I, Brooke Schmisseur, hereby submit this as part of the requirements for the degree of:

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It is entitled:

An Evaluation of Noise Reduction Effectiveness In Four Digital Hearing Aids

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AN EVALUATION OF NOISE REDUCTION EFFECTIVENESS IN FOUR DIGITAL HEARING AIDS

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by

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B.S., Miami University, 1998

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ABSTRACT

Background noise can have a detrimental effect on the intelligibility of speech for all listeners. However, for individuals with a cochlear hearing loss, these effects can have even greater consequence. As persons with cochlear damage are unable to make use of the “dips” and spatial separation of noise, they may require a greater speech to noise ratio than a person with a normal, non-impaired cochlea. Professionals in the field of audiology attempt to assist an individual compensate for their hearing loss, and the difficulties associated with it, by providing the appropriate amplification, usually in the form of a hearing aid. A current methodology for manipulating the signal-to-noise (S/N) ratio that hearing aid manufacturers have developed is “noise reduction”. The purpose of this study was to determine if there was a significant change in S/N ratio due to the internal noise reduction circuitry in four sample digital hearing aids, across five environmental noise conditions, and across the four sample digital hearing aids in conjunction with the five environmental noise conditions. Statistical analysis showed that for the sample the change in S/N ratio was significant at the 0.05 level of significance as an effect of the hearing aids. The analysis showed that for the sample the change in S/N ratio was not significant at the 0.05 level of significance across the five environmental noise conditions. The analysis showed that for the sample the change in S/N ratio was not significant at the 0.05 level of significance across the interaction of the four sample digital hearing aids in conjunction with the five environmental noise conditions.
ACKNOWLEDGEMENTS

To Dr. Donald Hayes, my committee chairman, I wish to extend my sincere thanks and appreciation for his valuable and able assistance throughout this study. To Dr. Thomas Goldman, I am indebted for his consultation and suggestions concerning this paper.

To my husband, John, I am grateful for his patience, support, counseling, and prayer, especially during this study. To my parents, I am appreciative of their constant willingness to help me in every life endeavor.
Observation and Analysis...................................................... 24

Description of Findings .................................................... 24

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS ...... 29

Summary of Hypothesis, Methods, and Findings .......... 29

Conclusion................................................................. 29

Recommendations ......................................................... 36

BIBLIOGRAPHY ............................................................ 38

APPENDIX ........................................................................... 40

Appendix One ............................................................ 40

Appendix Two........................................................... 41

Appendix Three........................................................ 42
### LIST OF TABLES

**TABLE I**  
Hearing Aids Used and Their Characteristics ....................... 17

**TABLE II**  
Thresholds and UCLs in dBHL by Frequency Used for Hearing Aid Fitting .............................................................. 17

**TABLE III**  
Environmental Noise Conditions and Their Characteristics ....................................................................... 19

**TABLE IV**  
Hearing Aids and Environmental Noise Tracks ....................... 22

**TABLE V**  
Phonemes Analyzed in Sentences They Occurred ............... 22

**TABLE VI**  
Tests of Between-Subjects Effects ................................................. 26

**TABLE VII**  
Homogeneous Subsets .................................................................. 27

**TABLE VIII**  
Environmental Noise Effects ....................................................... 28
LIST OF FIGURES

FIGURE I  Estimated Change in SNR By Hearing Aid ....................... 32
FIGURE II  SNR Changes by Phoneme in Jet Noise............................ 33
FIGURE III  SNR Changes by Phoneme in Fan Noise ......................... 33
FIGURE IV  SNR Changes by Phoneme in Rain Noise ......................... 34
FIGURE V  SNR Changes by Phoneme in Subway Noise ...................... 34
FIGURE VI  SNR Changes by Phoneme in Ocean Noise ...................... 35
CHAPTER ONE
INTRODUCTION

PURPOSE OF THE STUDY

Background noise can have a detrimental effect on the intelligibility of speech for all listeners. However, for individuals with a cochlear hearing loss, these effects can have even greater consequence. Normal hearing individuals are able to understand speech in a moderately noisy environment because speech is a redundant signal. Thus, even if part of the signal is masked by noise, other parts of the signal may be understood enough to convey information to make the speech intelligible. In this manner, normal hearing individuals can use temporal and spectral “dips” in the interfering sound to their advantage (Peters, Moore, & Baer, 1998).

In contrast, for a person with a cochlear hearing loss, the redundancy of the speech signal is diminished as part of the signal may not be audible or may be severely distorted. The individuals with cochlear damage cannot take advantage of the temporal and spectral “dips” of the target speech sound and the background of interfering noise. As persons with cochlear damage are unable to make use of the “dips” and spatial separation of noise, they may require a greater speech to noise ratio than a person with a normal, non-impaired cochlea.

Professionals in the field of audiology attempt to assist an individual compensate for their hearing loss, and the difficulties associated with it, by providing the appropriate amplification, usually in the form of a hearing aid. The primary goal of most hearing aid fittings is to restore audibility of speech through frequency-selective amplification (Moore, 1996). This amplification is used with the expectation of increasing the speech to noise ratio.

A current methodology for manipulating the signal-to-noise (S/N) ratio that hearing aid manufacturers have developed is “noise reduction”. A common misconception of audiologists
and their patients is that this kind of circuitry should reduce background noise as a whole. The real goal is to lessen the side effects of this background noise on speech understanding, thus improving the signal-to-noise ratio (SNR). The foundation of the majority of digital signal processing hearing instruments, includes using a process that allows for frequency band manipulation (Guthrie, 2001). This is used to simulate the frequency-specific, multi-band processing that is seen in an undamaged cochlea. Examples of instruments using this process are the Siemens Signia, Sonic Innovations Natura 2SE, and Danalogic 163D.

Given that a significant “selling point” of digital hearing aids is their ability to reduce background noise, it is important to determine if they are really performing as the manufacturers claim. This study examined the effectiveness of the noise reduction circuit of four digital hearing aids on reducing background noise in order to produce a more favorable SNR.

SIGNIFICANCE OF STUDY

While many manufacturers of the newer technology hearing aids attempt to enhance speech to compensate for the cochlear hearing loss, there have been few studies to date to verify that this new technology is effective. In this study, research was undertaken to better understand the effects of noise reduction circuits on speech and noise. Therefore, in the proposed study, four recently developed digital hearing aids were tested to determine if their noise reduction components were truly effective and if they did in fact maintain a strong speech signal.

Furthermore, as the reader will find in the Literature Review, the majority of the studies that have been conducted on the effects of noise reduction and other means of manipulating the S/N ratio have used subjective measures. Many of the studies have used humans as their
subjects. As a result, the outcomes of the studies have varied, leading to no definite conclusion as to whether the noise reduction circuit is in fact changing the S/N ratio, thus enhancing a hearing-impaired individual’s ability to understand speech.

STATEMENT OF THE PROBLEM

It was the purpose of this study to:

1. Determine if there was a significant difference in the change in SNR produced by each hearing aid.

2. Determine if there was a significant difference in the change in SNR produced under each environmental noise condition.

3. Determine if there is a significant difference in the change in SNR produced during the interaction between the digital hearing aids and the environmental noise conditions.

NULL HYPOTHESES

A. There will be no significant change in the S/N ratio as a variable of the digital hearing aids

B. There will be no significant change in the S/N ratio as a variable of the environmental noise conditions.

C. There will be no significant change in the S/N ratio as a variable of the interaction between the digital hearing aids and the environmental noise conditions.
CHAPTER TWO

REVIEW OF THE LITERATURE

The purpose and design of this section was to submit information from related literature pertaining to noise reduction. The first part of this section briefly reviews why there is a need for increased signal to noise ratio, thus noise reduction technology, in hearing aids. The remaining portion pertains to that literature and research relative to the significance of noise reduction circuitry on speech.

THE NEED FOR NOISE REDUCTION

As stated in the introduction, normal hearing individuals process speech, especially in noise, differently than those individuals with sensorineural hearing loss (SNHL). The difference between individuals with normal hearing and those with SNHL can be seen when comparing Speech Reception Thresholds (SRTs). At high noise levels, those with SNHL losses tend to have a greater SRT than those with normal hearing. The SRT difference can become even greater when there is a fluctuating background noise or a single competing talker is used instead of a steady noise (Moore, 1996). An individual with SNHL will have an SRT in the presence of noise that is significantly higher than that of a normal hearing individual because of a reduced ability to use temporal and spectral cues. Eisenberg et al (1994), found that the use of a varying noise or masker (one that’s amplitude changes over time) may give a more realistic view of speech recognition in hearing impaired individuals versus normal hearing individuals. Eisenberg et al found that hearing-impaired individuals were less likely to find a release from masking in this amplitude-modulated noise than their normal hearing counterparts. The peaks and valleys in
a variable masker provide brief periods with a favorable speech to noise ratio for normal hearing individuals. This results in improved speech recognition performance comparative to a steady-state noise. However the peaks and valleys of variable maskers are reduced for individuals with SNHL, therefore the perceived speech to noise ratio is altered from that of what a normal hearing individual needs.

Eisenberg et al attempted to determine if the release from masking in a variable noise was significantly greater for normal hearing versus hearing impaired individuals. Four adults with SNHL and 12 adults with normal hearing were used in this study. Subjects were asked to identify nonsense syllables presented in either a spectrally shaped broadband noise or an experimental masking noise presented as steady state or amplitude modulated. The researchers reported that the hearing-impaired subjects were less likely to experience release from masking during the fluctuating noise conditions than the normal hearing subjects.

Eisenberg et al concluded that the use of varying maskers may allow for a more precise measure for comparing speech recognition performance in noise between hearing-impaired individuals and normal hearing listeners (Eisenberg et al, 1995). This was important to note for the current study. Knowing the detrimental effects of a fluctuating masker, it was important to determine how noise reduction circuitry manages this kind of masker or noise versus a steady state noise.

The great difficulty of increasing the speech to noise ratio is that individuals with SNHL may have a reduced dynamic range. Though there is an increase in hearing thresholds, the loudness comfort level may remain relatively the same as that seen in normal hearing individuals. This becomes a problem when trying to decide upon the appropriate means of amplification, especially in linear amplification. One tactic to reduce this problem is to reduce
the dynamic range of the speech signal in order to match the dynamic range of the impaired ear, or compression (Kennedy et al, 1998). Another proposed method of aiding the impaired individual is through improving the consonant-vowel intensity ratio through phonetically based compression amplification. Further research is needed to determine the extent of the benefits of this type of compression.

Another phenomenon that may occur in hearing is an upward spread of masking. The human ear is a frequency-specific mechanism. In other words, there are regions of the cochlea, as well as various neurons, that are meant to respond to certain frequencies. A better way to describe this may be that the cochlea consists of narrowband filters that have some overlap. However, a critical band fixed on a higher frequency may pick up some lower frequency information. Thus, noise in a critical band may not just mask signals in that band, but the masking may also spread to other bands at higher frequencies. This effect may be small at low levels of intensity, but present more of a hindrance at higher intensities (Levitt, 2001).

Audibility plays a crucial role in speech intelligibility. One way to evaluate performance of audibility is to measure the SRT as a function of overall noise level (Moore, 1996). If a hearing impaired subject’s thresholds are below the region where speech occurs, the SRT, as expressed as speech to noise ratio, will decrease as noise increases. In other words, as the noise becomes louder, the subject’s SRT will become higher.

CURRENT RESEARCH METHODS AND FINDINGS

Van Tassel and Crain (1992) stated one strategy for noise reduction in hearing aids was to decrease the gain in the lower frequencies, as this is where the energy of most environmental noises occurs. This strategy however, changes the frequency response of the hearing aid. Van
Tassel and Crain also cite that when the gain is decreased at any frequency band, both speech and noise are attenuated by the same amount. This leads to the conclusion that the speech to noise ratio cannot be adjusted or increased, in-band.

Van Tassel and Crain go on to state that a simple method for verifying the reduction in noise created by a hearing aid with noise reduction, is through a comparison of the masking patterns (the amount of masking a noise produces for frequency-specific probes over a range of frequencies) observed on a subject wearing the hearing aid with noise reduction on versus noise reduction off. The researchers set out to determine if there was a release from the upward spread of masking effects of noise by observing the masking patterns of hearing aid wearers.

Van Tassel and Crain presented eight high-frequency monosyllables to three individuals (one normal-hearing subject and two hearing-impaired subjects) wearing In-The-Ear hearing aids and measured their SRTs. The monosyllables were presented with narrowband noise levels of 75 and 65 dB SPL. At each of these noise levels, three listening conditions were observed: 1). Unaided, 2). Aided, NR-Off, and 3). Aided, NR-On. SRTs were also obtained in quiet under these conditions: 1). Unaided and 2). Aided, NR-Off.

Van Tassel and Crain found that in the 75 dB noise, all subjects showed a significant improvement in SRTs, in the NR On condition. They also found a release from the masking effects of noise, most apparent at 1000 Hz and above. Their findings here correlated with the improvements in the SRT witnessed in the NR-On condition.

The noise reduction circuitry utilized in the digital hearing aids for this proposed study used adaptive noise cancellation strategies. This strategy allows for the waveform of the noise to be identified and then subtracted from the incoming signal so as to cancel the noise and have the speech remaining (Levitt, 2001). This appears to be a better strategy than that of the hearing aids
used in Van Tassel and Crain’s study. Because various noises do not always manifest in the low-frequency range, adaptive noise cancellation, in theory, will be looking for noise in a wider frequency spectrum.

Van Tassel, Larsen, and Fabry (1988) studied the effects of an “adaptive filter chip” (noise reduction) by measuring aided speech recognition threshold in noise with NR-Off and NR-On. Two separate speech materials and two separate types of noise were used in this study to further look at the interdependence of speech and noise, a complexity that makes noise reduction in theory even more difficult.

Van Tassel et al had six hearing-impaired subjects complete SRT testing using spondaic words (from the CID W-1 list) and monosyllables under speech noise and low-frequency noise. All subjects were given ITE hearing aids containing an adaptive filter chip (noise reduction strategy) that could be turned on and off. Unaided SRT was measured in quiet, followed by aided SRT in quiet and then at two different levels of noise. Aided SRTs were completed after the unaided measures. SRT measures with Filter-On versus Filter-Off were randomized and the subjects did not know under which condition they were being tested.

The writers found that the filter effects were associated with both the frequency spectrum of the noise and where the speech information is distributed by frequency. For measures completed under broadband speech and noise, no significant improvement was seen in SRT. More improvements in SRT were seen under the low-frequency noise and speech material conditions, as much of the important information of the speech was confined to the higher frequencies.

This author agrees that the strategy of subtracting the NR On responses from the NR Off to determine the effectiveness of the noise reduction circuit is a valid strategy. The hearing aids
used in the above study were similar in their processing to those used in the proposed study, in
that they attempt to determine if a noise component is contained in the signal and then attempts
to subtract it out of the signal for speech to remain. Thus, it is felt that the use of environmental
noises (of a broader frequency spectrum) would be better suited for a study of “real world”
situations, as would a sentence format SRT measure.

Sammeth, Dorman, and Stearns (1999) studied the effects of consonant-vowel amplitude
ratios in speech recognition of the hearing impaired listener. Prior studies (i.e. Picheny et al;
Montgomery and Edge; etc) that had attempted to enhance the consonant-vowel ratio (CVR) to
improve speech recognition had shown promising results. Many of the previous studies
however, had increased the amplitude of the consonant energy while holding the vowel energy
fixed, therefore improvements in speech perception may have been caused by increased
audibility or the change in CVR.

Sammeth, Dorman, and Stearns’ study was designed so as to keep the audibility of the
consonant energy fixed. Performance-intensity functions were measured with consonant
isolation first. Then the PI function was measured with re-insertion of the vowel at a normal
CVR and then under two enhanced CVR conditions. These conditions were obtained through
reduction of the vowel amplitude rather than increasing the consonant amplitude.

Subjects consisted of six hearing-impaired individuals and two individuals with normal
hearing. Phonemes to be used were chosen for various acoustical reasons. The consonants and
vowels were separated from each other using computer software called WAVED (from
Boystown National Research Institute). By decreasing the level of the vowel by 6 dB then 12
dB, from the original amplitude, the enhanced CVR versions were developed. The level of the
consonant remained constant. A broadband pink noise created the noise floor for testing.
Practice runs were completed. Then PI functions were measured, first for the isolated consonants and then for the CV syllables in each of the three CVR conditions. These CV trials were completed in random order.

Sammeth et al found that when consonant audibility was controlled, no significant improvements with CVR enhancement were seen in performance. A significant improvement was seen with the re-insertion of the vowel into the speech signal. It appears the vowel greatly aided the subjects in the identification of the consonant.

The results of this study are important as they indicate that vowels are a very important component of speech understanding. Therefore, in the proposed study, the author will want to take into account the effects of the noise reduction on the power of the vowels. Knowing that these phonemes are so important to speech understanding and recognition, it is important to assess whether the noise reduction circuit decreases the power of these phonemes.

Kennedy, Levitt, Neuman, and Weiss (1998), examined the effects of modifying the consonant-vowel intensity ratio on consonant recognition. Six subtests of the CUNY Nonsense Syllable Test, three unvoiced and three voiced, were used for this study. An auditory analysis was used to confirm segmentation of the vowels and consonants. The participants were placed into three groups, each with six individuals. Groups were determined by audiogram configuration. Most comfortable levels (MCLs) and uncomfortable loudness levels (UCLs) were determined for each subject. Subjects were then presented the nonsense syllable, with the vowel at MCL, followed by an increase of the consonant in each nonsense syllable (consonant enhancement). This increase was completed using 3 dB steps up from MCL up to 24 dB above the MCL. From this, a consonant enhancement maximum (CEmax) and consonant recognition
maximum (CRmax) were determined for each subject. These determinations resulted in a personalized modification of the C-V intensity ratio.

Kennedy et al found that the type of consonant used had a significant effect on the CRmax, the gain in consonant recognition, and CEmax. The placement of the vowel was also seen as significant. Additionally, Kennedy et al found that a personalized modification of the C-V intensity ratio and the consonant-vowel combination for each individual produced sizeable improvements in consonant recognition. This finding may not be clinically applicable, as individualized adjustments of the C-V intensity ratio in a hearing aid may not be possible, but it is important to realize that improvements in consonant identification may be accomplished with proper adjustments to the C-V intensity ratio.

From looking at these studies, it can be determined that more information is needed in the area of noise reduction and its effects on not only noise, but speech. Van Tassel and Crain provided a proficient strategy in the differences observed in NR Off versus NR On conditions. Kennedy et al and Sammeth et al offered information on which phonemes might be best to measure the effects of the noise reduction circuit. In reviewing these studies, it was determined that a larger sampling of environmental noises should be used in research as well as a more practical form of speech understanding measures. By “practical” the investigator means a measure of speech understanding more like what an individual encounters in every day speech, i.e. sentences.
CHAPTER THREE

METHOD

The purpose of this study was to determine if there was a significant reduction in background noise without affecting speech, in the presence of various environmental noises. This was done by obtaining four different manufacturers’ digital hearing aids with noise reduction circuits. Five environmental noises in conjunction with five sentences of the HINT test were processed through the hearing aids using the Knowles Electronic Manikin for Acoustic Research (KEMAR). After those recordings were completed, the outputs of the four hearing aids were measured using Cool Edit 2000.

HEARING AIDS

Four digital hearing aids were obtained from four different manufacturers. Hearing aids used and their descriptions can be seen in Table I. A moderate, flat hearing loss was programmed into Noah for each aid (as can be seen in Table II). Each hearing aid was set to the manufacturers’ specifications for that degree and configuration of hearing loss. The hearing aids were programmed as similarly as possible and all hearing aid parameters, including volume control, were held constant throughout the recording session except for the noise reduction circuitry.

Each hearing aid was attached to an unvented full shell acrylic earmold with #13 double walled tubing run to the end of the bore. The hearing aids were then placed in KEMAR’s left ear for the respective recordings.
**TABLE I**

Hearing Aids Used And Their Characteristics

<table>
<thead>
<tr>
<th>Hearing Aid</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Chan</td>
<td>Four channel NR with speech pattern detection</td>
</tr>
<tr>
<td>8 Chan</td>
<td>Eight channel NR with transitory speech enhancement</td>
</tr>
<tr>
<td>9 Chan</td>
<td>Nine channel NR with speech weighted expansion</td>
</tr>
<tr>
<td>14 Chan</td>
<td>Fourteen channel NR maybe 14 band NR with 64 band equalizer</td>
</tr>
</tbody>
</table>

**TABLE II**

Thresholds And Ucls In Dbhl By Frequency Used For Hearing Aid Fitting

<table>
<thead>
<tr>
<th></th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
<th>8000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold</td>
<td>35</td>
<td>35</td>
<td>40</td>
<td>40</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>UCL</td>
<td>---</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>---</td>
</tr>
</tbody>
</table>
ENVIRONMENTAL NOISE CONDITIONS

Five environmental noises were used in this study. The types of noises and their characteristics can be found in Table III.

HEARING AID PROCESSED RECORDINGS

A series of recordings were obtained of five HINT sentences in the presence of five types of environmental sounds. All recordings were made in an anechoic chamber using KEMAR. KEMAR was placed so that the sound source (loudspeaker) was at 0 azimuth and 44 inches from the left external auditory meatus. An Optimus CD-1660 compact disk player read the HINT sentences from a compact disk. The CD player output was routed through a Techron 5515 Power Supply Amplifier. The output of the amplifier was directed to the loudspeaker within the anechoic chamber. The sound levels were set so that the HINT sentences and each of the five environmental noise conditions measured in KEMAR’s unaided left ear equaled a Root Mean Square (RMS) long-term average level of 75 dBA. The RMS level was verified using a Bruel and Kjaer Type 2133 dual channel real-time frequency analyzer measuring 1/3 octave bands from 25 Hz to 20,000 Hz using an eight-second integrated summation. The microphone attached to the Zwislocki coupler in KEMAR’s left ear was wired through a preamplifier stage directly to the Bruel and Kjaer frequency analyzer. The frequency analyzer output was then run to a Panasonic ZV-255 digital tape recorder (DAT). Having set the input speech levels in the unaided condition, each hearing aid, in order, was put in place for the recording sessions. One set of recordings was made through each hearing aid with the noise reduction circuit enabled and another was made.
**TABLE III**

**Environmental Noise Conditions And Their Characteristics**

<table>
<thead>
<tr>
<th>Environmental Noise</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain (on tin roof)</td>
<td>- energy in the mid-high frequencies</td>
</tr>
<tr>
<td></td>
<td>- instantaneous wideband transients</td>
</tr>
<tr>
<td>727 (Jet in cabin at high altitude)</td>
<td>- steady state</td>
</tr>
<tr>
<td></td>
<td>- low frequency energy</td>
</tr>
<tr>
<td>Ocean Waves</td>
<td>- gradually rising and falling, broadband</td>
</tr>
<tr>
<td></td>
<td>- 10-15 dB temporal dips</td>
</tr>
<tr>
<td>Oscillating Fan</td>
<td>- gradually rising and falling, broadband</td>
</tr>
<tr>
<td></td>
<td>- 25-30 dB temporal dips</td>
</tr>
<tr>
<td>Subway (in a cabin)</td>
<td>- broadband transients</td>
</tr>
<tr>
<td></td>
<td>- tone complexes</td>
</tr>
</tbody>
</table>
with noise reduction disabled. For each recording, there was eleven seconds of the environmental sound prior to the first HINT sentence. This allowed for the noise reduction circuits with long attack times to become fully engaged before the onset of speech. For the first set of recordings the noise reduction circuit was turned off in all four hearing aids. Each recording was 21 seconds in length and was obtained at a 44 KHz sampling rate.

COMPACT DISK

The hearing aid processed recordings were taken from the DAT and translated into PCM WAV format using Cool Edit at a sampling rate of 22050. The NR On waveforms were placed in Channel One of each WAV file, while the NR Off recordings were placed in Channel Two for all hearing aids and noise conditions. Each waveform was 22 seconds in length, and the waveforms in each channel were precisely matched up to enable the acoustic analysis of the recordings. A list of tracks used in the acoustic analysis can be seen in Table IV.

The five HINT sentences used were:

1. Big dogs can be dangerous.
2. Somebody stole the money.
3. The player lost a shoe.
4. Rain came pouring down.
5. Tub faucet is leaking.

ACOUSTIC ANALYSIS

The RMS average amplitudes of 23 phonemes from the five sentences were measured using Cool Edit. A list of phonemes measured in the sentences where they occurred can be
found in Table V. Measurements were also taken of the noise levels during the times, where no speech occurred. Each measurement period for every phoneme and its surrounding noise space was made at the same point in time across all hearing aids and noise conditions. In other words, all of the hearing aid processed recordings for each phoneme of the five sentences occurred at exactly the same time frame within every WAV file. Once the time frame for a given phoneme was established within one file, that same time frame was used to measure that phoneme for each occurrence with every hearing aid and in all noise conditions.

Phonemes were first marked in Quiet, with the NR Off. Time periods for markings were determined by visual inspection of the spectrograph and also by listening to each phoneme. Once that was completed, the same time period was used to mark the phonemes in Quiet with NR On, and then in each of the noise conditions with NR On and Off. Due to the fact that the waveforms were lined up exactly the same, it was determined that even if the phoneme could not be seen in noise, it should occur at the same time in each waveform, thus the same time period could be used for each phoneme under each condition. Once the time period was chosen, a two millisecond time window was used to calculate the average RMS output of the hearing aid.

STATISTICAL ANALYSIS

A two-way analysis of variance was completed to determine the change in the speech-to-noise ratio due to the noise reduction circuit being active or on. There were four levels of hearing aids and five levels of environmental noise conditions. The level of significance was 0.05 across all parameters of the study.
### TABLE IV

Hearing Aids And Environmental Noise Tracks

<table>
<thead>
<tr>
<th>Manufacturer &amp; Hearing Aid</th>
<th>Environmental Noise + HINT (In order they were recorded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Chan</td>
<td>Quiet, 727, Fan, Rain, Subway, Waves</td>
</tr>
<tr>
<td>8 Chan</td>
<td>Quiet, 727, Fan, Rain, Subway, Waves</td>
</tr>
<tr>
<td>9 Chan</td>
<td>Quiet, 727, Fan, Rain, Subway, Waves</td>
</tr>
<tr>
<td>14 Chan</td>
<td>Quiet, 727, Fan, Rain, Subway, Waves</td>
</tr>
</tbody>
</table>

### TABLE V

Phonemes Analyzed In Sentences They Occurred

<table>
<thead>
<tr>
<th>Sentence</th>
<th>Phonemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big dogs can be dangerous.</td>
<td>/b/, /i/, /d/, /ah/, /k/, /d/, /s/</td>
</tr>
<tr>
<td>Somebody stole the money.</td>
<td>/s/, /s/, /t/, /m/, /n/</td>
</tr>
<tr>
<td>The player lost a shoe.</td>
<td>/th/, /ah/, /s/, /sh/</td>
</tr>
<tr>
<td>Rain came pouring down.</td>
<td>/k/, /p/, /o/</td>
</tr>
<tr>
<td>Tub faucet is leaking.</td>
<td>/t/, /f/, /ah/, /k/</td>
</tr>
</tbody>
</table>

CHAPTER FOUR
PRESENTATION AND ANALYSIS OF DATA

INTRODUCTION

This study examined the effectiveness of the internal noise reduction circuitry on four digital hearing aids in the presence of various representative environmental noise conditions.

PURPOSE OF STUDY

It was the purpose of this study to:

1. Determine if there was a significant difference in the change in SNR produced by each hearing aid.
2. Determine if there was a significant difference in the change in SNR produced under each environmental noise condition.
3. Determine if there is a significant difference in the change in SNR produced during the interaction between the digital hearing aids and the environmental noise conditions.

LIMITATIONS

It was intended that this study be experimental and descriptive in scope. It was limited in scope because only four manufacturer’s digital hearing aids were evaluated, while there are many more manufacturers and digital hearing aids currently on the market. It was also limited in that only five environmental noise simulations were used.
OBSERVATIONS AND ANALYSIS

As noted earlier all four of the hearing aids examined in this effort were programmed according to each manufacturer’s recommended settings for the same degree and configuration of hearing loss.

Throughout this study, two-way ANOVAs were employed to determine whether significant differences occurred in any of the testing conditions. The null hypothesis was sustained for all tests to the .05 level of significance, with the exception of across hearing aids.

DESCRIPTION OF FINDINGS

The mean differences in the S/N ratio across the three different variables are summarized in Table VI. From the statistics tabulated in Table VI, it can be seen that there was a significant Hearing Aid (HR AID) effect. (An expanded Tukey Table can be found in Appendix One). No significant differences were found across the environmental noise conditions or for the interaction of the hearing aids across environmental noise conditions.

A post-hoc analysis (Tukey HSD) was undertaken to parse out the source of any significant effects. Table VII is the summary of the Tukey HSD analysis of pairwise comparisons of the four hearing aids, which collapsed across all five environmental sounds. (In this summary table, hearing aids with similar noise reduction characteristics are grouped together into two subsets. The 4 channel, 8 channel, and 14 channel hearing aids make up one subset. The 9 channel hearing aid is the second subset. Therefore, the noise reduction performed by the 9 channel hearing aid was significantly different (in this case better) than the other three hearing aids. The other three hearing aids were all statistically equivalent in noise reduction performance. (The complete Tukey table can be found in Appendix Two).
Table VIII is the summary of the Tukey HSD analysis of pairwise comparisons for the five environmental sounds, which collapsed across all four hearing aids. The presence of only one subset is in agreement with the overall ANOVA in that there was no significant environmental sounds effect. The noise reduction for all five environmental sounds was essentially equivalent when collapsed across hearing aids. (An expanded Tukey table can be found in Appendix Three).
# TABLE VI

## Tests of Between-Subjects Effects

### Changes in S/N due to NR On

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<th>Observed Power(a)</th>
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TABLE VII

**Homogeneous Subsets**

Tukey HSD(a.5)

Change in S/N due to Noise Reduction Circuitry

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Alpha = .05
TABLE VIII

Environmental Noise Effects

Tukey HSD (a.b)

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Alpha = .05
CHAPTER FIVE
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY OF HYPOTHESIS, METHOD, AND FINDINGS

The purpose of this study was to determine if there was a significant change in S/N ratio due to the internal noise reduction circuitry in four sample digital hearing aids, across five environmental noise conditions, and across the four sample digital hearing aids in conjunction with the five environmental noise conditions. The initial portions of this study dealt with much of the background on the need for a change in S/N ratio, in this case through noise reduction circuits, and current literature/research relative to the effects of the noise reduction circuit or other S/N ratio manipulating strategies. It was this experimental research evidence that attested to the need for an objective measurement of the noise reduction circuit that led to the development of this study.

The four digital hearing aids used in this study were selected because each had a noise reduction circuit. The five noises used in this study were chosen for their varying characteristics (as can be seen in Table III).

CONCLUSION

This study was an attempt to determine if there was a significant change in S/N ratio as an effect of the various sample digital hearing aids, an effect of the various environmental noise conditions, or an interactive effect of the four sample digital hearing aids in conjunction with the five environmental noise conditions. Statistical analysis showed that for the sample the change in S/N ratio was significant at the 0.05 level of significance as an effect of the hearing aids. The analysis showed that for the sample the change in S/N ratio was not significant at the 0.05 level.
of significance across the five environmental noise conditions. The analysis showed that for the sample the change in S/N ratio was not significant at the 0.05 level of significance across the interaction of the four sample digital hearing aids in conjunction with the five environmental noise conditions.

Figure I shows the mean SNR change as an effect of the noise reduction by each sample digital hearing aid across all five noise conditions. The HR AID effect can be seen more clearly in this figure. It is apparent here that the 9 Channel digital hearing aid had the greatest mean change in S/N ratio across all five environmental noise conditions. An implication to this finding may be that more channels in a hearing aid, may not be better. A current trend in the marketing of hearing aids is the number of channels a hearing aid contains. The more channels a hearing aid has, the better, supposedly. However, after finding the 9 Channel hearing aid to be the best of the four that were used in this study, one might begin to question whether the number of channels really is as important as audiologists and the hearing aid manufacturers have made it. Perhaps a better focus for hearing aid manufacturers would be to first perfect their noise reduction circuit and then increase the number of channels in the hearing aid.

Another interesting factor to look at, which was not previously mentioned in the results, is how the various noise reduction circuits of the sample digital hearing aids reacted by phoneme. The mean change in the S/N ratio across the hearing aids for the Jet noise is shown in Figure II. As can be seen, there is a wide range of change in the S/N ratio by phoneme. This view may be a more clinically significant look at the hearing aid effects. It appears that even though there have been a great deal of advancements to the noise reduction circuits of today’s technology, it still performs best when the competing noise is a low frequency noise. The greatest change in SNR was seen for the Fan and Jet noise conditions. The bulk of the energy for these noises is in
the lower frequencies. It is apparent from this finding that there is still much improvement to be made at reducing those noises with energy in the mid-high frequencies.
FIGURE I

Change in SNR by Hearing Aid

Estimated Marginal Means (dB)

Environmental Sound

Fan  Jet  Ocean  Rain  Subway

-0.4

0

0.2

0.4

0.6

0.8

1

1.2

1.4

1.6

4 Chan
8 Chan
9 Chan
14 Chan
FIGURE II

SNR Changes by Phoneme in the Jet Noise

FIGURE III

SNR Changes by Phoneme in Fan Noise
SNR Changes by Phoneme in Rain Noise

FIGURE FOUR

Changes in SNR by Phoneme in Subway Noise

FIGURE FIVE
FIGURE SIX
RECOMMENDATIONS

Many questions have been answered through this study, but some remain unanswered. Some of these questions follow:

1. What effect does the noise reduction circuit have on the S/N ratio if the hearing aids are programmed for a higher output (as would be seen in a more severe or profound SNHL)?

2. What effect does the noise reduction circuit have on the S/N ratio for those phonemes that were not measured in this study?

It is the belief of the investigator that this study was a better indicator of the effectiveness of the noise reduction circuit of digital hearing aids in changing the S/N ratio. However, this study did not answer any questions related to whether this change in S/N ratio is beneficial to hearing impaired individuals. To answer this question, highly controlled subjective studies should be completed. (The investigator states “highly controlled” so as to reduce the amount of variability as much as possible.)

This investigator does not know whether the NR circuit and a change in S/N ratio would be beneficial for all individuals with SNHL. However, she can say, based on personal experience (as the investigator has a bilateral severe-profound SNHL and wears digital hearing aids with a noise reduction circuit), that these effects have been invaluable to her.

The research completed in this study and others like it may not always bring forth answers that are desired by those individuals in the hearing aid industry, but in many cases, it has pointed out the need for further research, or even changes to be made to current technology. Research does indicate a concern for assisting individuals with hearing loss understand speech in noise and the hope is that the noise reduction circuit is a step in the right direction. This study
has shown objectively that the noise reduction circuit (in various sample digital hearing aids) is a step forward to change the S/N ratio. It is the investigator’s expectation that further research in this area, by both objective and subjective means, will lead to further technological advances.
BIBLIOGRAPHY


APPENDIX ONE

Multiple Comparisons
Dependent Variable: Brookes Change in S/N due to NR On
Tukey HSD

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<th>95% Confidence Interval</th>
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Based on observed means
* The mean difference is significant at the .05 level.
### APPENDIX TWO

**Multiple Comparisons**

Dependent Variable: Brooke's Change in S/N due to NR On

Tukey HSD

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Based on observed means.
# APPENDIX THREE

## SNR Changes Due to NR

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