Factors Associated with Speech Recognition Outcomes for Prelingually Deaf Cochlear Implant Users: A CASE SERIES

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Cochlear Implants: Factors Associated with Speech Recognition Outcomes

BACKGROUND

In this technological day and age, the advancements in cochlear implant (CI) technology and procedures for individuals with profound sensorineural hearing loss are constantly improving. Research shows that earlier implantation in children leads to better speech and language development outcomes (Manrique, 2004) and, specifically, that implantation before two years of age is better than later (Holt & Svirsky, 2008). Thus, if “earlier is better,” individuals who are prelingually deafened, or, those whose hearing loss occurred before two years of age (Tye-Murray, 2009) may demonstrate less than ideal performance on clinical measures if he/she were not implanted until after the critical period of speech and language acquisition. This is because, without hearing, a person may experience difficulty learning and understanding spoken language (Gantz, Tyler, Woodworth, et al., 1994). Furthermore, CI users’ speech and language skills are often not as refined as individuals with normal hearing (Shpak et al., 2009), especially in prelingual CI users (Fitzpatrick & Schramm, 2006). In this paper, an individual deafened before two years of age but implanted post-critical speech/language development shall be termed a “prelingual CI user.”

Performance outcomes differ due to many variables “affecting performance in adults and children” (Cosetti & Waltzman, 2012). Maura Cosetti and Susan Waltzman (2012) discuss a myriad of factors associated with good and poor speech recognition scores, including CI technology, age at implantation, duration of deafness, neuroplasticity, meningitis, syndromes, hearing level, speech performance, mode of communication, education, rehabilitation services, family expectations and motivation, etc.

The objective of our research is to investigate eight prelingual CI users by reviewing seven factors which may affect their outcomes (speech recognition scores). They are gender, etiology, age of implantation, type of device, communication (oral, speech reading, or sign), patient compliance (attendance for scheduled medical appointments), and family and environment.

The *aim* of this study is to understand how the outcomes for prelingual CI users can be improved through increasing awareness of the seven factors in this study. The research question in this paper asks, 'what factors may be associated with positive outcomes following cochlear implantation for prelingual CI users?' The end result of our research will highlight the individual differences between patients and provide information about the factors related to speech recognition outcomes. Health professionals may consider these factors when counseling their clients regarding their outcome. CI users may use this information improve their outcome.

METHODS AND PROCEDURES

Design

For this case series study, data was collected retrospectively from notes, prepared by a graduate student research assistant, from the participants' medical files at the *Glenrose Rehabilitation Hospital*. From the data available (i.e., from the notes collected), participants for this study were chosen based on whether their records provided pre and post-implantation speech recognition scores, which resulted in a total of eight participants. In order to ensure consistency of outcome measurement, participants were included if they had records of speech recognition scores on the *Central Institute for the Deaf (CID) – Everyday Sentences test* or *the Hearing In Noise Test (HINT)*. These tests measure an individual's ability to correctly recognize words in sentences spoken out loud, expressed as a percentage of correctly recognized words.

With the eight participants eligible for this study, factors were extracted from the notes available from the medical charts pertaining to gender, etiology, age of implantation, type of device, method(s) of communication (e.g. oral, speech reading, sign), patient compliance (attendance for scheduled medical appointments), and family and environment.

The Sample

The participants in this study were all prelingually deaf people who had received a CI unilaterally. Inclusion criteria included the availability of both pre and post assessment measures (measured within one year after CI surgery for seven out of eight participants), prelingual deafness with severe to profound hearing loss, and CI surgery after two years of age. Since data was drawn from medical files, certain criteria were not always present for each participant; therefore, there were some “unknowns” for certain participant factors (e.g., etiology, compliance, etc.).

Measures

This paper looked at CI users’ speech recognition scores and addressed the influence of seven possible factors that may have contributed to either poor or successful speech recognition outcomes: Gender, etiology, age of implantation, type of device, method(s) of communication (e.g. oral, speech reading, sign), patient compliance (attendance for scheduled medical appointments) and family and environment. These factors (e.g. gender, age, etc.) are important because they have been studied by a number of investigators in the past as reviewed below.

FINDINGS *(For summary, see Table 1 – p.9)*

Participants

Patient #9. Nineteen year old female, bilaterally severe-profound SNHL, and etiology unknown. She had worn hearing aids on the right side at all times before her CI in 2002. At approximately ten years of age, her right ear was implanted with a CII Bionic 90k with Harmony speech processor. After implantation she had reported feelings of dizziness and off-balance. One year post-surgery she reported limited benefit from her CI and would only used it approximately three hours per day; however, she was beginning to wear it more often. Two and a half years later, she reported that she was beginning to use the telephone and could hear environmental noise. As well, she could sometimes understand people talking without having to look at them, and could also hear people call her name. Four years post implantation, it was noted that she was able to understand more speech and could speak more on the telephone. It was indicated from the file that she communicated orally, speech read, and did not use sign language in her daily activities. The CID everyday sentence test (auditory only) was given both pre and post implantation. Her results indicated that the score had decreased from pre to post assessment (i.e., 24% to 0~1% "unable to correctly identify any words in sentences with open set CID sentences, without visual cues").

Patient #17. Patient 17 was a twelve year old female. She was implanted in her left ear in 2003 with a Nucleus 24 Contours with Freedom speech processor when she was approximately four years old. Before implantation, she presented with profound SNHL and an unknown etiology. It was noted in the file that patient 17 communicated orally, as well as sign and speech reading. She had been making progress with her CI; however, she often complained that it was too soft and struggled using it for work. It was questioned in her file if the MAPs (mapping or programming the device to the needs of the user) had worked. It was also indicated that patient

17 wore her CI but used her FM system less often. Patient 17 was tested both pre and post implantation. As she was still a young child pre implantation, she was tested using the GASP sentences and received a score of 0%. Her post implantation scores after three to four years showed a speech recognition score of 22% on the CID everyday sentence test (auditory only).

Patient #22. Patient 22 was a forty-four year old female who presented with profound SNHL bilaterally. She had been wearing hearing aids since she was two years old and had had no history of balance problems or ear surgeries. She did have a history of arthritis. Patient 22 was implanted in 2008 and was forty-one years old at the time. She received a Freedom Contour Advance CI. It was indicated in her file that she had been slow to adjust to the CI device. Patient 22 communicated orally and had learned some sign language. The file reported that patient 22 had excellent family support and the etiology causing her deafness was unknown. Two years post implantation, she continued to show problems with speech recognition; however, according to the file, she had made some minimal gains over her previous performance with her hearing aids. Patient 22 had been assessed using the CID everyday sentence test (auditory only) both pre and post implantation. Her scores were 9% initially and 4% after one year of surgery. She was tested again two years post-surgery and received a score of 8%.

Patient #25. Patient 25 was a thirty-four year old female who was implanted in her left ear at age twenty-nine in December of 2007. She received a Freedom Contour with a speech processor 2. She had been fitted with hearing aids at the age of two years-six months. She had worn a hearing aid in her left ear until the age of twenty-four, but then discontinued wearing the device as she no longer benefited from using it. In addition, she did not use a hearing aid in her right ear as she did not report any benefit from wearing the device. Patient 25 presented with profound

SNHL bilaterally before implantation and did not have any auditory brainstem response for her right ear. She described constant tinnitus in her left ear, but did not report any serious balance problems. Since her surgery, patient 25 indicated that she had begun to rely less on speech reading and more on her auditory abilities. She started using the telephone in a limited fashion and stated that she was beginning to enjoy music. Continued benefit from the CI was noted for patient 25 from February 2009 to June 2010 as noted in her medical file. She had been assessed both pre- and one year post-surgery using the CID everyday sentence test (auditory only) receiving scores of 0% and 67% respectively.

Patient #26. Patient 26 was a twenty-six year old female who presented with profound SNHL in her right ear and severe-profound SNHL in her left before implantation. The underlying etiology and the progression of her hearing loss were unknown. It was stated in her medical file that she had had a history of middle ear problems, including otitis media, as well as had undergone a right mastoidectomy and had received many sets of pressure equalization tubes since 2005. The CI surgery had been re-scheduled many times due to the afore mentioned middle ear difficulties. In 2005, she received a Bionics 90k CI in her right ear at the age of nineteen. It was noted in the file that one year post-surgery, she had excellent hearing sensitivity and good speech discrimination with her CI; however, she continued to have problems with middle ear fluid and had severely reduced tympanic compliance bilaterally. Patient 26 had been assessed both pre and one year post-surgery using the HINT (in quiet). Her pre implantation score was 0% and her post implantation score was 20%. It was reported that patient 26 attended all medical appointments regarding her CI.

Patient #28. Patient 28 was a twenty-two year old male who presented with a diagnosis of Waardenburg's syndrome and profound sensorineural hearing loss bilaterally. He was implanted with a Freedom Contour advance in his right ear at the age of nineteen in 2008. It was discussed in patient 28's file that he used speech reading and note pads as a form of communication pre-surgery. He had used Signed Exact English (SEE) in high school but did not use it anymore. Patient 28 reported that he had always worn hearing aids and that his hearing had not changed a lot throughout his life. After surgery he experienced some dizziness/light headedness, fatigue and some facial nerve stimulation. A year post surgery, he stated that his primary benefit from the CI was improved sensitivity and that he was able to hear softer sounds better than he had with his hearing aids. Medical reports indicated that a year and a half after implantation, his speech intelligibility had improved since his last appointment, but he was not 100% intelligible. Two years post-surgery it was noted that patient 28 did not wear his device during the day due to his work environment; however, he wore both his CI and his hearing aid (in left ear) in the evenings. Patient 28 had been assessed both pre and post-surgery with the CID everyday sentence test (auditory only) and received a score of 1% and 2% respectively.

Patient #29. Patient 29 was a twenty-eight year old male who had profound SNHL bilaterally. It was speculated in his medical file that his hearing loss may have been due to his mother having German measles during her pregnancy. He had worn Behind-the-Ear (BTE) bilateral hearing aids until he was sixteen years old when he discontinued using his left hearing aid. Patient 29 used both oral and manual communication pre-implantation. He was implanted in his right ear with a CI 512 Nucleus in 2010 at the age of approximately twenty-seven. It was stated in his file that he enjoyed music (although he desired increased volume). Furthermore, he found it difficult to follow conversations. His CI was reprogrammed in 2011 and he reported a significant improvement in the area of clarity of speech. Patient 29 was assessed pre and post-surgery using the HINT (in quiet). His pre score was 44% and his post score was 48%.

Patient #33. Patient 33 was a fifteen year of female who presented with profound SNHL bilaterally. The etiology causing her hearing loss was DiGeorge Syndrome as well as an Aspergilis niger fungal infection at birth. Patient 33 had had a history of constant ear infections since birth, and had myringotomy tubes approximately fourteen times. She received hearing aids at approximately seven or eight years old, and had worn them since 2003 when she required a bilateral mastoidectomy due to her ear infections. This resulted in erosion of the facial nerve. She received a BAHA surgery in 2003 as well and used these until 2006 when she could no longer hear using the BAHA. Patient 33's right ear had closed twice in 2007 and her left ear was surgically closed at this time. Along with the many ear surgeries, patient 33 had also undergone four heart surgeries and had a cleft palate repair at six months of age. In 2007, a Nucleus Cochlear Freedom Contour CI was implanted in patient 33's right ear when she was approximately eleven years old. It was indicated in her file that she used her CI all waking hours and her speech had improved significantly, although still severely delayed. It was also reported that she is now able to use the telephone, however, has difficulty hearing in background noise. The file also indicated that she was an auditory oral communicator and reported being happy with her CI and required fewer programming changes compared to other CI users. It was noted that she attended medical appointments (number of attendance/appointments unknown) in regards to her CI. Patient 33 had been assessed both pre and post-surgery for speech recognition using the HINT (in quiet). Her scores were as follows, 0% pre implant and 100% post implant.

Table 1: Participant Information

Partici-pant #	Gender	Age	Age at implant-ation	Post-months when tested	Hearing Loss	Ear implanted	Speech Recognition Score (post-pre)	Type of Communication used	Etiology of Hearing Loss	Type of Device	Compliance
33	F	15	11	12 months	profound SNHL bilaterally	right	100% HINT	Oral	Digeorge Syndrome and Aspergilis Niger Fungal Infection at birth	Nucleus Freedom Contour	went to all appointments
25	F	33	29	12 months	profound SNHL bilaterally	left	67% CID	Oral and speech reading	Mother's rubella	Nucleus Freedom Contour	
26	F	25	19	7 months	severe-profound SNHL bilaterally	right	30% CID	Unknown	Unknown	Bionics 90k	went to all appointments
17	F	12	4	36 months	profound SNHL	left	22% CID	Oral, sign and speech reading	Unknown	Nucleus Freedom N24	
Mean			15.75				Range: 22 to 100%				
29	M	28	27	8 months	profound SNHL bilaterally	right	4% HINT	Unknown	Maternal German Measles	Nucleus 512	
28	M	21	18	8 months	profound SNHL bilaterally	right	1% CID	Speech reading and writing	Waardenburg's	Nucleus Freedom Contour	
22	F	44	41	7 months	profound SNHL bilaterally	unknown	4% CID	Oral and sign	Unknown	Nucleus Freedom Contour	
9	F	19	10	3 months	SNHL	right	2% CID	Oral and speech reading	Unknown	Bionics 90k	
Mean			24				Range: 1% to 4%				

The summary of the findings. The summary of the findings from the participants shows that oral communication, patient compliance and family and environment may trend towards positive outcome associations. While statistical evidence for these factors cannot be shown to be significant, the highlighted results below illustrate why it is believed that these factors may trend towards positive outcomes.

Additional information regarding factors

Gender. In the current study, retrospective data was collected for six female and four male prelingual CI users (3:2). Only female participants improved more than 20% on their speech recognition scores (comparing pre versus post results); however, two female participants also had the worst outcome measures and showed a decrease in speech recognition ability one year after implantation. The two male participants improved in their post-test clinical measures, but not enough to be considered successful (less than 20% improvement). The average performance of the six females was greater (i.e., a 32% improvement) than the average performance of the two males (i.e., a 2.5% improvement), which appears to be a significant difference; however, with only eight participants in the study, associations between gender and clinical outcome measures could not be made with certainty.

Type of CI device. In this study, participants were implanted in either the right or left ear with one of the following devices: *CII Bionic* with *Harmony* speech processor (participant 9), *Nucleus 24 Contours* with *Freedom* speech processor (participant 17), *Freedom Contour Advance* (participants 22 and 28), *Nucleus Cochlear Freedom Contour* with a speech processor *2* (participant 25), *Bionics 90k* (participant 26), *Nucleus 512* (participant 29), *Nucleus Cochlear Freedom Contour* (participant 33). Participant 9 was deemed as having unsuccessful speech recognition scores whereas participant 26 was deemed as having successful speech recognition scores. Both these participants used a Bionics device; however, the successful participant used a Bionics 90k instead of a harmony speech processor. The difference in speech processors may have played a part in the successfulness of the speech recognition outcome; however, as there are only two participants that used a Bionics device, this is just speculation. Looking at the data, it can be seen that both participants that used a Freedom Contour Advance CI (i.e., 22 and 28) were also classified as both having unsuccessful speech recognition outcomes. Two participants that were implanted with a *Nucleus Cochlear Freedom Contour* CI (i.e., 25 and 33) both were classified as having a successful speech recognition outcome. Again, more data would be needed to determine if there is a link between the type of CI and speech recognition outcomes. It was also observed that three out of the four participants that were deemed to have successful speech recognition scores also were implanted with relatively newer CI (e.g., *Nucleus Cochlear Freedom Contour* and *Bionics 90k*). More research is needed in order to determine if newer CIs aid speech recognition outcomes. Six of eight participants opted for a *Nucleus* device; the remaining two chose *Bionic*. The type of speech processor varied among participants, or was not available from the data available. Successful and unsuccessful speech recognition scores post-implantation were achieved by both Nucleus and Bionic users; therefore, based on the information available from the retrospective data, the type of device implanted in a prelingual individual with bilateral SNHL does not appear to be associated with either a poor or successful outcome.

Oral Communication. Oral, speech reading, and/or sign language were the modes of communication used among the participants in the current study. The chart shows the variability of this factor among participants; the majority of participants used combinations of communication type that were different from each other. It was observed from the findings that 75% of participants (i.e., three out of four) used oral communication before implantation as their main communication modality and had successful speech perception outcomes post cochlear implantation. In contrast, only 50% of participants (i.e., two out of four), deemed to have poor speech perception outcomes post cochlear implantation, used oral communication. For example, participant 17 used oral communication, speech recognition, and sign; she was determined to have relatively successful speech recognition scores. There were no other participants for comparison who used a combination of oral communication, speech recognition, and sign. Furthermore, participant 28 used speech reading and writing for communication; his post implantation speech recognition score was relatively unsuccessful. There were no other participants for comparison who used the same modes of communication. Participant 22, relatively unsuccessful, used oral communication and sign. Again, no other participants used a combination of oral communication and sign. The participant with the most successful speech recognition outcome, number 33, used only oral communication. She was the only known participant to use oral speech for communication exclusively (information unavailable for participant 26 and 29 regarding type of communication). Oral and speech reading was a common factor between participant 25 (relatively the second most successful participant) and participant 9 (relatively the least successful participant); the chart shows that the participant with a relatively successful outcome measure used common modes of communication as the relatively unsuccessful participant. As participant 25 and participant 9 were the only subjects with similar communication modes, the influence of communication mode on speech recognition outcome could not be determined. It appears that the use of oral communication only may yield relatively successful speech recognition outcomes, based on the outcome measure for participant 33. However, due to the limited available data and unknown communication types for two participants in this study, associations between type of communication and speech recognition outcome could not be determined with significance in the current study. Previous research has shown that children exposed to oral communication before implantation have better speech perception outcomes post implantation (Cosetti & Waltzman, 2012).

Compliance. It was noted that 50% of "successful" participants (i.e., those participants that showed improved speech perception outcomes post implantation) had attended all medical appointments. Two participants with successful outcomes, 26 and 33, were reported to have attended all scheduled medical appointments. Data for compliance (measured by the number of times the participant attended a scheduled medical appointment) was not available for the remainder of the participants. The authors of this paper speculated that the compliance demonstrated by the two participants, who were reported to have attended all scheduled medical appointments, may have contributed to their successful speech recognition outcomes (100% improvement on the HINT for 33 and 30% improvement on the CID for 26), thus supporting the findings from Fitzpatrick & Schramm (2006) and Tyler & Summerfield (1996). However, because the authors do not have this information for the other participants, there is not enough evidence from this case series study to support the hypothesis that attendance to medical appointments may be associated with successful post-implantation performance.

Family and Environment. 75% of participants that received improved speech perception outcomes appeared to have had positive family and environment interactions. Although not known for sure, it appears that several participants had positive family and environment interactions, as well as relatively successful speech recognition outcomes. For example, participant 33 was reported to talk on the telephone with her relatives. One may assume that participant 33's family supported her and was involved in her life; they took the time and effort to interact with her over the phone, even though these conversations may have been difficult due to her speech and hearing difficulties. Participant 25 also used the phone, as well as listened to music. These activities may suggest that the participant actively explored environments to maximize her engagement and CI performance. The youngest participant, 17, had been provided with many hours of help and assistance using her CI, suggesting that support may be an important environmental factor in successful speech recognition outcomes. The authors of this paper believe that supportive relationships and environments are integral to improving speech perception outcomes for all CI users.

Other. CI use was not specifically included as a factor in this study (there was not enough data available for comparison); however, the authors believe that the frequency and duration of CI use deserves mention as a possible influence on the clinical outcomes. Participant 9, for example, had reported limited use of the device as well as poor speech recognition outcomes pre and post-implantation. Participant 28 did not wear his device during the day due to his work environment, and he also had unsuccessful clinical measures post-implantation. It may be likely that the speech recognition skills of participant 9 and 28 were not progressing due to their limited use of the CI device; a lack of or reduction in CI use has been speculated to be associated with poor speech recognition abilities (Fryauf-Bertschy et al., 1997). Furthermore, participants 25 and 33 used listening devices frequently (i.e. every day), and they demonstrated relatively successful outcome measures for speech recognition. Participant 25 wore hearing aids starting at age two years and five months until age twenty-four when she no longer benefitted from wearing them. Approximately five years later, she received a CI; she reported satisfaction with her device, and that she was beginning to rely less on speech/lip reading. Participant 33 used her CI all waking hours, and it was reported that she is performing well with the device. According to Fu & Galvin (2007), CI recipients may have difficulty adjusting to the electrically stimulated speech patterns; however, through passive, daily-listening experiences, most implant recipients will adapt at least partially to the new patterns of electrically stimulated speech. The research by Fu & Galvin (2007) is consistent with the authors' speculation that the frequency and duration of CI use may influence the clinical outcome measures for speech recognition.

DISCUSSION

In this study, the authors looked at speech recognition abilities in prelingually deaf CI users who were implanted after two years of age in order to determine factors that may be associated with positive or negative speech recognition outcomes.

For this paper, speech recognition outcomes (approximately one year post-implantation) were deemed relatively successful if the participants improved by 20% or more in the clinical outcomes (based on HINT and CID scores); otherwise, the outcomes were deemed (relatively) poor. In this study, four out of eight participants had relatively successful speech recognition scores one-year post implantation. The remaining four participants had relatively poor speech recognition scores one year post implantation.

The authors organized and analyzed the retrospective data from the patient's medical records into seven factors: gender, etiology, age of implantation, type of device, method(s) of communication (e.g. oral, speech reading, sign), patient compliance (measured by the number of times the participant attended a scheduled medical appointment) and family and environment. The participants were compared using the data in each factor in order to explore possible associations to their clinical outcome measure:

1. Gender. Not many studies have been able to statistically associate gender with predictions of speech recognition scores post-implantation. A retrospective study of adult CI users (varying in pre-, peri- and post-lingual deafness) by Bodmer et al. (2007) found that neither poor nor excellent speech discrimination scores post-CI correlated statistically with gender (although 39% of excellent performers were male 61% were female). Another retrospective study of post-lingually deafened adults by Green and colleagues (2007) showed higher speech recognition scores (measured in correct number of keywords identified out of 100 total words) for females (mean score of 57.6) than for males (mean score of 48.9) on the *Bamford-Kowal-Bench (BKB) sentence test* but statistically found no significant difference between the two genders. In a study by Zhu and colleagues (2011) of Mandarin Chinese speech recognition by CI users (pre and postlingually deaf children), the authors did find better performance for females (84% correct on disyllable test and 85% correct on sentences) than for males (78% correct on disyllable test and 80% correct on sentences). Finally, a study by Lenarz and colleagues (2012) examined the effect of gender on the hearing performance for postlingual adult CI patients. Their study revealed that the men scored slightly higher than the women in all of the follow-up sessions for the HSM Test in quiet, a contradictory finding to this author's current study with prelingual individuals with CIs. It is clear that more research regarding gender and speech recognition for the prelingual individual is required, as studies with postlingual participants may yield different results.

2. Etiology of Hearing Loss. In their 1999 article, Johannes van Dijk and colleagues indicated that research was showing that there were no significant relationships found between etiology of hearing loss and speech understanding for post-lingually deafened CI users. More recently, in terms of genetics, Dalamon et al. (2009) found no differences in prelingually deaf CI users' speech perception scores whether their hearing loss was caused by non-syndromic genetic factors or by unknown etiology. Studies have only been able to conclude that **prelingual** hearing loss caused by meningitis, especially if the disease causes ossification of the cochlea (El-Kashlan et al, 2003), may lead to poorer outcomes and that post-lingual deafness caused by osteosclerosis may be associated with better outcomes (vanDijk et al, 1999).

Studies have indicated that individuals with congenital and prelingual loss of hearing show poorer outcomes than those with a progressive or postlingual loss (Taitelbaum-Swead et al, 2005). All of the participants in the current study had prelingual hearing loss, but not all showed poor outcomes. The known hearing loss etiologies in the current study included DiGeorge syndrome with aspergilis niger fungal infection, maternal rubella, maternal German measles and Waardenbug's syndrome. Like the research above, this study is unable to conclude that any particular etiology can be associated with good or poor speech recognition outcomes because of both a small sample size and the fact that the participants' underlying etiology either varied considerably or was unknown.

3. Age of implantation & duration of deafness. Age may possibly be an independent significant factor when speech recognition performance with an implant declines with duration of deafness (Tyler and Summerfield, 1996). According to Tyler and Summerfield (1996), the longer the period of profound deafness before implantation in post-lingual individuals, the poorer the outcome in Speech Recognition Testing (SRT). A longer duration of deafness and older age may be associated with reductions in the responsiveness of the nervous system and in the potential for relearning (Tyler and Summerfield, 1996).

Studies like that by Arisi et al. (2010) also suggest that speech recognition performance in adolescent CI recipients is affected by age at implantation and length of deafness. Prelingually deafened adolescents (N=45) with a mean age at implantation of 13.4 years (range 11–18 years) participated in their study. Arisi et al. (2010) found that age at implantation, duration of deafness, and preoperative hearing threshold affect speech recognition outcomes.

Cosetti & Waltzman (2012) presented many research studies that support improved auditory and linguistic outcomes in children who are implanted before twelve months of age. For instance, in 2010, Tajudeen et al. found that CI recipients less than one year old (N=35) may have a significant advantage in areas of speech recognition compared with later-implanted groups (as cited in Cosetti & Waltzman, 2012). Similarly, Dettman and colleagues, in 2007, examined receptive and expressive language of nineteen children implanted before twelve months of age using the Rosetti Infant-Toddler Language Scale (RI-TLS). Results indicated language scores comparable to typically hearing children, and better scores than children implanted between twelve and twenty-four months (as cited in Cosetti & Waltzman, 2012). Niparko et al (2010) showed similar results for children implanted before eighteen months of age in another study discussed by Cosetti & Waltzman (2012).

The studies above suggest that age at implantation and length of deafness have a clear impact on CI performance in children, prelingual adolescents, and post-lingual adults (Cosetti & Waltzman, 2012).

Age of implantation is linked to duration of deafness in the prelingually deaf population: all prelingually deaf individuals become deaf before learning language; therefore, they would have similar deafness durations. According to the literature discussed above, a shorter duration of deafness can be associated with better speech recognition outcomes post-implantation.

In this study, participants were implanted at variable ages (range = four to forty-one years). For the successful participants (speech recognition outcomes improving 20% or more), the mean age was 15.75 years. The mean age for participants with less than a 20% improvement, or poor clinical outcomes, was twenty-four years. Based on these findings, age of implantation (or perhaps the duration of deafness in this case) may have affected the participant's speech recognition ability. However, there are an insufficient number of participants in this study to support age of implantation as a factor that impacts speech recognition outcome. Furthermore, although the mean age is higher for the group with poor speech recognition outcomes, there are participants who improved less than 20% and that were implanted at a younger age than those in the successful group. Therefore, based on the limited retrospective data for the limited number of participants, there does not appear to be a direct association between age of implantation for the prelingually deafened individual and speech recognition scores; however, age at implantation was found to affect speech recognition outcomes in prelingual adolescents (Arisi et al., 2010). Further research regarding age of implantation for prelingual adults is necessary.

4. Type of CI device. At the time of this study, there were three major CI manufactures: *Cochlear Corporation*, *MedEI Corporation*, and *Advanced Bionics Corporation*. The success of a CI is dependent on the individual person, however, both the device type and the sound processing strategy used are variables that can influence the success of cochlear implementation.

Santerelli et al. (2009) tested a group of seventeen prelingually deaf children who had received the Nucleus 24 CI. All of these children had been implanted before the age of ten and had either received the Sprint or the Esprit 3G sound processor. Both of these sound processors had a limited input dynamic range. Spahr et al. (2007) had found that differences in speech recognition in a group of postlingually deaf CI users were mainly related to differences in the input dynamic ranges of the sound processor. Santerelli et al. (2009) found that when these children were given a sound processor with an increased input dynamic range (i.e., Freedom), their speech perception scores were superior to their scores with the Esprit 3G or the Sprint. It is thought that a sound processor with an increased input dynamic range allows for more phonemic discrimination.

Technical improvements in CIs are another factor that contributes to a patient's success with speech perception. Digisonic Convex and Digisonic SP are two recent, widely used Neurelec CI devices that were released in 1999 and in 2004 respectively. These devices were compared to each other by looking at speech recognition scores in one-hundred postlingually deaf CI adults who had either been implanted with the Digisonic Convex or the Digisonic SP. Speech perception scores were obtained a year after implantation; patients that had received the Digisonic SP (the newer CI devices) had better speech recognition scores overall than those with the Digisonic Convex device, and their skills continued to improve over a longer time frame (Lazard et al., 2010). It was found by Lenarz and colleagues (2011) that post lingual participants that had received more recent electrode designs and speech processing strategies (i.e., developed between 2002 and 2008) had better speech perception in noisy surroundings than those participants that had the earlier technology.

Improvements in CI technology continue to improve. New technologies include the totally implantable CI (TIKI) in which there are no external components. This allows people to utilize their CI in situations where they have previously been unable to due to the external component. Other technologies that have been seen to improve hearing outcomes are improvements in speech processing strategies, microphone technologies and electrode placement (Briggs, 2011).

In the current study, it was speculated that the sound processor of the CI device may be a factor that leads to either a poor or successful outcome. Spahr et al. (2007) found that the greater the input dynamic range of the sound processor, the better the speech recognition.

Lazard et.al. (2010) determined that the patients that had been implanted with the Digisonic SP device (a device where all twenty electrodes could be activated on the electrode array) had better identification scores than those patients that used the Digisonic Convex device (a device where only fifteen electrodes could be activated). Lenarz et al. (2011) preformed a study and determined that adult CI patients that had been implanted with the most recent electrode designs and speech processors had better speech perception in noisy environments than those patients that used an older/less recent speech processor.

5. Method(s) of Communication. It has been found that children, both pre- and peri- lingually deafened, who had been exposed to spoken language before implantation show better speech recognition outcomes post cochlear implantation (Cosetti & Waltzman, 2012). Taitelbaum-Swead et al. (2005) also showed that children, with congenital hearing loss, using CI's who used oral communication showed better speech recognition outcomes than children (CI users) who used sign language. Similarly, Kaplan et al. (2003) found that prelingually deaf adults implanted in adulthood who came from "a strong auditory-oral background" performed better on speech recognition tasks. The participant with the most successful speech recognition outcome in the current study, number 33, used only oral communication. Based on the outcome measure for participant 33, it appears that the use of oral communication only may yield relatively successful speech recognition outcomes. Moreover, the successful outcome of participant 33 is consistent with the findings of Kirk and colleagues (2002), where children who used oral communication (exclusively) had higher word recognition scores than children who used total communication. In conclusion, previous studies have shown that oral communication can be associated with better speech perception outcomes (Cosetti & Waltzman, 2012, Taitelbaum-Swead et al., 2005, Kaplan et al,, 2003 & Kirk et al., 2002), which is consistent with participant 33's performance in the current study.

6. Attendance to Medical Appointments (Compliance). A study by Fitzpatrick & Schramm (2005) identified patient motivation, perseverance, and commitment to rehabilitation as being factors that impact patient communication and the length of the rehabilitation period required for intelligible speech production in adults with prelingual deafness. Furthermore, accuracy of speech recognition for postlingually deafened adults with implants is thought to relate to the patient's preoperative motivation to learn to use the implant (Tyler R.S. & Summerfield A.Q., 1996). The authors of this paper propose that a patient who is highly motivated to use his/her implant may be more likely to follow the rehabilitation plan and use his/her implant in a variety of situations to communicate with others. We can only speculate that attendance to medical appointments can be associated with overall motivation and compliance. Motivation can come from external factors (e.g. family and friends) or internal factors (e.g. the desire to be understood by others).

7. Family and Environment. Positive family involvement and environment may improve speech recognition measures for prelingual CI users. Consistent with the authors' speculations that family and environment may influence outcome measures, Holt, Beer, Kronenberger, Pisoni, & Lalonde, (2012) found that for prelingually deafened children implanted between 0.7 and 6.8 years of age, family environment influences CI outcomes in language development. The authors of this paper believe that without sufficient family involvement and supportive environments, participants may abandon their efforts to succeed with their CIs; thus, their speech recognition abilities may not be maximized. However, as Holt et al. (2012) stated, "family environment can be modified and enhanced by therapy or education," which is important for clinicians to consider if speech recognition outcomes can be positively influenced.

KEY FINDING

Based solely on the retrospective data available to the authors, no significant associations between factors could be determined with certainty and statistics due to the small sample size of participants, the limited amount and at times the lack of information on each participant and the retrospective nature of the data (see limitations below). However, the results suggest that oral communication, compliance and family environment tend to be associated with positive speech recognition outcomes.

Limitations

The original intention of this study was to research factors associated with the oral speech of prelingually deaf individuals; however, due to the limited available retrospective data regarding oral communication in this population, speech recognition was selected as the clinical outcome measure. There were a number of limitations to this study that impacted the author's ability to make associations between factors and the clinical outcome measures:

The most significant limitation of the study was the sample size. First, there were not enough participants with pre and post scores from the HINT or the CID to run a statistical analysis. In addition, the authors of the paper did not collect the retrospective data, rather, another speech-language pathology graduate student, who was trained appropriately as a research assistant, accumulated the data from patient medical records at the Glenrose Hospital in Edmonton, Alberta. The student followed a template and a list of items for gathering data and was required to ask for assistance regarding questionable material or an identifiable issue; the authors of this paper reported on the retrospective data collected second-hand. Furthermore, data was not always available approximately one-year post-implantation; one patient was assessed three to four years post implantation. Although she had a successful clinical outcome measure at that time, there was no data available for one-year post-implantation. As mentioned earlier, patient information was not available for some factors (e.g. etiology, therapy attendance, etc); therefore, there was not enough information to make associations between factors with confidence. Research has indicated that hearing aid use before implantation may positively impact speech recognition outcomes post-implantation (Bodmer et al., 2007). The information collected from the retrospective data did not indicate for all participants where, when, or how often they wore their hearing aids. As a result of the limited information available, hearing aid use before implantation could not be included as a factor. The information regarding the method of communication used (e.g. oral, speech reading, and/or sign) was unclear as to whether or not the type of communication was used before or after implantation (or both). Thus, insufficient information prevented the authors from making possible associations between method of communication and clinical outcome measures. In terms of CI devices, information regarding the speech processor was not available for every participant. The type of speech processor may have affected the participant's ability to perceive and recognize stimuli used in the CID and HINT, and revealed possible associations between speech processor type and the clinical outcome measure. Factors that have been researched in other studies (e.g. family life, overall health, maturity, etc.) may have affected participant clinical outcomes; however, this information was not available from the retrospective data and could not be included as factors.

Strengths

There have been studies regarding the speech recognition outcomes of post-lingual (van Dijk et al., 1999) and pre-lingual CI users (Shpak et al., 2009). However, the study of pre-implantation and post-implantation factors that influence the clinical measures in the prelingual participant is unique; although researchers like Cosetti & Waltzman (2012) have considered pre-operative factors in their research, the majority of their studies targeted post-operative variables affecting CI performance. Furthermore, their research has focused on individual speech recognition outcomes, not necessarily the combination and associations of factors. The focus of this study was to make associations between factors and clinical measures, not solely the clinical measures. Limited retrospective data regarding oral speech for prelingually deaf CI users lead the authors to focus the study on speech recognition abilities for the same population. Speech recognition is vital for communication and social interaction; understanding the factors that influence speech recognition will contribute greater knowledge to the field of Speech-Language Pathology and Audiology, and will help prelingually deaf CI candidates make informed decisions regarding implantation. This paper is a building block for more in-depth research that analyzes factors contributing to disparities in both speech recognition and oral productions for prelingually deaf individuals who are implanted after the critical period (e.g. after two years of age). Furthermore, knowledge of such disparity can be implemented to improve auditory and oral communication skills for this population. An overarching goal of further research that stems from this paper shall provide a means to improve social interaction and participation in society for these users. The uniqueness of this study yields many opportunities for research in this area.

Clinical Implications

Based on the results of this research, there is no supporting evidence for Speech-Language Pathologists and Audiologists regarding factors that may determine successful speech recognition scores for their prelingual patients. Previous research has shown that factors such as neuronal cell physiology and function (e.g. duration of deafness), CI technology, binaural hearing, multiple disabilities, influences speech recognition ability, medical/surgical issues, preoperative function, hearing level and speech performance, education/rehabilitative environment, auditory training, and social factors (e.g. Socioeconomic status and parent/family expectations and motivation) can influence post-implantation performance (Cosetti & Waltzman, 2012). The limitations of this study prevented the authors from making associations between factors and the clinical outcome measures; however, the inability to make associations has clinical considerations: prelingually deaf individuals cannot be included or excluded as CI candidates based on the research methods and factors discussed in this paper. Furthermore, there may not be one single factor that determines successful or unsuccessful speech recognition outcomes for the prelingually deaf CI user rather, the issue may be multi-factorial. Finally, variability exists between individuals that cannot always be accounted for or used for comparison.

CONCLUSION

Due to the limitations of this study, the authors cannot be certain of the factors that influence speech recognition outcomes for prelingually deaf individuals. In the current data, associations cannot be made between improved speech recognition scores and the factors studied in this paper. However, although not conclusive, some factors such as patient compliance, oral communication, family environment, and/or frequency using the implant device may trend towards positive outcome associations. Therefore prelingual individuals should not be excluded as candidates for CI at this time. It is clear that additional and more in-depth research is necessary. Further studies involving factors affecting speech recognition outcomes for prelingual

CI users should involve more participants and use consistent and detailed criteria for data collection.

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