1990

Comparison of actual versus prescribed gain for school-aged, hearing-impaired children

Nancy M. Hohler
The University of Montana

Let us know how access to this document benefits you.
Follow this and additional works at: https://scholarworks.umt.edu/etd

Recommended Citation
https://scholarworks.umt.edu/etd/1853

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.
COMPARISON OF ACTUAL VERSUS PRESCRIBED GAIN
FOR SCHOOL-AGED, HEARING-IMPAIRED
CHILDREN

By

Nancy M. Hohler
B.A., The University of Montana, 1987

Presented in partial fulfillment of the requirements
for the degree of
Master of Arts
University of Montana
1990

Approved by:

[Signatures]
Chair, Board of Examiners

[Signatures]
Dean, Graduate School

[Signature]
Date

February 17, 1990
The purpose of the present study was to compare the actual gain school-aged, hearing-impaired children received from their hearing aids to the amount of gain that would have been prescribed utilizing the Desired Sensation Level (DSL) method proposed by Seewald, Ross and Stelmachowicz (1987). The DSL selection method (Seewald et. al., 1987) was used to calculate prescribed gain for the frequencies; 500, 1000, 2000 and 4000 Hz using the unaided thresholds for each of the twenty-two hearing-impaired subjects participating in this study. Functional gain, defined as the difference between aided and unaided thresholds, was calculated at the same frequencies. An acceptance criteria of ± 5 dB was employed to determine significant differences. Aided functional gain measures which were within the acceptance criteria were not considered significantly different from the prescribed gain for that frequency. The data was then described and analyzed to determine patterns which could possibly explain variance from the prescribed gain (i.e., testing facility, degree and configuration of loss, and subject age). In addition, speech audibility in the aided and unaided conditions was described using an articulation index proposed by Pavlovic (1988).

The results indicated that more than 50% of the subjects failed to satisfy the prescribed gain criteria. Analysis of group characteristics revealed a general pattern where low frequencies tended to be over amplified and the high frequencies tended to be under amplified. When comparing articulation indices, only one subject achieved an aided articulation index of 1.0 indicating all of the speech signal was audible.

Further research is suggested to investigate other electroacoustic problems such as distortion and saturation of the acoustic signal due to over amplification in the low frequencies and possible violation of tolerance levels.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>iv</td>
</tr>
<tr>
<td>List of Figures</td>
<td>v</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>vi</td>
</tr>
<tr>
<td>Chapters</td>
<td></td>
</tr>
<tr>
<td>I.   Introduction</td>
<td>1</td>
</tr>
<tr>
<td>II.  Review of the Literature</td>
<td>6</td>
</tr>
<tr>
<td>III. Methods</td>
<td>25</td>
</tr>
<tr>
<td>Subjects</td>
<td>25</td>
</tr>
<tr>
<td>Procedures</td>
<td>25</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>30</td>
</tr>
<tr>
<td>IV.  Results</td>
<td>32</td>
</tr>
<tr>
<td>V.   Discussion</td>
<td>48</td>
</tr>
<tr>
<td>References</td>
<td>58</td>
</tr>
<tr>
<td>Appendices</td>
<td>69</td>
</tr>
<tr>
<td>Appendix A: Authorization for Data Collection</td>
<td>69</td>
</tr>
<tr>
<td>Appendix B: Data Collection Form</td>
<td>70</td>
</tr>
</tbody>
</table>
List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number (and percentage) of subjects satisfying prescribed gain criteria</td>
<td>33</td>
</tr>
<tr>
<td>2. Number (and percentage) of subjects above or below prescribed gain criteria</td>
<td>36</td>
</tr>
<tr>
<td>3. Subject age and relation to prescribed gain</td>
<td>38</td>
</tr>
<tr>
<td>4. Degree of subject’s hearing loss and relation to prescribed gain</td>
<td>40</td>
</tr>
<tr>
<td>5. Configuration of subject’s hearing loss and relation to prescribed gain</td>
<td>43</td>
</tr>
<tr>
<td>6. Testing facilities and relation to prescribed gain</td>
<td>46</td>
</tr>
<tr>
<td>7. Subject’s unaided and aided articulation indices: mean, range and standard deviation</td>
<td>47</td>
</tr>
</tbody>
</table>
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Speech spectrum parameters as described by Pavlovic (1988)</td>
<td>28</td>
</tr>
<tr>
<td>2. A hypothetical client.</td>
<td>29</td>
</tr>
<tr>
<td>3. Percentage of subjects satisfying prescribed gain criteria</td>
<td>34</td>
</tr>
<tr>
<td>4. Percentage of subjects above or below prescribed gain criteria</td>
<td>37</td>
</tr>
<tr>
<td>5. Number of subjects satisfying prescribed gain criteria by degree of hearing loss</td>
<td>41</td>
</tr>
<tr>
<td>6. Number of subjects satisfying prescribed gain criteria by configuration of hearing loss</td>
<td>45</td>
</tr>
</tbody>
</table>
Acknowledgements

I wish to thank my committee members, Dr. Doug Martin, Dr. Michael Wynne and Dr. Larry Berger, for their understanding and support through out this endeavor. Dr. Martin for his sense of humor, Dr. Wynne for his inexhastable sense of optimism, and Dr. Berger for his patience. In addition, I would like to thank Ms. Sally Johnson for giving me the insight to begin this task and Ms. Shelia Miller for helping me compile the data.

As this project also reflects the end of my academic endeavors for at least a short time, I would also like to express my appreciation to my fellow students for their support and friendship during the past six years. Most especially I would like to thank Terry Foust for his friendship and support. His presence was my saving grace.

I would also like to thank my husband, Tom, for his love and silent support without which I could not have finished anything.

Finally, I would like to dedicate this thesis to my father who taught me that we can all accomplish great things.
Chapter I
Introduction

Normal hearing is generally considered a necessary precursor for normal speech and language development. In addition, normal hearing plays a critical role in the development of linguistic competency and the realization of optimal academic achievement (Matkin, 1984). Consequently, hearing-impaired children must be considered at risk for speech and language problems as well as academic difficulties. The main effect of hearing loss on the perception of speech is a decrease in the audibility of the signal. Additionally, hearing loss can affect auditory skills such as temporal and frequency resolution (French-St. George, 1986). While these skills contribute to the perception of speech, the effects of hearing loss on the audibility of the signal is of primary concern. As stated by Byrne (1978), "there may be other factors limiting auditory discrimination but clearly the amount of signal available, in various frequency regions, limits what is possible" (p. 12).

The impact of a hearing impairment is directly related to the listening needs of the individual. Because children rely on their hearing to learn speech and language, their listening needs are critically different than the hearing-impaired adult who has an intact speech and language system (Matkin, 1987). The adventitiously hearing-impaired adult
can rely on his intrinsic linguistic knowledge to compensate for the loss of information from the speech signal caused by the degrading effects of the hearing loss. The hearing impaired child does not yet have this intrinsic knowledge. Thus, ensuring audibility of the entire speech signal is of utmost importance in providing the child with the necessary sensory input for developing linguistic competence.

Many hearing-impaired children are fit with hearing aids in the hope that the amplification of the speech signal will help facilitate speech and language development. Due to the listening needs of the hearing-impaired child, the selection of amplification characteristics is critically important. Numerous strategies exist for determining appropriate amplification characteristics (i.e., gain as a function of frequency).

The most commonly used strategies are based on or are modifications of the half gain rule (Berger, 1988). The half gain rule evolved from studies exploring adult preferred use levels (i.e., the levels at which adventitiously hearing-impaired adults would chose to wear their hearing aids). According to the half gain rule, an appropriate gain level is equal to one half of the pure tone threshold at each particular frequency. For example, for a person with a pure tone threshold of 50 dB HL at a given frequency, an appropriate amount of gain would be 25
dB. As the half-gain strategies are based on the needs of the hearing impaired adult, they may not necessarily be the optimal approach when fitting children with hearing aids (Martin, 1989; Seewald and Ross, 1988).

Seewald, Ross and Stelmachowicz (1987) have proposed a method for selecting hearing aid gain for children, referred to as the Desired Sensation Level (DSL) approach. Their method evolved from the general goal to "provide an amplified speech signal which is audible, comfortable, and undistorted across the broadest relevant frequency range possible" (p.25). Based on previous studies, Seewald et al. have determined the levels (as a function of frequency) to which speech should be amplified, according to the child's detection thresholds, in order to afford optimal perception of the signal. Thus, the first step in this method is to determine the relationship between the desired (or target) amplified speech spectrum and the child's detection thresholds. After this relationship has been established, the specific frequency-gain characteristics required to provide the child with the optimal amplified speech signal can be identified; the actual gain values which are prescribed are defined by these calculations. Basically this approach advocates amplifying all portions of the speech spectrum to pre-determined suprathreshold levels. In contrast, most adult based methods (e.g., 1/2 gain, POGO and NAL) prescribe gain simply in proportion to
the degree of hearing loss with only secondary concern to the relationship between aided thresholds and the average speech spectrum.

As described, the DSL fitting strategy may be the most thoroughly developed and documented method for prescribing frequency-gain characteristics for children. In light of this and the critical need of hearing-impaired children to receive appropriate amplification, audiologists should strive to achieve the objectives of this procedure to the greatest extent possible. Unfortunately, the degree to which school aged, hearing-impaired children satisfy the Seewald, et al. hearing aid fitting criteria is unknown. Thus, this study will address how the actual functional gain received by hearing-impaired, school-aged children compares with the gain that would be prescribed utilizing the method proposed by Seewald et al. (1987).

As optimizing audibility of the speech signal is the ultimate goal in fitting children with hearing aids, the issue of audibility of the speech signal for the group of listeners will be addressed. Due to the underlying rationale, the amplification characteristics prescribed by the DSL method would, if realized, result in the perfect audibility of the speech signal (i.e., all portions of the speech spectrum amplified to suprathreshold levels). If no differences are found between the actual gain and the prescribed gain for the group of listeners, then perfect
audibility could be assumed. However, in the event that differences in the gain measure are discovered, the audibility of the speech signal may deviate from perfect. The second objective for this study will then be to describe the audibility of the speech signal in the actual aided condition for the experimental group and relate these findings to the predicted audibility based on the DSL fitting strategy.
Chapter II

Review of the Literature

This review will address the effects of hearing loss on speech perception and speech and language development (specifically the speech and language development of hearing-impaired children), as well as the impact of hearing loss on academic achievement. In addition, current selection strategies for determining amplification characteristics and measures available for determining amplification effectiveness will be discussed.

The Effects of Hearing Loss on Speech Perception

Hearing loss can affect the perception of speech in two ways. First, hearing loss can cause a decrease in the audibility or the perceived loudness of the speech signal. Second, hearing loss can distort the perceived quality of the speech signal. The distortion of the perceived quality may be due in part to interference with the psychoacoustic abilities such as frequency and temporal resolution, and with the perception of the time/intensity envelope of speech (Humes, 1982).

A conductive hearing loss can cause a decrease in the audibility of the speech signal by reducing or interfering with the normal transmission of sound from the external auditory canal to the inner ear. With a pure conductive hearing loss, the inner ear is capable of normal function but the intensity of the auditory stimulus must be
increased in order to stimulate the cochlea via the normal air conduction pathway (Northern and Downs, 1984). A purely conductive hearing loss generally affects the audibility of the perceived speech signal and sound source localization (Skinner, 1988).

A sensorineural hearing loss results from damage to the sensory end organ (e.g. cochlear hair cells) or to the auditory nerve (Northern and Downs, 1984). The audibility of the stimulus is affected as the signal (in the affected frequency band) must be more intense to stimulate the hair cells. Additionally, sensorineural hearing loss may cause distortion of the speech signal by affecting the temporal and frequency resolution of the cochlea (Humes, 1982).

Temporal resolution refers to the listener's ability to separate, or resolve, auditory events in the time domain (Humes, 1982). Temporal resolution has been evaluated through the use of temporal gap detection measures. Gap detection procedures require listeners to judge two stimuli as a function of the interstimulus duration between them (Boothroyd, 1983; Fitzgibbons & Whightman, 1982; Irwin & Purdy, 1982, Plomp, 1964; Stoker, 1977; Tyler, Summerfield, Wood & Fernandes, 1982). The results from these studies indicated that the temporal resolving power is impaired in some individuals with sensorineural hearing loss. The hearing-impaired individual may require longer interstimulus intervals in order to perceive two discrete
physical events as independent auditory stimuli. The temporal resolution of voiced onset time cues in terms of discriminating voiced from unvoiced stop consonants could be impaired in individuals with reduced temporal resolution skills (Tyler et al., 1982).

Frequency resolution refers to the ability of a listener to separate or resolve the spectral components of a complex sound (Humes, 1982). Several studies have indicated that the frequency resolution abilities of individuals with sensorineural hearing loss are impaired (Celmer, 1982; Florentine, Buus, Scharf, & Zwicker, 1980; Tyler, Summerfield, Wood & Fernandes, 1982; Zwicker & Schorn, 1978). It is believed that the impairment of the frequency resolution abilities results in the relatively poor performance on word discrimination tasks in noise exhibited by individuals with sensorineural hearing loss (Celmer, 1982; Tyler, Wood & Fernandes, 1982).

In addition to frequency and temporal resolution, a listener must be able to perceive the time/intensity envelope of speech in order to segment the continuous acoustic signal (French-St. George, 1986). Studies have indicated that profoundly hearing-impaired individuals may experience difficulty with this basic task (Vilchur, 1977). There is speculation that the alteration may be so severe that the audible signals do not "hold together" as a pattern thus impairing the person's ability to segment the
speech signal appropriately (French-St. George, 1986).

While sensorineural hearing loss can affect psychoacoustic abilities such as temporal and frequency resolution, the most important parameter affected is audibility of the speech signal. Audibility of the speech signal is a critical factor in the identification of speech sounds (Skinner, 1988). In terms of rehabilitation, the loss of audibility is the most important effect of hearing loss because it is the one parameter that can possibly be compensated for through the use of amplification.

The Effects of Hearing Loss on Speech, Language and Academic Development

As stated by Ling (1976), "among the many variables affecting speech development, hearing level is perhaps the most important" (pg. 16). There is a consensus that the greater the residual hearing, the greater the likelihood that the child's speech will be intelligible, though a profound hearing loss does not necessarily indicate that a child's speech will be completely unintelligible (Smith, 1975; Monsen, 1978). Black (1971) stated "the speech of deaf children differs from normal aspects in all regards". (pg. 156). Segmental (or phonemic) errors are evident as well as suprasegmental errors and both types of errors can affect intelligibility.

The components of speech production of the hearing-impaired which receive the most attention are
intelligibility, respiration, phonation, and rate. Perhaps the most critical issue regards the tendency for the hearing-impaired to demonstrate reduced speech intelligibility. In four separate studies, the percentage of words intelligible to listeners unfamiliar with hearing-impaired speech was less than 25% (Brannon, 1964; Markides, 1970; Heidlinger, 1972; Smith, 1975).

In attempting to explain speech intelligibility breakdown, numerous studies suggested that there is a general lack of coordination between the articulators (tongue, lips, and jaw) and the breath-voice system of hearing-impaired speakers (Hudgins, 1934, 1936, 1937, 1946; Rawlings, 1935; Voelker, 1938; Mason & Bright, 1937). Specifically these studies have found that hearing-impaired children tend to expend more breath during production, exhibit a more restricted range of vocal pitch, and prolong phonation to approximately 3 times greater than normal. The voice characteristics of hearing-impaired speakers can also include abnormal voice harshness and nasal/pharyngeal resonance characteristics (Easterbrooks, 1987). Phonemic errors can also contribute to the reduction in the overall intelligibility of speech (Brannon, 1964; Easterbrooks, 1987).

In addition to affecting speech development, hearing loss can also affect language development. Hearing-impaired children exhibit difficulties in the five main
areas of language; morphology, syntax, semantics, pragmatics and phonology.

Braine (1963) found that normal hearing children learn the rules of morphology by hearing morphemes in the temporal and spatial positions in which they occur. Easterbrooks (1987) postulated that hearing-impaired children miss these elements for three reasons. First, many of the morphological units carry the least amount of acoustical energy and are, therefore, not audible. Secondly, most morphological units are not easily identified by lipreading. Finally, morphological endings are not included in some of the sign system languages such as American Sign Language (ASL). Hearing-impaired children have difficulty with possessives, tense markers and noun-verb agreements (Taylor, 1969). These markers are low intensity and may be inaudible (e.g., /s/, /t,d/).

Studies investigating the development of syntax in hearing-impaired children have shown that their acquisition of syntactic rules was significantly delayed when compared to normal hearing children (Engen and Engen, 1983). These researchers found that 5- to 7-year-old hearing-impaired subjects understood less than their 4-year-old hearing counterparts and that they never caught up to their hearing peers. Most hearing-impaired children never reached the same level of comprehension or use of English structure as the average hearing child entering first grade. Kenworthy
(1986) concluded that hearing-impaired children appeared to learn the same content and structures of language that normal hearing children did but that many failed to integrate or apply them appropriately within a conversational setting.

Hearing-impaired children also exhibit delays in semantic development (Cooper and Rosenstein, 1966; Easterbrooks, 1987). One study indicated that the average hearing-impaired child acquired a vocabulary equivalent of a normal hearing fourth grader. Even those brighter students who were Gallaudet College entrants had only acquired a sixth grade vocabulary (Cooper and Rosenstein, 1966). Easterbrooks (1987) maintained that one reason hearing-impaired children have difficulty with semantic development is that they have a tendency to be tied to the immediate perceptual referent. Simmons (1962) found that hearing-impaired children use words in limited ways. For example, adjectives were only used in the predicate position versus as a modifier.

While research in the area of pragmatics is limited, the studies available have tended to show that pragmatic skills in hearing-impaired children are also delayed. Kolzak (1983) found that hearing-impaired children usually do not initiate communication and if they do, they do not have the skills needed to maintain the interaction. Kolzak (1983) also found that hearing-impaired children very often
do not understand the social use of language and therefore do not exchange greetings or other social gestures as required in certain social situations. To compound their difficulties, Kolzak (1983) maintains that hearing-impaired children are often too shy to ask speakers for clarification, confirmation or repetition.

Phonological errors can also be evident in the speech and language of hearing-impaired children. The speech of hearing-impaired children often exhibits both vowel and consonant production errors (Hudgins & Numbers, 1942; Angelocci, Kopp & Holbrook, 1964). In vowel production the most frequent errors are substitution, neutralization, dipthongization and nasalization (Hudgins & Numbers, 1942; Angelocci, Kopp & Holbrook, 1964). Consonant errors include numerous voicing errors, omission or distortion of final consonants, consonant blends, final consonants, nasalization, substitution of consonants and intrusive voicing between consonants (Hudgins and Numbers, 1942). Nober (1967) found that the least visible sounds tended to be the sounds misarticulated most frequently.

Just as they experience difficulties with spoken language, hearing-impaired children often demonstrate problems with written language. Furth (1966) found that only 1% of deaf children were functionally literate (having reading scores of Grade 4.9 or better) by the age of 11. Even by the age of 16, only 12% had reached functional
literacy. Other studies concluded that severe hearing-impairment from an early age is universally associated with serious problems in reading English (Conrad, 1977; Hammermeister, 1971; Berko-Gleason, 1985). While tests of reading achievement do not directly measure language ability, they can reflect the reader's knowledge about their language system (Thompson, Biro, Vethivelu, Pious and Hatfield, 1987).

While the problems associated with hearing loss have been described and documented, the remedial strategies and theories are still debated. One strategy that has achieved widespread acceptance is maximizing the use of residual hearing. It is generally accepted that the majority of hearing-impaired children have residual hearing usable for language comprehension (Boothroyd, 1976; Ling & Ling, 1978; Ross & Giolas, 1978). It is also generally accepted that the selection and fitting of appropriate amplification is perhaps the single most critical element of aural rehabilitation (Seewald and Ross, 1988). In order to choose a hearing-aid which will offer the most appropriate amplification, a hearing-aid dispenser will often rely on a selection strategy.

Selection Strategies

There are a variety of procedures available for selecting hearing aids for an individual. Two of the more widely recognized procedures are the comparison method and
the prescription procedure. The comparison method evolved from a series of articles written in the 1940s by Raymond Carhart (Millin, 1988). Speech audiometric test results were obtained from the prospective hearing aid wearer using a few different hearing aids, either body aids or behind-the-ear (BTE) styles, that were previously selected. These test results were then compared and the hearing aid that provided the best scores was ultimately recommended. This procedure's popularity decreased in the 1980s, due in part to the lack of published research pertaining to either its reliability or validity (Millin, 1988).

Many prescriptive procedures are threshold based, that is the amount of gain is based on the listener's thresholds (Lybarger, 1955, 1963; Fletcher, 1952; Byrne and Tonisson, 1976; Berger, Hagberg and Rane, 1984; McCandless and Lyregaard, 1983; Libby, 1985, 1986; Byrne and Dillion, 1986). Most threshold procedures are, in turn, based on or modifications of the half-gain rule first described by Lybarger in 1945. This procedure is based on research suggesting that the preferred listening level of adult hearing aid wearers is equal to approximately 1/2 of their threshold at each frequency tested. For example a person with a pure tone average (500, 1000, and 2000) of 70 dB HL will typically choose to set the volume control where it provides about 35 dB of gain. Several studies have confirmed the validity of this premise (Berger, Hagberg and
Rane, 1980; Brooks, 1973; Byrne and Fifield, 1974; Martin, 1973). However, studies have indicated that when half-gain rules, or variations thereof, are employed with the severely hearing-impaired, much of the amplified speech spectrum remains inaudible (Byrne and Dillion, 1986).

Many prescriptive procedures have been formulated based on the preferred listening levels of the adult hearing aid wearer. Byrne and Tonisson (1976) developed a threshold based procedure which they derived from the preferred listening levels of speech chosen by children with sensorineural losses. Later studies (Byrne and Dillion, 1986) found that too little gain was prescribed in the lower frequencies using this procedure and modifications were made resulting in the more well known NAL-R (National Acoustics Laboratory-Revised) procedure.

Another threshold based procedure is the Prescription of Gain/Output (POGO) of Hearing aids developed by McCandless and Lyregaard (1983). In this procedure the half-gain rule is modified so that the gain at 500 and 250 Hz is reduced by 5 and 10 dB respectively. This modification provides less amplification of low-frequency room noise. One disadvantage is that POGO does not prescribe the additional gain needed by those with conductive hearing losses or those with more severe hearing losses (Skinner, 1988).
The Libby method is another threshold based procedure which prescribes gain that is one-third of the hearing threshold level, with 3 and 5 dB less at 500 and 250 Hz. This procedure prescribes less overall gain and less difference in gain as a function of change in audiogram slope than any other threshold procedure (Skinner, 1988).

Threshold based procedures prescribe gain as a proportion of loss. Seewald et al. (1987) proposed a procedure, the Desired Sensation Level (DSL), for selecting amplification characteristics for children based on audibility of the speech spectrum. Seewald et. al. postulated that selection methods involving aided detection thresholds did not relate performance to expected speech input levels. They maintain that "audibility of the speech signal can be viewed as the most basic prerequisite to auditory linguistic growth and performance" (p. 230). Therefore, the DSL procedure was designed to calculate the level to which speech must be amplified in order to achieve the desired sensation levels above a given threshold.

Based on a study by Erber and Winn (1977), Seewald et. al. (1987) concluded that regardless of the degree of hearing loss, the speech signal should be delivered at levels sufficiently above threshold within all the frequency regions where residual hearing is present. This includes the high frequency regions of 4000 Hz and above. Research has shown that much of the energy of voiceless
phonemes, particularly /s/, /ʃ/, /f/, /θ/, and /tʃ/ fall above 4000 Hz. (Levitt, 1978). Additionally, morphological markers such as /s/ and /t/ also are primarily high frequency/low intensity phonemes (Levitt, 1978).

Seewald et al. (1987) postulated that an adventiously hearing-impaired adult does not necessarily need the high frequency emphasis in order to perceive speech because the acoustic information present in the high frequencies (4000 Hz. and above) is likely to be redundant. However, for a hearing-impaired child who is learning speech and language, the additional acoustic information present in the high frequencies is crucial for the development of speech and language skills.

For the optimal frequency response for frequencies below 1000 Hz., Seewald et al. (1987) prefer to reduce the amount of amplification within the low frequency range, especially if the child demonstrates usable residual hearing in the low frequencies. This principle is based on studies that indicate that the presence of a low frequency first formant can interfere with perception of the higher, second formant transitions at high sound pressure levels (SPL) through the upward spread of masking (Danaher, 1978). Additional studies have shown that by eliminating the first formant, the majority of hearing-impaired subjects have improved frequency discrimination of the second formant transition, which is an important cue in consonant
perception (Seewald and Ross, 1988). Punch and Beck (1986) found that positive subject judgments in the perceived speech quality increased when there was an increase in the low frequency response.

The DSL method is divided into three main steps. The first step is to quantify the child's residual hearing. This step incorporated threshold measures obtained through conventional behavioral audiometry as well as any physiological estimates. The second step was to define the electroacoustical dimensions that would optimize the child's auditory learning. This includes choosing frequency and gain characteristics as well as selecting maximum output levels. In order to accomplish the second step of electroacoustic selection, Seewald et al. (1987) developed estimates of desired sensation levels for amplified speech that varied both as a function of hearing level and frequency region. The gain required to amplify the average long-term speech spectrum to the desired levels, within each frequency region, is then calculated. The hearing aid and earmold combination providing gain and output characteristics closest to meeting the recommended gain at the most frequencies is then selected. The DSL selection model also provides the desired maximum real-ear sound pressure levels, the point at which the hearing aid output should be limited as a function of frequency.
The third step of the DSL method is to determine the adequacy of the selection process. Seewald et al. (1987) realized that not all of the audiologic information may be available when selecting amplification, especially when working with very young children. In addition, a child's hearing loss can be progressive. Therefore, Seewald et al. advocate re-evaluating the adequacy of the selection periodically, based on the premise that selection of electroacoustic characteristics for children is tentative and may change. The clinician must assume that the selection of amplification is an ongoing process. In order to determine the effectiveness of an amplification system, an appropriate method of evaluation must be chosen.

Methods for Determining Amplification Effectiveness

Many methods are currently used to determine the adequacy of a selected amplification system. These methods fall primarily into two categories; those which require subjective responses and those that rely on physical measurements of the amplification systems. One physical measurement method is to measure the electroacoustical output of the hearing aid. This can be accomplished with a probe-tube microphone system or with an electroacoustical analyzer and a 2 cc coupler. The probe-tube microphone system is designed to measure the output of the hearing aid and earmold placed on the listener's ear. This allows the natural ear canal resonating characteristics of the
perspective hearing aid wearer to be included in the measurement. The advantage of the probe-tube measurement system over traditional electroacoustical measures using any one of the 2 cc couplers is that with the probe-tube measures the clinician is able to measure the actual unaided and aided sound pressure level (SPL) in an individual's external ear canal.

The electroacoustical analysis is designed to analyze the hearing aid with or without the earmold while incorporating an average adult ear canal volume (2 cc). The advantage of using this method is that the effects of changes to the amplification system across subjects rather than within subjects and it doesn't require active subject participation. The disadvantage of both methods, however is often the formidable cost of the equipment.

Evaluation methods involving subject participation are often employed due to their relative low cost. Speech recognition tests and functional gain, defined as the difference between aided and unaided thresholds, are two of these methods. In addition, these methods offer the client a chance to participate in the selection process. Older children and adults can offer judgments in perceived sound quality and speech intelligibility. Speech recognition and functional gain measures can also give the clinician insight into differences in the performance with different hearing aids. These tests are often inappropriate for
young children and developmentally disabled adults as they often are not capable of responding appropriately or of understanding the task.

One method for subjectively evaluating amplification systems was originally developed to assist in the design of telephone communications system by the researchers at Bell Telephone Laboratories (French and Steinberg, 1947; Fletcher and Galt 1950). This method is known as the Articulation Index. After extensive experiments these researchers found that speech recognition could be predicted from the communication proficiency of the talker and listener, the auditory threshold of the listener, the spread of masking and the measurements of the intensity and spectra of the speech and noise. This theory has regained popularity in recent years and has been used to relate the residual hearing of hearing-impaired listeners to their ability to recognize speech (Dugal, Braida and Durlach, 1980; Kamm, Dirks and Bell, 1985; Pavlovic, Studebaker and Sherbecoe, 1985).

The selection of the most appropriate hearing aid and frequency response is often based upon the configuration yielding the highest Articulation Index (AI). Calculations of the AI value provide an index of the proportion of the speech spectrum that is audible, weighted by the contribution of specific frequency regions to intelligibility.
Nonaudiometric assessment tools used in determining amplification effectiveness can include documenting growth in speech and language as well as auditory, social and cognitive development by observations recorded by parents, teachers and other professionals (Seewald and Ross, 1988). However, many of these observations may not be reliable due to observer bias and lack of training. Regardless of the method chosen it is imperative that the child receives long term, consistent monitoring of his or her amplification device (Seewald and Ross, 1988).

Summary and Conclusions

Hearing loss generally affects the audibility of speech sounds as well as psychoacoustic abilities such as temporal and frequency resolution thereby affecting the quality of perceived speech (Northern and Downs, 1984; Humes, 1982). In addition, the effects of the hearing impairment on the speech and language development can be devastating. Consequently, social, cognitive and academic achievement and growth can also be impaired (Kolzak, 1983; Conrad, 1977; Hammermeister, 1971; Berko-Gleason, 1985). As stated by Johnson (1987), "hearing impairment is more than a loss of ability to hear sounds....the most devastating consequence is its impact on communication, the basis for cognitive growth and social development" (p. 241).
Appropriate amplification of the hearing-impaired child's residual hearing is often the first and most important step in rehabilitation. Appropriate amplification will increase the audibility of the speech. Therefore, it is imperative that hearing aid dispensers not only identify and use the most reliable and valid selection methods available, but continue to monitor the child's amplification system and the electroacoustic characteristics therein to insure the most appropriate fit. As few studies are reported, there exists a need to first quantify and describe the amplification characteristics of hearing-impaired children.
Chapter III

Methods

Subjects

Twenty-two hearing-impaired children drawn from Area 11 (Western Montana) of the Educational Hearing Conservation Program participated in this study. All subjects were school-aged children enrolled in the public school system for the 1988-89 school year. Subjects met the following audiometric criteria: fit with amplification and exhibiting at least one unaided high-frequency pure-tone threshold (1, 2, or 4K Hz) poorer than 70 dB HL (ANSI S3.6-1969). The upper limit for the pure tone average was chosen based on a study by Schwartz and Larson (1977) which indicated that for listeners with severe to profound losses, traditional threshold comparison methods (i.e., functional gain) tend to over-estimate the amount of useable amplification at conversational input levels due to interaction between the use gain and the saturation sound pressure level of the hearing aid.

Procedures

A retrospective review of the Educational Hearing Conservation Program (HCP) files yielded an audiogram for each subject. The audiograms contained aided and unaided thresholds obtained by various audiologists. The audiometric data for this study was compiled by a licensed audiologist who is responsible for the maintenance of the
files under contract with the Hearing Conservation Program in Montana and a grant from the U. S. West Foundation. Authorization to access these files was given by Merle DeVoe, State Director of the HCP, and by Shelia Miller, M.A., CCC-A, the audiologist maintaining the files for the HCP (see Appendix A).

The desired sensation level (DSL) selection method described by Seewald, et al. (1987) was used to calculate prescribed gain for the frequencies; .5, 1, 2, and 4K Hz. using the unaided thresholds for each child. Functional gain, defined as the difference between the unaided and aided thresholds, was calculated at the same frequencies (.5, 1, 2, and 4K Hz.). Subjects whose audiograms did not contain unaided and aided thresholds for at least three of the frequencies were not included in this study.

As defined, the functional gain measures were representative of the child's performance with the amplification system at the time of the aided testing only. As day-to-day functioning of hearing aids cannot be reliably predicted from only one test session, no attempt will be made to generalize these findings to the every day functioning of the amplification systems.

Other limitations with functional gain measures which could influence the results of this study include the sensitivity of functional gain measures to artifact from the noise floor of the test environment, internal noise
from the hearing aid, variability due to active subject participation (Haskell, 1987). Despite possible inherent limitations, the functional gain measure was employed as it was the most readily accessible measure of gain and frequency response available, given the chosen subject group, for answering the questions posed in this study.

The second question for this study involved analysis of speech audibility in the actual aided condition. An articulation index (AI) proposed by Pavlovic (1988), was utilized to predict speech audibility. Based on numerous studies, Pavlovic presents a simplified speech spectrum which defines the speech minima (m) and speech peaks (p) at 20 and 50 dB HL respectively while limiting the effective bandwidth from 500 to 4000 Hz. (see Figure 1). According to Pavlovic, estimation of speech audibility is accomplished by summing the individual's residual hearing (defined as the number of decibels between threshold and the upper limits of the speech spectrum) at 500, 1K, 2K and 4K Hz. and dividing this number by 120; the divisor for the calculation represents the total number of dB within the speech spectrum. The resulting value defines the articulation index of the speech spectrum as a ratio between the portion of the speech spectrum above threshold and the entire speech spectrum.

As an example of application of Pavlovic's procedure, Figure 2 represents a hypothetical patient with thresholds
Figure 1  Speech Spectrum Parameters as Described by Pavlovic (1988)
Figure 2  A Hypothetical Client
In relation to Pavlovic's speech spectrum, the residual hearing values (in decibels) are: 30 at 500 Hz., 25 at 1K Hz., and 0 at both 2K and 4K Hz. The sum of these values (i.e., 55) divided by 120 yields an AI score of 0.46. With 0 as the minimum and 1 as the maximum AI score possible, the score for this example indicates that 0.46 (or 46% if expressed as a percentage) of the speech spectrum is above the listener's threshold and, therefore, audible.

**Data Analysis**

The primary question posed for this study regards whether school age children's hearing aid fittings differ from prescribed optimal fittings according to Seewald et al. (1987). Functional gain and prescribed gain (at .5, 1, 2, and 4K Hz) were compared for each child. An arbitrarily selected acceptance criterion of ± 5 dB was employed to determine significant differences. Aided functional gain measures which were within the acceptance criteria were not considered significantly different from the prescribed gain for that frequency. The number of subjects which met this criterion were described and the data was analyzed to determine patterns which could possibly explain variance from the prescribed gain (i.e., fitting, facility, degree and configuration of loss, ect.).

The second portion of this study involved a simple description of speech audibility in the unaided and actual aided condition. Pavlovic's (1988) procedure was used for
calculating the AI scores for the group. The scores were presented in terms of range, mean, and standard deviation.
Chapter IV

Results

The total number of subjects meeting the selection criteria was 22 (n=22). The functional gain data obtained for these subjects was described in terms of its relationship to an idealized gain as prescribed by the DSL procedure. The functional gain/prescribed gain relationship was analyzed as a function of the following group characteristics: age, degree and configuration of hearing loss, and testing locale/facility. This analysis was performed in order to identify possible correlations between these group characteristics and the functional gain/prescribed gain relationship. Other characteristics such as the model of hearing aid, the user volume control setting, and the speech discrimination scores were not analyzed due to lack of information available for the subject group. Aided articulation indices will be presented in terms of range, mean and standard deviation.

Functional Gain Versus Prescribed Gain

Table 1 displays the number of subjects that satisfied the criteria level set as acceptable (within ± 5 dB of the gain prescribed at each of the frequencies; 500, 1K, 2K, and 4K Hz.) The majority of the subjects did not satisfy criteria at any of the frequencies. Figure 3 illustrates the relationship between the percentage of subjects that met criteria versus the subjects that did not at each of
<table>
<thead>
<tr>
<th>Prescribed Gain (n=22)</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satisfying Criteria</td>
<td>8 (36%)</td>
<td>10 (42%)</td>
<td>6 (27%)</td>
<td>4 (18%)</td>
</tr>
<tr>
<td>Not Satisfying Criteria</td>
<td>14 (64%)</td>
<td>12 (58%)</td>
<td>16 (73%)</td>
<td>18 (82%)</td>
</tr>
</tbody>
</table>
Figure 3  Percentage of Subjects Satisfying Prescribed Gain Criteria

![Percentage of Subjects Satisfying Prescribed Gain Criteria](image)

- Frequency in Hz
- Met Criteria
- Failed Criteria
the four frequencies tested. Table 2 displays the number of subjects that received too much or not enough gain in relation to the criteria level. The majority of the subjects were above criteria levels at 500 and 1000 Hz, and below criteria levels for 2000 and 4000 Hz. For those subjects that received too little gain, the range was from 1 to 26 dB below the prescribed gain. For those subjects that received too much gain, the range was from 1 to 32 dB above that prescribed. Figure 4 illustrates the relationship between the percentage of subjects that were below or above criteria level at each of the four frequencies tested.

Age

The data was analyzed according to the following age groups: preschool, primary and secondary education levels. The preschool group consisted of subjects 6 years old or younger (n=5). The primary education group consisted of subjects 7 to 14 years old (n=12), and the secondary educational level consisted of subjects 15 years and older (n=5). Table 3 displays the three age groups in terms of relationship to the gain prescribed by the DSL procedure, (e.g., overamplified, underamplified or within criteria), for each of the four frequencies. The majority of the children in the preschool age group met prescriptive criteria for 500, 1000 and 2000 Hz but were under amplified at 4000 Hz. Children in the primary and secondary age
Table 2  Number (and Percentage) of Subjects Above or Below Prescribed Gain Criteria

<table>
<thead>
<tr>
<th>Prescribed Gain</th>
<th>Frequency in Hertz</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500</td>
<td>1000</td>
<td>2000</td>
<td>4000</td>
</tr>
<tr>
<td>Below Criteria</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>4 (18%)</td>
<td>3 (14%)</td>
<td>13 (59%)</td>
<td>13 (59%)</td>
</tr>
<tr>
<td>Above Criteria</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>10 (45%)</td>
<td>9 (41%)</td>
<td>3 (14%)</td>
<td>5 (23%)</td>
</tr>
</tbody>
</table>
Figure 4  Percentage of Subjects Above or Below Prescribed Gain Criteria
Table 3 Subject Age and Relation to Prescribed Gain

<table>
<thead>
<tr>
<th>Subject Age Group</th>
<th>Relation to Prescribed Gain</th>
<th>Frequency in Hertz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>Preschool</td>
<td>Over</td>
<td>0</td>
</tr>
<tr>
<td>6 years old</td>
<td>Under</td>
<td>1(20%)</td>
</tr>
<tr>
<td>and younger (n=5)</td>
<td>Within</td>
<td>4(80%)</td>
</tr>
<tr>
<td>Primary</td>
<td>Over</td>
<td>7(58%)</td>
</tr>
<tr>
<td>7 - 14 years old</td>
<td>Under</td>
<td>2(17%)</td>
</tr>
<tr>
<td>(n=12)</td>
<td>Within</td>
<td>3(25%)</td>
</tr>
<tr>
<td>Secondary</td>
<td>Over</td>
<td>3(60%)</td>
</tr>
<tr>
<td>15 years and older</td>
<td>Under</td>
<td>1(20%)</td>
</tr>
<tr>
<td>(n=5)</td>
<td>Within</td>
<td>1(20%)</td>
</tr>
</tbody>
</table>
groups were generally over amplified at 500 Hz and underamplified at 2000 and 4000 Hz.

**Degree and Configuration of Hearing Loss**

The degree of hearing loss was determined by averaging the pure tone thresholds at 0.5, 1K, 2K and 4K Hz. re: ANSI-1969. The resulting pure tone average was then categorized according to the scale of hearing impairment presented by Yantis (1985). Table 4 displays each category of hearing loss and the number of subjects that were over fit, under fit or fit with amplification within the acceptable criteria level for meeting the prescribed gain levels as suggested by Seewald et al. (1987). Subjects with mild hearing losses were generally within criteria limits at 1000 and 2000 while under amplified at 4000. Moderately hearing-impaired subjects generally met prescriptive criteria at 500 Hz, were over amplified at 1000, and under amplified at 2000 and 4000 Hz. Subjects with moderately-severe hearing losses were generally over amplified at 500 Hz, under amplified at 1000 and 2000 Hz and equally over amplified and within criteria limits at 4000 Hz. Severely hearing-impaired subjects were generally over amplified at 500 and 1000 Hz, within criteria limits at 2000 Hz and under amplified at 4000 Hz. Figure 5 illustrates the relationship between the number of subjects that were below, above, or within criteria limits for each of the four categories of hearing loss for each of the four
Table 4  Degree of Subject’s Hearing Loss and Relation to Prescribed Gain

<table>
<thead>
<tr>
<th>Degree of Loss</th>
<th>Relation to Prescribed Gain</th>
<th>Frequency in Hertz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>Mild 26-40 dB HL (n=5)</td>
<td>Over</td>
<td>2(40%)</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>1(20%)</td>
</tr>
<tr>
<td></td>
<td>Within</td>
<td>2(40%)</td>
</tr>
<tr>
<td>Moderate 41-55 dB HL (n=10)</td>
<td>Over</td>
<td>3(30%)</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>1(10%)</td>
</tr>
<tr>
<td></td>
<td>Within</td>
<td>6(60%)</td>
</tr>
<tr>
<td>Moderately Severe 56-70 dB HL (n=4)</td>
<td>Over</td>
<td>3(75%)</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>1(25%)</td>
</tr>
<tr>
<td></td>
<td>Within</td>
<td>0</td>
</tr>
<tr>
<td>Severe 71-90 dB HL (n=3)</td>
<td>Over</td>
<td>3(100%)</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Within</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure 5  Number of Subjects Satisfying Prescribed Gain Criteria by Degree of Hearing Loss

Mild

Moderate

Moderately Severe

Severe
For this study configuration of hearing loss has been arbitrarily defined as:

1. flat - less than or equal to 20 dB difference between 500 and 4000 Hz.;
2. sloping - a 25 to 45 dB difference between 500 and 4000 Hz.;
3. precipitous - less than 25 dB HL through 1000 Hz, bilaterally and greater than 40 dB at 3000 Hz and above;
4. reverse - threshold at 2000 Hz. greater than threshold at 500 Hz.

(Based on Martin, 1983). Table 5 depicts the number of subjects in each category and the relationship of the category to the prescribed gain levels suggested by Seewald, Ross and Stelmachowicz (1987). Subjects with flat configurations were generally over amplified at 500 and 1000 Hz and under amplified at 2000 and 4000 Hz. Sloping configurations were generally over amplified at 500 Hz, over amplified or within criteria limits at 1000 Hz, under amplified at 2000 Hz, and either under amplified or within criteria limits at 4000 Hz. All subjects with precipitously sloping hearing losses met prescriptive criteria at 500, 1000, and 2000 Hz but were under amplified at 4000 Hz. Reverse sloping configurations were under amplified at 500 Hz, under amplified or within criteria
### Table 5  
**Configuration of Subject's Hearing Loss and Relation to Prescribed Gain**

<table>
<thead>
<tr>
<th>Configuration of Loss</th>
<th>Relation to Prescribed Gain</th>
<th>Frequency in Hertz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>Flat (n=13)</td>
<td>Over</td>
<td>8 (62%)</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>1 (7%)</td>
</tr>
<tr>
<td></td>
<td>Within</td>
<td>4 (31%)</td>
</tr>
<tr>
<td>Sloping (n=5)</td>
<td>Over</td>
<td>3 (60%)</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Within</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>Precipitous (n=2)</td>
<td>Over</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Within</td>
<td>2 (100%)</td>
</tr>
<tr>
<td>Reverse (n=2)</td>
<td>Over</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Under</td>
<td>2 (100%)</td>
</tr>
<tr>
<td></td>
<td>Within</td>
<td>0</td>
</tr>
</tbody>
</table>
limits at 1000 and 2000 Hz, and were either over or under amplified at 4000 Hz. Figure 6 illustrates the relationship between the number of subjects that were below, above, or within criteria limits for each of the four categories of hearing loss configuration for each of the four frequencies tested.

Facility/Locale

The audiometric results used in this study were obtained at eight different facilities in Western Montana. Table 6 displays the number of subjects tested at each facility (identified by number only) as well as the relationship to the prescribed gain the facilities achieved. Five of the eight testing facilities were generally over amplifying 500 and 1000 Hz. At 2000 Hz, there was equal distribution across the three categories of gain criteria. At 4000 Hz, seven of the eight facilities were either under amplifying or over amplifying.

Articulation Index

An articulation index proposed by Pavlovic (1988) was used to analyze the available speech audibility under unaided and aided conditions. Table 7 presents the mean, range and standard deviation for both the aided and unaided conditions for comparison to the articulation index of 1.0 that would be achieved if the DSL procedure had been utilized in prescribing gain. Of the 22 subjects in this study, only one achieved an aided articulation index of 1.0
Figure 6  Number of Subjects Satisfying Prescribed Gain Criteria by Configuration of Hearing Loss

Flat

Sloping

Precipitously Sloping

Reverse Slope
<table>
<thead>
<tr>
<th>Facility Number</th>
<th>Relation to Prescribed Gain</th>
<th>Frequency in Hertz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td># 1 (n=3)</td>
<td>Over 1(33%) 0 0 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under 0 0 2(67%) 2(67%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within 2(67%) 3(100%) 1(33%) 1(33%)</td>
<td></td>
</tr>
<tr>
<td># 2 (n=6)</td>
<td>Over 3(50%) 2(33%) 1(17%) 2(33%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under 1(17%) 0 3(50%) 4(67%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within 2(33%) 4(67%) 2(33%) 0</td>
<td></td>
</tr>
<tr>
<td># 3 (n=2)</td>
<td>Over 2(100%) 2(100%) 0 1(50%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under 0 0 1(50%) 1(50%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within 0 0 1(50%) 0</td>
<td></td>
</tr>
<tr>
<td># 4 (n=1)</td>
<td>Over 1(100%) 1(100%) 0 1(100%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within 0 0 1(100%) 0</td>
<td></td>
</tr>
<tr>
<td># 5 (n=3)</td>
<td>Over 0 2(67%) 0 1(33%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under 1(33%) 1(33%) 0 2(67%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within 2(67%) 0 3(100%) 0</td>
<td></td>
</tr>
<tr>
<td># 6 (n=2)</td>
<td>Over 2(100%) 2(100%) 0 1(50%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under 0 0 1(50%) 1(50%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within 0 0 1(50%) 0</td>
<td></td>
</tr>
<tr>
<td># 7 (n=4)</td>
<td>Over 1(25%) 1(25%) 0 1(25%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under 1(25%) 1(25%) 3(75%) 2(50%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within 2(50%) 2(50%) 1(25%) 1(25%)</td>
<td></td>
</tr>
<tr>
<td># 8 (n=1)</td>
<td>Over 1(100%) 1(100%) 1(100%) 1(100%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within 0 0 0 0</td>
<td></td>
</tr>
</tbody>
</table>
Table 7  Subject's Unaided and Aided Articulation Indices: Mean, Range and Standard Deviation

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Range</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unaided Thresholds</td>
<td>0.17</td>
<td>0.58(0-0.58)</td>
<td>0.20</td>
</tr>
<tr>
<td>Aided Thresholds</td>
<td>0.75</td>
<td>0.63(0.37-1.00)</td>
<td>0.15</td>
</tr>
</tbody>
</table>

indicating all of the speech signal was audible. However, when viewed in terms of group means, the aided AI did improve from the unaided (0.17) to aided (0.75) condition.
Chapter V
Discussion Section

The DSL selection method was used to calculate prescribed gain for the frequencies; 500, 1000, 2000 and 4000 Hz using the unaided thresholds for each of the twenty-two subjects. Functional gain, defined as the difference between the unaided and aided thresholds, was calculated for the same frequencies. Comparison of functional and prescribed gain indicated that more than 50% of the subjects failed to satisfy the prescribed gain criteria. Specifically, 64% failed to meet prescribed gain at 500 Hz, 58% failed to meet criteria at 1K Hz, 73% failed to meet criteria at 2K Hz, and 82% failed to meet criteria at 4K Hz.

These results have several implications. First, 45% of the subjects received too much gain at 500 Hz compared to the prescribed gain. Over amplification in the low frequencies can lead to the upward spread of masking which can interfere with perception of the higher frequency second formant transitions (Danaher, Wilson and Pickett, 1978). As the second formant transition is known to be an important cue in consonant perception (Seewald and Ross, 1988), any interference with the perception of the second formant can result in speech perception difficulties. Hearing-impaired subjects exhibited superior speech recognition scores in a condition where low frequency
amplification was reduced (Sweetow, 1977). However, Punch and Beck (1986) found that positive subjective judgements in perceived speech quality were related to an increase in the low-frequency amplification in adults. It is unclear whether these results can be generalized to hearing-impaired children.

The second implication concerns under amplification in the high frequencies. Over 50% of the subjects received too little gain at 2000 and 4000 Hz. This has phonemic and morphemic consequences. Phonemes such as /s/, /ʃ/, /f/, /θ/, and /ʒ/ are high frequency and low intensity (Levitt, 1978). The /t/ and /s/ phonemes are also tense and plural markers. If hearing-impaired children don't receive enough gain in the high frequencies they may fail to perceive the high frequency phonemes and morphemes. The additional acoustic information provided by the high frequency information in phonemes such as /s/, /ʃ/, /f/, /θ/, and /ʒ/ is necessary for children developing speech and language skills (Seewald and Ross, 1988).

The final implication regards a balance between low and high frequency amplification. Over 40% of the subjects received too much gain at 500 and 1000 Hz while 59% of the subjects received too little gain at 2000 and 4000 Hz. When there is an inappropriate balance between the low and high frequency gain, the hearing aid wearer tends to set the overall gain at a comfortable loudness level which
results in lowering the speech energy or causing parts of the speech spectrum to be inaudible (Skinner, 1988). If parts of the speech spectrum are inaudible, speech perception will be affected.

Hearing level is considered one of the most important factors affecting speech and language and academic development (Ling, 1976). A majority of the children in this study are clearly not receiving amplification considered optimal for speech, language or academic development according to levels prescribed by Seewald et al. (1987).

In order to determine any possible cause or pattern explaining these results, several group characteristics were analyzed. First, the subjects' ages were analyzed in relation to their prescribed gain. The majority of the subjects, regardless of age, were over amplified in the low frequencies and under amplified in the high frequencies. These results suggest that age was not a differentiating factor for explaining variance from the DSL target gain.

When the degree of hearing loss was analyzed, the results indicated that the majority of subjects with mild hearing losses met prescriptive gain criteria at 1000 and 2000 Hz but were under amplified at 4000 Hz and were equally over amplified and under amplified at 500 Hz. The majority of those subjects with moderate losses met prescriptive criteria at 500 Hz but were over amplified at
1000 Hz and under amplified at 2000 and 4000 Hz. The subjects with moderately severe hearing losses tended to be over amplified at 500 Hz, and under amplified at 1000 and 2000 Hz. Interestingly, 50% of these subjects received too much amplification at 4000 Hz and the other 50% met prescriptive criteria. It is ironic that half of the subjects with moderately-severe hearing losses would meet the prescriptive criteria or receive too much gain at 4000 Hz when those subjects with less severe hearing losses did not receive enough gain at 4000 Hz. Finally, every subject with a severe hearing losses was over amplified at 500 Hz, while 67% were over amplified at 1000 Hz, 67% met prescriptive criteria at 2000 Hz and 67% were under amplified at 4000 Hz. These results again suggested that, generally, the low frequencies were over amplified and the high frequencies were under amplified.

The configuration of hearing loss with relation to prescribed gain was also analyzed. The flat configurations were generally over amplified in the low frequencies and under amplified in the high frequencies. The sloping configurations were generally over amplified at 500 Hz, over amplified or within criteria limits at 1000 Hz, under amplified at 2000 Hz, and either under amplified or within criteria limits at 4000 Hz. Precipitously sloping losses all met prescriptive gain criteria at 500, 1000, and 2000 Hz but were under amplified at 4000 Hz. Reverse sloping
losses were under amplified at 500 Hz, under amplified or met prescriptive criteria at 1000 and 2000 Hz, and were either over amplified or under amplified at 4000 Hz. These results suggested that the majority of subjects received too much gain in the low frequencies and not enough gain in the high frequencies.

Testing facility was analyzed as to the number of subjects meeting prescribed gain. Four (number 3, 4, 6, and 8) of the eight testing facilities over amplified all subjects at 500 and 1000 Hz. Three facilities (number 1, 2, and 7) under amplified the majority of the subjects tested at 2000 and 4000 Hz. One facility (number 8) over amplified at every frequency (500, 1K, 2K, and 4K Hz). The results indicated that at least half of the testing facilities were over amplifying the low frequencies and five of the eight facilities under amplified 2000 or 4000 Hz or both in at least 50% of the subjects. Given this limited sample, there are a variety of hearing aid dispensers who are inappropriately fitting amplification on hearing-impaired children.

The articulation indices for the aided condition indicated that only one subject achieved an index of 1.0 indicating that all of the speech signal was audible. Again, if the entire speech signal is not audible, speech perception problems can occur. A considerable difference between unaided and aided articulation scores was noted but
it was not parallel with the threshold differences. The AI findings may be somewhat deceptive because the AI does not address the overamplification in the low frequencies.

Conclusion

The results of this research indicated that many of the subjects were receiving inappropriate gain. A majority of the subjects received too much gain in the low frequencies which could result in the upward spread of masking making consonant perception more difficult. Additionally, the high frequencies tended to be under amplified which could result in phonemic and morphemic perception errors. Speech and language as well as academic development could be adversely affected by inappropriate amplification.

The analyses of the group characteristics with regard to the subject's prescribed gain do not provide a clear explanation of why this study's subjects were not receiving optimal amplification. These results suggest that inappropriate amplification for children may be a global problem and not limited to testing facility, degree or configuration of hearing loss, or subject age. One possible explanation could be that hearing aid dispensers in general do not use a selection strategy designed for children.
Study Limitations

The limitations inherant in this study included the use of functional gain as a measure. Haskell (1987) has described the limitations of functional gain which include sensitivity to internal noise from the hearing aid, sensitivity to artifact from the background noise in the test environment, and the variability due to active subject participation. The sound/noise floor masking of functional gain in the low frequencies could possibly explain why the subjects with precipitously sloping configurations were within criteria limits at 500, 1000 and 2000 Hz. rather than being above criteria limits. In future research insertion gain would prove a more reliable measure.

Another limitation of this study is the small subject pool. Conclusions are difficult to draw due to the small size of some of the groups such as testing facilities. Ideally, a larger subject pool will be used in future research.

Clinical Implications

The primary implication of this study concerns selecting appropriate gain for children. It is imperative that hearing-impaired children receive the maximum benefit available from their amplification systems. Adult selection strategies are not necessarily appropriate for children. Hearing aid dispensers should review the
criteria they use to select hearing aids and select a method most appropriate for children. Appropriate amplification could make a difference in the hearing-impaired child's social, academic and speech and language development.

Implications for Future Research

Implications for future research include analyzing the maximum power output of each subject's hearing aid. Due to the trend of over amplification in the low frequencies, saturation and introduction of distortion of the acoustic signal is possible by additional low frequency amplification. Tolerance levels may also be violated by additional low frequency amplification. With the under amplification of high frequencies, the question is raised as to whether the amplification levels in the high frequencies can be increased without introducing feedback problems. In additional, can the ideal amplification in the high frequencies be realized with the frequency limitations found in the hearing aids available today?

Another implication for future research concerns the articulation index as a measure of amplification effectiveness. The articulation index only indicates when the speech is signal is partially or completely audible. It doesn't indicate when parts of the speech signal are overamplified. If there is too much gain in certain frequencies, the articulation index will not reflect it.
Finally, a survey of hearing aid dispensers would yield information regarding the number of dispensers who actually were aware of the DSL selection method and what selection methods they employ.

Summary

The present study was undertaken to determine if school-aged, hearing-impaired children who wore hearing aids were receiving gain comparable to the amount of gain that would have been prescribed employing the Desired Sensation Level (DSL) method proposed by Seewald, Ross and Stelmachowicz (1987). Utilizing the DSL method (Seewald, et. al., 1987) prescribed gain was calculated using the unaided thresholds for each of the twenty-two subjects for the frequencies; 500, 1000, 2000, and 4000 Hz. The prescribed gain was then compared to the functional gain, defined as the difference between aided and unaided thresholds. An acceptance criteria of ± 5 dB was employed to determine significant differences. Aided functional gain measures which were within the acceptance criteria were not considered significantly different from the prescribed gain for that frequency. The data was then described and analyzed to determine patterns which could possibly explain variance from the prescribed gain (i.e., fitting, facility, degree and configuration of hearing loss, etc.). An articulation index proposed by Pavlovic (1988) was employed to analyze speech audibility in the
aided and unaided conditions.

The results indicated that over 50% of the subjects failed to satisfy the prescribed gain criteria at the four frequencies analyzed; 500, 1000, 2000, and 4000 Hz. Analysis of group characteristics revealed a general trend where low frequencies tended to be over amplified and high frequencies tended to be under amplified. Comparison of articulation indices revealed that only one subject achieved an aided articulation index of 1.0 indicating that all of the speech signal was audible.

Future research is suggested to investigate other electroacoustic problems such as distortion and saturation of the acoustic signal due to over amplification in the low frequencies and possible violation of tolerance levels. In addition, a survey of selection methods utilized by hearing aid dispensers would provide information regarding strategies currently employed with children and would indicate how many dispensers are aware of the Desired Sensation Level method proposed by Seewald, Ross and Stelmachowicz (1987).
References


Appendix A
Authorization for Data Collection

Montana University
Affiliated Program Satellite
University of Montana • Missoula, Montana 59812 • (406) 243-5467

HEARING CONSERVATION PROJECT
C/O MUAPS-CORBIN HALL
UNIVERSITY OF MONTANA
MISSOULA, MT 59812

DATE: May 8, 1989
TO: Nancy Hohler
FROM: Sheila Miller, M.A. CCC-A
RE: Access to HCP audiological data.

As we discussed earlier, I would be most willing to help you extract data from the HCP aided student files. In order to maintain the confidentiality of these records, aided and unaided results may not be identified by name, age or county. I would be willing to provide you with aided and unaided pure tone test results as well as the certification status of the examining audiologist. In order to provide this information, I will need a data collection form from you.

This proposed use of HCP records has been approved by Merle DeVoe, State Director of the HCP (As per phone conversation May 8, 1989).
Appendix B
Data Collection Form

Subject Number ______
Male/Female ________
Age ______
Grade during 1988-89 School year ________

Audiometric Data

Unaided thresholds in dB HL

<table>
<thead>
<tr>
<th></th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>3000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RE</td>
<td>______</td>
<td>______</td>
<td>______</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>LE</td>
<td>______</td>
<td>______</td>
<td>______</td>
<td>______</td>
<td>______</td>
</tr>
</tbody>
</table>

Unaided discrimination RE______ LE______
Presentation level dBHL ________
Date of test results (mo/yr) ______

Aided thresholds in dB HL

<table>
<thead>
<tr>
<th></th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>3000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RE</td>
<td>______</td>
<td>______</td>
<td>______</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>LE</td>
<td>______</td>
<td>______</td>
<td>______</td>
<td>______</td>
<td>______</td>
</tr>
</tbody>
</table>

Aided discrimination RE _______ LE _______ 
Presentation level dBHL ________

Volume Setting _________
Date of test results (mo/yr) ______
Type and Model of Hearing aid _______________________
When fitted ________________
Facility/Locale # ____________