3-2014

Cochlear Implants, Language Acquisition, and Speech Intelligibility: The Effect of Age at Implantation

Danielle Becker
Bethel University

Cochlear Implants, Language Acquisition, and Speech Intelligibility: The Effect of Age at Implantation

Danielle Becker

Bethel University

Author Note

Danielle Becker, Department of Psychology, Bethel University.

Correspondence concerning this article should be addressed to Danielle Becker,

Bethel University MSC 330, Saint Paul, MN 55112. Email: dmb29639@bethel.edu

Abstract

A review of the current literature on outcomes of individuals using cochlear implants, especially in the relationship between age at implantation and speech intelligibility was conducted. Literature describing norms for language acquisition and hearing outcomes with the use of other devices (i.e. hearing aids) was also assessed. A clear pattern of normal language acquisition is shown by the literature of this field. Literature assessing the effectiveness of cochlear implants shows that although most cochlear implant users are not able to catch up to hearing age-mates, cochlear implants are significantly more effective than traditional hearing aids in language acquisition. The research also suggests that the earlier children are implanted, the more successful they are in language acquisition.

Keywords: Cochlear implants, language acquisition, speech intelligibility.

Cochlear Implants, Language Acquisition, and Speech Intelligibility: The Effect of Age at Implantation

When critiquing research that has to do with any human ability, it is first crucial to establish what is considered "normal" for that specific attribute. When talking about hearing, however, discussion of this nature can become quite controversial. Among deaf individuals, there exists a culture that views deafness as something to be proud of. Members of Deaf culture do not view themselves as having a disability or as being "hearing-impaired" but instead view their Deafness as a distinct cultural identity centered around the language, American Sign Language. For these people, talking about deafness as being "abnormal" or as needing a cure is highly offensive (Tucker, 1998).

For this reason, the use of cochlear implants as a "cure" for deafness is highly controversial. A cochlear implant is a device that is surgically implanted into the inner ear of a severely to profoundly deafened individual that simulates hearing through the use of electrodes that directly stimulate the auditory nerve. These devices began to be used as a "cure" for deafness in the mid-1980s (Bat-Chava, Martin & Kosciw, 2005; Tucker, 1998). Throughout their use, they have been continuously opposed by Deaf individuals and proponents of Deaf culture.

The controversy is magnified by the fact that most deaf children are born to hearing parents. According to the National Association of the Deaf (2013), of the 0.002-0.003 percent of all children that are born deaf, 90 percent are born to hearing parents. These hearing parents of deaf children are faced with a dilemma – will they raise their child in the hearing world or in the Deaf world? Should children be implanted at a young age or should they be raised in a world of silence? Advocates of Deaf culture suggest waiting until the child is old enough to decide for themselves as to whether they want to be a part of the hearing world or of Deaf culture. However, research suggests that waiting until the child is old enough to decide may eliminate the possibility that they will ever be able to function in hearing culture. It is accepted that there is a sensitive period for language development, although the cutoff for this period is under dispute (Berk, 2009). Also, research suggests that younger age at implantation is associated with better outcomes for speech development (e.g. Niparko et al., 2010). Because of these two findings, cochlear implantation and the age at which cochlear implants are received is an important issue that needs to be addressed. Research has suggested that the earlier children are implanted, the more likely that they will be successful in language acquisition.

Method

The literature search for this review was conducted in the Fall of 2013. Many different sources were used in an attempt to create a comprehensive review of the current research on the topic. Literature was found through the use of electronic bibliographic databases, which included such databases as Academic Search Premier, EBSCO MegaFile, ERIC, PsychINFO, and Science Direct. All research examined was published within the last 20 years. A more stringent cutoff was not used because of the relative infrequency of research on this topic. Sources used included primary sources and one textbook. Database search terms included such terms as cochlear implants, speech development, language acquisition, age at implantation, and speech intelligibility. Studies chosen were quantitative in nature and each contained an adequate number of participants according to acceptable standards for psychological research, but also taking into account the difficulty of obtaining participants for studies of this nature. Other things taken into consideration when choosing literature for this review included relevance of the research topic and the validity of testing methods. Specifically, literature was included if findings were applicable to the topic of interest (i.e. the effectiveness of cochlear implants and the effect of age at implantation). Research methods were scrutinized for apparent soundness of methodology and applicability of results to the topic at hand. The following review presents a synthesis and analysis of the search results.

Norms for Language Acquisition

In order to examine the effectiveness of cochlear implants in relation to language acquisition, the “norm” for hearing-based language acquisition needs to be established. The existence of a norm for language acquisition can be seen in the fact that there are several language milestones that each baby learning language for the first time accomplishes, even babies learning American Sign Language (ASL) (Berk, 2009). Babies first make cooing noises at two months and begin babbling at six months of age. Babies who are deaf also exhibit babbling, which takes the form of mimicking ASL hand gestures. By one year, babies begin saying their first words, which are soon combined into two- and three-word sentences. From this point, toddlers begin learning the rules of conversation. Awareness of specific words and their pronunciation continues to improve until it is mastered at age six. The last thing to appear is an understanding for irony and other uses of nonliteral word meanings (Berk, 2009). This pattern of language learning is followed by nearly all individuals, which helps to establish a baseline for expected language acquisition.

Brain Plasticity and Language Development

A key issue in language development is brain plasticity. Traditionally, it has been theorized that as individuals age, brain plasticity and the ability to acquire new skills, including language, decreases. Erik Lenneberg first proposed a sensitive period for language development.

He believed that children must acquire language before the process of brain lateralization is complete, suggesting that puberty is the cutoff for language acquisition (Berk, 2009).

Research with individuals with traumatic brain injuries has provided evidence for this theory. In a study by Tavano et al., the cognitive and neurophysiological functioning of a bilingual child was followed over a period of six years after a severe left hemisphere traumatic brain injury that occurred at the age of seven months. Tests of cognitive ability and scans of brain activity were administered at intervals of 40 days and 18, 31, 62, and 73 months after brain surgery. It was initially observed that the child presented with brain developmental arrest. Later on, it was observed that motor and some cognitive abilities were able to be recovered through extensive therapy. Language ability, however, retained a severe impairment in both expressive and receptive domains (Tavano et al., 2009). This research, which shows a significant decrease in left hemisphere activity and plasticity following brain injury, provides support for the theory that language development is tied to brain plasticity.

A second study by Stein et al. also provides evidence for a relationship between brain functional changes and language learning. In this study, English-speaking foreign exchange students in Switzerland were tested for language skills in German upon arrival in the country and again after five months of residency. Brain functional change was measured as the density of grey matter through the use of MRI scans. It was found that all subjects showed significant improvement in German language skills between test administrations ($p < 0.001$). Analyses performed also revealed a significant relationship between language ability and grey matter density change in the brain ($p < 0.05$). Greater increase in language ability was shown to be correlated with greater increase in grey matter density (Stein et al., 2012). The results of this study suggest that the ability of the brain to reprogram for a new function (i.e. brain plasticity) is significantly correlated with language development. This suggests that the greater the brain plasticity, the greater the ability to learn language.

Each of these studies discussed have major implications for the language learning process, especially among deaf individuals. There is clear evidence for the effect of brain plasticity on language learning, which suggests that there may be a sensitive period for language development. This evidence has been shown through studies involving individuals with traumatic brain injuries as well as studies with second language learners. The relationship between brain plasticity and language-learning ability has important implications for the expectation of language-learning success among cochlear implant recipients; if brain plasticity does in fact decrease with age, cochlear implant recipients would be the most successful in language acquisition if implanted at a young age.

The Effectiveness of Cochlear Implants

In looking at the effect of age at implantation on language learning success, it is first important to establish the effectiveness of cochlear implants in general. Studies to date have had mixed results; some studies have shown that cochlear implant recipients are able to be as successful as hearing peers in language development while others show that they are not able to catch up.

Language Development Over Time

There are two different designs generally used to study the effectiveness of cochlear implants. The first design looks at how individual language acquisition develops over time. In this type of study, it has generally been found that cochlear implant recipients improve in speech intelligibility over time. For example, in a study done by Blamey et al. (2001), conversational speech samples were collected from nine cochlear implant recipients over a period of six years.

Speech samples were analyzed by a speech pathologist or linguist and were scored for the percentage of words that were produced without error. It was found that participants exhibited steady improvement in intelligibility over time and that there was no plateau for language development. A finding suggesting a plateau for language development would decrease the strength of the evidence for the effectiveness of cochlear implants, as it would suggest that cochlear implant recipients are only able to acquire language up to a certain level and may not be able to catch up with hearing peers. Similar results showing steady improvement over time were also found in all other studies examined (Bouchard, Le Normand & Cohen, 2007; Flipsen & Colvard, 2005; Huttunen, 2008).

While most studies following the development of speech intelligibility over time have measured intelligibility by analyzing speech samples for correctly produced words (e.g. Blamey et al., 2001), one study by Richter, Eibelle, Laszig, and Lohle (2002) used a standardized language assessment scale to measure speech intelligibility. The scales used included the expressive language scales of the Reynell Developmental Language Scales III (RDLS), which is a set of scales that has been standardized for children with normal hearing between 1.09 and 7.03 years of age. Like the previous studies mentioned, this study also found that when comparing current language assessment scores with scores from assessments taken immediately post-implantation, there was clear improvement in expressive language and receptive language, as well as in functional hearing. The results of this study also suggested a correlation between age at implantation and language learning success (Richter et al., 2002). Because of the limited age range that the RDLS has been standardized for, there is a potential concern about whether or not this scale is appropriate for its use in this study. An inappropriate use of the measure could potentially lead to inaccurate results. For example, if participants are older than the standardized age range, they could be reported to exhibit better speech intelligibility than they actually have when compared with normal-hearing peers. The authors did not specify the age range of the participants in this study, but only noted that they had each been using a cochlear implant for at least two years. The RDLS has also only been standardized for children with normal hearing and not children with a hearing loss, but there is evidence that this measure is commonly used in the assessment of language in deaf and hard of hearing children. Because of this, the RDLS, is most likely an appropriate measure to use, but differences in patterns of speech and language acquisition of children with a hearing loss compared with children with normal hearing is a concern that should be kept in mind when interpreting results.

Cochlear Implant Recipients v. Hearing Controls

Along with assessing intelligibility improvement over time, studies have also been done to compare cochlear implant recipients with age norms or hearing control subjects. Studies of this nature, however, have shown mixed results. Several studies have shown that cochlear implant recipients are not able to achieve age-normative language development. A study done by Chin, Bergeson, and Phan (2012) found that performance on standardized tests of intelligibility and prosody was significantly related to hearing status (cochlear implant recipient or normal hearing individual, $p < 0.012$), with hearing individuals scoring significantly higher than cochlear implant recipients, as well as being related to hearing age (the time since cochlear implantation, $p < 0.006$). A study which analyzed speech samples of cochlear implant users and age-, sex-, and education-matched controls also found that hearing children scored higher and had significantly higher speaking-rates ($p < 0.0003$) than cochlear implant users (Chuang, Yang, Chi, Weismer & Wang, 2012).

A few studies, however, have shown that some cochlear implant users are able to achieve speech intelligibility at the level of normal-hearing individuals. In a study done by Boons et al., about half of the cochlear implant recipients were able to achieve age-normative language production. No systematically strong or weak aspects of language were identified. The size of the sample (70 cochlear implant recipients and 70 hearing controls) as well as the adequacy of methods used suggest that this conclusion is warranted. The investigators used a matched-subjects design to control for age, gender, and regional differences. Investigators also closely examined normative information available for the standardized measures used to verify the use of each test for the desired purpose (2013). Other studies have also shown similar results (Geers, Moog, Biedenstein, Brenner & Hayes, 2009; Inscoe, Odell, Archbold & Nikolopoulos, 2009). Each of these studies involved assessment of speech samples by trained speech pathologists or speech therapists.

Because many different methods have been used to determine the effectiveness of cochlear implants in relation to speech intelligibility, it is difficult to come up with a clear answer to the question. While some studies have shown that as many as half of the cochlear implant recipients were able to achieve language development at the same level as hearing age-mates, many studies have also shown that a gap still exists between the performance of hearing children and children with cochlear implants. Additionally, research has consistently shown that the speech intelligibility of children who receive cochlear implants continues to improve over time without any indication of a plateau in performance.

Part of the discrepancy in results could be due to the fact that procedures for assessing intelligibility are not standardized. Although the majority of studies assessed intelligibility through analyzing speech samples of participants and many used standardized measures to do so, each study used a slightly different method or a different combination of standardized measures. However, the two largest studies looking at the effectiveness of cochlear implants compared with normal hearing children (Boons et al., 2013 and Geers et al., 2009) used similar measures and showed similar results. Both used the Expressive One-Word Picture Vocabulary Test and at least some subscales from the Clinical Evaluation of Language Fundamentals. In addition, Geers et al. (2009) also used several other measures. Both studies also showed that around 50 percent of cochlear implant recipients were able to achieve age-appropriate levels of language production. The fact that this combination of measures has shown consistent results in two fairly large studies – Boons et al. (2013) had 70 cochlear implant recipients and 70 normal-hearing children while Geers et al. (2009) had 153 cochlear implant recipients compared with age norms – suggests that the measures are effectively assessing speech intelligibility in cochlear implant recipients. The consistent results showing that half of the participants in each case were able to achieve age-normative levels of language leads to the question, why did only half of the participants achieve age-normative results? What were the characteristics of those that were able to achieve age-appropriate language levels versus those that did not? Discovering what external factors play a role in successful language acquisition would be a valuable topic to consider for future research.

Cochlear Implants v. Other Devices

To establish the effectiveness of cochlear implants, it is also important to understand how outcomes with cochlear implants compare with outcomes of traditional hearing aids or other devices. Many studies have been done in this area and results have continuously shown that cochlear implants are by far more effective than hearing aids. One study done by Bat-Chava, Martin, and Kosciw (2005) looked at the development of communication, socialization, and daily living skills among individuals with hearing aids and cochlear implants after several years of device use. A scale assessing each of these domains was used in a phone interview with the parent or primary caregiver of the child. Using this method, it was found that for all children, communication skills improved over time, but for children with cochlear implants, improvement was at a faster rate than it was for children with hearing aids. It was also found that after years of use, both hearing aid and cochlear implant users were able to obtain normal levels of development. The authors also note that it appears that the participants with cochlear implants were developmentally further behind the participants using hearing aids, so the fact that both participant groups were able to achieve age-appropriate levels of development on average shows even more evidence for the effectiveness of cochlear implants.

The method that is by far the most prevalent in this area of research, however, has been to record speech samples for each participant and play the samples back to a panel of judges. The judges would then attempt to identify what was being said and intelligibility would be judged by how many words were correctly identified.

Studies vary, however, in the judges' experience with identifying speech. In a study done by Baudonck, Dhooge, and Van Lierde (2010), for example, the intelligibility of speech was judged subjectively by two speech pathologists and the child's primary caregiver (i.e. the mother) from recorded speech samples of participants reading words, sentences, and a short story. The investigator then counted the total number of words correctly understood and determined an intelligibility percentage, according to a specified intelligibility index. It was shown that while the speech of hearing aid recipients was the least intelligible, the intelligibility of the speech of cochlear implant users and hearing children was comparable. The scores of hearing aid users differed significantly from both cochlear implant users ($p < 0.017$) and individuals with normal hearing ($p < 0.001$), with the difference between cochlear implant users and normal hearing children being nonsignificant. Osberger, Maso, and Sam (1993) used the same method of testing. Speech samples in this study were played for a panel of three judges, with the score for each judge being the number of words identified correctly. It was shown that although children implanted before the age of ten had the best speech intelligibility, those implanted after ten had the worst. In this case, the judges were primarily undergraduate students with no experience with the speech of deaf or hard of hearing individuals.

Finally, in a study done by Van Lierde, Vinck, Baudonck, De Vel, and Dhooge (2005), speech was analyzed by two speech pathologists with experience in identifying speech. In this study, speech samples were recorded and then rated by speech pathologists on a scale from 0 to 3, with 0 denoting normal speech and 3 denoting severely impaired speech. According to these ratings, it was shown that children with cochlear implants had significantly higher speech intelligibility than those with hearing aids ($p < 0.05$).

Among these studies and others that used similar methods to assess speech intelligibility, only one reported any measures taken to assess interrater reliability, so the issue is primarily an issue of reliability. In order for the validity of measures to be questioned, it must first be established that measures were reliable in that judges were able to achieve ratings within a certain level of accuracy. However, if we assume that raters were reliable, the difference in expertise of judges in each of these studies could also theoretically be problematic for establishing the effectiveness of cochlear implants in comparison with hearing aids. Very different results could be obtained in each case when different judges are used. For example, speech pathologists or primary caregivers who are experienced with listening to and understanding the speech of individuals who are deaf or hard of hearing may have identified more words than undergraduate students with no experience. As a result, in the studies in which speech pathologists or primary caregivers were used to rate speech, there may have been less of a difference perceived between the speech of hearing aid users and the speech of cochlear implant users or individuals with normal hearing. It follows that in the study using undergraduate students as raters, there may have been a greater difference perceived between the speech samples of hearing aid users, cochlear implant users, and individuals with normal hearing. In order to standardize results, it may be beneficial to investigate which method of judging is most effective for understanding differences in speech and conduct more studies using that method.

Studies have also shown substantial differences in the history of deafness among participants. Because of the fact that hearing aids are typically only effective when there is some residual hearing and the fact that children are usually only implanted when hearing loss is too great for hearing aids to be effective, most hearing aid users in these studies have substantially more hearing than cochlear implant recipients. One study reported that hearing aid users had significantly better hearing than cochlear implant users ($p < 0.001$) (Bat-Chava et al., 2005). The rest of the studies analyzed mentioned differences in level of hearing as well as differences in years of training (Baudonck et al., 2010; Law & So, 2006; Osberger et al., 1993; Van Lierde et al., 2005). These differences add a potential confound to each of the studies in establishing the effectiveness of cochlear implants. Although each study showed that cochlear implants were more effective than hearing aids, there is at least the possibility that the observed effects were caused by individual hearing differences rather than the device being used. This sampling problem may be difficult to deal with, however, as it would be difficult to find participants with hearing aids with the same level of residual hearing as participants with cochlear implants. This complexity and the fact that the population for each group is also limited would make this confound difficult to address. Sample size also appeared to be an issue in general. Two of the studies had less than ten participants in each group (Law & So, 2006; Van Lierde et al., 2005) and only one had more than 20 in each group (Baudonck et al., 2010). This pattern of small samples can be partially attributed to the fact that there are relatively few deaf individuals in comparison with the general population and even fewer cochlear implant and hearing aid users. As such, conclusions based on these studies should be tentative in nature.

The Effect of Age at Implantation

One clear trend seen in the literature is that the earlier a child receives a cochlear implant, the better their chances are at language learning success. The majority of studies analyzed have shown clear support for this hypothesis, with only a few failing to show support. Many studies dividing subjects into groups based on the age at implantation found significant differences in speech intelligibility and language acquisition for each group. For example, in a study done by Svirsky, Chin, and Jester (2007), participants were split into five different groups: those implanted in the second year, third year, fourth year, fifth or sixth year, and seventh or eighth year of life. The results of this study indicated significant language learning advantages of younger groups over all older groups ($p < 0.001$), except in the case of those implanted in the third year versus those implanted in the fourth year. Other studies using similar methods to group participants also found significant differences between age groups (Niparko et al., 2010; Svirsky, Teoh & Neuburger, 2004).

Other studies have found only suggested relationships for an effect of age at implantation on speech intelligibility and language acquisition. In one such study, participants were grouped according to age at implantation: before three years, between three years and four years, and between four years and five years and three months of age. Through testing using standardized measures, a suggested relationship was found between implant age and language outcome, with children implanted earlier being more likely to develop speaking and listening skills. No significant relationships were found (Miyamoto, Kirk, Svirsky & Sehgal, 1999). Several other studies also found non-significant evidence for relationships between language outcomes and age at implantation using standardized measures (Peng, Spencer & Tomblin, 2004; Tobey et al., 2013; Tye-Murray, Spencer & Woodworth, 1995). A few studies not using standardized measures also found similar non-significant relationships (May-Mederake, 2012; Nicholas & Geers, 2007).

Studies generally agree that the earlier a child is implanted the better their chances at language learning success but disagree as to the precise age cutoff before which results are best. Older research suggests that those implanted before the age of three or five had best language learning results (Miyamoto, Kirk, Svirsky & Sehgal, 1999; Tye-Murray, Spencer & Woodworth, 1995). However, this observation could be due to the fact that up until the last few years, children were not implanted before the age of two. This has changed fairly recently, with children now being implanted at as early as one year of age. More recent research reflects this change, with the best outcomes in speech intelligibility and language acquisition occurring in cases in which children were implanted before the age of two (May-Mederake, 2012; Nicholas & Geers, 2007; Niparko et al., 2010; Svirsky, Chin & Jester, 2007; Svirsky, Teoh & Neuburger, 2004; Tobey et al., 2013).

Although most of the studies reviewed showed at least a suggested relationship between age at implantation and speech intelligibility, a few studies showed no relationship or a stronger relationship with other variables. For example, Khawaileh and Flipsen (2010) found a significant correlation between implant experience and speech intelligibility ($p < 0.017$), but found no relationship between speech intelligibility and chronological age or age at implantation. Habib, Waltzman, Tajudeen, and Svirsky (2010) on the other hand, showed a significant effect of age at testing on speech intelligibility, with the oldest children scoring the highest ($p < 0.001$), but also found that of the older children, those who had been implanted earliest had the greatest speech outcomes ($p < 0.05$). Children tested were between the ages of two and a half years and eighteen years and all participants had been implanted between eight and 40 months.

Methodology

The majority of the studies analyzed for this review used standardized measures to assess speech intelligibility. The most common measures used were the Beginner's Intelligibility Test and the Reynell Developmental Language Scales. Other scales used included the Children's Speech Intelligibility Measure, the Peabody Picture Vocabulary Test, the Preschool Language Scale, the Short-Long Sentence Test, the Monsen Sentences task, the MacArthur Communication Development Inventories, and the Comprehensive Assessment of Spoken Language. Spontaneous speech samples were also assessed in several studies. All assessments in which listeners were used to code for speech intelligibility were done with naive listeners who were unfamiliar with the speech of deaf or hard of hearing individuals. Normative information for standardized measures was only provided in a few studies, but the information provided suggests that standardized measures were used appropriately, especially in the case of the Beginner's Intelligibility Test and the Reynell Developmental Language Scales. There is evidence that these two measures especially are commonly used in studying speech intelligibility and language ability in children and even in children with hearing loss. The age ranges for each of the studies also appeared to match the normative age ranges provided.

Limitations

A final issue that should be taken into consideration when reviewing the results of the research is the fact that most studies did not assess cochlear implant experience, experience prior to implantation, or communication and language learning methods when evaluating speech intelligibility and language acquisition. Some studies mentioned differing levels of communication and speech learning strategies among participants (e.g. oral communication versus total communication, Svirsky, Teoh & Neuburger, 2004). Others mentioned differing hearing experiences prior to implantation (e.g. amount of residual hearing, time wearing hearing aids, etc., Khawaileh & Flipsen, 2010). Finally, most studies also mentioned that participants used varying cochlear implants (i.e. different brands) with differing speech processing systems (e.g. Peng, Spencer & Tomblin, 2004). Each of these factors could potentially have an effect on language acquisition and should be controlled for in future research. For example, participants using one type of cochlear implant and the total communication speech-learning strategy could have substantially higher success in language learning than those using another type of cochlear implant or the oral communication strategy. In order to determine whether differences in language learning ability are indeed caused by age at implantation, all other potentially confounding variables must be controlled.

Although there are flaws in the present research methodology that should be addressed, the prevalence of data suggesting a relationship between age at implantation and speech development outcomes cannot be ignored. The fact that most studies assessing age at implantation and language learning ability show that there is a relationship between the two variables suggests that a connection does exist. This relationship, if true, could have substantial implications for advising parents in the best path for language learning success for their deaf child and makes the case for the use of cochlear implants even stronger.

Conclusion

Research on norms for language acquisition has shown that all individuals follow the same pattern of language acquisition. It has also been suggested that there is a sensitive period for language development, which has support in the fact that children are able to become more proficient in language learning than adults. A clear link has also been shown between brain plasticity and language acquisition, which indirectly supports the theory that language learning ability decreases with age. Cochlear implants have been shown to be effective for language acquisition in longitudinal studies and studies in which recipients are compared with hearing control subjects. Cochlear implants have also been shown to be more effective than traditional hearing aids. Finally, research suggests that the earlier children are implanted, the greater their chances at success in language acquisition and speech intelligibility.

Practically, research on cochlear implants and their effectiveness is difficult. Because the use of cochlear implants involves surgery and extensive hearing and speech therapy, the entire process is very expensive. Also, because of ethical issues, this type of research cannot be experimental; researchers must rely on correlational data only. The relative infrequency of cochlear implant use among the already small population of deaf individuals also leads to sampling issues. In order to obtain enough participants to make a study worthwhile, random sampling is next to impossible. Researchers must instead rely on convenience and snowball sampling. Because of these factors, research with cochlear implants is difficult to conduct.

Further research in this area is needed to investigate whether there is a plateau for language acquisition. The limited research up until this point suggests that there is no plateau, but additional research is necessary to confirm this trend. Research to investigate whether external factors, such as the amount of support provided to the child or the method of communication used, interact with age at implantation to increase or decrease language learning outcomes is also important, as no two children receive the same amount of support. Lastly, the majority of research up until this point has been done with cochlear implant recipients who are children, so it would be interesting to investigate what outcomes are like for deaf adult recipients or adults who lost hearing later in life.

References

Bat-Chava, Y., Martin, D., & Kosciw, J. G. (2005). Longitudinal improvements in communication and socialization of deaf children with cochlear implants and hearing aids: Evidence from parental reports. *Journal of Child Psychology and Psychiatry, 46*(12), 1287-1296. doi:10.1111/j.1469-7610.2005.01426.x

Baudonck, N., Dhooge, I., & Van Lierde, K. (2010). Intelligibility of hearing impaired children as judged by their parents: A comparison between children using cochlear implants and children using hearing aids. *International Journal of Pediatric Otorhinolaryngology, 74*(11), 1310-1315. doi:10.1016/j.ijporl.2010.08.011

Berk, L. (2009). Language development. *Child development* (8th ed., pp. 356-397). Boston: Pearson Education.

Blamey, P., Barry, J., Bow, C., Sarant, J., Paatsch, L., & Wales, R. (2001). The development of speech production following cochlear implantation. *Clinical Linguistics & Phonetics, 15*(5), 363-382. doi:10.1080/02699200010017823

Boons, T., de Raeve, L., Langereis, M., Peeraer, L., Wouters, J., & van Wieringen, A. (2013). Expressive vocabulary, morphology, syntax and narrative skills in profoundly deaf children after early cochlear implantation. *Research in Developmental Disabilities, 34*(6), 2008-2022. doi:10.1016/j.ridd.2013.03.003

Bouchard, M. G., Le Normand, M., & Cohen, H. (2007). Production of consonants by prelinguistically deaf children with cochlear implants. *Clinical Linguistics & Phonetics, 21*(11-12), 875-884. doi:10.1080/02699200701653634

Chin, S. B., Bergeson, T. R., & Phan, J. (2012). Speech intelligibility and prosody production in children with cochlear implants. *Journal of Communication Disorders*, *45*(5), 355-366. doi:10.1016/j.jcomdis.2012.05.003

Chuang, H., Yang, C., Chi, L., Weismer, G., & Wang, Y. (2012). Speech intelligibility, speaking rate, and vowel formant characteristics in mandarin-speaking children with cochlear implant. *International Journal of Speech-Language Pathology, 14*(2), 119-129. doi:10.3109/17549507.2011.639391

Flipsen, P. J., & Colvard, L. G. (2006). Intelligibility of conversational speech produced by children with cochlear implants. *Journal of Communication Disorders*, *39*(2), 93-108. doi:10.1016/j.jcomdis.2005.11.001

Geers, A. E., Moog, J. S., Biedenstein, J., Brenner, C., & Hayes, H. (2009). Spoken language scores of children using cochlear implants compared to hearing age-mates at school entry. *Journal of Deaf Studies and Deaf Education, 14*(3), 371-385. doi:10.1093/deafed/enn046

Habib, M. G., Waltzman, S. B., Tajudeen, B., & Svirsky, M. A. (2010). Speech production intelligibility of early implanted pediatric cochlear implant users. *International Journal of Pediatric Otorhinolaryngology, 74*(8), 855-859. doi:10.1016/j.ijporl.2010.04.009

Huttunen, K. (2008). Development of speech intelligibility and narrative abilities and their interrelationship three and five years after paediatric cochlear implantation. *International Journal of Audiology, 47,* S38-S46. doi:10.1080/14992020802322619

Inscoe, J. R., Odell, A., Archbold, S., & Nikolopoulos, T. (2009). Expressive spoken language development in deaf children with cochlear implants who are beginning formal education. *Deafness & Education International*, *11*(1), 39-55. doi:10.1002/dei.252

Khwaileh, F. A., & Flipsen, P. J. (2010). Single word and sentence intelligibility in children with cochlear implants. *Clinical Linguistics & Phonetics, 24*(9), 722-733. doi:10.3109/02699206.2010.490003

Law, Z. W. Y., & So, L. K. H. (2006). Phonological abilities of hearing-impaired cantonese-speaking children with cochlear implants or hearing aids. *Journal of Speech, Language, and Hearing Research, 49*(6), 1342-1353. doi:10.1044/1092-4388(2006/096)

May-Mederake, B. (2012). Early intervention and assessment of speech and language development in young children with cochlear implants. *International Journal of Pediatric Otorhinolaryngology, 76*(7), 939-946. doi:10.1016/j.ijporl.2012.02.051

Miyamoto, R. T., Kirk, K. I., Svirsky, M. A., & Sehgal, S. T. (1999). Communication skills in pediatric cochlear implant recipients. *Acta Oto-Laryngologica, O1 119*(2), 219-224. doi:10.1080/00016489950181701

National Association of the Deaf. *Early intervention for infants and toddlers.* (2013, November 03). Retrieved from http://nad.org/issues/early-intervention.

Nicholas, J. G., & Geers, A. E. (2007). Will they catch up? the role of age at cochler implantation in the spoken language development of children with severe to profound hearing loss. *Journal of Speech, Language, and Hearing Research, 50*(4), 1048-1062. doi:10.1044/1092-4388(2007/073)

Niparko, J. K., Tobey, E. A., Thal, D. J., Eisenberg, L. S., Wang, N., Quittner, A. L., & Fink, N. E. (2010). Spoken language development in children following cochlear implantation. *JAMA: Journal of the American Medical Association, 303*(15), 1498-1506. doi:10.1001/jama.2010.451

Osberger, M. J., Maso, M., & Sam, L. K. (1993). Speech intelligibility of children with cochlear implants, tactile aids, or hearing aids. *Journal of Speech & Hearing Research*, *36*(1), 186-203.

Peng, S., Spencer, L. J., & Tomblin, J. B. (2004). Speech intelligibility of pediatric cochlear implant recipients with 7 years of device experience. *Journal of Speech, Language, and Hearing Research*, *47*(6), 1227-1236. doi:10.1044/1092-4388(2004/092)

Richter, B., Eißele, S., Laszig, R., & Löhle, E. (2002). Receptive and expressive language skills of 106 children with a minimum of 2 years' experience in hearing with a cochlear implant. *International Journal of Pediatric Otorhinolaryngology, 64*(2), 111.

Stein, M., Federspiel, A., Koenig, T., Wirth, M., Strik, W., Wiest, R., . . . Dierks, T. (2012). Structural plasticity in the language system related to increased second language proficiency. *Cortex: A Journal Devoted to the Study of the Nervous System & Behavior, 48*(4), 458-465.

Svirsky, M. A., Chin, S. B., & Jester, A. (2007). The effects of age at implantation on speech intelligibility in pediatric cochlear implant users: Clinical outcomes and sensitive periods. *Audiological Medicine, 5*(4), 293-306. doi:10.1080/16513860701727847

Svirsky, M. A., Teoh, S., & Neuburger, H. (2004). Development of language and speech perception in congenitally, profoundly deaf children as a function of age at cochlear implantation. *Audiology & Neurotology, 9*(4), 224-233. doi:10.1159/000078392

Tavano, A., Galbiati, S., Recla, M., Formica, F., Giordano, F., Genitori, L., & Strazzer, S. (2009). Language and cognition in a bilingual child after traumatic brain injury in infancy:

Long-term plasticity and vulnerability. *Brain Injury, 23*(2), 167-171. doi:10.1080/02699050802657012

Tobey, E. A., Thal, D., Niparko, J. K., Eisenberg, L. S., Quittner, A. L., & Wang, N. (2013). Influence of implantation age on school-age language performance in pediatric cochlear implant users. *International Journal of Audiology, 52*(4), 219-229.

Tucker, B. P. (1998). Deaf culture, cochlear implants, and elective disability. *Hastings Center Report, 28*(4), 6-14.

Tye-Murray, N., Spencer, L., & Woodworth, G. G. (1995). Acquisition of speech by children who have prolonged cochlear implant experience. *Journal of Speech & Hearing Research, 38*(2), 327-337.

Van Lierde, K. M., Vinck, B. M., Baudonck, N., De Vel, E., & Dhooge, I. (2005). Comparison of the overall intelligibility, articulation, resonance, and voice characteristics between children using cochlear implants and those using bilateral hearing aids: A pilot study. *International Journal of Audiology, 44*(8), 452-465. doi:10.1080/14992020500189146