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Acoustic vowel space differences between cochlear implant and hearing aid users

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NORTHERN ILLINOIS UNIVERSITY

Acoustic Vowel Space Differences Between Cochlear Implant and Hearing Aid
Users

A Thesis Submitted to the

University Honors Program

In Partial Fulfillment of the

Requirements of the Baccalaureate Degree

With Upper Division Honors

Department Of

Allied Health and Communicative Disorders

By

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DeKalb, Illinois

May 2010

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Capstone Approval Page

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Acoustic Vowel Space Differences Between Cochlear Implant and Hearing Aid Users

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Abstract

This study examines the acoustic vowel space of three children aged 4 to 5 years with varying levels of hearing. One of the children had cochlear implants with a profound unaided hearing loss. One child wore hearing aids with a mild unaided hearing loss. One child had normal hearing. Participants' production of isolated vowels, words, and a sentence were acoustically analyzed using the Speech Filing System program to determine the acoustic distinction between each child's vowels. It was hypothesized that the child with normal hearing would have the largest acoustic vowel space due to her ability to utilize auditory feedback and sufficiently differentiate each vowel category. Unexpectedly the child with the hearing aid exhibited the greatest vowel space across all speech tasks indicating neither normal hearing nor the cochlear implant offered an advantage over hearing aids. The small sample and lack of control of aided hearing levels may have created these unexpected results.

BACKGROUND

Humans depend on their hearing to learn a spoken language system. The auditory system provides a feedback loop that allows hearing individuals to modify their speech productions so they match the underlying cognitive representations of each specific phoneme or sound. Specifically, the feedback loop tells the brain to control the finer speech movements and, "...detects discrepancies between intended phonemic contrasts and those produced" (Vick et al., 2001). Because individuals with hearing loss have degraded or no auditory input, the efficiency and/or availability of the auditory feedback loop is impacted; often resulting in speech errors. The problem then arises, when a child with a prelingual, or pre-language, hearing loss misarticulates a sound or misses the suprasegmentals (features of speech such as pitch or stress), due to the deficient auditory feedback. This often results in less distinct productions and it is common for children with profound hearing loss to have a restricted vowel space which in turn reduces intelligibility. Vowels for hearing-impaired and deaf speakers are often neutralized, or produced more like 'uh', according to Horga and Liker (2006).

When applicable, amplification devices can aid with the acquisition to fine tune the acoustic properties of the incoming segmental and suprasegmental signals. Two common types of amplification devices for use by individuals with hearing loss are hearing aids and cochlear implants. Although both were developed to increase the auditory input provided, they function very differently and provide different benefits. The microphone in hearing aids picks up sound waves and the receiver converts the amplified sound back into an electrical signal to deliver the speech sounds through the ear canal (Bess & Humes, 2008). Cochlear implantation is a surgical procedure that involves implanting electrode arrays into the cochlea to stimulate the auditory nerve.

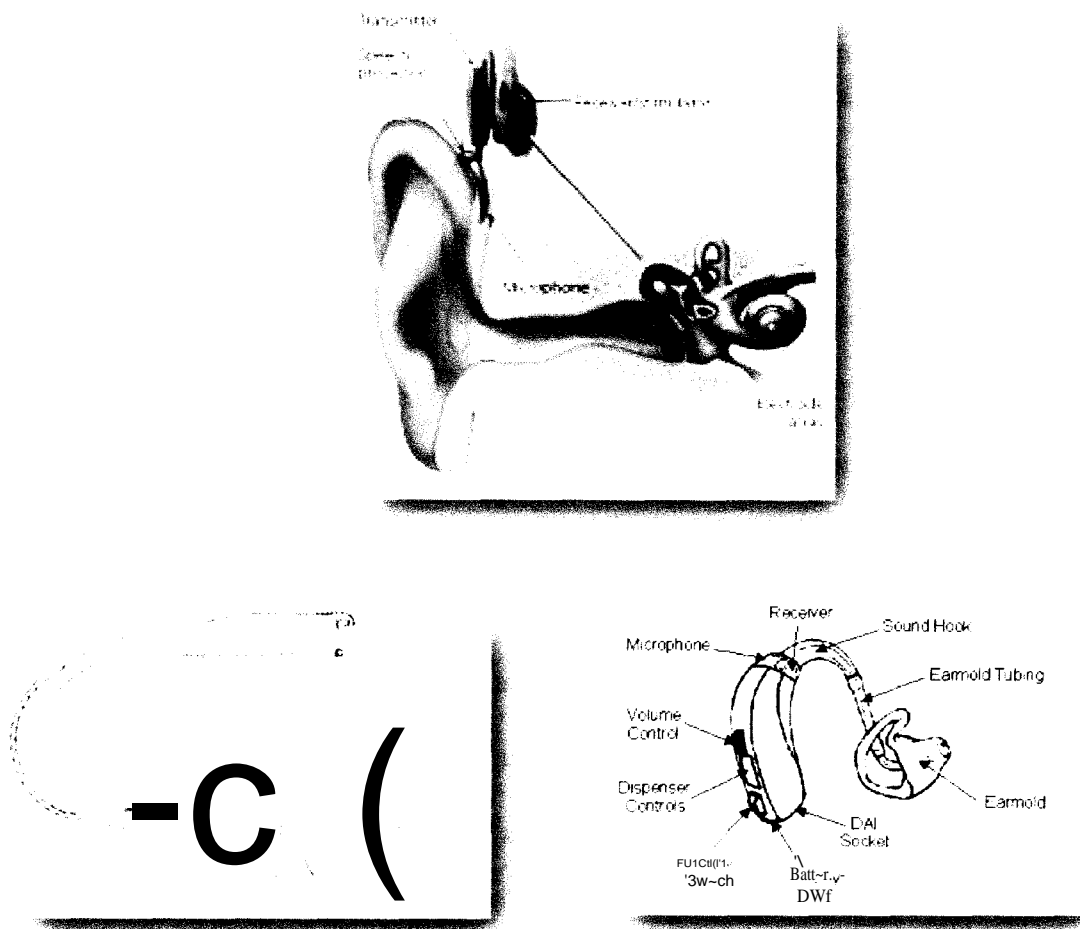


Figure 1. The first picture represents the parts of a cochlear implant, courtesy of Cochlear.

Implant.. *National Institute on Deafness and Other Communicative Disorders*. Web. 19 Oct 2009.

<http://www.nidcd.nih.gov/health/hearing/ear_coch_img.htm>. ... The picture at the bottom and to

the left is of the electrode portion that is implanted in the cochlea, courtesy of Schraer-loiner, L.

& Prause-Weber, M. (2009, September). Strategies for working with children with cochlear

implants. *Music Educators Journal*, 96,48 - 55. The third picture shows a labeled behind-the-

ear hearing aid, courtesy ofBTE. *Brad Ingraio*. Web. 19 Oct 2009.

<http://www.bradingraio.com/Hearing_Aid_Images.htm>. ...

Once sound waves are funneled in the outer ear, or pinna, they vibrate the eardrum, which begins a complicated process in the hearing ear. Three tiny bones, or the ossicles, located in the middle ear transmit the sound from the eardrum, and vibrate the cochlea. The cochlea is a fluid-filled organ positioned in the mastoid bone of the skull behind each ear. Within the cochlea is the basilar membrane which contains small hair cells. These hair cells vibrate and generate nerve impulses that send information to the brain. The basal end of the basilar membrane is closest to the middle ear and it responds to high-pitched sounds. Conversely, the apex is farthest from the middle ear and responds to the low-pitched speech signals. (Kishon-Rabin, et al., 1999). Because cochlear implants were designed to mimic the functioning of the cochlea, they generate a more natural sounding acoustic signal. Whereas hearing aids require the impaired ear to make sense of an amplified, yet still degraded, signal.

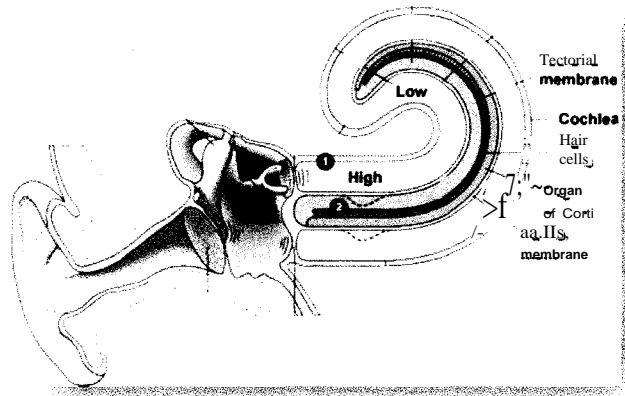


Figure 2. This picture shows the cochlea unfolded to show the basal end (labeled High) and the apical end (labeled Low), courtesy of Cochlea. *Human Physiology*. Web. 19 Oct 2009.

<<http://www.colorado.edu/intphys/ClassIIPHY3430-200/008sensory.htm>>. ...

The American Speech-Language-Hearing Association (ASHA) provides guidelines concerning the characteristics of individuals who will benefit from a cochlear implant. The most important criterion is profound hearing loss. A profound hearing loss is one where an individual requires a signal to be presented 95dB or higher (the loudness of a motorcycle engine) in order to hear, while a normal hearing person can hear between a 0-10 dB level (Defining hearing loss, 1996). "Children as young as 12 months of age with profound hearing loss in both ears and who demonstrate little progress in the development of auditory skills may be considered [for cochlear implants]," (Cochlear implants fact sheet, 2009). The push for cochlear implantation to occur earlier than 12 months has been considered because of the speech and language development that occurs during the first year.

Researchers believe cochlear implantation shows an improvement over hearing aids in the speech production of individuals with profound hearing loss. They are particularly effective if implantation occurs early when the central auditory pathways have maximum responsiveness and are prepared for stimulation (Sharma & Nash, 2009). As the brain develops, the child is very receptive to incoming information. Auditory development happens rapidly so it is crucial for children to receive cochlear implants before age 3.5 years, which is - "...the most optimal period for central auditory development," (Sharma & Nash, 2009). Additionally, Horga and Liker (2006) found that 13 cochlear implant subjects' voice quality and intelligibility were closer to the hearing control group versus the hearing aid users. According to Vick et al. (2001), a study on postlingual deaf speakers' vowel space found that after 6 months of implantation vowel space was expanded.

Like severity of loss, time of hearing loss onset impacts speech and language acquisition outcomes. The occurrence of a hearing loss can be prelingual (before acquisition of language),

perilingual (during acquisition of language), and postlingual (after acquisition of language). The negative effects on speech in an individual with a postlingual hearing loss is less severe than for an individual with a prelingual hearing loss, because the person has already acquired language and speech with a normal auditory feedback loop.

The severity of loss can affect how the listener perceives incoming speech signals. A child with a mild hearing loss, 25-40 dB loss (difficulty hearing whispered voice), may miss 25-50% of the speech signal. A moderate loss, 40 - 55dB loss (difficulty hearing normal conversation), will affect 50 - 75% of the speech signal. A moderate-severe loss, 55 - 70dB loss (difficulty hearing a dog bark), can cause a child to miss 100% of the speech signal. Reasonably, severe (70 - 90dB) and profound (90 dB and greater) hearing losses affect the child from receiving the acoustic signal completely. The severity of losses need to be considered in order to appropriately fit the child for a prosthetic hearing device so they can understand the incoming speech signals (Cole & Flexer, 2007).

Although the goal of an amplification device is to improve hearing acuity, it may not adequately maximize auditory skills therefore, other modes of communication should be considered. Total communication and oral communication are two programs developed to enhance communication in children with a hearing loss. Total communication (TC) comprises of both oral speech and sign language. American Sign Language, developed for people who are deaf, was the first form of a complex language, which employs the use of signs made with hands (American Sign Language, 2000). For TC, the goal is to maximize language development by learning through the use of spoken and sign language. In oral communication programs, children are required to use spoken language and wear their hearing aids to develop auditory skills (Geers & Moog, 1992).

Research conducted by Meyer et al. (1998), shows that children who use oral communication are more dependent on using their cochlear implants in order to communicate than are the children in total communication who rely on sign language. This provides support that oral communication programs requires full capacity of hearing through cochlear implants, which enables fine-tuned speech capabilities. On the other hand, total communication programs rely on sign language, along with spoken language, for communication, emphasizing visual and auditory aids. Even though speech is used in a total communication program, children do not have to rely on hearing to receive the information. Scores on speech perception tests from the children receiving oral communication tend to be higher than the children in total communication programs (Meyer et al., 1998).

Management of amplification devices can also affect speech and language outcomes. One role of audiologists and speech-language pathologists (SLP) is to monitor the care of the cochlear implant or hearing aid. When an infant is fitted with a cochlear implant or hearing aid, the initial reaction of the infant is to pull the transducer off their head. It is important for the SLP to provide training to the parents on how the devices should be inserted and to look for signs of damage as well as battery function. If the device is low on battery, then the child is not receiving his or her maximum potential hearing (Robbins, 2009).

Considering the severity of loss, type of communication system, and requirements concerning maintenance of the device, research has shown that cochlear implantation can provide benefits over hearing aids. Many acoustical aspects of speech can be analyzed to describe speech productions. Because vowel space is often reduced in individuals with hearing loss (Horga & Liker, 2006), it is often used as a measure of speech therapy progress.

Vowel space is calculated by determining the formant frequencies, or resonances in the vocal tract, of the first and second formant of the reference point vowels- *lii*, *lael*, *lui*, and *la!*. The production of the four point vowels represents the maximum vowel space in the oral cavity. Formant values can be determined by looking at a schematic of a spectrogram, a three-dimensional graphic display of time (x-axis), frequency (y-axis) and amplitude (z-axis). The resultant formant values are plotted on a F1F2 plot; Formant 1 as the x-axis and Formant 2 as the y-axis. The results form a quadrilateral representing the acoustic vowel space for an individual. The larger the quadrilateral space, the more distinct of vowel productions.

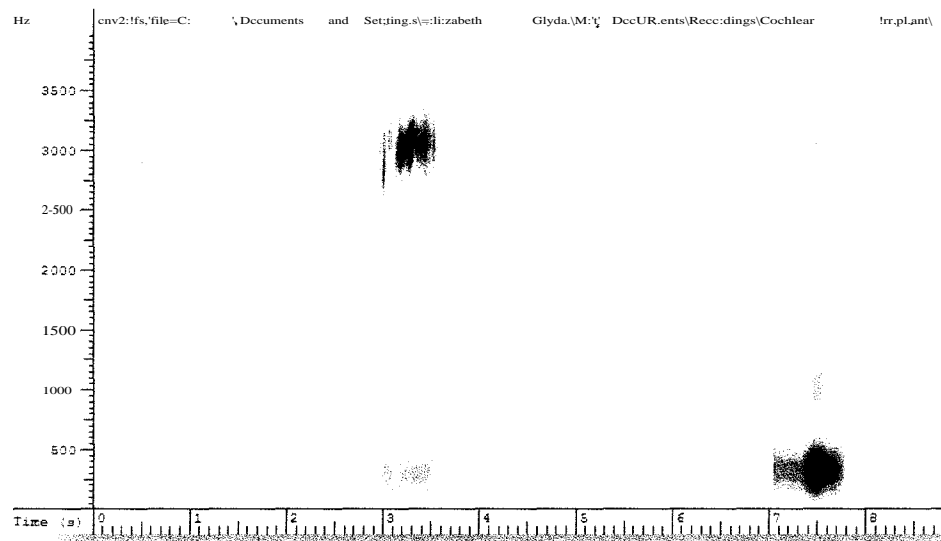


Figure 3. Above is a spectrogram from CI saying *lii*. The x-axis represents time in seconds and the y-axis represents frequency. The z-axis is represented by the dark bands of energy, or the amplitude. The dark bands indicate the resonances in the vocal tract, also known as formants.

Lane, et al. (2001) indicated that deaf speakers tend to produce trajectories that are more neutralized. Because of the inability to use auditory feedback, they rely on tactile feedback

instead. Hence, hearing aid users articulate in a centered location in the oral cavity which provides them more tactile feedback.. The electrical signals of cochlear implants are thought to provide more finely tuned frequency information than hearing aids; thereby cochlear implant users have access to expanded auditory as well as tactile feedback.. Subsequently, it is expected for cochlear implant users to have closer vowel space values to normal hearing subjects and hearing aid users to have values farther from the normal hearing subjects.

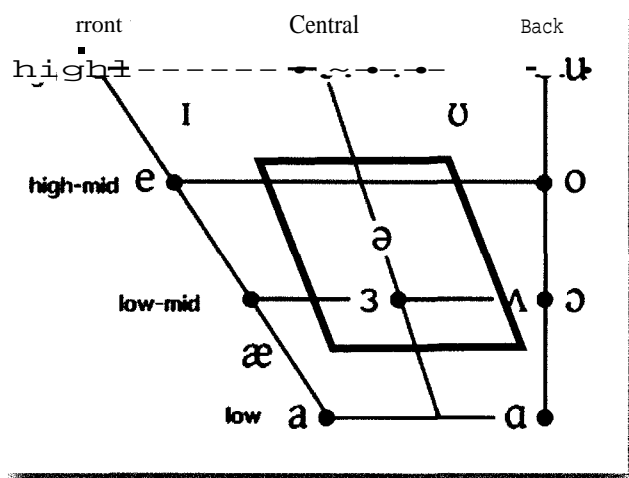


Figure 4. The chart above is a vowel quadrilateral. . Vowel space is determined by tongue height and advancement; the vowel quadrilateral is a schematic that represents the vowel space of a normal hearing individual.. A hearing impaired individual's vowel space is more neutralized, as indicated on the chart in red. Picture courtesy of English Vowels. *Vowels*. Web. 28 Nov 2009. <www.azlifa.com/p=199>

METHOD

A. Subjects

Cochlear Implant (CI) Group

The CI subject, age 4;9, was diagnosed at 3-weeks-old with a moderate to severe hearing loss. She was implanted with Freedom BTE at age 22 months for the right ear and 30 months for the left ear. The participant's audiogram shows a normal hearing configuration in both ears with cochlear implants (See Appendix A). Along with implants the subject uses bilateral FM systems in a mainstreamed Oral Communication classroom with a hearing specialist. Services include direct, consultative, or monitoring the student and the specialist also provides training to the school staff on hearing loss is and how to accommodate the child. The subject has been in speech-language therapy for 4 1/2 years. Articulation therapy consists of the Kaufman program for Apraxia and she is working on speech production using a motor planning approach. It is also documented that CI has motor impairments, which affects her fine motor movements such as speech. According to her recent hearing evaluation, the subject's parents were concerned because she keeps confusing *lm!* and *lw!*. The SLP stated concerns that the child was not appropriately responding to sounds in the lower frequency region.

Hearing Aid (HA) Group

The HA subject, age 4;9, was diagnosed at 1-year-old with a mild progressive loss. The subject received hearing aids at about 2;5 years and started receiving speech-language therapy. She is enrolled in an Oral Communications program at school. The most recent evaluation concluded that the subject demonstrated a moderately-severe hearing loss for 500 Hz through 2000 Hz, rising to moderate to mild hearing loss for 4000 Hz and 8000 Hz in each ear. (See Appendix B for audiogram). Aided speech discrimination testing in quiet revealed 88%

B. Assessments

After teaching the participants the names of the target pictures 'seat', 'hat', 'hoot', and 'hot' and the target sentence, "Pete had hot food," participants sustained each point vowel /i/, /ae/, and /a/ for five seconds. The participants then said the names of the pictures and sentence. They produced each speech task twice.

C. Measurements

The recordings took place in a quiet room and the participants were seated on a padded office chair and asked to clearly speak into a microphone that was positioned at the edge of the table. The participants were advised not to talk directly on the microphone. The microphone was attached to a RCA RP 5130 Voice Recorder and later transmitted onto a secured laptop to analyze data through Speech Filing System.

D. Analysis

All the recordings were converted to .wav files for analysis and viewed as a wideband spectrogram in the Speech Filing System. Vowels are characterized by formant frequencies, or resonances in the vocal tract. The reference vowels -/i/, /ae/, and /a/ can be identified by tongue height and advancement. Tongue height is the greatest at the high-front vowel, /i/ and it decreases as the tongue moves down and back to create the vowel /a/. When the tongue placement is at the highest, as in /i/, F1 is the lowest due to limited space in the vocal tract. As the vocal tract opens to produce /a/, F1 increases. In respect, an inverse relationship exists: the higher the tongue position, the lower the F1 frequency, and the lower the tongue position, the higher the F1 frequency. Since vowels are characterized by the formants, energy levels intensify at the specific formant frequencies. The characteristics provide a standard in identifying the vowels on

a spectrogram. Once the vowel was identified and segmented from surrounding consonants in each speech task, the steady-state portion of the vowel was examined to establish the values of formant 1 and formant 2. A fundamental frequency contour line was also displayed to determine Fo.

Table 1. The normative formant frequencies, according to Peterson & Barney (1952), for children are as follow:

/i/	/ae/	/u/	/a/
370	3200	1010	2320
430	1170	1030	1370

These norms are references for comparing formant frequencies in children, but a wider range of numbers should be considered because of different speech patterns. The numbers are important to identify the relationship of formant frequencies between tongue height and advancement. . Along with comparing formant frequencies, acoustic vowel space (AVS) was calculated to determine neutralization of vowels (Evans & Deliyski, 2006). The Euclidean distance formula is applied to determine vowel space:

$$DV_{ij} = \sqrt{(F_1^{Vi} - F_1^{Vj})^2 + (F_2^{Vi} - F_2^{Vj})^2} \quad i, j = 1, 2 \dots 4$$

VI, V2, V3, and V4 represent the vowels *lii*, *lael*, *lui*, and *la!* respectively. The quadratic mean (DV) between the values of *lii* and *lae*; *lii* and *lui*; *lui* and *la!*; *lii* and *la!*; *lael* and *la!* were calculated to determine the vowel space.

DATA AND RESULTS

Fundamental frequency. Fundamental frequency is the natural vibratory frequency of the vocal folds. It is dependent on the mass of the vocal folds; the more mass the folds contain, the lower the fundamental frequency. Obtaining Fo measurements can identify a vocal pathology that may exist. In children, the average fundamental frequency is expected to be between 270Hz and 300Hz (Ferrand, 2007). If a vocal pathology was present in a child, Fo might be abnormally lower than the norm because of added mass from nodules or polyps. Because vocal fold vibration provides the energy needed to create resonances within the vocal tract, it is essential for Fo to be within the normal range; otherwise other measurements might be altered.

Table 2. The chart below indicates the mean fundamental frequency (Fo) of all three participants.

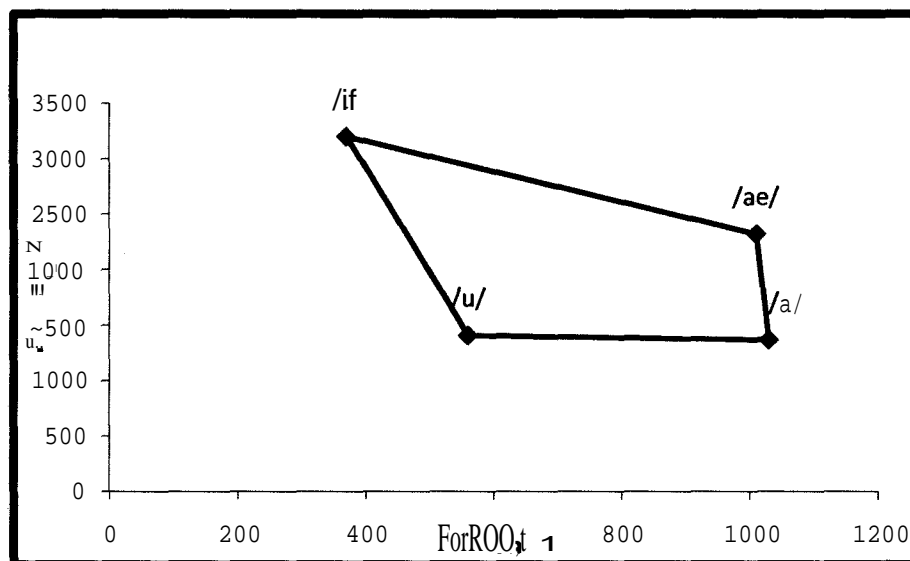
	Isolated Vowels	Words	Sentence
CI	283	270	255
HA	240	296	258
NH	335	354	351

The mean Fo was obtained for isolated vowels, vowels in words, and vowels in sentences. The Fo for all of the children was within normal limits even though NH's Fo was slightly higher than CI and HA.

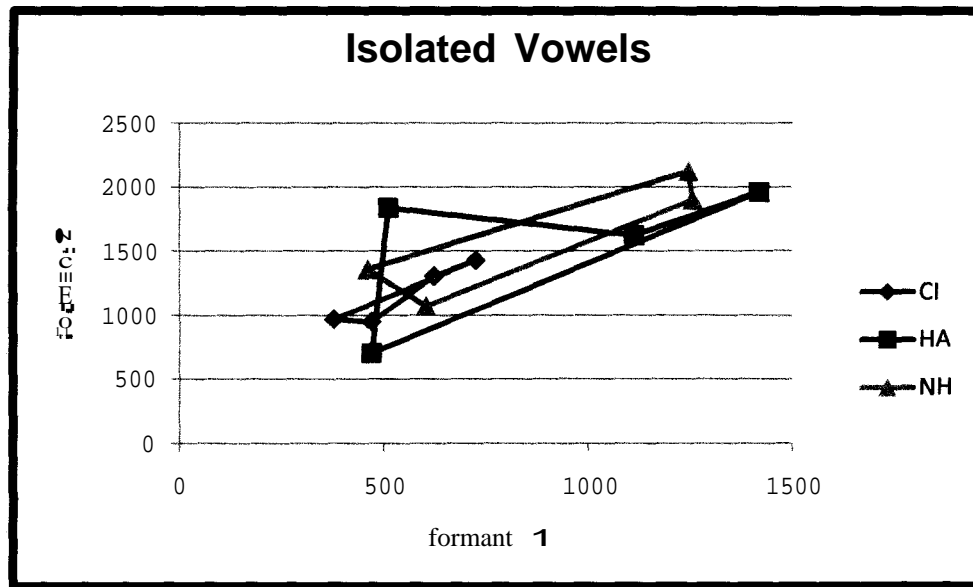
Vowel Space. Vowel space has been widely used to identify speech intelligibility. Lane, et al. (2001) explained that deaf speakers produce speech in a centralized location in the vocal cavity, causing a lower level of articulation. Once the speakers are fitted for an amplification device, they adjust their planning of articulation to increase vowel space. Graphing a vowel quadrilateral of an individual helps determine tongue placement in an individual because it displays the frequencies associated with certain tongue heights and advancements. Speech-language

pathologists provide therapy for proper placement of the tongue when producing vowels. In this case, a vowel quadrilateral can help chart progress of accurate vowel production. The goal is to maximize the vowel space to increase intelligibility.

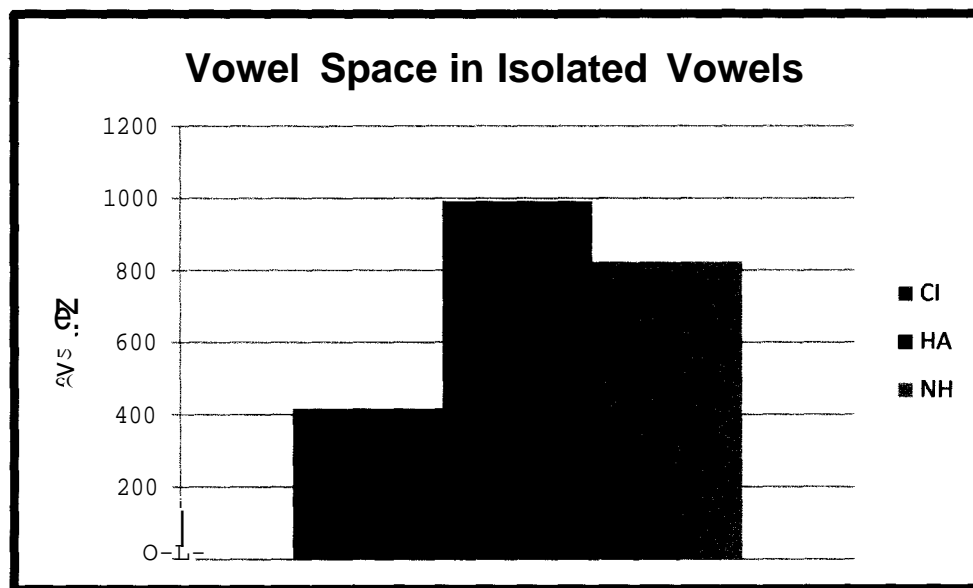
Figure 6. Below is a normal vowel formant space in children taken from Peterson & Barney's (1952) data.



Evans & Deliyski (2007) measured vowel space of vowels in phrases in children with cochlear implants and children with normal hearing. For the first group, the child with cochlear implants had 533Hz for vowel space post 6 months of implantation. The child with normal hearing had a vowel space of 1081Hz. In Evans & Deliyski's study, a big gap existed between the two subjects' vowel space. Graphs 2, 4, and 6 from the present study reveal a similar pattern.



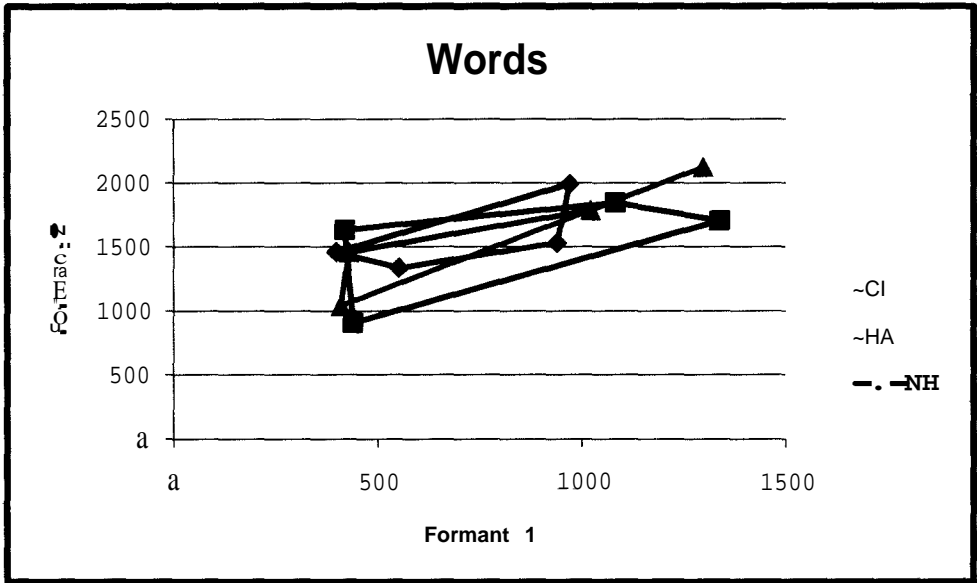
Graph 1. Vowel formant space of isolated vowels for the three groups.



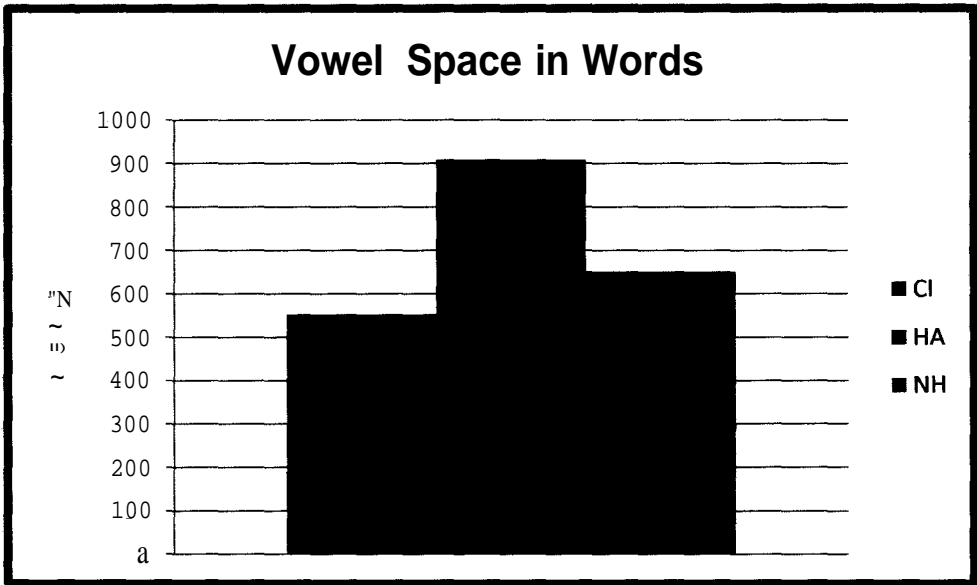
Graph 2. Average vowel space in CI, HA, and NH in isolated vowels.

AVS was less for CI than for HA and NH in the isolated word context.. HA shows the greatest vowel space in the isolated vowel context, compared to NH and CI. Additionally, HA's vowel quadrilateral represents a wider space than CI and NH, as shown in Graph 1. CI represents the

smallest space. In the second graph, HA has the greatest vowel space that exceeds NH vowel space. CI's vowel space is unexpectedly lower.



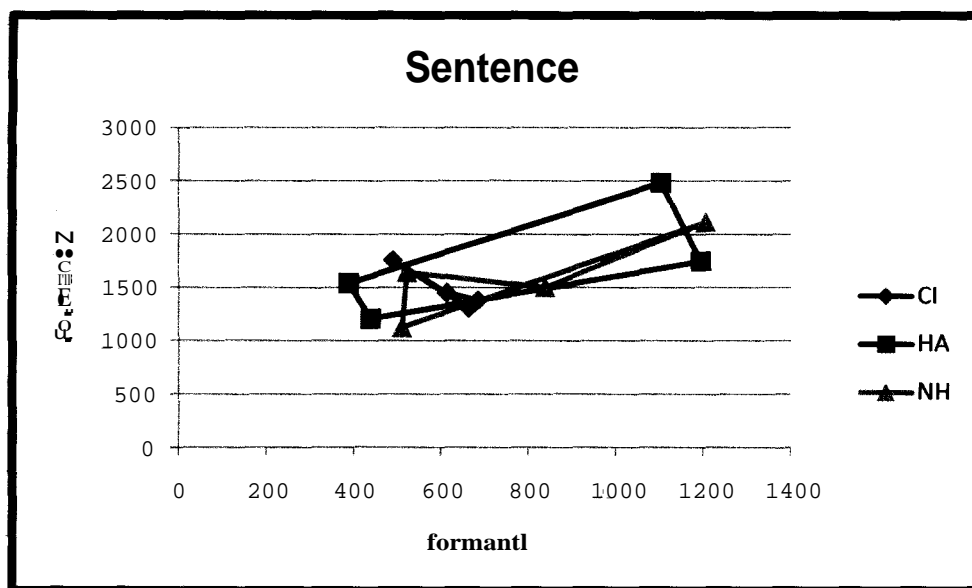
Graph 3. Vowel formant space in CI, HA, and NH in word context..



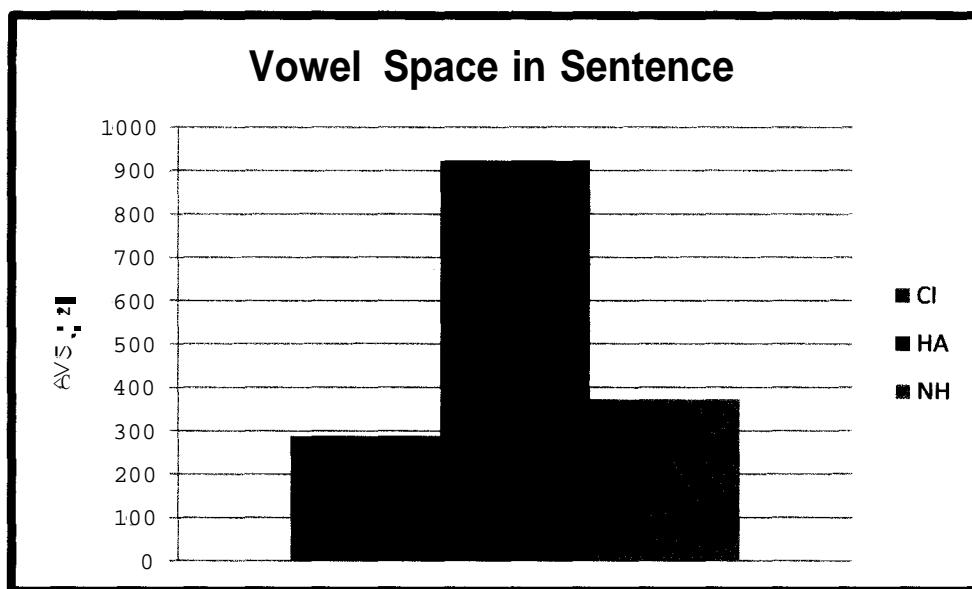
Graph 4. Average vowel space in CI, HA, and NH in word context..

The average vowel space in CI did improve from isolated vowel to word context as shown in graph 3, but still smaller than HA. The vowel quadrilateral of HA remained larger than NH and

CI, NH's vowel quadrilateral appeared to decrease when speaking isolated words. A better indicator of decrease in vowel space of NH is represented in graph 4. HA still exceeds the vowel space of NH and CI. CI increased vowel space in words from isolated vowels.



Graph 5. Vowel formant space for CI, HA, and NH in sentence context..



Graph 6. Average vowel space in CI, HA, and NH in sentence context.

The overall average vowel space remained constant for HA in all three contexts, as represented by graph 5 and graph 6. CI decreased vowel space drastically when transitioning to the sentence

context, having the lowest vowel space across all three contexts. Graph 6 shows NH's vowel space to be considerably low, possibly due to poor articulation and pronunciation.

DISCUSSION

Findings from the present study contradict findings from other research, regarding vowel space of cochlear implant and hearing aid users. The results from the present study suggest that children with a prelingual hearing loss who receive hearing aids exhibit greater vowel space than children who receive cochlear implants. It was predicted for CI to have a vowel space closer to NH and for HA to have a smaller vowel space than CI. Unexpectedly, HA's vowel space was greatest across all three subjects. However, CI's vowel space was closer to NH in the word and sentence context, but both subjects' values were lower than expected. Improper articulation could explain the abnormal low values of NH. It is advised for further research for the subjects to properly pronounce the speech samples in order to obtain their true vowel space. Also, it is important to consider the fine motor movement impairments of CI since it affects a decrease in vowel space, due to poor muscle planning. These impairments affect the participant's speech intelligibility, causing unpredicted results.

The degree of hearing loss also impacts the speech outcome. The hearing aid participant exhibits an aided mild hearing loss, which indicates she can hear the majority of incoming speech signals, except for the high-frequency sounds- f, s, and th. Since vowels contain low-frequency energy, around 250Hz to 500Hz, the hearing aid participant is able to accurately produce the speech sounds because she is able to detect and identify the signals. On the other hand, the cochlear implant subject is unable to hear all incoming speech signals across all frequencies without amplification. A profound hearing loss considerably affects the acquisition

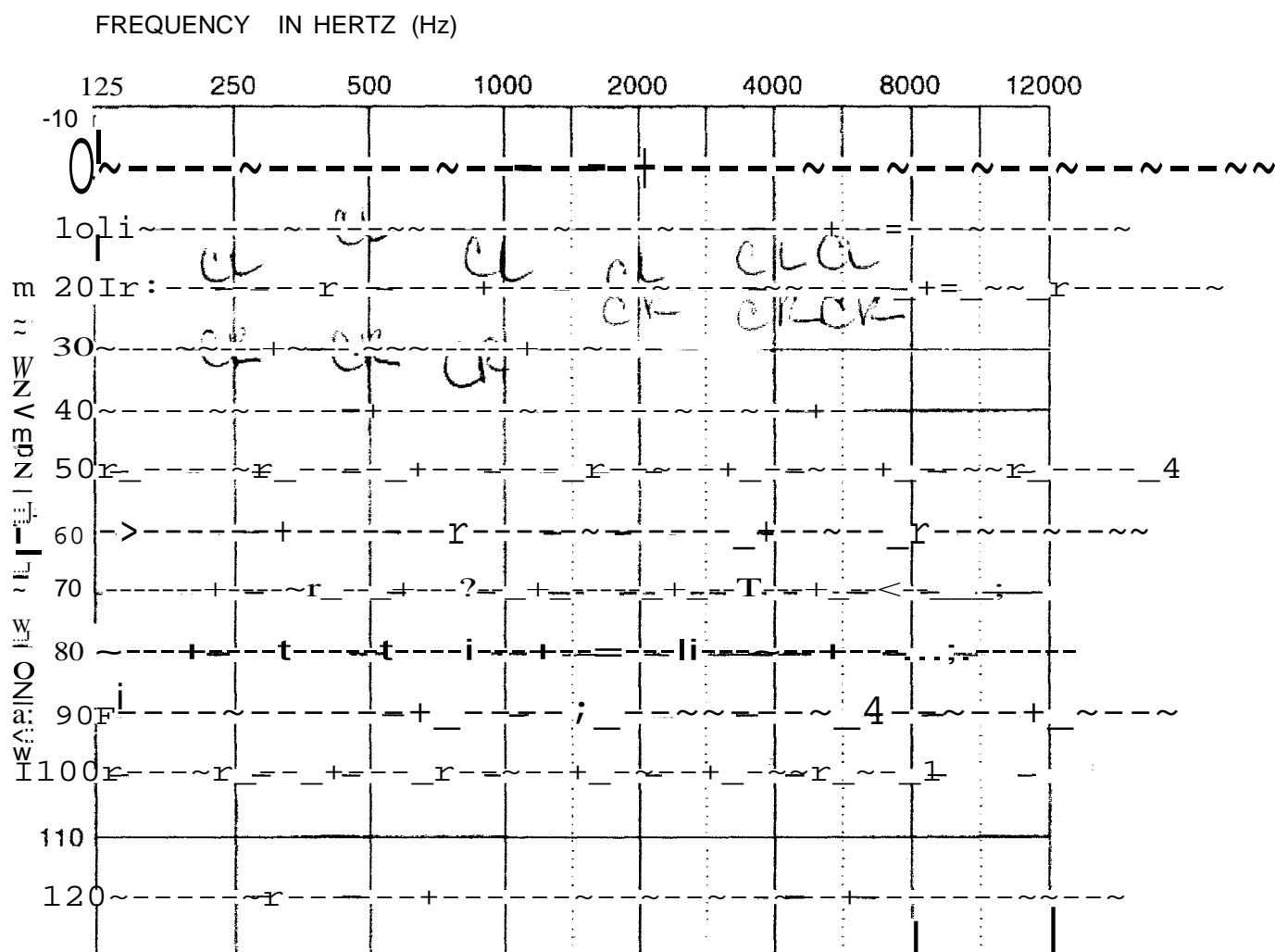
of speech without the intervention of amplification. The cochlear implant assists the participant to hear across all frequencies because it stimulates the hair cells pertaining to certain frequencies. Even with amplification, the latest hearing evaluation indicated the subject had difficulty identifying vowels. This greatly impacts the production of her vowels, also resulting in a smaller vowel space. Also, although the child with cochlear implants receives a better signal than the hearing aid, she is still considered deaf if the external device is off. If the device is off or not functioning, she is unable to receive any input since cochlear implants eliminate residual hearing. Therefore, it is important to note that speech is acquired differently between mild hearing loss and profound hearing loss. Thus, for future research, it is imperative that the hearing aid subjects must also exhibit a profound hearing to compare to matched profound hearing cochlear implant users. Otherwise, the outcomes are going to be skewed, as in the present research.

Furthermore, the onset of amplification is crucial for acquiring speech. For instance, a child that is implanted at 1-years-old will obtain input and acquire speech more efficiently than if the child was implanted at 5-years-old. Although the subjects received their amplification at the same time, the child with hearing aids had input early on with only a mild hearing loss. The child with cochlear implants did not receive any speech input until she was implanted. This allowed the hearing aid child to develop the feedback loop.

Also, it is suggested to obtain more subjects to validate the present and other research. Obtaining an average vowel space from a greater sample between both groups is more realistic to compare than comparing one subject from each group. Although both of the groups were in oral communication programs at school, it is also important to match the communication modes of each group. A child who uses American Sign Language as a primary mode of communication will have a different speech outcome than a child who primarily uses audition and speech.

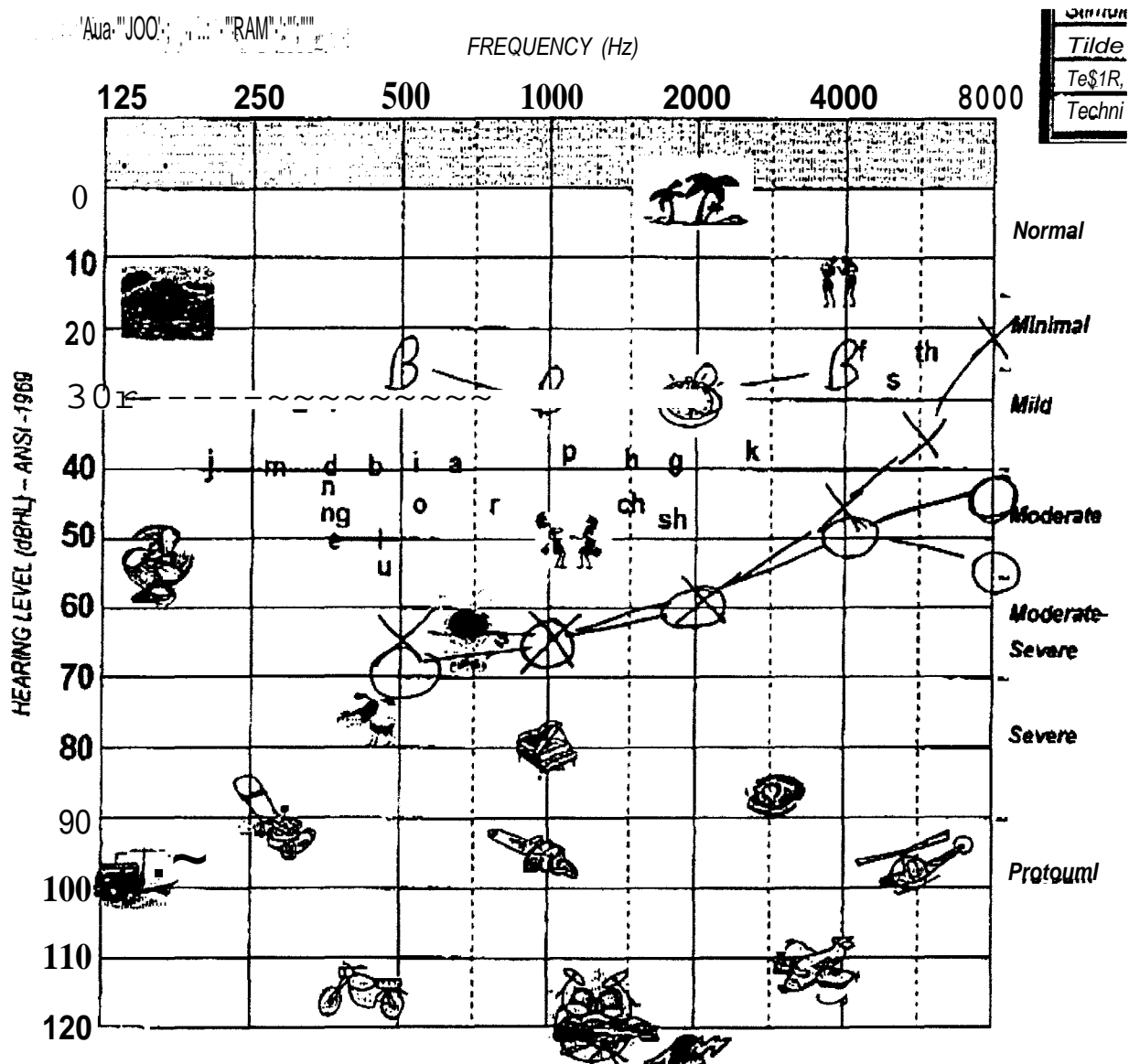
For further research, it is concluded to match the degrees of hearing loss and communication mode between the groups. To make the research credible, obtaining more subjects is suggested.

CI's audiogram with amplification- showing normal to mild hearing with cochlear implants.



AppendixB

HA's audiogram :- without amplification, the participant has a low frequency moderate-severe hearing loss and rising to a mild high frequency loss in the left ear (X) and a moderate high frequency loss in the right ear (0).



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