty consolidating what they have learned. Repeated exposure and review of curriculum-based vocabulary is needed to maintain robust representations of newly learned words.

We hypothesize that these findings may be framed within an associationist or connectionist perspective on word learning. Children with NH are exposed to statistical regularities in language through the consistent input they perceive from birth. This permits them to form strong connections through a distributed neural network in the brain, which aids in word learning. Children with CIs may experience neural reorganization due to lack of early auditory experience, which leads to weaker connections and affects their processing of phonological information in working memory. Studies have shown that the initial acquisition period in the learning process is weak and susceptible to interference and competition (Walker, 2005). This is especially true with regards to initial word learning (Horst & Samuelson, 2008). When this already weak link is combined with limits in working memory, children with CIs cannot achieve the same level of activation between nodes or synapses as children with NH, and therefore, cannot consolidate knowledge in memory to the same degree as their NH counterparts. Although it is tempting to make this speculation, however, we need additional research to support these preliminary hypotheses.

Relationships Between Word Learning and Vocabulary Size, Speech Perception, and Age at Implantation

The third prediction was that receptive vocabulary size, speech perception abilities and age at implantation would influence word learning performance in children with CIs. Inconsistent with this prediction, none of the variables were significantly correlated with fast mapping. In contrast, receptive vocabulary size and speech perception both accounted for a significant proportion of the variance in word retention. Age at implantation did as well, but not in the direction we expected.

It is fascinating that none of the independent variables accounted for a significant proportion of the variance in fast mapping, but they did for word retention. It seems more intuitive that factors like speech perception and lexical knowledge would influence the initial link between a spoken word and referent because one has to be able to accurately perceive the phonological sequence in order to form that map. The lack of a significant finding for fast mapping is not without precedent, however. Willstedt-Svensson and colleagues (2004) reported similar results from school-age children with CIs. When they entered their independent variables (age at implantation, nonword repetition) into a regression, none significantly predicted fast mapping, but they were able to account for 72% of the variance in word retention. On the basis of our findings and that of Willstedt-Svensson et al., we conclude that fast mapping and word retention are different processes in word learning.

Other researchers have come to similar conclusions. Horst and Samuelson (2008) posited that competition among the number of word-referent maps in a given experimental session may account for differences between fast mapping and word retention performance. Consistent with Horst and Samuelson's study, we included eight novel word-referent pairs in our paradigm. We also labeled objects ostensively, as they did in their fourth experiment. Our protocol differed in that our participants were tested on fast mapping approximately five minutes after training, which would be more comparable to the word retention testing in Horst and Samuelson's protocol. The suggestion that competition is playing a role in both processes of word learning may still apply to the present findings, however. During initial acquisition, the ostensive naming may have been sufficient to reduce competition among the other novel objects and provide CI participants with a robust representation of the word-referent pair, regardless of their individual speech perception abilities or vocabulary size. Unfortunately, for children who have poorer speech perception or lexical knowledge, the level of competition among the eight trained pairs may have been too great for them to hold the fragile phonological representations in the long-term, even with ostensive naming. Conversely, children with better speech perception and stronger lexical skills may have the capacity to maintain robust representations at word retention testing despite competition among words and referents. As a result, we see both speech perception and vocabulary size as significant predictors of word retention abilities but not fast mapping.

The difference in the results on the fast mapping and word retention regressions has direct applications for clinicians. It will be critical for clinicians to recognize that children with weaker speech perception skills and smaller vocabularies may be able to form an initial word-referent link, but they will have a more difficult time retaining new words in memory. As seen in the present findings, speech perception and vocabulary size are important predictors of how a child with a CI will perform on long-term word retention and should be taken into account with regards to treatment plans. Furthermore, there may be a cumulative effect of poor speech perception on word retention. Children who demonstrate weaker speech perception skills will have more difficulty encoding and retaining words in their mental lexicon. This leads to smaller vocabularies, and smaller vocabularies contribute to even poorer encoding and retention. This is not dissimilar to the “Matthew effect” that is often discussed in the reading and education literature.

The third variable considered as a predictor of word learning was age at implantation. This variable is nearly always included in correlational studies for children with CIs because there is a strong negative relationship between the age at which children receive a cochlear implant and outcome measures (Connor et al., 2000; Fryauf-Bertschy, Tyler, Kelsay, Woodworth, & Gantz, 1997; Tomblin et al., 2005; Tye-Murray, Spencer, & Woodworth, 1995). In other words, children who receive CIs at younger ages performed better on dependent measures than children receiving CIs at older ages. In the present study, chronological age and age at implantation did not significantly account for any proportion of the variance in fast mapping. The regression model was significant, and age at implantation had stronger beta weights and partial correlations than chronological age, indicating that the former variable was accounting for the majority of the variance in word retention.

Previous studies have all found a negative correlation, however. We saw a relationship in the opposite direction; children who received their CIs at older ages did better on the word retention measure. Only one other study has reported similar results; Willstedt-Svensson et al. (2004) also found a significant positive correlation between age at implantation and word learning scores. Inexplicably, the authors do not discuss the direction of this correlation, but instead state that age at implantation was the best predictor of fast mapping and retention (when compared to length of CI use and chronological age).

Why did we find a positive correlation between age at implantation and word retention? These results appear to be a perfect example of age at implantation and word retention being mediated by a third unknown factor. One specific variable that we must consider is the influence of preimplant residual acoustic hearing on both age at implantation and word learning. It is well-established that having some residual hearing prior to implantation has a positive impact on language outcomes (Nicholas & Geers, 2006). Most likely, some of the children in the present study had more preimplant residual hearing than others. These children might have received their CIs at older ages because it would be difficult to determine early in life if they were receiving adequate benefit from hearing aids. They would have had the benefits of some early auditory experience through their hearing aids (however minimal) and perhaps better neural survival than children with more profound losses. This could lead to better scores on the word retention measure, even though these children had received their CIs at later ages. Unfortunately, we were unable to obtain preimplant audiograms for all of the children so we can only speculate as to the effects of residual hearing on word learning scores.

Another mediating factor could be educational setting. Of the 20 participants who completed the second visit, 15 attended one private auditory-verbal program, Child’s Voice in Chicago, whereas 7 attended another auditory-verbal program, St. Joseph Institute for the Deaf (the last participant, CI034, was fully mainstreamed). The St. Joseph’s students lived in two different states, but the curriculum is consistent across both sites. Children at the Chicago-based program received their CIs, on average, at a younger age than children in the St. Joseph’s schools. On the other hand, the children at St. Joseph’s tended to be older. The St. Joseph’s students also did significantly better on word retention composite scores, compared to the children in Chicago. We can tentatively rule out length of CI experience and vocabulary size as contributing factors because all of these variables were virtually the same across groups. Instead, it is possible that chronological age is interacting with school setting, giving the children at St. Joseph's more of an advantage on the word learning tasks. Another possibility is that socioeconomic status (SES) is interacting with school setting. Although children at the two schools did not differ in terms of maternal education level, we did not collect data on paternal education level or family income. It is possible that the children at Child's Voice had a lower overall SES than the children at St. Joseph's, but this difference does not show in the data we collected. Previous research has shown that socioeconomic status and amount of parent talk can play a significant role in vocabulary acquisition over time (Hart & Risley, 1995), as children from lower SES backgrounds tended to show smaller vocabulary sizes and heard fewer words compared to their peers in higher SES families.

In all likelihood, there is a complex relationship between a number of factors that are mediating the relationship between age at implantation and word retention, and we lack the power in the present study to separate out the effects of all of these variables. Given our current state of knowledge about age of implantation effects, however, it seems wise to be skeptical of the present data suggesting that children who receive CIs at older ages are better at retaining words than children who receive CIs at younger ages.

When we look at the whole picture it is clear that there is still a large amount of variability that is not accounted for by the current regression models. The present study could account for no variance in fast mapping and although the regression models were significant for word retention, over 50% of the variance remained unaccounted for. What other variables are contributing to the individual differences in fast mapping and word retention for children with CIs? As previously discussed, Pisoni (2000) strongly advocates for looking at the role of phonological short-term memory on speech perception and production. Pisoni and his colleagues have provided strong evidence in support of their hypothesis. Using speaking rate on a sentence repetition task and forward digit span as their independent measures, they accounted for as much as 25% of the variance in speech perception scores in pediatric CI users (Pisoni & Cleary, 2003). It seems plausible that working memory efficiency and storage capacity could also mediate word learning performance in children with CIs.

We have evidence for a close relationship between phonological short-term memory and novel word learning in typically-developing children (Gupta & MacWhinney, 1997; Gathercole, Hitch, Service, & Martin, 1997). There is additional evidence for this link in children with CIs (Willstedt-Svensson et al., 2004). In the Willstedt-Svensson et al. study, however, they only included school-age children. Gathercole (1999) contends that nonword repetition is a less sensitive predictor of vocabulary development by age 6 because long-term lexical and phonotactic knowledge interact with phonological short-term memory to reconstruct temporary memory traces. We do not know if this holds true for children with CIs, who are already delayed in language development. It may be possible that phonological working memory accounts for an even greater proportion of the variance in fast mapping and word retention for preschool-age children with CIs, compared to school-age children. It may also be true that phonological working memory continues to be a strong predictor of novel word learning after age 6, unlike in children with normal hearing.

To summarize our conclusions from the regression analyses, our findings indicate that both vocabulary size and speech perception account for a significant proportion of the variance in word retention, but not fast mapping. Although these results must be interpreted with caution, the differences we see underscore the fact that fast mapping does not equal word retention (see also Horst and Samuelson, 2008). It appears that the same variables do not predict what contributes to better or worse performance in word acquisition and word retention for children with CIs. Future studies must look at other variables to help clarify these relationships.

Gesture as a Scaffold to Word Learning

The fourth prediction was that children with CIs and their VM peers would perform better at identifying and naming novel objects during fast mapping and word retention that have been labeled with a touch+eye gaze cue than an eye-gaze only cue. AM hearing peers would show no difference in identifying or naming novel objects that are labeled with a touch+eye gaze cue or eye-gaze only cue. The goal was to expand on previous research investigating gesture as a support to word learning. Booth et al. (2008) previously examined this in normal-hearing children and found differential effects for word learning, depending on the type of gesture cue that was used during labeling. Word learning scores improved as an experimenter provided more gestural support in the word learning context.

Based on the present findings, contact gesture cues did not provide significantly more scaffolding for word learning compared to non-contact gesture cues in young children with CIs, nor for their AM or VM peers. Our VM group was on average, 3 years, 9 months old, approximately one year older than the children in the Booth et al. study. The AM and CI groups were 4 years, 10 months old, on average. When the findings of both studies are considered in relation to one another, we may speculate that we are seeing a gradual decline in the effectiveness of gesture cues as a support to word learning, as children age. In other words, as children become more sophisticated word learners by age 4 or 5, they no longer need the additional scaffolding that contact cues provide over eye gaze cues.

It is also possible that the lack of a significant main effect for gesture cue could be due to a combination of competing factors, namely the amount of exposure during training and the number of word-referent pairs. The memory load of these factors may have usurped whatever benefit the touch gesture cues provided. Perhaps if we reduced the number of word-referent pairs or increased training, we would see more learning taking place in the touch cue condition. Booth et al. (2008) trained children with only three novel words and had a total of 12 exposures prior to testing, compared to eight words and three exposures in the present study. Thus, these results offer an interesting contrast of the influence of task demands and the facilitative effects of gestural cues on word learning. Gesture cues do scaffold word learning, but only to the extent that memory load is minimized and training is maximized.

Finally, within the CI group there was a marginally significant effect for touch+eye gaze cues over eye gaze alone at Visit 1 for production. Given our small n, we must allow for the possibility that inadequate power was at play. Additional studies of gesture support for the word learning of children with CIs may be informative.

Gesture cues were not the only strategies for scaffolding in our protocol. We also used a phonological cue to facilitate naming in the production task. The addition of a phonological cue did appear to scaffold novel word production across all three groups, to an extent. This would suggest that even if the phonological representation of the novel word was weak, some children in the CI group were able to retrieve it when provided with a cue. Nevertheless, the phonological cue only helped with novel word production 6% of the time at both visits for the CI group. The VM and AM children did not fare much better. It is possible that competition among the novel words may have limited production scores, as the novel words all had the same length and syllable structure. We also attempted to control for phonotactic probability by selecting novel word sequences with relatively high biphone and segmental probabilities (Storkel, 2001; Vitevitch & Luce, 2004). Future research may address how lexical factors such as phonotactic probability and wordlikeness affect production during novel word learning tasks in children with CIs.

We utilized gesture cues and phonological cues to scaffold word learning in the present study. What are other appropriate means for facilitating vocabulary development in young children with CIs? Given the lack of research on the process of word learning in children with CIs, it is not surprising that there is also a paucity of research on vocabulary training. The few studies that have examined it have used drill instruction to train words (Massaro & Light, 2004) or have utilized real words and objects within training (Mollink, Hermans, and Knoors, 2008; Paatsch, Blamey, Sarant and Bow, 2006). The difficulty with these methodologies is that drills are not how children learn words on an everyday basis (although they are an important component of therapy), and participants could vary in their familiarity with the training words or objects if they are not novel. In addition, the use of real words/objects in vocabulary training studies may not reflect how children handle the word learning process when they are encountering something novel.

In the present study, we used deictic gestures as a scaffold rather than iconic gestures, which represent meaningful aspects of the word. Mollink, Hermans, and Knoors (2008) tested the effects of using iconic and non-iconic signs to establish which method might be most effective in facilitating word learning. Participants included 14 children in with mild-to-severe hearing loss (age 4 years, 4 months to 8 years, 3 months). Researchers divided 64 unfamiliar pictures into four sets of 16: a control set in which no training took place, a spoken Dutch condition, a spoken Dutch + sign language condition, and a Dutch-color condition involving pairings of pictures and colors (e.g., “I think of the color green when I see this picture”). Objective adults judged approximately half of the words in the sign language condition to have strong iconicity and the other half to have weak iconicity. Post-tests took place one week and five weeks after training.

Children learned significantly more words in the condition with sign support than in the other three conditions. There was no effect of iconicity at the one-week post-test, but there was at the five-week post-test; children displayed significantly higher scores with the strong iconicity words compared to the weak iconicity words. These results suggest that the iconicity of a sign (how similar the shape of a sign looks to its meaning) may act as a scaffold for long-term spoken word retention.

One of the drawbacks of this study is that all of the children, regardless of degree of hearing loss, were in a simultaneous communication classroom in which teachers utilized spoken Dutch and sign-supported Dutch (similar to Signing Exact English). The authors did not describe the reliance the children had on sign language or spoken language; therefore, it can be assumed that this varied across participants. It would be interesting to replicate this study using novel iconic and non-iconic signs or gestures in a group of orally-trained children, to determine if merely using a gesture can scaffold lexical acquisition and retention. This would be similar to the experimental designs used by Capone and McGregor (2005) and McGregor et al. (2009) with typically-developing children. Results for those studies indicated that toddlers were most successful for word retrieval with the objects presented with gesture cues, indicating that enhanced semantic representation can influence word retention. Perhaps iconic gestures would be more facilitative for word retention than the deictic gestures that we used in the present study. Of course, this would be anathema to proponents of auditory-verbal programs, who advocate for relying almost entirely on auditory input to facilitate language development. The results in the present study indicate that word retention is a challenge for children with CIs, even when compared to their vocabulary-matched peers. Iconic gestures may be a worthwhile future direction to pursue when looking at means for scaffolding word acquisition and word retention in this population.

Given the limited amount of research looking at how we can best facilitate word learning in children with CIs, it would seem highly advantageous to conduct experiments that replicate the scaffolding techniques used in studies on children with normal language (Capone & McGregor, 2005; McGregor et al., 2009) and children with SLI (Gray, 2005). This line of experiments could provide us with information on how to best facilitate word learning in children with CIs, as well as children who use HAs, something is undeniably lacking in the current literature on this population.

Limitations

The major limitation of this study is the small number of subjects within each group. This is a problem inherent in most cochlear implant research because it is challenging to find a sufficient number of participants who meet the inclusion criteria. We attempted to control for a number of variables within our CI group. We excluded children who used sign language to communicate because we were interested in spoken language development. We also excluded children with post-lingual onsets of hearing loss because of the obvious impact language experience has on outcomes. All of the participants had at least one year of CI experience. Controlling for these variables allowed us to avoid a number of confounds, but it also limited our sample size. The small number of subjects particularly affected our regression analysis. We entered three independent variables (chronological age, vocabulary size, speech perception) into the fast mapping and word retention regressions, but it is questionable whether we had adequate power to support such an analysis. Therefore, we must interpret any conclusions from the regression analyses with extreme caution. That we did not achieve significance for the fast mapping regressions could be related, in part, to insufficient numbers of subjects, rather than to a lack of predictive validity among the independent variables.

Another limitation of the study may explain the lack of a significant main effect with regards to gesture cue scaffolding. By necessity, we had to employ a within-subject design for gesture, in contrast to the between-subject design used in the Booth et al. study. It would have been extremely difficult to find enough CI participants to complete a between-subject design. At the same time, it is possible that including both gestures in one protocol may have biased the conditions and led to contamination of the data. There is no way to avoid this limitation, but findings for the effects of gesture cues should still be interpreted with caution given the design of the study.

A third limitation is that there were several test measures that we did not include, which in hindsight would have been useful information. We initially decided not to include working memory measures because of the young ages of the children. We did not feel that they would have the attentional capabilities to perform these tasks, particularly for the 3-year-olds. It now seems possible that working memory might have accounted for some of the unexplained variance in word learning. We still would have encountered the issue of entering too many variables into a regression equation, however, so including working memory, in addition to vocabulary size and speech perception would not have been feasible.

Finally, the MLNT was perhaps not the best choice for a speech perception measure. We selected it because it is considered to be age-appropriate for the children we tested; it was too easy for most of the CI participants, however. We could have used the Lexical Neighborhood Test (LNT; Kirk, Pisoni, & Osberger, 1995) instead, which is the monosyllabic version of the MLNT. That measure would have given us more variation in the speech perception data. We still would have encountered the same problem as the MLNT, in that traditional open-set speech perception measures are highly collinear with receptive vocabulary measures, and it is impossible to separate out the effects of vocabulary knowledge, articulation, and auditory perception without performing complicated mathematical models requiring large numbers of subjects (Paatsch et al., 2004). For research purposes, we need to develop valid and reliable nonlinguistic speech perception measures so that we can effectively assess the role of hearing on linguistic outcomes in children with hearing loss.

Future Directions

Our findings raise a number of questions and there are many more studies that could emerge from this line of research. First, we found a marginal interaction for comprehension between session, gesture, and group. This was due to children in the VM group learning slightly more words with touch+eye gaze cues over eye gaze cues, but only at the second visit. We also saw a marginal three-way interaction for production. This appeared to be due to the CI showing an effect for touch+eye gaze at Visit 1 and the VM group showing the same marginal effect at Visit 2. It is unclear why contact gestures would not facilitate word learning for fast mapping in the VM group, but they would for word retention. There were also marginal effects within the VM group when we tested for simple main effects and corrected the alpha level because of multiple comparisons. It is possible that we had insufficient power to demonstrate significant effects with the younger NH group and the CI children. Further investigation is warranted. Future research could explore these possibilities and provide us with more insights on these trends.

Second, it would be interesting to explore the effect of sleep and memory consolidation on word learning more closely. To do this effectively, we would need to do a between-subject design that controls for the amount of time between training and retention testing. This would require a condition in which half of the subjects are trained in the morning and then tested at night with no interval of sleep (Walker, 2005). The other half would be trained at night immediately prior to an interval of sleep and then tested in the morning. Realistically, it would be challenging to conduct a study like this using a pediatric population. One alternative could be to have children nap between the training and testing. Other studies have had success eliciting recall with artificial grammars in 15-month-old infants using a protocol that included a “nap” group and a “no-nap” group (Hupbach, Gomez, Bootzin, & Nadel, 2009). Another alternative would be to test adults with CIs instead of children. This methodology has been shown to work in college-age adults with and without language impairments (McGregor, in progress). We are now reaching at point at which a substantial number of individuals who received CIs as children are reaching adulthood. One possible experiment would be to test the effects of sleep on word learning in a group of young adults with prelingual deafness who received CIs as children, a control group of hearing adults, and a third group of adults with postlingual deafness with CIs. If young adults with CIs showed more limited enhancement compared to postlingual adults and hearing adults, we could conclude that this is not just due to the degraded signal they are receiving from the CI, but also from the experience of a period of auditory deprivation during childhood.

On a different note, it has been posited that the locus of working memory deficits in children with CIs is automatized phonological processing, or the efficient encoding of incoming sensory information (Pisoni et al., 2008). This directly affects a child's ability to retrieve novel speech-sound sequences from phonological short-term memory. If inefficiency in working memory is occurring, then we might also predict that children with CIs would have difficulties with automaticity in long-term memory as well. This would take the form of difficulties in retrieving items from long-term lexical memory. Word retrieval has been linked with automaticity in typically-developing children (Bjorkland, 1987). It has also received attention in SLI research as children with SLI show more word retrieval errors than typically-developing children (Lahey & Edwards, 1999). Although children with hearing loss have documented delays in vocabulary size, we know little about their semantic knowledge of the lexicon. We do not know if they show a higher rate of word retrieval errors compared to hearing children, although this seems plausible given their difficulties with working memory processes. There are important theoretical implications to this work; if children with CIs have a higher rate of word retrieval errors than their NH peers, this may be evidence for reduced automaticity of lexical forms in long-term memory as well as working memory.

In addition, we do not know if children with CIs or even children who are hard of hearing show naming error patterns that are consistent with children with normal language or even SLI. Both groups generally show the same pattern of errors, with semantic errors (errors that share meaning, such as “truck” for “car”) occurring more often than phonological errors (errors that approximate the word form) or indeterminate errors (nonspecific responses) (McGregor, 1997). More research in this area seems warranted, as it would have important implications for treatment. Children with CIs may benefit from intervention focusing on strengthening semantic representations of words because stronger semantic representations may lead to fewer word retrieval errors (if this is an area of difficulty for these children).

Finally, in our word learning paradigm we labeled novel nouns ostensively. Children did not have to make any inferences regarding which object was being labeled, with the possible exception that they had to recognize the experimenter's intent to label something when she was looking at it. Although this gave us a clear view on how children with CIs learn words in a highly scaffolding context compared to AM and VM children, our paradigm lacks ecological validity. It is very rare even in Western cultures for objects to be labeled directly. In fact, less than 20% of mothers' speech involves ostensive naming for children under age 3 (Newport, Gleitman, & Gleitman, 1977; Snow, 1977). We can assume that ostensive labeling occurs even less often for children older than 3. With NH children it seems to make little difference that indirect labeling occurs much more frequently than ostensive labeling, as they can form equally robust mappings in either context (Jaswal & Markman, 2001; 2003).

These findings appear to be mixed for children with hearing loss, including those with CIs. Lederberg and Spencer (2009) found that approximately 50% of their participants with hearing loss did better on a direct word learning task compared to an indirect task, while the other half showed no difference. In the indirect trials, they gave children three familiar objects and one novel object and asked participants to give them "a dax." In other words, they utilized mutual exclusivity to indicate the referent in the indirect learning task. There are other linguistic cues that children can employ to infer the name of a referent, however. For example, children can use their knowledge of syntax to identify a proper noun from a common noun (Jaswal & Markman, 2001) or a verb from a noun (Brown, 1957). Currently, all studies on novel word learning in children with hearing loss have only included nouns as the target word. We know nothing about their representations of verbs, or if they are able to infer a word-referent map using linguistic cues (referred to as syntactic bootstrapping). Therefore, a possible future study would involve teaching novel nouns and verbs through direct and indirect training. This would allow us to replicate the results by Lederberg and Spencer as well as compare performance across word classes (noun vs. verb). We could also investigate if there is an interaction for grammatical word class and type of word learning. Perhaps nouns can be learned equally well through direct and indirect teaching in this population, but verbs are learned better through direct teaching. Regardless, this line of research would provide us with more information on how we can use syntax to facilitate word learning across different contexts.

Summary

In conclusion, the present study contributes new information to our understanding of word learning processes in children with CIs. We already know that children with CIs show delays in vocabulary compared to their hearing age mates (Hayes et al., 2009). They also show slower rates of growth, at half to two-thirds the rate of their peers (Blamey et al, 2001; Connor et al., 2000). The common assumption has been that these documented delays are due to the initial period of auditory deprivation that they experience, as well as challenges with learning words incidentally. Although these certainly contribute to vocabulary delays, we have reason to suspect that they are not the only contributors. It has also been documented that children with CIs have difficulty forming initial word-referent links. One of the contributions of the present study is that we have replicated the findings in previous studies on fast mapping in children with CIs, but with a larger number of subjects that were controlled across several important variables. Therefore, we can be confident in stating that children with CIs do experience a reduced ability to form initial word-referent links in relation to their same-age peers with normal hearing.

Although it is often conflated with word learning, fast mapping is only one component in the actual process of forming a mental representation of a word (Horst & Samuelson, 2008). The other major contribution of this dissertation is our investigation into longer-term word retention. Previously, it has been suggested that children with CIs are able to retain word-referent maps following a delay, similar to performance by hearing children (Houston et al., 2005). Our findings are consistent with this proposal, in that the children in this study did not show a decline in comprehension and production over time. This does not mean that they are performing like their hearing peers, however. Hearing age-mates and vocabulary-mates showed enhancement in their novel word learning, while the CI group maintained performance. Thus, children with CIs may not take the same route in learning new words as typically-developing children. These results could help explain, in part, why this population consistently demonstrates slower rates of vocabulary learning over time.

The results of the regression analyses were surprising, yet informative. We expected that several key variables, speech perception, vocabulary size, and age at implantation, would be related to variations in fast mapping, as well as word retention. None of these variables proved to be significant predictors of word acquisition, but they were all highly significant for word retention. The differences in the regression analyses emphasize our point that fast mapping and word retention should not be equated. The factors that account for acquiring that first link between a word and its referent are not the same as those that are important for storing in a word in long-term memory.

An integration of these findings leads us to conclude that fast mapping and word retention are distinct word learning processes. Children with CIs have significant difficulty with both. On a more positive note, children with CIs have a much better likelihood for success than children who had a profound hearing loss 25 years ago, prior to the advent of CI technology. We can also expect that advances in early identification of hearing loss and improvements in intervention services will continue to improve the outcomes of these children.

REFERENCES

Atienza, M., Cantero, J.L., & Dominguez-Marin, E. (2002). Mismatch negativity (MMN): an objective measure of sensory memory and long-lasting memories during sleep. *International Journal of Psychophysiology, 46*, 215-225.

Bates, E., Marchman, V., Thal, D., Fenson, L. et al., (1994). Developmental and stylistic variation in the composition of early vocabulary. *Journal of Child Language, 21*, 85-123.

Behrend, D. A., Scofield, J., & Kleinknecht, E. E. (2001). Beyond fast mapping: Young children's extensions of novel words and novel facts. *Developmental Psychology, 37*, 698-705.

Benedict, H. (1979). Early lexical development: Comprehension and production. *Journal of Child Language, 6*, 183-200.

Bishop, D.V.M., North, T., & Donlan, C. (1996). Nonword repetition as a behavioural marker for inherited language impairment: evidence from a twin study. *Journal of Child Psychology and Psychiatry, 37*, 391-403.

Bjorkland, D.F. (1997). How age changes in knowledge base contribute to the development of children's memory: an interpretive review. *Developmental Review, 7*, 93-130.

Blamey, P. J., Sarant, J. Z., Paatsch, L. E., Barry, J. G., Bow, C. P., Wales, R. J., Wright, M., Psarros, C., & Rattigan, K. (2001). Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. *Journal of Speech, Language, and Hearing Research, 44*, 264-285.

Bloom, L., Margulis, C., Tinker, E., & Fujita, N. (1996). Early conversations and word learning: Contributions from child and adult. *Child Development, 67*, 3154-3175.

Booth, A. E., McGregor, K. K., & Rohlfing, K. J. (2005). From eye gaze to manipulation. Paper presented at the meeting of the International Association for the Study of Child Language, Berlin, Germany.

Booth, A. E., McGregor, K. K., & Rohlfing, K. J. (2008). Socio-pragmatics and attention: Contributions to gesturally guided word learning in toddlers. *Language, Learning, and Development, 4*, 179-202.

Boothroyd, A., & Eran, O. (1994). Auditory speech perception capacity of child implant users expressed as equivalent hearing loss. *Volta Review, 96*, 151-167.

Briscoe, J., Bishop, D.V.M., & Norbury, C. (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*, 329-340.

Briscoe, J., & Rankin, P.M. (2009). Exploration of a "double-jeopardy" hypothesis within working memory profiles for children with specific language impairment. *International Journal of Language and Communication Disorders, 44*, 236-250.

Brown, R. (1957). Linguistic determinism and the part of speech. *Journal of Abnormal and Social Psychology, 55*, 1-5.

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,* 63-88.

Capone, N. C., & McGregor, K. K. (2005). The effect of semantic representation on toddlers' word retrieval. *Journal of Speech, Language, and Hearing Research, 48,* 1468-1480.

Carey, S. (Ed.). (1978). The child as a word learner. Cambridge, MA: MIT Press.

Carney, A. E., & Moeller, M. P. (1998). Treatment efficacy: Hearing loss in children. *Journal of Speech, Language, and Hearing Research, 41,* S61-S84.

Carney, A. E., Osberger, M. J., Carney, E., Robbins, A. M., & et al. (1993). A comparison of speech discrimination with cochlear implants and tactile aids. *Journal of the Acoustical Society of America, 94,* 2036-2049.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development, 63,* 1-176.

Ching, T. Y., Hill, M., Brew, J., Incerti, P., Priolo, S., Rushbrook, E., et al. (2005). The effect of auditory experience on speech perception, localization, and functional performance of children who use a cochlear implant and a hearing aid in opposite ears. *International Journal of Audiology, 44,* 677-690.

Chute, P. M., & Nevins, M. E. (2006). *School professionals working with children with cochlear implants.* San Diego, CA: Plural Publishing.

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 & Hearing, 22*, 395-411.

Connor, C.M., Hieber, S., Arts, H., & Zwolan, T. (2000). Speech, vocabulary, and the education of children using cochlear implants: Oral or total communication? *Journal of Speech, Language, and Hearing Research, 43,* 1185-1204.

Connor, C. M., & Zwolan, T. A. (2004). Examining multiple sources of influence on the reading comprehension skills of children who use cochlear implants. *Journal of Speech, Language, and Hearing Research, 47,* 509-526.

Conway, C.M., Karpicke, J., & Pisoni, D.B. (2007). Contribution of implicit sequence learning to spoken language processing: some preliminary findings with hearing adults. Journal of Deaf Studies and Deaf Education, 12, 317-334.

Dale, P. S., & Fenson, L. (1996). Lexical development norms for young children. *Behavior Research Methods, Instruments & Computers, 28,* 125-127.

Dawson, P. W., Blamey, P. J., Dettman, S. J., Barker, E. J., & Clark, G. M. (1995). A clinical report on receptive vocabulary skills in cochlear implant users. *Ear & Hearing, 16,* 287-294.

Dawson, P. W., Blamey, P. J., Rowland, L. C., Dettman, S. J., & et al. (1992). Cochlear implants in children, adolescents, and prelinguistically deafened adults: Speech perception. *Journal of Speech & Hearing Research, 35*, 401-417.

Dettman, S. J., Fiket, H., Dowell, R. C., Charlton, M., Williams, S. S., Tomov, A. M., et al. (2004). Speech perception results for children using cochlear implants who have additional special needs. *Volta Review, 104*, 361-392.

Dollaghan, C. (1985). Child meets word: "Fast mapping" in preschool children. *Journal of Speech & Hearing Research, 28*, 449-454.

Dollaghan, C. (1987). Fast mapping in normal and language-impaired children. *Journal of Speech & Hearing Disorders, 52*, 218-222.

Dorman, M. F., Loizou, P. C., Kemp, L. L., & Kirk, K. I. (2000). Word recognition by children listening to speech processed into a small number of channels: data from normal-hearing children and children with cochlear implants. *Ear & Hearing, 21*, 590-596.

Dowell, R. C., Dettman, S. J., Hill, K., Winton, E., Barker, E. J., & Clark, G. M. (2002). Speech perception outcomes in older children who use multichannel cochlear implants: older is not always poorer. *Annals of Otology, Rhinology, & Laryngology - Supplement, 189*, 97-101.

Dromi, E. (2008). Old data - new eyes. Theories of word meaning acquisition. In V.C.M. Gathercole (Ed.), *Routes to language: studies in honor of Melissa Bowerman*, pp. 39-59. Hove, England: Psychology Press/Taylor and Francis.

Dumay, N. & Gaskell, M.G. (2007). Sleep-associated changes in the mental representation of spoken words. *Psychological Science, 18*, 35-39.

Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test-III.* Circle Pines, MN: American Guidance Services.

Ellis Weismer, S., Tomblin, J.B., Zhang, X., Buckwalter, P., Chynoweth, J., & Jones, M. (2000). Nonword repetition performance in school-age children with and without language impairment. *Journal of Speech, Language, and Hearing Research, 43*, 865-878.

Ertmer, D. J., & Mellon, J. A. (2001). Beginning to talk at 20 months: Early vocal development in a young cochlear implant recipient. *Journal of Speech, Language, and Hearing Research, 44*, 192-206.

Farran, L.K., Lederberg, A.R., & Jackson, L.A. (2009). Maternal input and lexical development: the case of deaf pre-schoolers. *International Journal of Language and Communication Disorders, 44*, 145-163.

Fenson, L., Dale, P. S., Reznick, J., Bates, E., & et al. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development, 59*, 1-173.

Fryauf-Bertschy, H., Tyler, R.S., Kelsay, D.M., Gantz, B.J., & Woodworth, G.G. (1997). Cochlear implant use by prelingually deafened children: the influences of age at implant and length of device use. *Journal of Speech, Language, and Hearing Research, 40*, 183-199.

Gantz, B. J., Rubinstein, J. T., Tyler, R. S., Teagle, H. F., Cohen, N. L., Waltzman, S. B., et al. (2000). Long-term results of cochlear implants in children with residual hearing. *Annals of Otology, Rhinology, & Laryngology - Supplement, 185*, 33-36.

Gaskell, M.G., & Dumay, N. (2003). Lexical competition and the acquisition of novel words. *Cognition, 89*, 105-132.

Gathercole, S.E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Sciences, 3*, 410-419.

Gathercole, S. E., & Baddeley, A. D. (1990). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *British Journal of Psychology, 81*, 439-454.

Gathercole, S. E., & Baddeley, A. D. (1993). Phonological working memory: A critical building block for reading development and vocabulary acquisition? *European Journal of Psychology of Education*, *8*, 259-272.

Gathercole, S.E., Hitch, G.J., Service, E., & Martin, A.J. (1997). Phonological short-term memory and new word learning in children. *Developmental Psychology, 33*, 966-979.

Geers, A., & Brenner, C. (1994). Speech perception results: Audition and lipreading enhancement. *Volta Review, 96*, 97-108.

Geers, A., Brenner, C., & Davidson, L. (2003). Factors associated with development of speech perception skills in children implanted by age five. *Ear & Hearing, 24(1 Suppl)*, 24S-35S.

Geers, A., & Moog, J. (1994). Spoken language results: Vocabulary, syntax, and communication. *Volta Review, 96*, 131-148.

Geers, A. E., Nicholas, J. G., & Sedey, A. L. (2003). Language skills of children with early cochlear implantation. *Ear & Hearing, 24(1 Suppl)*, 46S-58S.

Gilbertson, M., & Kamhi, A. G. (1995). Novel word learning in children with hearing impairment. *Journal of Speech & Hearing Research, 38*, 630-642.

Goldman, R., & Fristoe, M. (2000). *Goldman-Fristoe Test of Articulation, 2nd Edition*. Bloomington, MN: Pearson Assessments.

Golinkoff, R. M., & Hirsh-Pasek, K. (2006). Baby wordsmith: from associationist to social sophisticate. *Current Directions in Psychological Science, 15*, 30-33.

Golinkoff, R. M., Hirsh-Pasek, K., Bloom, L., Smith, L. B., Woodward, A. L., Akhtar, N., Tomasello, M., & Hollich, G. (2000). *Becoming a word learner: A debate on lexical acquisition.* New York: Oxford University Press.

Golinkoff, R. M., Mervis, C. B., & Hirsh-Pasek, K. (1994). Early object labels: The case for a developmental lexical principles framework. *Journal of Child Language, 21,* 125-155.

Gray, S. (2003). Word-learning by preschoolers with specific language impairment: What predicts success? *Journal of Speech, Language, and Hearing Research, 46,* 56-67.

Gray, S. (2004). Word learning by preschoolers with specific language impairment: predictors and poor learners. *Journal of Speech, Language, and Hearing Research, 47,* 1117-1132.

Gray, S. (2005). Word learning by preschoolers with specific language impairment: Effect of phonological or semantic cues. *Journal of Speech, Language, and Hearing Research, 48*, 1452-1467.

Gupta, P. & MacWhinney, B. (1997). Vocabulary acquisition and verbal short-term memory: computational and neural bases. *Brain and Language, 59*, 267-333.

Gupta, P. & Tisdale, J. (2009). Word learning, phonological short-term memory, phonotactic probability and long-term memory: towards an integrated framework. *Philosophical Transactions of the Royal Society, 364*, 3755-3771.

Hart, B. & Risley, T. (1995). *Meaningful differences in the everyday experience of young American children.* Baltimore: Brookes Publishing.

Hayes, H., Geers, A.E., Treiman, R. & Moog, J.S. (2009). Receptive vocabulary development in deaf children with cochlear implants: Achievement in an intensive auditory-oral educational setting. *Ear & Hearing, 30*, 128-135.

Heibeck, T. H., & Markman, E. M. (1987). Word learning in children: An examination of fast mapping. *Child Development, 58*, 1021-1034.

Hirsch-Pasek, K, Golinkoff, R.M., & Hollich, George (1999). Trends and transitions in language development: Looking for the missing piece. *Developmental Neuropsychology, 16*, 139-162.

Hoff, E. (2001). *Language development* (2nd ed.). Belmont, CA: Wadsworth/Thomson Learning.

Hollich, G. J., Hirsh-Pasek, K., Golinkoff, R. M., Brand, R. J., Brown, E., Chung, H. L., et al. (2000). Breaking the language barrier: An emergentist coalition model for the origins of word learning. *Monographs of the Society for Research in Child Development, 65*, v-123.

Horst, J. S., & Samuelson, L. K. (2008). Fast mapping but poor retention by 24-month-old infants. *Infancy, 13*, 1288-157.

Houston-Price, C., Plunkett, K., & Duffy, H. (2006). The use of social and salience cues in early word learning. *Journal of Experimental Child Psychology, 95*, 27-55.

Houston, D. M., Carter, A. K., Pisoni, D. B., Kirk, K. l., & Ying, E. A. (2005). Word learning in children following cochlear implantation. *Volta Review, 105*, 41-72.

Houston, D. M., Pisoni, D. B., Kirk, K. I., Ying, E. A., & Miyamoto, R. T. (2003). Speech perception skills of deaf infants following cochlear implantation: a first report. *International Journal of Pediatric Otorhinolaryngology, 67,* 479-495.

Hupbach, A., Gomez, R.L., Bootzin, R.R., & Nadel, L. (2009). Nap-dependent learning in infants. *Development Science, 12,* 1007-1012.

Ireton, H. & Thwing, E. (1974). *Minnesota Child Development Inventory*. Minneapolis, MN: University of Minnesota.

Jaswal, V.K. & Markman, E.M. (2001). Learning proper and common names in inferential versus ostensive contexts. *Child Development, 72,* 768-786.

Jaswal, V.K. & Markman, E.M. (2003). The relative strengths of indirect and direct word learning. *Developmental Psychology, 39*, 745-760.

Jerger, S., Damian, M. F., Tye-Murray, N., Dougherty, M., Mehta, J., & Spence, M. (2006). Effects of Childhood Hearing Loss on Organization of Semantic Memory: Typicality and Relatedness. *Ear & Hearing, 27,* 686-702.

Jones, S.S., Smith, L.B, & Landau, B. (1991). Object properties and knowledge in early lexical learning. *Child Development, 62,* 499-516.

Karni, A., Tanne, D., Rubenstein, B.S., Askenasy, J.J., & Sagi, D. (1994). Dependence on REM sleep of overnight improvement of a perceptual skill. *Science, 265*, 679-682.

Kaufman, A.S. & Kaufman, N.L. (2004). Kaufman Brief Intelligence Test, Second Edition. Circle Pines, MN: AGS Publishing.

Kittler, J.E., Menard, W., & Phillips, K.A. (2007). Weight concerns in individuals with body dysmorphic disorder. *Eating Behaviors, 8,* 115-120.

Kirk, K. I., Hay-McCutcheon, M., Sehgal, S. T., & Miyamoto, R. T. (2000). Speech perception in children with cochlear implants: effects of lexical difficulty, talker variability, and word length. *Annals of Otology, Rhinology, & Laryngology - Supplement, 185,* 79-81.

Kirk, K. I., Miyamoto, R. T., Ying, E. A., Perdew, A. E., & Zuganelis, H. (2000). Cochlear implantation in young children: Effects of age at implantation and communication mode. *Volta Review, 102,* 127-144.

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

Lahey, M. & Edwards, J. (1999). Naming errors of children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 42*, 195-205.

Landau, B., Smith, L. B., & Jones, S. (1992). Syntactic context and the shape bias in children's and adults' lexical learning. *Journal of Memory and Language, 31*, 807-825.

Landau, B., Smith, L. B., & Jones, S. S. (1988). The importance of shape in early lexical learning. *Cognitive Development, 3,* 299-321.

Lederberg, A. R. (2003). Expressing meaning: From communicative intent to building a lexicon. In M. Marschark and P.E. Spencer (Eds). *Oxford Handbook of Deaf Studies, Language, and Education*. New York: Oxford University Press.

Lederberg, A. R., Prezbindowski, A. K., & Spencer, P. E. (2000). Word-learning skills of deaf preschoolers: The development of novel mapping and rapid word-learning strategies. *Child Development, 71*, 1571-1585.

Lederberg, A. R., & Spencer, P.E. (2009). Word-learning abilities in deaf and hard of hearing preschoolers: Effect of lexicon size and language modality. *Journal of Deaf Studies and Deaf Education, 14*, 44-62.

Locke, J.L. (1997). The theory of neurolinguistic development. *Brain and Language, 58*, 265-326.

Massaro, D.W., & Light, J. (2004). Improving the vocabulary of children with hearing loss. *Volta Review, 104*, 141-174.

Mayne, A. M., Yoshinaga-Itano, C., & Sedey, A. L. (1998). Receptive vocabulary development of infants and toddlers who are deaf or hard of hearing. *Volta Review, 100*, 29-52.

Mayne, A. M., Yoshinaga-Itano, C., Sedey, A. L., & Carey, A. (1998). Expressive vocabulary development of infants and toddlers who are deaf or hard of hearing. *Volta Review, 100*, 1-28.

McGregor, K.K. (1997). The nature of word-finding errors of preschoolers with and without word-finding deficits. *Journal of Speech, Language, and Hearing Research, 40*, 1232-1245.

McGregor, K. K., Friedman, R. M., Reilly, R. M., & Newman, R. M. (2002). Semantic representation and naming in young children. *Journal of Speech, Language, and Hearing Research, 45*, 332-346.

McGregor, K.K., Rohlfing, K.J., Bean, A., & Marschner, E. (2009). Gesture as a support for word learning: The case of *under*. *Journal of Child Language, 36*, 807-828.

Mervis, C. B., & Bertrand, J. (1994). Acquisition of the novel name^nameless category (N3C) principle. *Child Development, 65*, 1646-1662.

Metsala, J.L. (1997). An examination of word frequency and neighborhood density in the development of spoken-word recognition. *Memory & Cognition, 25*, 47-56.

Miyamoto, R. T., Houston, D. M., Kirk, K. I., Perdew, A. E., & Svirsky, M. A. (2003). Language development in deaf infants following cochlear implantation. *Acta Oto-Laryngologica, 123*, 241-244.

Miyamoto, R. T., Osberger, M. J., Todd, S. L., Robbins, A. M., Stroer, B. S., Zimmerman-Phillips, S., et al. (1994). Variables affecting implant performance in children. *Laryngoscope, 104*, 1120-1124.

Mollink, H., Hermans, D., & Knoors, H. (2008). Vocabulary training of spoken words in hard-of-hearing children. *Deafness and Education International, 10*, 80-92.

Newport, E., Gleitman, H., & Gleitman, L. (1977). Mother, I'd rather do it myself: some effects and non-effects of maternal speech style. In C. Snow & C. Ferguson (Eds.), *Talking to children* (pp.109-150). New York: Cambridge University Press.

Nicholas, J.G. & Geers, A.E. (2006). Effects of early auditory experience on the spoken language of deaf children at 3 years of age. *Ear & Hearing, 27*, 286-298.

Niparko, J.K. (2000). *Cochlear implants: principles & practices.* Philadelphia, PA: Lippincott Williams & Wilkins.

O'Donoghue, G. M., Nikolopoulos, T. P., Archbold, S. M., & Tait, M. (1998). Speech perception in children after cochlear implantation. *American Journal of Otology, 19*, 762-767.

Paatsch, L.E., Blamey, P.J., Sarant, J.Z., Martin, L.F.A., & Bow, C.P. (2004). Separating contribuations of hearing, lexical knowledge, and speech production to speech-perception scores in children with hearing impairments. *Journal of Speech, Language, and Hearing Research*, *47*, 738-750.

Paatsch, L.E., Blamey, P.J., Sarant, J.Z., & Bow, C.P. (2006). The effects of speech production and vocabulary training on different components of spoken language performance. *Journal of Deaf Studies and Deaf Education, 11*, 39-55.

Paul, R. (1996). Clinical implications of the natural history of slow expressive language development. *American Journal of Speech-Language Pathology, 5*, 5-21.

Pisoni, D.B., (2000). Cognitive factors and cochlear implants: some thoughts on perception, learning, and memory in speech perception. *Ear & Hearing, 21*, 70-78.

Pisoni, D.B., Conway, C.M., Kronenberger, W.G., Horn, D.L., Karpicke, J., & Henning, S.C. (2008). Efficacy and effectiveness of cochlear implants in deaf children. In M. Marschark and P.C. Hauser (Eds.), *Deaf cognition foundations and outcomes* (pp.52-101). New York: Oxford University Press.

Pisoni, D. B., & Cleary, M. (2003). Measures of working memory span and verbal rehearsal speed in deaf children after cochlear implantation. *Ear & Hearing, 24*(1 Suppl), 106S-120S.

Pittman, A. L., Lewis, D. E., Hoover, B. M., & Stelmachowicz, P. G. (2005). Rapid word-learning in normal-hearing and hearing-impaired children: effects of age, receptive vocabulary, and high-frequency amplification. *Ear & Hearing, 26*, 619-629.

Pruden, S. M., Hirsh-Pasek, K., Golinkoff, R. M., & Hennon, E. A. (2006). The birth of words: ten-month-olds learn words through perceptual salience. *Child Development, 77*, 266-280.

Reznick, J., & Goldfield, B. A. (1992). Rapid change in lexical development in comprehension and production. *Developmental Psychology, 28*, 406-413.

Samuelson, L. K. (2002). Statistical regularities in vocabulary guide language acquisition in connectionist models and 15-20-month-olds. *Developmental Psychology, 38*, 1016-1037.

Samuelson, L.K., & Smith, L.B. (1999). Early noun vocabularies: do oncology, category structure and syntax correspond? *Cognition, 73,* 1-33.

Samuelson, L. K., & Smith, L. B. (2000). Children's attention to rigid and deformable shape in naming and non-naming tasks. Child Development, 71(6), 1555-1570.

Samuelson, L. K., & Smith, L. B. (2005). They call it like they see it: Spontaneous naming and attention to shape. *Developmental Science, 8,* 182-198.

Smith, L.B., Jones, S.S., Landau, B, Gershkoff-Stowe, L., & Samuelson, L.K. (2002). Object name learning provides on-the-job training for attention. *Psychological Science, 13*, 13-19.

Snow, C.E. (1977). Mothers' speech research: from input to interaction. In C. Snow & C. Ferguson (Eds.), *Talking to children* (pp.31-50). New York: Cambridge University Press.

Spencer, L. J., Barker, B. A., & Tomblin, J. B. (2003). Exploring the language and literacy outcomes of pediatric cochlear implant users. *Ear & Hearing, 24*, 236-247.

Spencer, L.J., & Oleson, J.J. (2008). Early listening and speaking skills predict later reading proficiency in pediatric cochlear implant useres. *Ear & Hearing, 29*, 270-280.

Spencer, L. J., Tomblin, J. B., & Gantz, B. J. (1997). Reading skills in children with multichannel cochlear-implant experience. *Volta Review, 99*, 193-202.

Spencer, L. J., Tye-Murray, N., & Tomblin, J. B. (1998). The production of English inflectional morphology, speech production and listening performance in children with cochlear implants. *Ear & Hearing, 19*, 310-318.

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., & Lewis, D. E. (2004). Novel-word learning in children with normal hearing and hearing loss. *Ear & Hearing, 25,* 47-56.

Storkel, H. L. (2001). Learning new words: Phonotactic probability in language development. *Journal of Speech, Language, and Hearing Research, 44,* 1321-1337.

Swingley, D., & Aslin, R.N. (2000). Spoken word recognition and lexical representation in very young children. *Cognition, 76,* 147-166.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences, 28*, 675-735.

Thelen, E., & Bates, E. (2003). Connectionism and dynamic systems: are they really that different? Developmental Science, 6, 378-391.

Tomblin, J.B., Barker, B.A., & Hubbs, S. (2007). Developmental constraints on language development in children with cochlear implants. *International Journal of Audiology, 46*, 512-523.

Tomblin, J.B., Barker, B.A., Spencer, L.J., Zhang, X., & Gantz, B.J. (2005). The effect of age at cochlear implant initial stimulation on expressive language growth in infants and toddlers. *Journal of Speech, Language, and Hearing Research, 48*, 853-867.

Tomblin, J. B., Spencer, L. J., Flock, S., Tyler, R., & Gantz, B. J. (1999). A comparison of language achievement in children with cochlear implants and children using hearing aids. *Journal of Speech, Language, and Hearing Research, 42*, 497-511.

Tomblin, J. B., Spencer, L. J., & Gantz, B. J. (2000). Language and reading acquisition in children with and without cochlear implants. *Advances in Oto-Rhino-Laryngology, 57*, 300-304.

Tye-Murray, N., Spencer, L, & Woodworth, G.G. (1995). Acquisition of speech by children who have prolonged cochlear implant experience. *Journal of Speech and Hearing Research, 38,* 327-337.

Vitevitch, M. S., & Luce, P. A. (2004). A Web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods, Instruments & Computers, 36*, 481-487.

Walker, M.P., Brakefield, T., Morgan, A., Hobson, J.A., & Stickgold, R. (2002). Practice with sleep makes perfect: sleep-dependent motor skill learning. *Neuron, 35*, 205-211.

Walker, M.P., Brakefield, T., Seidman, J., Morgan, A., Hobson, J.A., & Stickgold, R. (2003). Sleep and the time course of motor skill learning. *Learning & Memory, 10,* 275-284.

Walker, M.P. (2005). A refined model of sleep and the time course of memory formation. *Behavioral and Brain Sciences, 28*, 51-104.

Waltzman, S.B., Cohen, N.L., Gomolin, R.H., Green, J.E., Shapiro, W.H., Hoffman, R.A., & Roland, J.T. (1997). Open-set speech perception in congenitally deaf children using cochlear implants. *American Journal of Otology, 18*, 342-349.

Wass, M., Ibertsson, T., Lyxell, B., Sahlen, B., Hallgren, M., Larsby, B., & Maki-Torkko, E. (2008). Cognitive and linguistic skills in Swedish children with cochlear implants - measures of accuracy and latency as indicators of development. *Scandinavian Journal of Psychology, 49*, 559-576.

Watson, D.R., Titterington, J., Henry, A., & Toner, J.G. (2007). Auditory sensory memory and working memory processes in children with normal hearing and cochlear implants. *Audiology & Neurotology, 12,* 65-76.

Waxman, S.R. & Booth, A.E. (2000). Principles that are invoked in the acquisition of words, but not facts. *Cognition, 77,* B33-B43.

Werker, J.F., Fennell, C.T., Corcoran, K.M., & Stager, C.L. (2002). Infants' ability to learn phonetically similar words: effects of age and vocabulary size. *Infancy, 3,* 1-30.

Willstedt-Svensson, U., Lofqvist, A., Almqvist, & Sahlen, B. (2004). Is age at implant the only factor that counts? The influence of working memory on lexical and grammatical development in children with cochlear implants. *International Journal of Audiology, 43*, 506-515.

Woodward, A. L., Markman, E. M., & Fitzsimmons, C. M. (1994). Rapid word learning in 13- and 18-month-olds. *Developmental Psychology, 30*, 553-566.