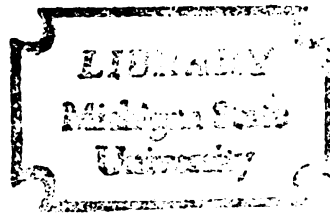


TIME-COMPRESSED SPEECH IN
HEARING AID EVALUATIONS

Thesis for the Degree of M. A.
MICHIGAN STATE UNIVERSITY
SUSAN D. DALEBOUT
1975



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ABSTRACT
TIME-COMPRESSED SPEECH IN
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BY
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A review of the audiological literature indicates that although hearing aid evaluation procedures are not standardized, discrimination test scores serve as the primary basis for the objective selection of hearing aids. Many audiologists report, however, that conventional discrimination tests are not difficult or realistic enough to produce differential results among hearing aids. The scores frequently do not reflect the electroacoustic quality of hearing aids, or the listener's subjective impressions of them. The procedures that have been suggested as alternatives to conventional discrimination testing do not seem clinically feasible in terms of time and convenience.

The purpose of this study was to investigate the potential use of time-compressed monosyllables as a more difficult listening task for hearing aid evaluations. Specifically, the effects of aided listening on the perception of time-compressed speech were examined. Also, the potential of a time-compressed monosyllabic word test to produce differential results among hearing aids and to reflect their electroacoustic qualities was studied.

Three lists of Form B of the Northwestern University Auditory Test No. 6 (NU#6) were compressed to levels of 40% and 60% using the Zemlin-modified version of the Fairbanks Time Compressor. A 0% control condition was also used, resulting in a total of nine experimental tapes. Seventy normal hearing

subjects were then randomly assigned to one of seven experimental conditions which corresponded to one of the six pre-selected experimental hearing aids or the unaided group. The aided conditions were characterized by the presentation of the three lists at the three levels of time-compression in random order at a sensation level of 32 dB, re: the aided speech reception threshold (SRT). All aids were worn at a constant gain setting of 30 dB, re: 1000 Hz. Subjects in the unaided group received all three lists at all three levels of time-compression at 32 dB sensation level, re: the unaided SRT. Right ears were used exclusively and all left ears were covered with a protective earmuff throughout experimental testing.

The results revealed that as the level of time-compression increased, intelligibility decreased. A significantly wider spread of mean hearing aid scores, however, was not observed with increasing levels of time-compression. Additionally, the discrimination scores obtained both through hearing aids and in the soundfield employed in this study were found to be lower than those obtained under earphones by Beasley, Schwimmer, and Bintelmann (1972). SRT's decreased by means of 2 to 4 dB when obtained in the aided rather than unaided condition. Finally, a change in rank order for four of the six aids was seen. This means that the aids which produced the best scores at 0% time-compression produced the poorest scores at 60% time-compression, and the aids which produced the poorest scores at 0% time-compression produced the best scores at 60% time-compression. Although electroacoustic measurements of the experimental aids showed physical differences among them to be minimal, it was found that the best 60% time-compression scores were produced by the aids with the superior electroacoustic qualities.

The results of this study indicated that time-compressed monosyllables did indeed constitute a more difficult listening

task which may be used efficiently and expediently in hearing aid evaluations. It was also seen that time-compression improved the ability of monosyllables to reflect the electro-acoustic quality of aids. This has important clinical implications in that an aid which may be eliminated from selection on the basis of conventional discrimination test scores might actually provide the best amplification for an individual in more realistic listening situations. On the other hand, the aid selected on the basis of conventional discrimination scores might actually provide the poorest amplification for an individual in more difficult situations.

Time-compression did not produce differential results among the scores for the six hearing aids. The range of mean scores for the six aids was increased by only one to two words when the level of time-compression was increased from 0% to 60%. Hence, it was recommended that time-compressed monosyllables be re-evaluated using a hearing impaired population since the use of a normal hearing population and the lack of physical differences among experimental hearing aids left no variable to create differential results.

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HEARING AID EVALUATIONS

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Department of Audiology and Speech Sciences

1975

Accepted by the faculty of the Department of Audiology
and Speech Sciences, College of Communication Arts, Michigan
State University, in partial fulfillment of the requirements
for the Master of Arts degree.

Thesis Committee:



This thesis is
dedicated to

Mrs. Beverly Goodwin,

who gave me support when it was needed.

ACKNOWLEDGMENTS

I am grateful for the opportunity to thank some of the people who helped me during the preparation of this thesis. I thank my committee co-directors, Dr. Daniel Beasley and Dr. Steven White, and my committee member, Dr. Linda Lou Smith, for sharing their research knowledge and experience with me. Special thanks goes to Dr. White for his friendship, readiness to listen, and his incredibly constant good humor.

I also wish to thank Dan Kunkle and Barry Freeman, two of the finest men and best audiologists I have had the pleasure of knowing. These busy Ph.D. students were always willing to answer and pose questions, to offer help and suggestions, to listen and to encourage. They have taught me a great deal.

I thank my friends, especially Suzanne Goodwin, who helped me maintain good spirits, keep my work in perspective, and not to give in to discouragement.

Last, but most importantly, I want to thank my family for their ceaseless love, encouragement, tolerance, and support. Their enthusiasm and confidence in me and all my endeavors is appreciated more than they will ever know.

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CHAPTER I

INTRODUCTION

In the past two decades, the literature in audiology has indicated that a wide range of opinion exists regarding the kind of role the audiologist should play in hearing aid evaluations, the procedures and methods to be used, the type and efficacy of the instrumentation to be employed, and whether the dividends of present day selection procedures justify the audiologist's clinical efforts (Davis, Hudgins, Marquis, Nichols, Peterson, Ross, and Stevens, 1946; Glorig, 1952; Fairbanks, 1958; Jeffers, 1960; McConnell, Silber, and McDonald, 1960; Shore, Bilger, and Hirsh, 1960; Resnick and Becker, 1963; Shore and Kramer, 1963; Jerger, Malmquist, and Speaks, 1966; Jerger, Speaks, and Malmquist, 1966; Castle, 1967; Kreul, Nixon, Kryter, Bell, Lang, and Schubert, 1968; Zink and Alpiner, 1968). While there is some consensus that the goal of hearing aid evaluations should be to select ". . . the most appropriate electroacoustic amplification for those hearing impaired individuals who can profit from such amplification . . ." (Castle, 1967, p.1), there is no such consensus regarding the validity or reliability of the methods currently employed to accomplish this goal or the superiority of any of the methods that have been suggested to replace them.

Conventional Hearing Aid Evaluation Procedures

Burney (1972) surveyed practicing audiologists and reported that current hearing aid evaluation procedures follow one of

three basic formats. The first format involved the administration of audiometric tests to a client while he wore a succession of possibly beneficial hearing aids that had been pre-selected by the audiologist. In the second format, audiometric tests were performed without a hearing aid. Based on the results of pure tone and speech audiometry, the client was advised of the general nature of his hearing loss and the characteristics of the hearing aid required to compensate for the deficit. In the third format, a master hearing aid was used to measure the client's maximum tolerance for intensity, his minimum gain requirements, and the frequency response needed for maximum discrimination. The audiologist then reviewed the results and recommended a hearing aid to the client based on this data.

Reportedly, 85% of the hearing aid evaluations conducted at the time of Burney's survey followed the first format, while the remaining 15% followed the second. Although many of the institutions that reported had master hearing aids, no evaluations of the third type were reported.

Generally, the first method described by Burney was similar to the procedure described by Carhart (1946) several years earlier. According to Ross (1972), the most widely used modification of Carhart's method was characterized by three basic parts. First, a complete audiologic evaluation was performed to determine hearing aid candidacy. This evaluation was comprised of a case history interview and the audiologic battery deemed necessary by the audiologist. If considered a candidate, the client's aided and unaided performance in a soundfield was sometimes evaluated and a personal earmold sometimes made. On the basis of these results the ear to receive amplification, the hearing aid type, and the required electroacoustic characteristics were determined. Client counseling was emphasized. The second portion of the method described by Ross was a thorough otologic examination. The third part was the hearing aid evaluation itself. Although Burney found that specific procedures varied from clinic to

clinic and from audiologist to audiologist, Ross reported that typically three to six aids of the same generic family meeting the tolerance, gain, and frequency response requirements of the client's hearing loss were selected. The electroacoustic properties of the aids were then checked against manufacturer specifications and appropriate electroacoustic adjustments, such as tone control or power control, were made by the audiologist. Next, while speech stimuli were presented at a constant level approximating that of normal conversational speech, the client or the audiologist adjusted the gain of the first aid to the level which was most comfortable.

Burney reported that an average of three to four tests were administered during hearing aid evaluations. A small number of the tests were expansions or modifications of measures used in the audiologic differential diagnostic battery, for example, Bekesy and recruitment testing. In order, the most frequently used measures were speech discrimination (administered either in quiet or both in quiet and noise), speech reception threshold (SRT), tests of tolerance, and pure tone thresholds. In addition, the use of subjective evaluations elicited from the client, tone decay tests, and competing message tests were reported. Successive aids were evaluated in the same manner and all results compared. Finally, after obtaining all pertinent objective and subjective data, the audiologist again counseled the client. Based on the data, a referral was made to one or more hearing aid dealers for, in some cases, a specific hearing aid. A trial period was offered by most dealers, after which the client returned to the clinic for a hearing aid recheck, additional counseling, and the procuring of aural rehabilitative services if desired.

As mentioned by Burney, subjective evaluations elicited from the client, either formally or informally, have frequently played a part in the final selection of a hearing aid. These subjective preferences have been found by some audiologists to be valid and reliable indicators of the electroacoustic

quality of aids. It has been suggested that perhaps they are better indicators than objective test scores (Jeffers, 1960; Witter and Goldstein, 1971). Jeffers reported that the preferences of conductively impaired individuals were indeed valid and reliable. These persons were able to consistently rank order a group of aids in terms of subjective preference. Further, their judgements were found to correlate with the electroacoustic characteristics of the aids. It must be noted, however, that Jeffers made no physical measurements on the aids used in her study but relied solely on manufacturer specifications. Still, the aids reputed to have superior electroacoustic properties, according to manufacturer specifications, were always preferred. Zerlin (1962) found that the preferences of normal hearing subjects also yielded reliable clear-cut choices among six hearing aids. He was unable to relate subjective preference to the frequency response of the aids, however, and he neglected to measure any characteristics except that of frequency response. Witter and Goldstein (1971) reported findings similar to those of Jeffers and Zerlin for their normal hearing subjects. They agreed with Jeffers in concluding that subjective evaluations did reflect superior electroacoustic characteristics in hearing aids. In various combinations, the characteristics that most commonly influenced the listeners' preferences were transient response, frequency range, and harmonic distortion. Transient response was described as the overall measure of the system's linearity. The measurement of transient response consisted of passing a square wave through the electrical system while monitoring its output to see what changes in the square wave occurred. In terms of frequency response, Witter and Goldstein found that for normal listeners, aids that amplified further into the high frequencies than most aids correlated positively with behavioral performance, while aids that amplified further into the low frequencies correlated negatively with behavioral performance.

The results of Burney's survey indicated that the procedures

most frequently employed in the selection of hearing aids have changed little during the last 30 years. During that time, however, substantial technologic advancements and improvements have been made in hearing aids themselves. These improvements have taken the form of greater choices in microphone type and placement, maximum power output (MPO) limiters, receiver and earmold types, more external tone controls, less distortion, increased frequency range, and better batteries. Although the improvements may have diminished quality differences among hearing aids, differences do remain and are subjectively important to hearing aid users in real world situations (Jeffers, 1960; Zerlin, 1962; Jerger, Speaks, and Malmquist, 1966; Chaiklin and Stassen, 1968; Rassi and Harford, 1968; Zink and Alpinier, 1968; Haug, Baccaro, and Guilford, 1971; Witter and Goldstein, 1971; Carhart and Tillman, 1972). Hence, there is a need for updated procedures to evaluate the subtle, yet important, differences among improved hearing aids.

The Effects of Amplification on Speech Intelligibility

Unfortunately, hearing aids in many cases serve to reduce rather than to enhance speech intelligibility, as measured in the test situation. Several investigators found that thresholds for speech and speech discrimination scores were consistently worse when obtained through hearing aids than when obtained under earphones or in the soundfield, at the same sensation level (Zink and Alpinier, 1968; Tillman, Carhart, and Olsen, 1970; Zelnick, 1970). Bode and Kasten (1971) suggested that the reduction in intelligibility could be attributed to the better linear response of the earphones or the loudspeakers, the increase in environmental noise when testing in the aided condition, the reduced frequency range of the hearing aid, and/or the excessive harmonic distortion in the hearing aid.

Tillman, Carhart, and Olsen (1970) compared unaided soundfield speech reception thresholds and speech discrimination

scores to those obtained through hearing aids for normal listeners, conductively impaired individuals, sensorineurally impaired individuals, and presbycusics. All hearing impaired subjects had SRT's ranging from 23 to 49 dB. The soundfield conditions were similar to those employed clinically, but the aided conditions were quite different. In the aided conditions speech was presented to an artificial head placed at a 45° azimuth to the loudspeakers, on which two hearing aids were mounted. The hearing aid transduced signal was then sent to the subject who sat in a second test chamber wearing the hearing aid receivers and earmolds covered by protective earmuffs. The gain for both hearing aids was set at 50 dB, re: 1000 Hz. In order to obtain aided discrimination scores, monosyllabic words were presented through the loudspeakers at a level of 70 dB SPL. Before reaching the subject in the second chamber a second attenuator was used to adjust the signal to a level of 30 dB sensation level (SL), re: the listener's aided SRT. Tillman, et al. found that for normal listeners, aided speech reception thresholds were poorer by a mean of 12.4 dB than the corresponding unaided soundfield thresholds. They attributed this result to the change from testing in the soundfield to testing with insert receivers. A 12 dB decrease for this change had been reported by Tillman, Johnson, and Olsen (1966). Beyond the 12 dB decrease found for normal listeners, aided SRT's were poorer than their corresponding unaided SRT's by means of 2.6 dB, 5.7 dB, and 8.5 dB for conductively impaired, sensorineurally impaired, and presbycusic individuals, respectively. When aided discrimination scores obtained in quiet were compared to unaided soundfield scores obtained at the same sensation level (measured at the listener's ear), mean reductions of 8.6%, 19.8%, 20.1%, and 14.1% were found for normal listeners, conductively impaired individuals, sensorineurally impaired individuals, and presbycusics, respectively. For normal hearing subjects, noise masked speech by an additional 10 dB when it was heard in the aided rather than

unaided condition. Corliss, Kobal, and Berghorn (1960) had reported that noise masked speech by an additional 7 to 12 dB when heard in the aided rather than unaided condition. The aided condition increased masking effectiveness by 17 to 18 dB for conductively impaired subjects and by even greater and more variable amounts for individuals with sensorineural and presbycusis impairments.

Using aided conditions similar to those of Tillman, et al., Zelnick (1970) reported a 10.8% decrease between discrimination scores obtained under earphones at 30 dB SL and those obtained through hearing aids at 30 dB SL, for hearing impaired listeners. Zelnick was not comparing earphone and hearing aid discrimination scores for one listener, however, but earphone scores for one group of hearing impaired listeners and hearing aid scores for another group of hearing impaired listeners.

In spite of reported decreases in both aided SRT's and aided discrimination scores, the objective hearing aid evaluation goals of some audiologists (Haug, Baccaro, and Guilford, 1971; Wilson and Linnell, 1972) were, first, to obtain an aided speech reception threshold that was within normal limits and therefore better than that obtained under earphones, but, second, to obtain an aided discrimination score that was only equal to that obtained under earphones. This may be because amplification tends to improve hearing sensitivity, or the ability to hear sounds, but does not always improve the listener's ability to make fine discriminations between speech sounds.

Speech Discrimination Testing

Although gain, as measured by comparing aided and unaided speech reception thresholds, and aided tolerance tests are taken into consideration, hearing aids are most often selected on the basis of aided speech discrimination scores and subjective preference (Zerlin, 1962; Ross, 1972). Discrimination

tests, as used in hearing aid evaluations, have therefore become the subject of extensive research, criticism, and modification. According to both Zerlin and Ross, the method of discrimination testing most widely accepted was the presentation of phonetically balanced monosyllables at a level of 20 to 40 dB SL or 40 to 50 dB hearing level (HL), in quiet or against a competing message of speech or noise. Unfortunately, the scores from this test, which are serving as the primary basis for the selection of amplification for an individual, have been found by some to be unreliable and/or unable to produce differential results among hearing aids. Discrimination scores are likely to be similar for all aids tested, even those with demonstrable electroacoustic differences.

Reliability. Shore, Bilger, and Hirsh (1960) questioned the reliability of conventional discrimination tests. Fifteen hearing impaired subjects, five in each of three diagnostic categories, were tested with four different hearing aids on four different occasions. In addition to aided speech reception thresholds, aided speech discrimination scores were obtained with the Rush Hughes recordings of the Phonetically Balanced (PB) 50 Lists (Egan, 1944) administered at 40 dB SL in quiet and in noise. The test-retest variations were so large that they concluded ". . . the reliability of these measures is not good enough to warrant the investment of a large amount of clinical time with them in selecting hearing aids. . ." (Shore, Bilger, and Hirsh, 1960, p. 167). The use of half lists might have confounded the reliability of the results obtained in this study, however.

Conversely, McConnell, Silber, and McDonald (1960) compared discrimination scores obtained in one session to those obtained in a session two weeks later and found satisfactory test-retest reliability. An aid of the same type, but not the same aid, was used during the second session. Only the discrimination results of the selected aid, however, were

compared in this study. The rank ordering of aids was not retested. McConnell, et al. also compared monosyllabic discrimination test scores obtained in quiet by one clinician to those obtained in quiet by another clinician, for the same client. The scores were obtained with the same hearing aid, on the same day, with the same test, and the results showed good reliability.

Olsen and Carhart (1967) found good test-retest reliability when monosyllables were presented in quiet and against two types of competing signals, at four signal to noise ratios. The listeners wore three aids with known electroacoustic differences. For the more difficult listening situations (poorer signal to noise ratios and indirect listening conditions) the aids were rank ordered on the basis of discrimination scores in the same way during two different sessions. The investigators noted, however, that to demonstrate the reliability of rank order it is necessary to ensure a wide range of scores, and hence, more difficult tests must be used. Therefore, reliability was more easily demonstrated, statistically, for subjects with sensorineural impairments since their scores covered a wider range than those of conductively impaired subjects.

Cohen and Schleifer (1969) compared discrimination scores obtained during clients' initial hearing aid evaluations to those obtained during follow-up hearing aid recheck evaluations. They found that scores were reliable when the intervening period between test sessions was less than two months. A slight discrepancy between results, in the direction of decreased scores, was noted when more than 63 days had passed. The fact that the disparity continued to increase with time led the authors to note the need for hearing aid recheck appointments after one year.

It appears, therefore, that discrimination tests are potentially reliable measures for use in hearing aid evaluations. Whether they are useful in differentiating among

hearing aids, however, is another issue.

Differential Sensitivity. There is a concern among audiologists that open-ended monosyllabic word tests and the conditions under which they are presented may serve to obscure rather than to accentuate real differences among hearing aids. As a result, Zink and Alpiner (1968) reported that they based hearing aid selection on the known electroacoustic characteristics of aids. It was their experience that discrimination tests often produced similar scores for aids that spectral analysis showed to be markedly different, in terms of distortion and effective bandwidth. Not only are conventional discrimination measures inefficient in terms of reflecting physical differences among aids, but they frequently fail to reflect subjective differences on the part of the listener. In the previously cited study by Jeffers (1960), the consistent subjective preferences of conductively impaired listeners were not reflected in discrimination scores. In that study seven out of 115 discrimination scores fell below 94% and only two fell below 90%. Unfortunately, when all scores are excellent it is difficult to objectively select the most appropriate aid for a client. Zerlin (1962) also reported the inability of conventional monosyllabic tests to reflect the clear and definite subjective preferences of his listeners. Chaiklin and Stassen (1968) reported a case in which ". . . an extensive battery of audiometric tests was unable to reflect the patient's perception of excessive distortion in her moderately impaired poorer ear . . ." (Chaiklin and Stassen, 1968, p. 270) during a hearing aid evaluation.

Jerger, Malmquist, and Speaks (1966) assessed the sensitivity of different discrimination tests and test conditions in current use. They presented the Psychoacoustical Laboratory (PAL) 8 multiple choice sentence discrimination test (Hudgins, Hawkins, Karlin, and Stevens, 1947) under competing signal conditions, the Central Institute for the Deaf (CID) W-22

monosyllabic word discrimination test (Hirsh, Davis, Silverman, Reynolds, Eldert, and Benson, 1952) in quiet, the Consonant-Nucleus-Consonant (CNC) word lists (Lehiste and Peterson, 1959) in quiet, and the PAL PB 50 monosyllabic word lists processed through a low pass filter. They found that the only test that clearly differentiated among aids was the sentence test. This test produced differences of 30% among aids, while the other tests produced differences only as great as 9%. They concluded that monosyllabic tests as presently used ". . . do not necessarily reflect meaningful hearing aid performance differences . . ." (Jerger, Malmquist, and Speaks, 1966, p. 256). This conclusion was in agreement with that of Shore, et al. (1960) who found that neither speech reception threshold, discrimination tested in quiet, or discrimination tested in noise, were particularly effective in differentiating among aids.

Jerger, Speaks, and Malmquist (1966) demonstrated that for normal listeners and listeners with sensorineural hearing impairments, psychoacoustic tests could be devised to reflect the electroacoustic differences among aids. Further, these fairly stable differences were due to individual subject interactions with hearing aids. They presented the PAL 8 sentence discrimination test to one ear of the subject and a competing message of continuous discourse to the other ear. Each signal had been processed through each of three hearing aid systems and recorded on one channel of a two channel tape recorder at signal to noise ratios of -6 and -12 dB. Aid presentations were counterbalanced. It was found that the aids could be rank ordered consistently on the basis of the sentence test scores and that the rank order related to the aid's measured amount of harmonic distortion. However, the fact that the experimental stimuli were presented via hearing aid transduced tapes makes the validity of this method somewhat questionable.

Another measure intended to be more sensitive involved

the replacement of sentences for monosyllables. Speaks and Jerger (1968) devised the synthetic sentence identification test (SSI) which has received limited use in hearing aid evaluations. Sentences are more like "everyday speech" (Harris, Haines, Kelsey, and Clack, 1961) and their inherent redundancy permits a certain susceptibility to distortion. Jerger and Thelin (1968) stated that ". . . the basic technique of sentence identification coupled with the competing message concept can well be recommended as a point of departure for the design of new approaches to hearing aid evaluation in the clinical context . . ." (Jerger and Thelin, 1968, p. 183). Thus, it appears that an increase in stimulus complexity may permit improved hearing aid evaluations.

Some modifications have been suggested for increasing the effectiveness of monosyllabic word tests to distinguish among hearing aids. Hood (1970) administered discrimination tests, in quiet and in noise, at three intensity levels that approximated soft, average, and loud conversational speech. He reported a number of instances in which the scores of different aids could not be differentiated at one intensity level, but could be differentiated at a different level. However, since this method is so time-consuming only a limited number of words can be presented, or a limited number of aids evaluated.

Alternative Methods of Hearing Aid Selection

Because of the lack of difficulty and reliability associated with traditional hearing aid evaluation measures, a number of alternative procedures have been suggested. As cited previously, Jeffers (1960) used a paired-comparison method to differentiate among aids. In her study, 34 subjects with conductive impairments listened to passages of cold running speech that had been recorded through five different hearing aids and sent through a loudspeaker. The five aids with markedly "good", "fair", and "poor" electroacoustic characteristics, according to manufacturer specifications exclusively,

were arranged in four pairs. Each subject listened to speech recorded through the first aid of a pair followed by speech recorded through the second member of the pair. The subjects were able to differentiate among the aids and preferred the aids with the objectively more desirable electroacoustic characteristics. Jeffers concluded that subjective preference on the part of the listener was a reliable predictor of hearing aid suitability. It must be noted, however, that Jeffers failed to counterbalance the order of aid presentation, and hence, cannot account for the possible contributions of an order effect upon her results. Further, only conductively impaired subjects were used in this study and the results might be different for subjects with sensorineural impairments. Finally, the time requirements of this method would limit its clinical practicality.

Zerlin (1962) also used a paired-comparison method to differentiate among hearing aids. He presented 21 hearing impaired listeners with tapes of conversational speech against cafeteria noise at a signal to noise ratio of 5 dB. The material had been recorded through six different hearing aid systems. The subjects had access to a selector switch which allowed them to listen alternately to speech recorded through two aids. The several aids were then compared to each other in terms of preference. Following the paired-comparisons, each subject was given a 25 word monosyllabic discrimination test (CID W-22) in quiet, which had also been transduced through the hearing aids. Zerlin found that his paired-comparison procedure permitted differentiation among the aids, while the monosyllabic word test did not. It would seem, however, that the problems of recording, storage, rapid retrieval, playback, and the amount of clinical time involved with pairing every aid in clinic stock would be insurmountable.

Jerger (1967) also described a paired-comparison technique. He recorded two pure tones, one at 1000 Hz and one at 1600 Hz, on each channel of a two channel tape recorder. One signal

was recorded directly and the other was recorded through a hearing aid. Again, the subjects were asked to listen to pairs and to make comparisons between the undistorted signal and the signals recorded through aids with markedly different electroacoustic characteristics. Prior to the paired-comparison test the subjects had been given the PAL 8 sentence intelligibility test at a signal to noise level of -6 dB. This intermodulation distortion paired-comparison technique produced the same rank ordering of aids as the sentence test. However, as with the other paired-comparison techniques, the administrative difficulties involved are noteworthy.

The measures discussed may be capable of differentiating among hearing aids, but Jeffers (1960) and Jerger (1967) used aids with exaggerated electroacoustic differences. These differences were substantially more marked than those usually encountered in the clinical situation and this may account, in part, for the success of the measures used by Jeffers and Jerger. Further, as mentioned above, the validity of measures in which the experimental stimuli consist of tape recordings of hearing aid transduced speech is somewhat questionable. This method is obviously less realistic than a method in which speech is presented directly to a listener through a hearing aid. Also, in the process of recording alteration of the signal is unavoidable. We are left then with the need for a more effective and clinically efficient way to reflect the electroacoustic and subjective differences among hearing aids.

Distorted Speech Tests

It has been shown that routine clinical tests of hearing sensitivity and acuity are not adequate when diagnosing lesions beyond the cochlea (Bocca and Calero, 1963). The stimuli used in these conventional tests are replete with extrinsic redundancies and the multiple cues inherent in our language (Harris, 1960). Therefore, even a severely disordered central

auditory system may be able to integrate and analyze the signals, producing normal or near normal test results. In addition, the pathways in which the message travels in the central nervous system are intrinsically redundant in terms of the large number of duplicate neural fibers and internural connections. Consequently, accurate identification of spoken messages is possible even if part of the neurologic population is destroyed. In order to override the intrinsic redundancy (Teatini, 1970), the extrinsic redundancy of the speech signal must be reduced via some form of signal modification or degradation.

In recent years speech has been degraded and distorted in various ways so that it might constitute a more difficult listening task. Jerger (1960) hypothesized that beyond the peripheral auditory system the auditory pathways increase in complexity and the tasks needed to assess their function must likewise increase in complexity and difficulty. To this end, speech has been masked, interrupted, filtered, and alternated between ears. An intact auditory system can compensate for the distortion, but an auditory system that is deficient in some way may be unable to process speech information that has been altered. One means of signal alteration that has been studied is that of time-compressed speech.

Time-Compressed Speech

Time-compressed speech has been useful in the diagnosis of central auditory lesions. Several methods have been devised for the compressing of speech and these methods have been used to increase the difficulty of discrimination measures as well as the difficulty of other auditory perceptual processing measures.

The simplest method of time-compressing speech is for the speaker to talk more rapidly than normal. While this procedure has the advantage of requiring no special equipment, it has

the disadvantage of introducing the undesirable qualities associated with a speaker attempting to temporally alter his normal verbal output. The speaker deviates from normal habitual inflection and intonation patterns, consonant/vowel durations, pauses, and articulatory productions. Not only are undesirable and unintentional changes in the talker's speech unavoidable, but the method is limited in that a speaker can only shift his rate of speaking by about 30% (Beasley and Maki, 1975).

Some investigators have employed the "speed changing" method. With this method speech is reproduced at a faster rate than that at which it was originally recorded. This method has some significant advantages in that it is simple to perform, requires no special apparatus, and can be modified to allow the speed of reproduction to be continuously variable. Unfortunately, the primary disadvantage outweighs all the advantages; the procedure produces a frequency shift in the end-product that is proportional to the change in playback speed. Frequency variation interacts with temporal variation and this interaction may introduce error into the data obtained with this method (Beasley and Maki, 1975).

The most effective form of time-compression that has been developed is that of interval discard, described by Fairbanks, Everitt, and Jaeger (1954). In this process the taped sample is copied onto a tape loop from which 18 to 20 millisecond (msec) segments of the signal are randomly discarded. The remaining sampled portions of the signal are electromechanically abutted in time to form a continuous message. This method has the advantage of preserving the original pitch of the signal while allowing for continuously variable percentages of time-compression. The original electromechanical apparatus described by Fairbanks, et al. has been modified and now takes the form of a small computerized mechanism, which is the size of a portable cassette recorder (Lee, 1971), known as the Lexicon Varispeech I. The Lexicon device has been shown to

produce signals equal in quality to the original cumbersome Fairbanks device (Beasley, Nikam, Riggs, Freeman, and Konkle, 1975).

Intelligibility of Time-Compressed Speech for Normal Listeners

Several investigations of the intelligibility of time-compressed speech have been carried out. Danilooff, Shriner, and Zemlin (1968) studied the effects of time-compression, with and without frequency distortion, on the perception of vowels embedded in a /h-d/ context. They electromechanically compressed the stimuli to ratios of 30%, 40%, 50%, 60%, 70%, and 80%. It was found that vowel confusions under frequency distortion were related to shifted format frequency positions, and under time-compression were related to duration. The major decrease in vowel intelligibility was found to be at a compression ratio of 70%. It was also found that the female speaker was more intelligible under all conditions.

Fairbanks and Kodman (1957) investigated the relationship between the degree of time-compression and intelligibility. In their study, a dramatic breakdown in intelligibility occurred at a time-compression ratio of 80%. Beasley, Schwimmer, and Rintelmann (1972) time-compressed four lists of the Northwestern University Auditory Test Number 6 (NU#6) monosyllabic word test (Tillman and Carhart, 1966) to compression ratios of 30%, 40%, 50%, 60%, and 70%, and presented them at sensation levels of 8, 16, 24, and 32 dB to 96 normal listeners. The results of this study indicated that as the amount of time-compression increased intelligibility decreased, but that the effect was partially offset by an increase in intensity. Ear differences were found to be minimal. The subjects in this study were unaffected by time-compression until a level of 40% was reached, whereby there was a gradual breakdown in intelligibility up through 60% time-compression. At a ratio of 70% time-compression, there was a dramatic breakdown in intelligibility. At this

level PB Max (the maximum discrimination score for a subject) was not achieved even at the highest sensation level used in this study (32 dB). Beasley, Forman, and Rintelmann (1972) extended the Beasley, Schwimmer, and Rintelmann study to include a sensation level of 40 dB. Although at 40 dB SL the drop at 70% time-compression was not as severe, it was still dramatic. At compression levels lower than 60% the scores for 32 dB SL and 40 dB SL presentation levels were essentially the same.

Several possible reasons for the difference between the results obtained by Fairbanks and Kodman and those obtained by Beasley, et al. (1972 a,b) can be noted; 1) Fairbanks and Kodman used a smaller discard level (10 msec as opposed to 30 msec) thus making the listening task easier, 2) Fairbanks and Kodman used trained listeners while Beasley, et al. used naive subjects, and 3) Fairbanks and Kodman used a maximum sensation level of 80 dB, as opposed to the maximums of 32 dB and 40 dB used in the Beasley, et al. studies.

Several studies have used time-compressed speech to assess intelligibility as a function of subject age. Beasley, Maki, and Orchik (1973) did a study designed to obtain time-compression norms for children. They used the Phonetically Balanced Kindergarten word test (PB-K 50) and the Word Intelligibility by Picture Identification test (WIPI) as stimuli. Their results indicated that children, when compared to adults, were more adversely affected by time-compression. A dramatic breakdown in intelligibility scores occurred at a 60% level of time-compression and was attributed to the use of different stimuli and the reduced language processing performance levels of children.

Calearo and Lazzaroni (1957), deQuiros (1964), and Bocca and Calearo (1964) found that the length of time needed for processing accelerated speech increased with age. Sticht and Gray (1969) studied four groups of listeners; 1) normal hearing young adults, 2) normal hearing aged subjects, 3) young adults with sensorineural hearing impairments, and 4) aged adults

with sensorineural impairments. They presented the listeners with the CID W-22 monosyllabic word lists compressed to ratios of 36%, 46%, and 59%. They found that both groups of aged listeners showed a decrease in intelligibility different from that of the young listeners. Their findings serve to advance the theory that age in some way alters the central auditory pathways. Schon (1970), using time-compression ratios of 30% and 50%, found that normal hearing young and aged subjects and sensorineurally impaired young and aged subjects experienced a decrease in speech intelligibility as a function of time-compression. Schon found that subjects also had reduced intelligibility as a function of time-expansion. However, only time-compression produced a difference in the intelligibility curves of young and aged subjects. Luterman, Welsh, and Melrose (1966) also used time-compressed speech to study the perceptual abilities of a geriatric population. They compressed CID W-22 monosyllabic word lists to ratios of 10% and 20% and presented them to young and aged listeners with high frequency hearing losses. They found no differences between the intelligibility curves of the two groups, however.

Konkle, Beasley, and Bess (1974) studied the intelligibility of time-compressed speech for elderly subjects with discrimination scores of 90% or better, using the NU#6 monosyllabic word lists. They compressed the NU#6 words to ratios of 0%, 20%, 40%, and 60% and presented them at sensation levels of 24, 32, and 40 dB. They found that the articulation function curves of these subjects did not parallel those of younger subjects. Listener discrimination difficulty occurred at low time-compression levels, even at higher sensation levels. These findings point to an impairment of the central auditory system associated with the aging process.

Thus, several investigators have shown that speech signals can be altered in such a manner as to reduce the extrinsic redundancy of the signal, thereby making the listening task more difficult. This increased difficulty, in turn, can be

used to tax the intrinsically redundant central nervous system in such a manner as to allow for the delineation of auditory impairments which may go undetected when using more conventional measuring techniques.

Time-Compressed Speech Intelligibility for Impaired Listeners

Investigations have shown that persons with sensorineural hearing impairments are more susceptible to various forms of auditory distortion than normal hearing persons (Harris, 1960; Tillman, Carhart, and Olsen, 1970; Cooper and Cutts, 1971; Gengel, 1971; Nabelek and Pickett, 1974). Foulke (1971) found that normal listeners required an increase of 10 dB to attain PB Max when the rate of presentation was increased from 140 words per minute (wpm) to 250 wpm, and another 10 dB increase when the rate was increased to 350 wpm. He found that persons with sensorineural hearing losses required more than a 10 dB increase in intensity for the same rate increases and that subjects with higher central nervous system disorders required even greater increases in intensity.

Kurdziel (1972) presented nine subjects, who had noise induced sensorineural hearing losses, with time-compressed monosyllabic words. She found that these persons had reduced discrimination scores at all levels, but that their intelligibility patterns were similar to those of normal hearing persons. Like normal listeners, intelligibility decreased gradually up through 60% time-compression and then decreased dramatically at 70% time-compression. Further, as time-compression increased, a higher sensation level was needed to reach optimum discrimination.

Kurdziel and Noffsinger (1973) presented NU#6 monosyllables time-compressed to ratios of 40% and 60% to subjects with unilateral temporal lobe lesions, at a level of 40 dB SL. Although conventional test results were normal for all subjects, at 40% time-compression no subject achieved a discrimination

score of 90% or better. Further, scores for ears ipsilateral to the lesion showed a moderate decrease in intelligibility, while scores for ears contralateral to the lesion were significantly depressed.

Statement of the Problem

It has been shown that monosyllables, as presently used, are insufficient stimuli for hearing aid evaluations in that they are incapable of demonstrating physical differences among aids. Consequently, they are not particularly effective in assisting the audiologist in hearing aid selection. It has also been shown that the stimulus materials and techniques suggested to replace them are, to date, clinically impractical. These findings led Burney (1972) to state that the development of techniques to more thoroughly examine the differences among hearing aids was an appropriate area for future research. Jerger (1970), speaking in reference to traditional speech audiometry, stated that it is still of limited diagnostic value, that it cannot distinguish among hearing aids, and that it is not a true representation of speech in the real environment. He stated that traditional speech materials are based on the oversimplified assumption that distinguishing between phonemes with similar acoustic spectra is essential to speech understanding. This is a false assumption according to Jerger. He concluded that it is becoming increasingly clear that the key parameter for speech intelligibility is that of time. Thus, it is not only necessary to develop hearing aid evaluation tools that are effective as well as efficient, but it is also necessary to develop tools that control for temporal as well as spectral information. Further, it is necessary to make these tools difficult enough to adequately and realistically tax the aided listener in the hearing aid evaluation situation. One method of increasing signal difficulty which has already proven clinically effective and efficient in diagnostic evaluations and which may subsequently

prove valuable in hearing aid evaluations, is that of time-compressed speech.

The purpose of the present investigation is to evaluate the potential use of time-compressed speech as a discriminative tool in the selection of hearing aids. Specific questions to be investigated are:

- 1) What will the effects of aided listening be on the intelligibility of time-compressed speech?
- 2) Can time-compressed speech be used to objectively differentiate among hearing aids?

CHAPTER II

EXPERIMENTAL PROCEDURES

This study consisted of 70 subjects randomly assigned to one of seven experimental conditions. Each condition was characterized by three lists of a standardized measure of speech discrimination, presented at three levels of time-compression. The lists were heard monaurally in the unaided soundfield or through one of the six pre-selected moderate gain ear level hearing aids worn monaurally at a gain setting of 30 dB, re: 1000 Hz.

Subjects

The subjects were 70 normal hearing speakers of General American English between the ages of 18 and 29, selected from a university population. Each of the subjects were randomly assigned to one of seven groups corresponding to one of the six hearing aids or the unaided condition. Air conduction and bone conduction thresholds were obtained for both ears of each subject at the octave intervals between 250 Hz and 4000 Hz. All thresholds were 20 dB or better, re: ANSI (1969) specifications. Appendix A shows the mean air conduction and bone conduction thresholds, the ranges, and the standard deviations for the right and left ears of the 70 subjects. Right ears were used exclusively in this study since Beasley, Schwimmer, and Rintelmann (1972) found no ear differences for time-compressed speech. Left ears were covered with a

David Clark Company Model 117 protective earmuff throughout all post-threshold testing.

A taped presentation of a CIB W-1 word list was presented through a loudspeaker (Electrovoice 15 TRX) in order to obtain a right ear, unaided soundfield speech reception threshold. One of the four taped lists of Form A of the NU/6 Auditory Test was randomly selected and presented at 28 dB SL (re: SRT), through the same loudspeaker in order to obtain a right ear, unaided soundfield speech discrimination score. All subjects had discrimination scores of 90% or better. Responses were written on the answer sheet provided by the experimenter (see Appendix B). These results were obtained immediately prior to experimental testing. A subject release form was also signed at this time (see Appendix C).

Stimulus Generation

The experimental stimuli used in this study were taken from Beasley, et al. (1972a) and consisted of Lists I, II, and III of the Northwestern University Auditory Test Number 6 (NU/6) (Tillman and Gerhart, 1966). The lists are shown in Appendix D. A copy of these lists was made using an Ampex Model 601 tape deck (frequency response 50-12,000 Hz $\pm$ 2 dB) and an Ampex Model AG 600-2 tape deck (frequency response 50-13,000 Hz $\pm$ 2 dB). Each list was compressed to levels of 40% and 60% using the Fairbanks electromechanical time-compression apparatus (Fairbanks, Everitt, and Jaeger, 1954), as modified by Zemlin (1971). In order to control for the variable of possible fidelity distortion due to the time-compression procedure, each list was also passed through the time-compression apparatus under the 0% time-compression condition. In all there were nine experimental lists, ie, each of three lists at three levels of time-compression. Copies of each experimental list were then made using an Ampex Model 601 tape deck and an Ampex Model AG 600-2 tape deck, monitored by an Ampex Model AA 620

power amplifier. A Bruel and Kjaer (Model 1024) Sine Random Generator was used to generate a 1000 Hz tone which was recorded at the beginning of each stimulus tape for earphone calibration. A Grason-Stadler (Model 1701) pure tone audiometer was used to generate speech noise, which was also recorded at the beginning of each tape for soundfield calibration. Approximately five seconds of silent interval response time was allotted between each stimulus item on the experimental tapes.

Instrumentation

An Allison (Model 22) dual channel audiometer was employed in this study. The instrument has an SPL output range of -10 to 100 dB (re: ANSI, 1969). An Electrovoice 15 TRX loudspeaker was used with the Allison-22 audiometer (frequency response 300-5000 Hz $\pm$ 5 dB). Placement of the loudspeaker was at a 0° azimuth (re: the listener). The experimental tapes were presented to the listener via an Ampex Model 600-2 tape deck (frequency response 40-10,000 Hz $\pm$ 3 dB).

All subjects were tested while sitting in a prefabricated double walled chamber (IAC 1200 series). Sound level measurements, made with a Bruel and Kjaer portable precision Sound Level Meter (Model 2204/S) showed ambient noise levels to be within the limits (45 dB-C) specified as acceptable by ANSI (1969). The experimenter sat in a single walled control room (IAC 400 series).

Calibration measurements of the test audiometer were performed every two weeks according to ANSI (1969) specifications. Frequency variation, harmonic distortion, sound pressure output, attenuator linearity, and stimulus rise/decay times were checked. Sound pressure output levels for speech noise were measured to determine loudspeaker calibration. The output levels were adjusted to exceed the audiometer attenuator setting by 12 dB (Dirks, Stream, and Wilson, 1949). The

calibration noise at the beginning of each stimulus tape was designed to peak the VU meter of the audiometer at -2 dB VU.

The hearing aids used in this study were the Qualitone TSP, the Fidelity F-59, the Siemens 24 E SL, the Dahlberg HT 1233, the Telex 334, and the Oticon E 11 V. These aids were selected from clinic stock on the basis of similar frequency response. They were electromechanically measured according to ANSI 3.3 (1969) specifications on a weekly basis to ensure compliance with manufacturer specifications. Each aid was placed in a Bruel and Kjaer (Model 4212) Sound Chamber for measuring electroacoustic characteristics. A signal was sent to the aid by a Bruel and Kjaer (Model 1024) Sine Random Generator, monitored by a Bruel and Kjaer (Model 2607) Measuring Amplifier. The hearing aid output was monitored by a Bruel and Kjaer (Model 2112) Audio Frequency Spectrometer and graphically recorded on a Bruel and Kjaer (Model 2305) Level Recorder. The electroacoustic characteristics of the hearing aids can be found in Tables 1-6. Table 1 shows the gain, saturation, effective bandwidth, and harmonic distortion for hearing aid number 1, the Qualitone TSP, measured according to the Hearing Aid Industry Conference (HAIC) (1961) specifications. Also shown in Table 1 is the gain, saturation, effective bandwidth, and harmonic distortion for hearing aid number 1, according to the proposed Food and Drug Administration (FDA) (1975) specifications. Tables 2-6 show the results of the same measurements for hearing aid numbers 2-6.

Experimental Procedures

The right ear of each subject (excluding the ten subjects in the unaided group) was fitted with one of the six experimental hearing aids, set for a gain of 30 dB (re: 1000 Hz). Regular Lucite occluding stock earmolds were used. All left

Table 1. Gain, saturation, effective bandwidth, and harmonic distortion for hearing aid number 1, the Qualitone TSP, measured according to HAIC (1961) and proposed FDA (1975) specifications.

HEARING AID NUMBER 1, QUALITONE TSP

GAIN	SATURATION	EFFECTIVE BANDWIDTH	HARMONIC DISTORTION			
			HAIC:	500 Hz:	10%	FDA: 800 Hz: 0%
HAIC: 52 dB	126 dB	310-5100 Hz		700 Hz:	0%	1000 Hz: 0%
FDA: 50 dB	127 dB	350-4100 Hz		900 Hz:	6.3%	1600 Hz: 0%
				1500 Hz:	8%	
			Average: 6%			Average: 0%

Table 3. Gain, saturation, effective bandwidth, and harmonic distortion for hearing aid number 3, the Siemens 24 E SL, measured according to HAIC (1961) and proposed FDA (1975) specifications.

HEARING AID NUMBER 3, SIEMENS 24 E SL

GAIN	SATURATION	EFFECTIVE BANDWIDTH	HARMONIC DISTORTION			
			HAIC:	500 Hz:	10%	FDA: 800 Hz: 0%
HAIC: 51 dB	127 dB	140-5000 Hz				
FDA: 50 dB	125 dB	500-4200 Hz		700 Hz:	5%	1000 Hz: 1.4%
				900 Hz:	5.6%	1600 Hz: 1.6%
				1500 Hz:	5%	
			Average: 6.4%			Average: 0.7%

Table 5. Gain, saturation, effective bandwidth, and harmonic distortion for hearing aid number 5, the Telex 334, measured according to HAIC (1961) and proposed FDA (1975) specifications.

HEARING AID NUMBER 5, TELEX 334

GAIN	SATURATION	EFFECTIVE BANDWIDTH	HARMONIC DISTORTION			
			HAIC:	500 Hz:	0%	FDA: 800 Hz: 0%
HAIC: 50 dB	119 dB	150-5500 Hz		700 Hz:	0%	1000 Hz: 0%
FDA: 40 dB	114 dB	200-5100 Hz		900 Hz:	0%	1600 Hz: 1.4%
				1500 Hz:	0%	
			Average: 0%			Average: 0.3%

ears remained covered with the protective earmuff. A taped presentation of a CID W-1 word list was again presented through the loudspeaker, and an aided SRT was obtained. The subject was then presented with each of the three discrimination lists under a different level of time-compression, at a constant level of 32 dB SL (re: the aided SRT). Each subject was presented with all three lists and all three levels of time-compression in random order. All subjects were read standard instructions which appear in Appendix E, and responses were written on the answer sheet shown in Appendix B.

Procedures were identical for the ten subjects in the unaided group except that they were not fitted with hearing aids. They received all three lists and all three levels of time-compression at a sensation level of 32 dB (re: the unaided SRT).

Analysis

The data were hand scored by the experimenter and converted into percentage correct scores. The scores represented the seven experimental conditions corresponding to the six aided conditions and one unaided condition, at each of the three levels of time-compression.

CHAPTER III

RESULTS

The results of this study showed certain trends associated with the intelligibility of monosyllables at varying levels of time-compression, when heard in the aided and unaided conditions. The results revealed decreased intelligibility and greater variability among hearing aids as the level of time-compression was increased. The discrimination scores obtained through hearing aids and in the unaided soundfield condition employed in this study were found to be lower than those obtained under earphones by Beasley, Schwimmer, and Rintelmann (1972). Further, speech reception thresholds were found to decrease by 2 to 4 dB when obtained in the aided rather than unaided condition. Finally, a change in rank order with increasing time-compression was seen for four of the six experimental hearing aids. Thus, the aids which produced the best scores at 0% time-compression produced the poorest scores at 60% time-compression, whereas, the aids which produced the poorest scores at 0% time-compression produced the best scores at 60% time-compression.

Speech Reception Threshold

All speech reception thresholds obtained for right ears in the unaided soundfield were within normal limits. Differences of 0 to 10 dB were found when speech thresholds were remeasured through hearing aids. Forty-six of the 60 subjects showed a decrease in SRT's obtained in the aided condition,

two showed improvement, and 12 thresholds remained unchanged. Table 7 shows the mean difference between unaided and aided speech reception thresholds, the difference ranges, and the standard deviations for each hearing aid group. On Table 7, it can be observed that SRT's were poorer by means of 2 to 4 dB when measured through the six experimental hearing aids. Hearing aid number 5, the Telex 334, showed the largest decrease and hearing aid number 4, the Dahlberg HT 1233, showed the smallest decrease. The decrease in aided SRT's found in this study is 8 to 10 dB less than that reported by Tillman, Carhart, and Olsen (1970).

Aided Discrimination Scores at 0%, 40%, and 60% Time-Compression

Intelligibility scores decreased with increasing levels of time-compression for all hearing aid groups and the unaided condition. Scores for each subject at each level of time-compression are shown in Appendix F. Hearing aid number 1, for example, produced a mean discrimination score of 98.2% at 0% time-compression, a mean score of 91.0% at 40% time-compression, and a mean score of 86.4% at 60% time-compression. Table 8 shows the mean discrimination scores, the ranges, and the standard deviations for each hearing aid group and the unaided group at each level of time-compression. It can be seen that the mean score of the unaided group falls below four of the six hearing aid groups at 0% time-compression and falls to last place at 60% time-compression. A slight trend toward increased variability among aids with an increase in time-compression can also be observed. The seven group means for 0% time-compression span a range of only 4.6%, whereas, at 40% time-compression the means span a range of 7.4%, and at 60% time-compression the means span a range of 7.0%. Reference to Table 8 shows no general trend toward greater intersubject variability with each level of time-

Table 7. Mean decrease, range, and standard deviation in dB between unaided and aided SRT's for each hearing aid group. Negative sign indicates improvement in dB between unaided and aided SRT.

No.	HEARING AID	SRT DIFFERENCE		
		Mean	Range	S.D.
No. 1	Qualitone TSP	3.60 dB	-2 to 10 dB	1.20 dB
No. 2	Fidelity F-59	2.90 dB	-4 to 9 dB	2.94 dB
No. 3	Siemens 24 E SL	3.20 dB	-2 to 10 dB	3.10 dB
No. 4	Dahlberg HT 1233	2.20 dB	0 to 6 dB	2.09 dB
No. 5	Telex 334	4.00 dB	0 to 8 dB	2.68 dB
No. 6	Oticon E 11 V	2.70 dB	0 to 8 dB	2.53 dB

Table 8. Mean discrimination scores, ranges, and standard deviations for each hearing aid group and the unaided group at each level of time-compression.

	HEARING AID	TIME-COMPRESSION		
		0%	40%	60%
No. 1	Qualitone TSP	mean: range: s.d.:	91.0% 80-98% 5.74%	86.4% 82-92% 3.67%
No. 2	Fidelity F-59	mean: range: s.d.:	87.8% 72-98% 7.82%	81.6% 68-94% 7.89%
No. 3	Siemens 24 E SL	mean: range: s.d.:	95.2% 88-100% 3.37%	87.0% 82-92% 3.26%
No. 4	Dahlberg HT 1233	mean: range: s.d.:	90.8% 74-96% 5.81%	85.2% 86-98% 3.92%
No. 5	Telex 334	mean: range: s.d.:	93.0% 90-98% 2.24%	87.4% 72-96% 7.54%
No. 6	Oticon E 11 V	mean: range: s.d.:	93.2% 88-100% 3.12%	87.6% 78-94% 5.04%
No. 7	Unaided Condition	mean: range: s.d.:	91.0% 86-96% 4.12%	80.6% 76-100% 11.4%

compression. Only the unaided group showed increased variability with each level of time-compression. At 0% time-compression hearing aid number 6 produced its most variable score, at 40% time-compression hearing aids numbers 2, 3, and 4 produced their most variable scores, and at 60% time-compression hearing aids numbers 2 and 5 produced their most variable scores. Hearing aid number 2 was equally variable at 40% and 60% time-compression.

The Interaction Between Time-Compression and Hearing Aids

The trend toward decreased intelligibility with increasing levels of time-compression was also found by Beasley, Schwimmer, and Rintelmann (1972) when time-compressed NU#6 monosyllabic lists were presented to normal hearing subjects under earphones at 32 dB SL. The breakdown reported by Beasley, et al. was more gradual, however. Table 9 shows the difference between the mean scores obtained by Beasley, et al. at 0%, 40%, and 60% time-compression, the grand means for all hearing aid groups, and the means for the unaided group in this study. It can be seen that at 0% time-compression, scores obtained under earphones (Beasley, et al.), scores obtained monaurally in the soundfield, and scores obtained through hearing aids were comparable. The decrease in aided discrimination scores reported by Zink and Alpiner (1968), Tillman, Carhart, and Olsen (1970), and Zelnick (1970) was not found in the present study. At 40% time-compression, however, earphone scores were 1.4% better than aided scores and 2.2% better than soundfield scores. Aided scores were .8% better than unaided soundfield scores. At 60% time-compression, earphone scores were better than aided scores by 4.2% and better than unaided soundfield scores by 9.4%. Aided scores were 5.2% better than unaided soundfield scores. The trend toward better earphone than soundfield scores was also found for children when discrimination scores for the

Table 9. Mean speech discrimination scores obtained under earphones by Beasley, Schwimmer, and Rintelmann (1972), obtained through all hearing aids in this study, obtained monaurally in an unaided soundfield in this study, and the differences between them at 0%, 40%, and 60% time-compression. All discrimination scores were at a sensation level of 32 dB.

	TIME-COMPRESSION		
	0%	40%	60%
Beasley, Schwimmer, and Rintelmann (1972)	97.0%	93.2%	90.0%
Grand mean for all hearing aids	97.0%	91.8%	85.8%
Mean for the unaided condition	97.6%	91.0%	80.6%
Difference between earphone and aided scores	00.0%	01.4%	04.2%
Difference between aided and unaided scores	00.6%	00.8%	05.2%
Difference between earphone and unaided scores	00.6%	02.2%	09.4%

time-compressed WIPI, obtained under earphones by Shoup (1975), were compared to time-compressed WIPI scores for children of the same age, obtained in a soundfield at the same sensation level by Beasley, Maki, and Orchik (1975). The amount by which earphone scores exceeded soundfield scores increased with increasing levels of time-compression.

Rank Ordering of Hearing Aids with Time-Compression

A change in rank order was observed for all but two of the six experimental hearing aid groups. In other words, the aids that produced the best scores at 0% time-compression produced the poorest scores at 60% time-compression, and the aids that produced the poorest scores at 0% time-compression produced the best scores at 60% time-compression. Table 10 shows the rank order for each hearing aid group at each level of time-compression. An attempt was made to correlate the physical characteristics of the aids with the reversal effect. Factors such as the amount of harmonic distortion present in each aid, the amount of intermodulation distortion present in each aid, the effective bandwidth of each aid, the irregularity of each aid's frequency response, the difference between the energy peaks produced by an aid, and the amount of internal noise generated by each aid were examined.

Harmonic distortion was initially measured according to HAIC (1961) and FDA (1975) specifications and found to be non-existent for all but two experimental aids (see Tables 1-6). The amount of measurable harmonic distortion for hearing aids numbers 1 and 3 was within the limits (10%) specified as acceptable by HAIC (1961) specifications. Subsequently, harmonic distortion was remeasured with a gain setting of 20 dB (re: 1000 Hz), or as worn by the listeners in this study, rather than with the 5 dB gain setting designated by HAIC (1961) specifications. Again, the amount of harmonic

Table 10. The rank order of the six experimental hearing aids
at 0%, 40%, and 60% levels of time-compression.

HEARING AID	TIME-COMPRESSION		
	0%	40%	60%
No. 1 Qualitone TSP	1	4.5	4
No. 2 Fidelity F-59	2	7	6
No. 3 Siemens 24 E SL	3	1	3
No. 4 Dahlberg HT 1233	4.5	6	5
No. 5 Telex 334	6	3	2
No. 6 Oticon E 11 V	7	2	1
No. 7 Unaided Condition	4.5	4.5	7

distortion associated with each aid was minimal and did not appear to influence the rank ordering of aids. Finally, harmonic distortion was measured a third time in a sweep frequency mode and again found to be minimal. The harmonic distortion averages for the frequencies of 500 Hz, 700 Hz, 900 Hz, and 1500 Hz, measured with an input of 75 dB and with a gain setting of 30 dB (re: 1000 Hz), are displayed in Table 11.

Intermodulation distortion was measured with paired input signals of 75 dB at frequencies of 500 Hz and 1500 Hz, 700 Hz and 1700 Hz, 900 Hz and 1900 Hz, 1100 Hz and 2000 Hz, 1300 Hz and 2000 Hz, and 1500 Hz and 2000 Hz. The hearing aids were set for 30 dB of gain (re: 1000 Hz). Intermodulation distortion was found to be non-existent for four aids and minimal for hearing aids numbers 1 and 3. The intermodulation distortion averages for the above frequencies are also displayed in Table 11.

Differences in effective bandwidth were also minimal and did not seem to influence rank order. The effective bandwidth, as calculated according to HAIC (1961) specifications, for each aid can also be found in Table 11.

The irregularity of frequency response was calculated according to the irregularity response index (IRI) proposed by Jerger and Thelin (1968). Jerger and Thelin described a method by which the irregularity or jaggedness of the frequency response is calculated by counting the number of times the frequency response curve intersects lines drawn in 2.5 dB steps from a baseline. The baseline is a line drawn to intersect the lowest point of any reversal in the frequency response curve. Jerger and Thelin found a negative correlation between high IRI and the behavioral performance associated with an aid. No such trend was seen in this study. The IRI values for each aid are shown in Table 11.

Since time-compression would have a negative effect on the intelligibility of consonants, which are weaker, shorter,

and of higher frequency, before negatively affecting the more intense, longer, and lower frequency vowels (Daniloff, Shriner, and Zemlin, 1968), it was hypothesized that a difference between the first and second energy peaks of the frequency response of an aid might be significant. An aid permitting a greater concentration of energy in the higher frequencies might be more resistant to distortion under time-compression. When calculated, however, the peak to peak differences were found to be minimal and comparable for all aids. The peak to peak differences for each aid are shown in Table 11. They had no apparent influence on rank order. Table 11 also shows the difference between the average of energy found at 500 Hz and 1000 Hz and the energy found at 2000 Hz, for each aid. This difference also had no apparent influence on rank order.

The internal noise generated by each aid was determined by calculating the difference between the output of an aid at its maximum gain setting with a 50 dB input and the output of the aid at its maximum gain setting with no input. The differences between the internal noise values for all aids were minimal. Subsequently, internal noise was remeasured with inputs of 50 dB and gain settings of 30 dB (re: 1000 Hz), or as worn by the listeners in this study. Again, differences between aids were minimal and did not seem to influence rank order. Finally, internal noise was calculated using broadband random noise as the input signal. No significant differences between aids were found. The values found at the 30 dB gain settings, with inputs of 50 dB, are shown in Table 11.

Table 11. Harmonic distortion averages for 500 Hz, 700 Hz, 900 Hz, and 1500 Hz measured with a 75 dB input and a gain setting of 30 dB, re: 1000 Hz (H.D.), intermodulation distortion averages obtained with a gain setting of 30 dB, re: 1000 Hz and paired input signals of 75 dB (IM.D), effective bandwidth calculated according to HAIC (1961) specifications (BANDWIDTH), IRI values (IRI), energy peak to peak differences (P_1/P_2), the difference between the average of energy at 500 Hz and 1000 Hz and the energy at 2000 Hz (LE/HE), and internal noise measured at a gain setting of 30 dB, re: 1000 Hz (I.N.), for each experimental aid.

	HEARING AID	H.D.	IM.D.	BANDWIDTH	IRI	P_1/P_2	LE/HE	I.N.
No. 1	Qualitone TSP	5.7%	4%	310-5500 Hz	10	8 dB	0 dB	36 dB
No. 2	Fidelity F-59	5.5%	0%	500-5000 Hz	8	3 dB	-2 dB	36 dB
No. 3	Siemens 24 E SL	7.5%	2.6%	150-5500 Hz	5	12 dB	4 dB	33 dB
No. 4	Dahlberg HT 1233	0%	0%	350-5000 Hz	13	16 dB	6 dB	40 dB
No. 5	Telex 334	0%	0%	300-5100 Hz	10	4 dB	1 dB	36 dB
No. 6	Oticon E 11 V	4.7%	0%	250-6000 Hz	22	2 dB	1 dB	35 dB

CHAPTER IV

DISCUSSION

Time-compressed monosyllabic words were used to devise a clinically efficient and expedient hearing aid evaluation measure which would constitute a more difficult, and thus more realistic, listening task. An attempt was made to allow the procedure to create a wider range of objective scores for several aids and to produce scores commensurate with the electroacoustic quality of aids.

The results of this study showed that as the level of time-compression was increased intelligibility decreased. It was also seen that intelligibility decreased more rapidly for aided normal listeners than for the normal listeners tested under earphones by Beasley, Schwimmer, and Rintelmann (1972). Intelligibility decreased even more rapidly for unaided normal listeners tested monaurally in the soundfield. Unaided scores were poorer than aided scores and earphone scores under 40% and 60% time-compression. Aided speech reception thresholds were poorer than unaided speech reception thresholds by 2 to 4 dB. Electroacoustic measurements indicated that there were no significant physical differences among the six experimental aids. Finally, an increase in the level of time-compression also created a change in rank order for four of the six aids.

The trend toward decreased intelligibility with an increase in time-compression was expected since it had been previously reported by a number of investigators (Fairbanks and Kodman, 1957; Luterman, Welsh, and Melrose, 1966; Daniloﬀ, Shriner,

and Zemlin, 1968; Sticht and Gray, 1969; Schon, 1970; Beasley, Schwimmer, and Rintelmann, 1972; Beasley, Maki, and Orchik, 1973; and Konkle, Beasley, and Bess, 1974). The fact that intelligibility decreased more rapidly for normal hearing subjects tested through hearing aids than for normal hearing subjects tested under earphones was also expected since Harris (1960) reported that two types of distortion in combination serve to more drastically reduce intelligibility. The introduction of a hearing aid system constitutes a second distortion factor in the form of the non-linear distortion present in the system itself, and in the form of the more restricted frequency response of the system which acts as a filter for speech. When a normal listener is tested in the aided condition the amplification of ambient noise also becomes a factor.

The 8.6% decrease in aided, compared to unaided sound-field, discrimination scores reported by Tillman, et al. (1970) for normal hearing subjects was not found in this study. At 0% time-compression aided scores were decreased by only .6% and at 40% and 60% time-compression, aided scores were better than unaided scores by means of .8% and 5.2%, respectively. The greater decrease in aided scores obtained by Tillman, et al. may be attributable to any of several factors; 1) a 45° azimuth was used by Tillman, et al., whereas, a 0° azimuth was employed in the present study, 2) additional signal distortion may have been unavoidably introduced by the extra transducers employed in the aided conditions of the Tillman, et al. study, and/or 3) the aids used in the Tillman, et al. study may have had electroacoustic characteristics that were inferior to those of the aids used in the present study.

The increasing decrease in unaided scores, as compared to aided scores, that was seen as the level of time-compression was increased from 0% to 60% may be the result of the interaction between intensity and time-compression reported by

Beasley, Schwimmer, and Rintelmann (1972). Those investigators concluded that as time-compression increased an increase in intensity was required to offset the reduction in intelligibility. The unaided listeners lacked the 30 dB of gain provided by the hearing aids. At 0% time-compression the additional intensity provided by the aid apparently was not required. As the level of difficulty was increased, however, the advantage of hearing aid amplification was reflected in improved scores for the aided condition, as compared to the unaided condition. The amplification advantage was perhaps great enough to counteract the disadvantage created by the two factor distortion combination described by Harris (1960).

Unaided soundfield scores that were poorer than earphone scores, obtained at the same sensation level, were not expected since Sivian and White (1933), Breakey and Davis (1959), and Tillman, Johnson, and Olson (1966) reported soundfield thresholds that were better than earphone thresholds. Dirks, Stream, and Wilson (1972) reported that speech reception thresholds obtained in the soundfield at a 0° azimuth were better than those obtained under earphones by 3.5 dB. The decrease in soundfield scores found in the present study may be attributable to the soundfield listener's lack of protection from ambient noise, or to the fact that the TDH 39 A/X earphones used by Beasley, et al. (1972b) had a broader and more linear frequency response than the loudspeaker used in the present study. These factors apparently played a more prominent role as the difficulty of the task was increased, since greater decreases in soundfield scores were seen with increasing levels of time-compression.

The trend toward speech reception thresholds that were poorer when measured in the aided rather than unaided condition was expected. The 2 to 4 dB mean decreases were attributed to the undesirable effects of aided listening cited previously, such as, the amplification of ambient noise, the addition of distortion by the hearing aid system, and/or the more restricted

frequency response of the hearing aid which acts as a filter for speech. The 12.4 dB decrease in aided SRT's found for normal hearing subjects by Tillman, et al. (1970) is much larger than the decrease found in this study. Factors cited previously as possible reasons for the greater decreases in aided discrimination scores found by Tillman, et al., such as their use of a 45° azimuth, the extra transducers required by their experimental design, and the possible use of hearing aids with inferior electroacoustic characteristics, may again be the basis of the discrepancy between the results obtained in that study and those obtained in the present study.

The absence of measurable physical differences among the experimental aids was not expected since it is commonly assumed that stock hearing aids are electroacoustically different from one another, frequently do not meet their manufacturer specifications, and have characteristics that do not remain stable over time. None of these assumptions were true for the aids used in this study. These particular aids met their manufacturer specifications within reasonable limits and their characteristics remained virtually unchanged over a period of twelve weeks. It was also unexpected that the differences among the aids would be so small.

Although all differences among aids were minimal, it was found that the two aids with superior electroacoustic qualities, the Oticon E 11 V and the Telex 334, produced the poorest scores at 0% time-compression but the best scores at 60% time-compression. Superior electroacoustic qualities were defined as the least amount of harmonic distortion, the least amount of intermodulation distortion, the broadest frequency response, the smallest IRI, the best peak to peak ratio, and the least internal noise. The two aids with the poorest electroacoustic qualities, the Siemens 24 E SL and the Dahlberg HT 1233, retained their rank order as the level of time-compression was increased. In other words, the rank of these aids neither rose nor fell with an increase in time-compression, but remained

in the middle. The aids whose electroacoustic qualities were judged to be between the most superior and the most inferior, the Qualitone TSP and the Fidelity F-59, produced the best scores at 0% time-compression, but the poorest scores at 60% time-compression. This means that the monosyllabic lists presented under normal conditions, or at 0% time-compression, did not produce scores reflective of the physical properties of the aids, but that the monosyllabic lists presented under more difficult listening conditions, or at 60% time-compression, were reflective of those properties. This finding, however, is based upon minimal physical differences.

Clinical Implications

Time-compressed monosyllables may be a promising tool for hearing aid evaluations. They may provide an alternative to the use of undistorted monosyllables or monosyllables presented against noise. As a new hearing aid evaluation tool, the time-compressed monosyllabic word test met at least three of the four suggested requirements for hearing aid evaluation improvements. First, it was found that compressed monosyllables did indeed constitute a more difficult listening task in that scores decreased with an increase in time-compression. Second, it was found that time-compression improved the ability of monosyllables to reflect the electroacoustic quality of aids in that the aids with superior physical characteristics produced the best scores at 60% time-compression, but the poorest scores at 0% time-compression. Therefore, an aid that might be eliminated from selection on the basis of conventional discrimination test results could actually provide the best amplification for an individual in more difficult listening situations. Conversely, the aid selected for the individual on the basis of conventional discrimination test results might actually perform the most poorly for him in more realistic (ie, difficult) listening situations. Again,

this finding was based on minimal physical differences among aids. Thirdly, the task was found to be clinically expedient and efficient. The use of time-compression did not permit a wide spread of scores for the six hearing aids, however. The spread of scores at 60% time-compression was only 2.6% greater than the spread of scores at 0%. This is a difference of only one to two words. The design of this study did not permit the use of subjective evaluations on the part of the listener since each subject wore only one aid. Hence, it is not known whether time-compression improved the ability of monosyllables to reflect subjective preference. Therefore, although time-compressed monosyllables do not fulfill every requirement suggested for new hearing aid evaluation test stimuli, they do constitute a potentially valuable tool and can be added to the limited battery of hearing aid evaluation techniques.

Time-compressed speech might be particularly useful in the determination of hearing aid candidacy and the selection of amplification for presbycusic clients or hearing impaired clients with concurrent central nervous system disorders. Since the perception of time-compressed speech is related to central auditory processing (Bocca and Calero, 1964; deQuiros, 1964), it might provide the audiologist with additional insight into the suitability of amplification for an individual with a central auditory lesion.

Implications for Future Research

The results of this study failed to show a wide spread of scores for hearing aids as a function of increased time-compression. This could be due to the fact that the experimental aids were much the same electroacoustically, the possibility that the time-compression levels used were too small, or the fact that only normal hearing subjects were employed. It is recommended, therefore, that the usefulness of time-

compressed monosyllables be re-evaluated using hearing aids with exaggerated electroacoustic differences. Only when measurable differences exist can they be reflected in objective scores. Further, speech at a time-compression level of 70% should be presented to normal listeners under aided conditions. This is the time-compression level at which normal listeners show a marked reduction in intelligibility and it would be interesting to examine aided performance at this level, as well. Perhaps a wider range of hearing aid scores would be obtained. The usefulness of the time-compressed monosyllabic test must also be re-evaluated with hearing impaired subjects. The testing of these subjects would permit an examination of individual interaction with hearing aids and may permit differential results among aids. Finally, studies designed to assess the performance of individuals with presbycusis hearing losses and hearing impaired individuals with central nervous system disorders might provide valuable information about the ability of those listeners to benefit from amplification.

In the future, sentences should be more closely examined as potential hearing aid evaluation stimuli. The results of the present study could be construed to support the conclusions of Jerger, Malmquist, and Speaks (1966), Jerger (1968), and Jerger and Thelin (1968) who reported that monosyllables were not meaningful enough to reflect real differences among hearing aids. They felt that more complex stimuli such as sentences were more appropriate for hearing aid evaluations. A sentence test must be used, however, which would sufficiently tax the aided listener and would not allow him to make use of the abundant contextual clues inherent in sentences. The use of time-compressed sentences in hearing aid evaluations is an area appropriate for future research.

CHAPTER V

SUMMARY

The results of this study indicate that time-compressed monosyllables constitute a more difficult listening task which may be used in hearing aid evaluations. Intelligibility scores were found to decrease with increasing levels of time-compression. Time-compression did not produce differential results among hearing aids, however. The spread of hearing aid group scores was increased by less than 3% when the level of time-compression was increased from 0% to 60%. This is a difference of one to two stimulus words.

Electroacoustic differences among the six experimental hearing aids were found to be minimal. The six stock aids met their manufacturer specifications and their characteristics remained stable over a period of twelve weeks. A change in rank order was seen with increased levels of time-compression for four of the six aids, and this change reflected the electroacoustic quality of the aids. Although physical differences among aids were minimal, the aids with the superior electroacoustic characteristics produced the best scores at 60% time-compression, but the poorest scores at 0% time-compression. Superior electroacoustic characteristics were defined as the least amount of harmonic distortion, the least amount of intermodulation distortion, the broadest frequency response, the smallest IRI, the best peak to peak ratio, and the least internal noise. The aids that produced the best scores at 0% time-compression also reversed order and produced the poorest scores at 60% time-compression. Hence, time-compression improved the ability of monosyllables to reflect the physical quality of hearing aids.

Intelligibility scores obtained through hearing aids and in the monaural soundfield condition used in this study were poorer than those obtained under earphones by Beasley, et al. (1972a) at 32 dB SL, under both 40% and 60% time-compression. Speech reception thresholds were poorer by means of 2 to 4 dB when obtained in the aided rather than unaided condition.

APPENDICES

APPENDIX A

Mean air conduction and bone conduction thresholds, ranges,
and standard deviations for the right and left ears
of the 70 subjects.

Table 12. Mean air conduction and bone conduction thresholds, ranges, and standard deviations for the 70 subjects.

EAR	FREQUENCY					
	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
Right ear air conduction threshold	mean:	5.00 dB	1.93 dB	1.86 dB	-0.43 dB	0.93 dB
	range:	-10 to 20 dB	-10 to 20 dB	-10 to 20 dB	-10 to 15 dB	-5 to 20 dB
	s.d.:	5.41 dB	5.62 dB	5.42 dB	5.65 dB	6.27 dB
Left ear air conduction threshold	mean:	1.64 dB	3.14 dB	0.79 dB	1.14 dB	6.57 dB
	range:	-10 to 20 dB	-10 to 15 dB	-10 to 15 dB	-10 to 15 dB	-10 to 25 dB
	s.d.:	7.56 dB	5.08 dB	5.89 dB	6.05 dB	7.20 dB
Better bone conduction (right mastoid placement)	mean:	0.29 dB	3.07 dB	-1.57 dB	-0.50 dB	-1.00 dB
	range:	-10 to 10 dB	-10 to 20 dB	-10 to 10 dB	-10 to 10 dB	-10 to 20 dB
	s.d.:	6.49 dB	7.33 dB	5.77 dB	6.39 dB	7.30 dB

APPENDIX B

Subject Answer Sheet

SUBJECT ANSWER SHEET

NAME _____
 DATE _____
 SUBJECT _____
 AGE _____
 EAR _____
 SRT _____
 DISCRIMINATION SCORE _____
 HEARING AID _____
 SRT _____
 0% _____
 40% _____
 60% _____

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____
9. _____
10. _____
11. _____
12. _____
13. _____
14. _____
15. _____
16. _____
17. _____
18. _____
19. _____
20. _____
21. _____
22. _____
23. _____
24. _____
25. _____
26. _____
27. _____
28. _____
29. _____
30. _____
31. _____
32. _____
33. _____
34. _____
35. _____
36. _____
37. _____
38. _____
39. _____
40. _____
41. _____
42. _____
43. _____
44. _____
45. _____
46. _____
47. _____
48. _____
49. _____
50. _____

1.	1.	1.
2.	2.	2.
3.	3.	3.
4.	4.	4.
5.	5.	5.
6.	6.	6.
7.	7.	7.
8.	8.	8.
9.	9.	9.
10.	10.	10.
11.	11.	11.
12.	12.	12.
13.	13.	13.
14.	14.	14.
15.	15.	15.
16.	16.	16.
17.	17.	17.
18.	18.	18.
19.	19.	19.
20.	20.	20.
21.	21.	21.
22.	22.	22.
23.	23.	23.
24.	24.	24.
25.	25.	25.
26.	26.	26.
27.	27.	27.
28.	28.	28.
29.	29.	29.
30.	30.	30.
31.	31.	31.
32.	32.	32.
33.	33.	33.
34.	34.	34.
35.	35.	35.
36.	36.	36.
37.	37.	37.
38.	38.	38.
39.	39.	39.
40.	40.	40.
41.	41.	41.
42.	42.	42.
43.	43.	43.
44.	44.	44.
45.	45.	45.
46.	46.	46.
47.	47.	47.
48.	48.	48.
49.	49.	49.
50.	50.	50.

APPENDIX C

Subject Release Form

SUBJECT RELEASE FORM

I do hereby authorize Susan Dalebout to measure my hearing sensitivity and speech discrimination ability, both with and without a hearing aid.

Signature _____

Date _____

APPENDIX D

Three Lists of Form B of the Northwestern University Auditory
Test No. 6

THREE LISTS OF FORM B OF THE NORTHWESTERN UNIVERSITY AUDITORY TEST
NUMBER 6

List I

1. burn
2. lot
3. sub
4. home
5. dime
6. which
7. keen
8. yes
9. boat
10. sure
11. hurl
12. door
13. kite
14. sell
15. nag
16. take
17. fall
18. week
19. death
20. love
21. tough
22. gap
23. moon
24. choice
25. king
26. size
27. pool
28. vine
29. chalk
30. laud
31. goose
32. shout
33. fat
34. puff
35. jar
36. reach
37. rag
38. mode
39. tip
40. page
41. raid
42. raise
43. bean
44. hash
45. limb
46. third
47. jail
48. knock
49. whip
50. met

List II

1. live
2. voice
3. ton
4. learn
5. match
6. chair
7. deep
8. pike
9. room
10. read
11. calm
12. book
13. dab
14. loaf
15. goal
16. shack
17. far
18. witch
19. rot
20. pick
21. fail
22. said
23. wag
24. haze
25. white
26. hush
27. dead
28. pad
29. mill
30. merge
31. juice
32. keg
33. gin
34. nice
35. numb
36. chief
37. gaze
38. young
39. keen
40. tool
41. soap
42. hate
43. turn
44. rain
45. shawl
46. bought
47. thought
48. bite
49. lore
50. south

List III

1. sheep
2. cause
3. rat
4. bar
5. mouse
6. talk
7. hire
8. search
9. luck
10. cab
11. rush
12. five
13. team
14. pearl
15. soup
16. half
17. chat
18. road
19. pole
20. phone
21. life
22. pain
23. base
24. mop
25. mess
26. germ
27. thin
28. name
29. ditch
30. tell
31. cool
32. seize
33. dodge
34. youth
35. hit
36. late
37. jug
38. wire
39. walk
40. date
41. when
42. ring
43. check
44. note
45. gun
46. bag
47. void
48. shall
49. lid
50. good

APPENDIX E

Subject Instructions

SUBJECT INSTRUCTIONS

You are about to hear three lists of words. Each word will be preceded by the carrier phrase, "you will say". For example, you will hear "you will say dog". Your task is to write the last word you hear on your answer sheet. In the example, you would write the word "dog". Some of the words may sound faster than normal, so listen very carefully. Feel free to guess if you need to. Are there any questions?

APPENDIX F

Raw Scores of the 70 Subjects at 0%, 40%,
60% Time-Compression

Table 13. Raw scores of the 70 subjects at 0%, 40%, and 60% time-compression. Groups are numbered according to the order of testing.

	TIME-COMPRESSION		
	0%	40%	60%
GROUP NUMBER 1: FIDELITY F-59			
Subject			
1	98%	98%	90%
2	98%	72%	72%
3	100%	80%	72%
4	100%	92%	68%
5	100%	88%	76%
6	96%	94%	88%
7	98%	98%	94%
8	98%	88%	76%
9	92%	86%	92%
10	100%	82%	88%
GROUP NUMBER 2: OTICON E 11 V			
Subject			
1	98%	96%	92%
2	86%	88%	80%
3	80%	100%	78%
4	96%	92%	88%
5	100%	92%	90%
6	100%	90%	92%
7	98%	94%	84%
8	98%	94%	94%
9	94%	94%	90%
10	98%	92%	88%
GROUP NUMBER 3: TELEX 334			
Subject			
1	98%	92%	90%
2	96%	98%	84%
3	100%	94%	96%
4	98%	94%	80%
5	100%	94%	96%
6	98%	94%	82%
7	94%	90%	90%
8	80%	92%	72%
9	96%	90%	88%
10	100%	92%	96%

Table 13 (cont'd):

TIME-COMPRESSION

	0%	40%	60%
GROUP NUMBER 4: QUALITONE TSP			
Subject			
1	98%	98%	92%
2	100%	96%	84%
3	100%	80%	88%
4	98%	96%	82%
5	96%	94%	82%
6	96%	86%	92%
7	98%	84%	86%
8	98%	90%	84%
9	100%	90%	90%
10	98%	96%	84%

GROUP NUMBER 5: DAHLBERG HT 1233

Subject			
1	100%	98%	82%
2	98%	90%	84%
3	96%	86%	82%
4	92%	94%	88%
5	98%	90%	96%
6	100%	86%	88%
7	96%	90%	82%
8	98%	86%	74%
9	100%	94%	84%
10	98%	94%	92%

GROUP NUMBER 6: SIEMENS 24 E SL

Subject			
1	98%	88%	84%
2	100%	98%	86%
3	96%	94%	92%
4	100%	94%	82%
5	98%	98%	92%
6	98%	94%	88%
7	98%	100%	86%
8	94%	98%	84%
9	98%	96%	90%
10	98%	92%	86%

GROUP NUMBER 7: UNAIDED

Subject			
1	100%	96%	96%
2	94%	96%	84%
3	100%	94%	98%
4	98%	96%	90%

Table 13 (cont'd):

TIME-COMPRESSION			
	0%	40%	60%
5	96%	86%	88%
6	100%	86%	92%
7	100%	92%	90%
8	98%	86%	100%
9	92%	90%	76%
10	98%	88%	82%

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