A Comparison of Speech Audiometric Performance of Hypacusics With Clinic-Fitted Hearing Aids and With Master Hearing Aid

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A COMPARISON OF SPEECH AUDIOMETRIC PERFORMANCE OF HYPACUSICS WITH CLINIC-FITTED HEARING AIDS AND WITH MASTER HEARING AID

by

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Kent Jay Nielsen

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ABSTRACT

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by

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Clinical audiologists at Utah State University have been using a master hearing aid as a basic part of hearing aid evaluation procedures. To ascertain the usefulness of the master hearing aid in predicting patient success with a wearable hearing aid, 20 subjects were given speech audiometric tests under the following conditions: (1) without amplification; (2) with the headset system of the master hearing aid (a system which utilizes chassis mounted microphones and external receivers of the type used with body-worn hearing aids); (3) with the ear-level system of the master hearing aid (a system which utilizes a microphone and receiver mounted in an ear-level hearing aid case); and (4) with a wearable ear-level hearing aid which had been previously selected for each subject on the basis of master hearing aid data.

Using the ANOV procedure, statistically significant differences ($\alpha = .05$) were found between the mean speech reception thresholds obtained under the three aided test conditions, but differences were not clinically significant. The mean speech reception thresholds agreed within 4.0 dB.

No significant difference was found between the mean speech discrimination scores obtained in quiet under the three aided test conditions. However, the mean speech discrimination score obtained in noise under the headset system condition was significantly poorer ($\alpha = .05$) than the mean speech discrimination scores obtained under the ear-level system condition and also the wearable hearing aid condition. Differences as specified were 9.1 percent and 10.2 percent respectively.

Conclusions were that the ear-level system of the master hearing aid and the headset system of the master hearing aid can be used to predict the SRT and speech discrimination score in quiet of hearing aid candidate using a wearable hearing aid, but that the ear-level system of the master hearing aid should be used exclusively when attempting to predict a patient's success with a wearable hearing aid on speech discrimination tasks in noise.

(95 pages)

CHAPTER I

INTRODUCTION

The majority of the audiological clinics in the United States are concerned with hearing aid evaluations. The desired outcome of each consultation is the reasonably successful matching of a hearing aid to the hearing aid candidate. Many philosophies relative to hearing aid selection procedures have evolved over the past 30 years (Carhart 1946, Davis et al. 1946, Jeffers 1960, Resnick and Becker 1963, Zerlin 1962, Reddell and Calvert 1966, Jerger 1967). The basic question has concerned hearing aid evaluation procedures which can satisfactorily help the greatest majority of hearing aid candidates. Many of the philosophies are in some ways similar, but each reflects the biases of the author and each differs in some respects as to procedures to be followed in the hearing aid evaluation. A comparison of these different philosophies will be outlined in the literature review section of the present investigation.

Over the past several years a hearing aid evaluation philosophy has evolved at Utah State University (U.S.U.). Partly because of the problems and expenses involved in maintaining a hearing aid inventory and making the inventory worthwhile in a rural area, the use of a master aid has been instituted in the Utah State University Hearing Clinics. A procedure involving hearing aid selection on the basis of data obtained from the master hearing aid has seemed to work very well here at Utah State University. The same type of hearing aid evaluation is used at other institutions in the state of Utah. The master hearing aid is used to obtain data which is used to order a suitable hearing aid through a dispensory program to be outlined in more detail in Chapter II. The present study was undertaken to provide information and basic research relative to the efficacy of master hearing aid use and to answer questions which have evolved over the past two years.

It was the aim of the current investigation to evaluate use of the master hearing aid as a tool in the selection of a suitable wearable amplification system for the hearing aid candidate. The current study compares audiological data in the form of speech reception thresholds and speech discrimination scores obtained in sound field. This data was obtained from 20 experimental subjects using the master hearing aid. Similar data was obtained with the 20 experimental subjects wearing a hearing aid ordered from the master hearing aid data. The basic question related to the degree to which master hearing aid data could be used to predict how the patient would function with a wearable hearing aid. Stated differently, it was the concern of the present study to assess how reliably the master hearing aid will predict patient performance using a hearing aid selected using master hearing aid data. The data resulting from the study has been evaluated in an effort to determine the effectiveness of the procedures currently being used. The most important question of the current investigation related to whether or not the master hearing aid can be used to obtain an appropriate hearing aid fitting for the candidate in the majority of instances.

It is the hope that information gained will validate use of the master hearing aid as a clinical tool in hearing aid selection procedures.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

The most suitable procedure for the selection of hearing aids has been a point of heated debate and discussion for many years. Probably as many philosophies of hearing aid evaluation exist as there are clinics currently participating in hearing aid evaluation procedures. It is the purpose of the present chapter to review some of the hearing aid evaluation procedures that have developed over the past 30 years in an effort to formulate a basis for the type of hearing aid evaluation procedure used at Utah State University. Four main topics will be discussed in the chapter. The first topic will be the philosophies that suggest futility of selective amplification as a hearing aid evaluation procedure. The second area of discussion will relate to the area of selective amplification, and studies advocating selective amplification as a hearing aid evaluation procedure. The third area of discussion involves use of the master hearing aid in the selective amplification process, and information related to how the master hearing aid can be used to prescribe appropriate hearing aid fittings for hearing aid candidates. The final area of discussion will be the procedures of hearing aid evaluation that are in use at the Utah State University Hearing Clinic. A review of the philosophies and practices of the past 30 years which have shaped the current practice of hearing aid evaluation will be attempted.

Studies Suggesting Futility of Selective Amplification

One of the first reports of hearing aid evaluation was published by Davis, Hudgins, Marquis, Nichols, Peterson, Ross and Stevens (1946). The purpose of the report was to provide a theoretical basis for hearing aid selection procedures, and a critique of procedures in use at that time. This report by Davis, et al. has become well known as the "Harvard Report". The report was based on hearing test results and articulation function curves obtained from a heterogeneous group of eighteen hard-of-hearing patients. The articulation function curves were plotted from the responses to Harvard PB-50 word lists presented to the hard-of-hearing listener through a "master hearing aid" which could be adjusted to yield five different frequency response curves. The five different frequency response curves employed by Davis, et al., involved (1) a flat response curve within ± 1 dB from 100 to 7000 Hz, (2) a response curve rising at the rate of 6 dB per octave over the same range, (3) a response curve rising at the rate of 12 dB per octave, (4) a response curve with a downward slope of 6 dB per octave, and (5) a response curve with a downward slope of 12 dB per octave.

The sample of patients involved in the Harvard Report included 9 males and 9 females ranging in age from 17 to 70 years. Of the 36 ears involved, 11 could not be included because of type of loss. This left 25 ears with a hearing loss suitable for purpose of the study. Analysis of data shows that over 50 percent of the subjects tested had conductive or mixed losses, while 76 percent of the subjects had flat or gradually sloping audiograms. Of the patients that were tested, 20 percent of the ears showed flat audiograms, 40 percent showed gradually sloping audiograms, 24 percent showed markedly sloping audiograms, and 16 percent showed rising audiograms.

The conclusion which emerged from the Harvard Report was that the fitting of hearing aids could not be based on the relationship between the frequency response characteristics of the instrument and the patients' audiogram. Davis, et al., suggested that for all types of hearing loss, an amplification system with a frequency response which rises at the rate of 6 dB per octave, or one which is flat is most satisfactory. At first glance, it appears that this may be true, On the other hand, Davis, et al., generalized their conclusions to cases with markedly sloping audiometric configurations on the basis of atriculation test results on only six ears. Perhaps the writers of the Harvard Report based their thesis on the fact that the test results on three of the six ears evidencing markedly sloping audiometric configurations did not change and that one score was poorer in the 6 dB per octave rise condition than in the flat condition. Also, in no case were scores in the condition involving a 12-dB per octave rise in frequency response better than scores in the condition involving a 6 dB per octave rise (see Table 1).

The sweeping conclusions reached by the Harvard group are generalized to the population of markedly sloping losses, yet are based on the test scores of six ears with markedly sloping audiometric configurations. Perhaps these conclusions could be questioned when considering this group of the hard-of-hearing population.

Another group, Shore, Bilger and Hirsh (1960) published the results of study supporting the findings of the Harvard group. Fifteen clinical patients with moderate hearing losses in three diagnostic

Table 1. Tabular information taken from the Harvard Report showing the type of audiogram, the signal-to-noise ratio utilized in testing, the ear tested, the amount of loss at 1000 cps, and the discrimination scores obtained for each of five frequency responses utilized in the study (Davis, et al., page 66)

Subject	Ear	Type **	Loss	Condition S/N	LP-12	LP-6	Flat	HP-6	HP-12
MD	R*	R	63	Q		71	84	84	
MD	L*	R	70	Q		63	82	77	
RR	R	R	63	N 10		67	70	69	
RR	L	R	57	N 10	50	65	67	71	
RA	R	F	80	N 10		66	78	71	56
RC	L	F	55	N 10		56	60	60	
BD	R	F	83	N 15		13	60	60	34
DL	L	F	67	N 15		70	78	79	
HM	R	F	63	N 10	70	82	83	84	62
HB	R	G	68	N 5		68	71	71	38
TR	R	G	90	Q			78	80	42
FB	L	G	69	N 10		62	80	80	60
FS	R	G	35	Q		56	86	87	
BL	L	G	97	Q			55	77	
HB	L	G	66	N 5		77	85	86	48
RW	R	G	53	N 15			68	68	62
WW	R*	G	79	Q		63	76	92	
WW	L*	G	73	Q		55	62	62	52
RW	L	G	51	N 15		42	66	66	
PP	L	M	74	Q		58	81	70	51
PP	R	M	71	Q		56	71	71	
IS	R	M	46	Q		56	80	80	77
MC	L	M	51	Q		58	69	88	88
JH	R*	M	63	Q		80	84	86	76
JH	L	M	62	Q		29	52	66	57

*Tested with special lists

**Under the column labeled "Type" R refers to progressively less loss for higher frequencies, F refers to equal loss within 5 dB at all frequencies from 250 to 4000, G refers to progressively greater loss for higher frequencies, sloping not more than 10 dB per octave, M refers to audiograms sloping downward at a rate of at least 15 dB per octave.

categories designated as mixed, sensorineural and conductive were used to obtain three hearing aid performance scores. The three measures were: (1) gain hearing level for speech, (2) speech discrimination in quiet, and (3) speech discrimination in noise. Speech material utilized in testing the subjects were recorded W-2 spondee word lists, and W-22 P.B.-50 word lists. Test results were obtained with the patient using one of four selected hearing aids over four test periods. Each hearing aid could be set to one of two settings. Setting 1 was labeled "Good"; this setting would be a most appropriate setting of tone and internal settings for each patient. Setting 2 would be the most inappropriate combination of settings for each patient, as judged by several experienced audiologists. The large variations in test-retest scores (see Table 2), for different hearing aids, settings, and days of testing led to the conclusions that the reliability of audiometric speech measurements is not good enough to warrant the investment of a large amount of clinical time in the hearing aid evaluation process.

Shore, Bilger and Hirsh (1960) do not imply that there are no differences among conventional hearing aids, but rather feel that results suggest that whatever differences there might be are not detectable by the usual measurements of speech audiometry. The results of this study have long been a point of discussion as to whether audiometric speech discrimination scores can be used to predict the appropriate aid for a hearing aid candidate. For instance, other researchers, McConnell, Silber and McDonald, (1960); Carhart and Olsen, (1967); Bode, et al., (1968); Kasten, et al., (1967) have indirectly shown results that would tend to refute the results and

Table 2. Hearing aid performance for individual patients by Shore, Bilger and Hirsh (1960) page 160

Patient	Original HL	Tone Setting	HL for Speech Aids A	B	C	D	Sig. Effect*	Discrimination in Quiet Aids A	B	C	D	Sig. Effect*	Discrimination in Noise Aids A	B	C	D	Sig. Effect*
1	39	Good	4	1	4	4	A	67	50	59	58	a, sd	21	26	26	23	
		Bad	3	3	10	1		65	54	60	57		19	18	22	17	
2	27	Good	-4	5	4	0	D,A	76	64	73	65		21	31	31	23	sd
		Bad	-4	8	-1	-4		64	67	75	51		28	32	34	27	
7	42	Good	2	3	6	3		48	48	49	59		10	7	8	12	
		Bad	6	-2	8	2		55	42	48	52		12	6	13	9	
8	37	Good	-1	2	2	5	d	54	44	61	53		18	13	17	19	D
		Bad	0	0	2	0		63	49	56	59		25	22	17	22	
15	34	Good	3	1	9	6	D,A	43	31	31	45	a	10	9	6	4	
		Bad	2	3	8	0		46	34	13	41		9	6	7	7	
9	29	Good	10	10	11	10		68	65	60	63		46	38	44	50	
		Bad	12	8	10	11		71	63	61	72		52	39	50	50	
10	36	Good	-2	-1	11	-2	D,A	65	63	63	66	A,s,as	31	27	34	29	
		Bad	2	2	6	-2		64	56	29	65		25	27	23	29	
11	35	Good	-3	0	3	-2	a	64	52	46	60		17	17	17	11	D
		Bad	-3	0	-1	-1		56	52	55	55		15	10	15	17	
12	27	Good	4	4	5	4		54	59	52	60	A,AD,as	16	19	21	24	
		Bad	2	8	8	10		57	57	31	62		23	33	18	25	
13	36	Good	6	8	13	6	S	59	48	57	61	a,as	30	16	39	16	
		Bad	5	4	5	5		70	61	32	66		37	23	24	22	
3	27	Good	1	4	4	3		19	29	25	28		3	5	6	5	
		Bad	2	2	1	4		31	25	31	29		8	6	4	3	
4	30	Good	16	19	24	19		53	35	38	52	SD	34	24	32	29	D
		Bad	18	20	20	17		50	47	55	48		38	29	32	33	
5	32	Good	2	4	10	4	A	48	36	40	45	S	8	9	11	10	
		Bad	2	7	9	7		23	28	45	31		7	8	10	11	

Table 2. Continued

Patient	Original HL	Tone Setting	HL for Speech Aids A	B	C	D	Sig. Effect*	Discrimination in Quiet Aids A	B	C	D	Sig. Effect*	Discrimination in Noise Aids A	B	C	D	Sig. Effect*
6	55	Good	10	10	30	26	d	1	0	0	1		0	0	0	1	
		Bad	20	8	20	20		1	1	0	2		0	0	0	0	
14	51	Good	2	3	2	5	S	43	32	22	48	S	10	5	4	7	
		Bad	4	11	9	3		37	24	16	33		11	8	10	3	

*Significant sources of variance as indicated: D for day, A for aids, S for settings
Capital letters for 1 percent level and lower-case letters for 5 percent significance

conclusions of Shore, et al. The present writer feels that extended, careful research into the reliability of speech audiometry would be of great benefit, because of the discrepancies that exist in past research, and the importance of the general area to clinical audiology.

Three years following the report of Shore, et al., (1960), Shore and Kramer (1963) reported on a new hearing aid evaluation procedure in which no specific hearing aid was recommended to the patient. The patient was given a list of specifications obtained from the results of an audiological evaluation; the list suggested to the patient what to look for in buying a hearing aid. Questionnaires were sent to two groups of people, those for whom a specific recommendation had been made, and those for whom such recommendation had not been made. The questionnaire was designed to obtain information concerning preference for the hearing aid evaluation. A statistical analysis of the two groups of subjects showed only that more people in Group I, those given a list of specifications for a hearing aid, bought hearing aid, although not necessarily a hearing aid conforming to the specifications provided. On the basis of their findings, Shore and Kramer suggests a hearing aid evaluation where no specific hearing aid is recommended to the patient.

Resnick and Becker (1963) reported that the traditional hearing aid evaluation is based on three assumptions: (1) that significant differences in speech-transmitting characteristics exist between hearing aids; (2) that these differences change from one hearing aid user to the next; and (3) that these differences can be demonstrated by monosyllabic word intelligibility scores. They felt that the first assumption is largely irrelevant. That is, Resnick and Becker reasoned that even if hearing aids were different, they should operate the same for everyone. If hearing aid A is better than hearing aid B for a given patient, then hearing aid A should be better for all patients than hearing aid B. The second assumption seems relatively untested. The authors stated that "It seems more reasonable to assume that the better of the two speech amplifying circuits for any one patient is likely to be the better for all patients." (Resnick and Becker, 1963, p. 695) The authors reported further that the third assumption has been questioned following the careful study by Shore, Bilger, and Hirsh, (1960). Resnick and Becker suggest that the hearing aid evaluation be broken down into four parts. The first part should involve audiological assessment of the hearing loss. The second part should involve counseling of the patient regarding the nature of the loss, the nature of hearing aids, the assistance that can be expected from a hearing aid, and the availability of other areas of aural rehabilitation. The third section of hearing aid evaluation should involve the measurement of speech gain and intelligibility through various hearing aids and should result in the recommendation of a specific fitting. Finally, counseling of the patient regarding care and use of the recommended hearing aid should be accomplished. Resnick and Becker argued that the first and second phases should be accomplished. Resnick and Becker argued that the first and second phases should be the strict domain of the hearing aid dealer. They reasoned that this leaves the professional audiologist out of the unprofessional discussion of the price of the instrument, and relieves the audiologist of time-consuming testing required to find an appropriate hearing aid. A plan was suggested wherein the clinic refers to hearing aid dealers on a rotation basis. The dealers must agree to abide by written standards specified by the audiological clinic. Resnick and Becker admit that the plan is not adaptable to certain situations, such as the Veterans Administration or the Army Audiological Program, but note that the program has worked in the Washington, D. C. area for a year at the printing of the article.

The above studies outline a philosophy of hearing aid evaluation that has evolved around the "Harvard Report;" that is, that selective amplification is an audiological process that is time-consuming, of no real benefit to the patient, and that the hearing aid dealer is more qualified to make judgment as to which hearing aid to recommend for a specific candidate. Under this philosophy, it is the audiologist's role to give counsel and obtain audiometric data that may be helpful to a doctor or hearing aid dealer.

It is evident that the Harvard philosophy is not universally accepted. Many authors, such as Carhart (1946), Menzel (1963), Jeffers (1960), Jerger (1967), and others, adhere to a selective amplification procedure of hearing aid evaluation. The next section will discuss in some detail the philosophy of selective amplification in the hearing aid evaluation process.

Studies Advocating Selective Amplification

About the time that the Harvard Report emerged, another philosophy was developed and introduced. Raymond Carhart (1946) described the procedure of selective amplification used to evaluate hearing aid candidates at the Deshon General Hospital. With some variations, these procedures are still rather widely practiced (ASHA 1967).

Four dimensions of patient performance with a hearing aid are explored. These include: (1) sensitivity or effective gain, (2) tolerance limit or psychophysical ceiling, (3) efficiency in background noise, or signal-to-noise ratio, and (4) discrimination, or efficiency in distinguishing small speech sound differences. Carhart spent some time explaining how these four dimensions are incorporated in the hearing aid evaluation procedure. Basically, the following information is an outline of the method outlined by Carhart. The speech reception theshold technique offers an appropriate method for estimating improvement in sensitivity yielded by a hearing aid. The steps outlined by Carhart for determining patient sensitivity with a hearing aid are as follows: (1) the patient's sound field speech reception threshold is obtained unaided. The speech reception threshold yields a point of reference against which to compare thresholds of the patient using wearable hearing aids. (2) The patient's sound field speech reception threshold is then obtained using various hearing aids in an aided condition. The patient is placed in the same position that, the unaided speech reception threshold was obtained and the hearing aid is set at the patients "comfort level" for incoming speech. The "comfort level" method of setting the gain control involved having the patient adjust the volume of the hearing aid to a comfortable listening level for conversational level voice. (3) The speech reception threshold is again obtained, with the volume control at full on. The "residual loss" for speech and the "effective gain" at full volume is computed by taking the difference between the unaided threshold and the aided threshold at full gain. (4) Several instruments are examined utilizing the procedure outlined above.

The second dimension discussed by Carhart is the tolerance limit. Increasingly higher levels of speech are presented to the unaided ear and to the ear fitted with the hearing aid under test. The patient is asked to report the point at which he experiences a definite sensation such as tickle, pain, etc. The tolerance test involves use of connected speech of sufficient duration to allow the patient to make an adequate judgement as to whether or not the sound is tolerable.

The test of efficiency in noise is the third dimension discussed by Carhart. The steps listed below have proven a useful method for comparison of hearing aids on the basis of signal-to-noise ratio. (1) Using connected speech discourse presented at a sensation level of 50 dB (re SRT), the patient is instructed to adjust the volume of the first hearing aid by the "comfort level" method as explained earlier. (2) Speech samples continue to the patient at a sensation level of 50 dB while the intensity of noise in the test chamber is slowly increased in successive steps. The patient is given a discrimination test using at each level of noise using the Harvard PB-50 word lists. At the noise level where the patient no longer understands the test items, the test procedure is reversed. (3) The signal-to-noise ratio is computed by taking the difference between the sensation level (50 dB) at which speech was presented and the level of the strongest noise at which understanding was possible.

The fourth and final dimension described by Carhart is auditory phonemic discriminatory capacity. A simple procedure for the estimation of speech discrimination with different hearing aids consists of the following steps: (1) if possible, an unaided discrimination score is obtained at a level 25 dB above the unaided speech reception threshold, (2) the hearing aid to be evaluated is adjusted so that speech presented at a 40 dB hearing level is received at a comfortable level, (3) a speech discrimination score is then obtained at the comfort level. The test is then repeated at a level 25 dB higher than the aided speech reception threshold.

After an aid is judged as being satisfactory to the patient, a trial period is given to assess the suitability of the hearing aid in everyday situations. Carhart incorporated what he called the "listening hour" during the trial period. These sessions were one hour in duration, and required that every patient attend the clinic to listen to programmed sound stimuli. The patient listened for a complete hour with each hearing aid retained for the final trial. These sessions were used to obtain a basis for judging the benefit a patient could reasonably expect from amplification in real-life situations. The final selection of the hearing aid was based upon the listening hour score and supplementary factors, such as: (1) relative instrument quality, (2) subjective impressions of the patient from use of the aid outside of the clinic, (3) cost of the hearing aid, (4) service and repair availability, and (5) aesthetic considerations. Once the final selection was made, the patient was instructed as to how to procure the recommended aid from a local dealer.

Jeffers (1960) used a quality judgement method of hearing aid evaluation which involved a subjective comparison of the acoustic characteristics of two hearing aids at a time. As shown in Table 3, Jeffers selected five hearing aids to cover a range of good, fair and poor acoustic characteristics as defined according to harmonic

Table 3. Tabular information from five hearing aids used in Jeffers study (1960), page 260

Hearing Aid	Maximum Acoustic Gain	Effective Range	Frequency Response	Acoustic Output	Limiting Factor
1	70-75 dB at 1000 cps; av. 500-3000 dps, 71 dB	240 cps-3500 cps	Relatively	Maximum 129 dB at 1000 cps	Automatic volume control
2	73 dB at 1000 cps; av. 500-3000 cps, 65 dB	650 cps-3600 cps	Peaked	Maximum 138-140 dB at 1000 cps	Natural peak c lipping
3	59.5 dB at 1000 cps; av. 500-3000 56.2 dB	250 cps-3000 cps	Relatively flat	119.5 dB at 1k cps av. 500-2000 cps, 118 dB. (full gain)	Natural peak clipping
4	62 dB at 1000 cps; av. 500-3000 cps, 56 dB	550 cps-3000 cps	Relatively flat	121 dB at 1k cps av. 500-2000 cps, 115 dB (full gain)	Natural peak clipping
5	62 dB at 1000 cps; av. 500-3000 cps, 60 dB	250 cps-1700 cps	Markedly peaked	112 dB at 1k cps av. 500-2000 cps 114 dB (full gain)	Natural peak clipping

* Measured 15 dB down from the highest area and at a level which provided at least 35 dB gain. These are manufacturers' data. Laboratory measurements showed the effective range for hearing aid 3 to be from 330-2700 cps and for hearing aid 4 from 450-2950 cps, narrowing the assumed difference between these two instruments, all other measurements proved to be close to those given.

distortion tests (see Table 3). Jeffers arranged the hearing aids into four pairs. The four pairs were: (1) hearing aid I, good, high-gain, versus hearing aid II, fair, high-gain, (2) hearing aid III, good, low-gain, vs. hearing aid IV, good, low-gain, (3) hearing aid III, good, low-gain, vs. hearing aid V, poor, low-gain, and (4) hearing aid I, good, high-gain, vs. hearing aid III, good, low-gain. The 34 conductive hearing loss subjects listened to one-minute recordings of cold running speech reproduced through a sound field system. The subject first used one hearing aid of a pair and then the other hearing aid. The subjects were asked to comment on their preferences and describe apparent differences in the hearing aids. The results indicated that the subjects definitely and unambiguously preferred the aids with the more desirable acoustic characteristics.

Jeffers used only patients with conductive hearing loss and, on this basis, generalization to the general hearing aid candidate population is not possible. The results give strong evidence to the ability of persons with conductive lesion to make accurate judgements as to good, fair, and poor hearing aid characteristics.

In the same year Jeffers reported her findings, McConnell, Silber, and McDonald (1960) reported test-retest consistency results of speech reception threshold (SRT) and discrimination scored of patients given clinical hearing aid evaluations. The first portion of the study was designed to determine the test-retest reliability of speech discrimination scores and SRT when the tests were repeated by different clinicians with the same subject wearing the same hearing aid on the same day. A second portion of the study was designed to determine the test-retest reliability of tests repeated by the same clinician, but after two or more weeks following the initial evaluation.

McConnell, Silber, and McDonald (1960) reported that speech discrimination scores were found to have a markedly high degree of test-retest consistency in both test conditions. Coefficients of correlation for discrimination scores ranged from .83 to .92. Aided SRT's were less consistent on repeated testing, with coefficients of correlation ranging from .48 to .68.

Conclusions were that the present tests administered by trained personnel have highly predictive test-retest reliability in hearing aid selection procedures, but other tests and experiences are needed for the hearing aid candidate.

Zerlin (1963) used a paired comparison method to evaluate differences among hearing aids. Six different hearing aids were equated for gain and were presented, in pairs, with an input of cold running speech in the presence of cafeteria noise. The pair of hearing aid outputs were simultaneously recorded onto a dual-channel tape. The procedure was repeated for all possible combinations of pairs of hearing aids. Half-lists of the CID W-22 monosyllabic recordings were also recorded in the same way. The 21 sensorineural hearing loss subjects listened to the 15 pairs of recordings through an earphone, where, by manipulation of a two-position switch, the subjects could alternately listen to either of the recordings. Each subject then made a paired-comparison choice on each set of two hearing aids and ultimately generated a rank-ordered preference series for all six hearing aids. Likewise, each subject was given an intelligibility test with each hearing aid; from these results, an intelligibility score was computed for each of the six hearing aids.

The results of Zerlin's (1963) study showed that five of the six hearing aids tested yielded about the same average intelligibility score. Consequently no significant difference was found between the aids tested in terms of intelligibility; however significant differences were found between aids in the paired comparison test. The results showed that the subjects selected the hearing aid with the best electroacoustic characteristics.

Menzel (1963) reviewed the history of hearing aid fitting procedures and concluded that choosing the optimal combination of electroacoustic characteristics suitable for a given patient is not a simple task and should not be attempted by an untrained person. Menzel expressed the opinion that two principles often overlooked by untrained personnel were that hard-of-hearing persons with sensori-neural lesion cannot always judge the best merits of a hearing aid, and that audiometric tests alone cannot be a basis for a prescription hearing aid fitting. Menzel suggested that if a hearing aid enables a patient to hear and understand faint speech in everyday situations, the main objective has been met. He noted that it is important to remember that people differ in the amount of amplification needed even though the magnitude of hearing loss may be nearly the same. Careful attention should be given to the maximum acoustic gain of the hearing aid in relation to the tolerance of the patient. Menzel mentioned that skillful adjustment of the acoustic output is necessary to prevent distortion by under- or overdriving the hearing aid system. Finally, the author mentioned that the comfort of the ear insert and its effectiveness in delivering the amplified sound to the ear is too important to overlook. The article culminated in a hopeful statement that hearing aid fitting may someday be as accurate as the correction of visual defects by optical means.

In 1966, Reddell and Calvert gave support to the results reached by Zerlin (1963), i.e., that subjects or hearing aid candidates are good judges of hearing aids. Reddell and Calvert suggested that many clinics needed a method of hearing aid evaluation not as time consuming as extensive selective amplification procedures. Reddell and Calvert's study evaluated hearing aid performance with frequency responses that were custom-fitted to each of 24 sensori-neural hearing loss subjects. Two control hearing aids were also selected for each subject through evaluation of audiometric test results by members of an audiological staff. In controlled test conditions, speech reception thresholds, discrimination scores in quiet, and discrimination scores in noise were obtained with CID W-22 Word Lists for each of the two control hearing aids and the experimental hearing aid for each subject. The subjects also rated the three hearing aids subjectively as to order of preference.

The mean speech reception thresholds and discrimination scores in quiet and noise were only slightly better for the experimental aids. However, subjects preferred the experimental hearing aid to the two control hearing aids. The results of Reddell and Calvert are in some ways questionable since only 17 out of the initial 24 subjects' hearing aid preference ratings were calculated and shown in the results. These seven subjects, or 29 percent of the original 24 subjects, could obviously have significantly affected the results presented by Reddell and Calvert, although no reason was given by the authors for the omission of these seven subjects' results.

Jerger (1967) reported the results of four experiments involving hearing aid fitting and use. The four experiments will be reviewed individually with the question that formed the basis of each.

First, is it possible to find a behavioral technique that will differentiate among hearing aids? In answering the question, multiple-choice sentence intelligibility tests (PAL-8) were played through three different hearing aids and recorded on magnetic tape along with a competing speech message at a primary-to-secondary ratio of +6 dB. The three hearing aids were described as follows: (1) Aid "A," flat frequency response and minimal harmonic distortion; (2) Aid "B," peaked frequency response and moderate distortion; and (3) Aid "C," flat frequency response and considerable distortion. The recorded sentence tests were played for six normal listeners over six trials on each hearing aid. Results showed that appropriate sentence test materials would reflect differences in the distortion of various hearing aids in normal ears.

The second question was to determine whether such behavioral differences were smaller, the same, or larger in patients with hearing loss. Six subjects with moderate sensorineural hearing loss were tested with the same procedures as were the normal listeners. The results revealed relatively little difference in sentence speech discrimination between the normal group and the group possessing hearing loss. Differences among hearing aids in terms of sentence speech discrimination were slightly larger in the normal group, implying that differences among hearing aids are at least as important to normal listeners as to hard-of-hearing listeners.

The third question considered by Jerger (1967) was whether differences were the same for all hearing-impaired patients regardless of type or extent of hearing loss. A wide variety of speech materials were recorded through the three experimental hearing aids and played to 36 hearing-impaired subjects which represented every conceivable type and degree of hearing loss for which a wearable hearing aid would be considered appropriate. The 36 subjects were asked to rank the three hearing aids according to preference. The results were that the hearing aids were ranked according to their measurable distortion with all types of speech material. The results obtained with conventional monosyllabic word lists, which were part of the battery of speech material used, were quite ambiguous, however. No pattern seemed to exist for any of the hearing aids or aid-by-listener interaction. Further analysis of the data showed that differences in speech discrimination among hearing aids with different harmonic distortion are larger for mild, flat, conductive losses than for severe, sloping sensorineural losses.

The fourth question Jerger (1967) investigated was that of the optimal technique for differentiating among hearing aids. The Intermodulation Distortion Test (IDT) procedure was designed to test for intermodulation distortion, specifically between input signals of 1000 and 1600 Hertz. A two-channel tape was prepared to carry one channel of "clean" signals, that is, signals directly from signal sources, and another channel of signals as recorded through one of the three hearing aids. The tape was presented to six subjects of unspecified hearing ability under signal-to-noise ratios from -8 to 0 dB in 2-dB steps. Aid "A" produced so little intermodulation distortion that listeners could not easily differentiate the signal recorded through the aid from the "clean" signal until the signal-to-noise ratio was 0 dB, or the most favorable condition. Aid "B" was easily distinguished from the other channel at favorable signal-to-noise ratios, but was not so easily distinguished as the signal-to-noise ratio approached the unfavorable conditions. Aid "C" was easily distinguished from the direct channel, even at the very unfavorable signal-to-noise ratios, because of the intermodulation distortion introduced by this system.

Through the four experiments discussed, Jerger (1967) tested four very basic questions regarding hearing aid fitting procedures. The IDT test outlined by the article seems to warrant further consideration as a test for differentiating among hearing aids.

The present section has been devoted to a review of various articles dealing with the philosophy of selective amplification, more or less following the idea that different people need different hearing aids. In some cases, the ideas presented were directly opposed to those ideas contained in the previous section dealing with the Harvard Philosophy, while, at other times, many points were agreed upon. Some of the viewpoints shared include hearing aid candidate requirements and general ideas of maximum output requirements, or tolerance measurements. Divergent views include the questions regarding the importance of differences in hearing aids to the individual hearing aid candidate, which professional is to actually measure the hearing, decide which aid to fit, order the aid, and subsequently fit the hearing aid to the candidate. Other points of argument consider the follow-up of the patient to ensure satisfaction with the instrument and how to determine, even approximately, which instrument to use for a particular patient.

The next section will deal with two articles that concern master hearing aid use. Perhaps it is worth noting that the literature is very limited in the area of studies involving master hearing aid use.

Studies Advocating Master Hearing Aid Use

Master hearing aids are certainly not new items, as the Davis, et al., study involved the use of a so-called "master hearing aid." More recent developments have resulted in further research into their use. Following are studies discussing the philosophical and practical approaches to master hearing aid usage.

Typically, the master hearing aid has two separate and complete channels, with external microphones which can be mounted on the head for either monaural or binaural reception, or on the body for "conventional" application. Conventional hearing aid parts are used throughout, and otherwise constructed to approximate the distortion characteristics of commercially available hearing aids. There are usually three variables in master hearing aid adjustment: (1) gain (from 30 to 75 dB in 5-dB steps, in one current model); (2) maximum power output (from 110 to 140 dB in 10-dB steps, in one current model); and (3) frequency response adjustment (providing five different frequency responses in one current model).

Bergman (1959) discussed the proposed use of a master hearing aid to arrive at a "prescription" for each patient in the audiology programs. Spokesmen for the Hearing Aid Industry Conference (HAIC), at that time, placed estimates of approximately one million dollars when asked how much the hearing aids were worth which were in the hearing aid banks in the U.S. The sum of one-quarter million dollars was given as the amount lost each year due to obsolescence in these hearing aid banks. For these reasons, the master hearing aid was proposed, namely, to eliminate the necessity of maintaining hearing aid banks at such costs as mentioned.

Bergman discussed several questions regarding variables influencing the benefits of hearing aid use. One question in particular was regarding the selection of a commercial hearing aid after the performance characteristics had been indicated by the master hearing aid. The suggestion was that the patient be given the prescription data and that he be allowed to choose the particular dealer he preferred. Other questions considered the applicability and validity of the master hearing aid as models and characteristics of hearing aids change. Because of these and other questions, further investigation of master hearing aid use was encouraged by Bergman (1959).

Gillespie, Gillespie, and Creston (1965) reported results of a clinical evaluation of a master hearing aid at Walter Reed Army Hospital. Two questions were mentioned. Specifically, (1) is the master hearing aid a time-saver in hearing aid evaluations? and (2) is the accuracy using the master hearing aid procedure comparable with the accuracy using the traditional method of hearing aid selection? The major factors of consideration were gain, maximum output level, and the frequency response. The authors chose to measure these factors and to make subsequent comparisons of hearing aid performance, by measuring the speech discrimination of 24 adult male subjects with primarily sensorineural hearing losses. The master hearing aid was used to determine the maximum tolerable sound pressure, minimum gain requirements, and best frequency response for maximum speech discrimination for 12 patients in group A. A hearing aid was then selected that met the requirements specified by the master hearing aid. Nine of the 12 aids selected were within ± 10 dB in gain and in maximum output of the master hearing aid settings previously chosen for maximum speech discrimination. For group B, 12 patients were originally fitted with hearing aids in the traditional method, and then were evaluated with the master hearing aid. With the exception of one gain setting, all 12 hearing aids utilized by the patients in group B met the ±10dB criteria in gain and maximum output level. However, even though the master hearing aid technique seemed to be as accurate as the traditional method of fitting hearing aids, the authors decided that the master hearing aid technique does not save appreciable time in a hearing aid evaluation. Also, the authors noted the importance of patient counseling to hearing aid satisfaction, regardless of the method used.

These studies have illustrated the rationale and typical procedure followed in connection with master hearing aid use in a clinical program. The present section was intended to introduce the next section, which will be devoted to a description of the philosophy and procedures utilized at Utah State University in evaluating hearing aid candidates with the master hearing aid, providing them with hearing aids, and counseling them appropriately. It may be appropriate to note in passing that it was under the procedures outlined below that the subjects involved in the present study obtained the wearable hearing aids utilized in part of the experimentation to be described in the third chapter.

The U.S.U. Rationale and General Procedures

The method of hearing aid evaluation used by the staff of audiologists at Utah State University involves three separate individuals. The three persons concerned in the program are the audiologist, otolaryngologist, and commercial hearing aid dealer. Each person involved provides that portion of the total service package in which he is specifically trained and which he is uniquely prepared to provide. The steps typically followed are outlined below.

The first step involves a medically related audiometric evaluation to determine the degree and type of hearing loss demonstrated by the patient. The otolaryngologist decides concerning whether or not the hearing loss is medically or surgically correctable. If medical or surgical treatment is not possible, a determination relative to hearing aid candidacy is made. The patient's needs for amplification are explored both subjectively and objectively by an audiologist. Case history information, data from questionnaires, and audiological data are utilized in determining hearing aid candidacy. In terms of the prognosis, probable benefits and drawbacks of hearing aid use are discussed at length with the patient. If, at this point, it is jointly decided by the patient and the audiologist that a hearing aid is needed and is usable, determination of the particular instrument requirements is accomplished through use of the master hearing aid. The exact procedure will be discussed in the next section. A reasonable estimate of benefit can be made at this point in the evaluation, and a decision is reached as to whether or not to order a hearing aid. At this point, the patient is given an option to obtain the hearing aid through any commercial hearing aid dealer, or through the hearing aid dispenser. If the second option is chosen, an instrument is ordered, the patient is fitted with the required hearing aid, and a follow-up evaluation is given by the audiologist at the U.S.U. hearing clinic. In either case, a commercial hearing aid dealer obtains a hearing aid according to the particular specifications obtained using the master hearing aid. The commercial hearing aid dealer handles the service and repair of the hearing aid, billing of the patient for the cost of the hearing aid, and handles insurance provided by the hearing aid manufacturer. If the patient chooses the second option, the aid(s) may be obtained on a trial basis through the hearing aid dispenser, and returned to the manufacturer by the audiologist if the patient elects not to purchase the hearing aid subsequent to the trial period. Routine counseling of the patient occurs at 6 to 12 weeks after the fitting of the hearing aid, and again before the 12-month warranty on the hearing aid expires.

The program at U.S.U. was initiated early in 1971. The total cost to the patient for the hearing aid and audiological hearing aid evaluation usually is the same or slightly less than if he were to rely totally upon the services of a traditional commercial hearing aid dealer. Under the U.S.U. procedure, the patient receives professional service from each specialist at appropriate times in the evaluation process. The program conforms completely to the American Speech and Hearing Association Code of Ethics, allows the hearing aid dealer to operate freely within his domain, and allows the audiologist to obtain a fee for the services rendered to the patient.

As a result of services rendered on the part of the audiological staff at U.S.U., the hearing aid dispensary was conceived. Under the dispensary program, the hearing aid itself costs considerably less than through a traditional hearing aid dealer. A profit is available to the commercial hearing aid dealer operating the dispensary, and the audiologist obtains reasonable and ordinary fees for the initial evaluation, subsequent counseling, fitting of the hearing aid, and all follow-up checking with the hearing aid patient.

The U.S.U. Master Hearing Aid Evaluation

A key part of the general procedure described above is the actual clinical hearing aid evaluation using the master hearing aid at U.S.U. This procedure will be discussed in detail in the present section.

Specifically, at the point in the general course of events where the patient and the audiologist discuss the needs of the patient and the probable benefits and limitations of hearing aid use, the patient makes a decision to either obtain an aid permanently, on a trial basis, or not to obtain an aid at all. If either of the two former choices is made, the following procedure is typically used.

The patient is placed in a sound-treated environment when available, and the master hearing aid receivers are placed on the patient's ears. The channel of the master hearing aid corresponding to the ear of the patient selected as the most suitable for amplification is activated by turning the pitch control to #2, or flat response. Next, the gain control is rotated while the audiologist talks in a normal-intensity voice. The patient is instructed to indicate when the speech he hears is comfortably loud. The average gain for three trials is noted. The audiologist continues to talk at approximately conversational intensity, and asks the patient to note the quality of amplification, so as to make a judgement of preference as the audiologist changes to other frequency responses and gain settings. At each frequency response, the gain control is rotated to achieve comfortable loudness by taking an average of three trials. In this way, a comfort level is established for each pitch setting utilized in the hearing aid evaluation. After the patient selects one frequency response as the preferred "pitch," and the comfort level is established at that "pitch", the patient's tolerance limits using that pitch setting are explored. The patient is asked to report when the intensity becomes distinctly "unpleasant", such that he would definitely not want to listen to the speech at that intensity. The average of three trials is noted and the appropriate compression setting on the master hearing aid is selected.

After the data regarding the patient's pitch, comfort level, and maximum output level preferences are set on the master hearing aid, speech reception threshold testing and speech discrimination testing is accomplished. In speech discrimination testing, the input to the hearing aid microphone is approximately the intensity of normal conversational speech (65-70 dB SPL). If the patient performs as well as can be expected considering his loss of hearing, an aid is ordered using the specifications obtained with the master hearing aid. If the patient does not perform satisfactorily, another frequency response is utilized, and additional SRT and discrimination data is obtained. If the patient does not, for some reason or another, perform satisfactorily with any configuration of master hearing aid settings, or if the patient feels that the hearing aid will not satisfactorily improve his hearing, no hearing aid is ordered. If there is some question relative to the ability to profit from a hearing aid, an aid may be ordered on a trial basis. If an aid is to be obtained, an earmold impression is taken of the patient's ear, and an appropriate earmold is ordered.

This concludes the discussion of the hearing aid evaluation procedures used at U.S.U. involving the master hearing aid. Because of the limited funds available at U.S.U., no attempt has been made for the University to maintain a hearing aid inventory. Furthermore, the population density in the area surrounding U.S.U. is such that a dealer-contributed hearing aid inventory is economically not feasible from the standpoint of the number of referrals. Utilization of the master hearing aid provides a solution to these problems; furthermore, the master hearing aid is portable, and is easily used in the evaluation rooms of otolaryngologists' offices.

However, the staff of audiologists at Utah State University have been concerned as to the benefit patients have received from their hearing aids as compared to the predicted benefit on the basis of the master hearing aid evaluation given each patient. Specifically, the following questions have arisen:

(1) How does the speech reception threshold a patient obtains with his own wearable hearing aid compare with the SRT's obtained with the two systems of the master hearing aid?

(2) How does the speech discrimination score obtained in quiet obtained by a patient wearing his own hearing aid compare with the speech discrimination scores obtained in quiet using each of the two microphone-receiver systems of the master hearing aid?

(3) How does the speech discrimination score obtained in noise with the patient utilizing his own wearable hearing aid compare with the speech discrimination score obtained using the headset system of the master hearing aid, and the ear-level system of the master hearing aid?

The above questions form the basis of the present study. In an attempt to provide answers to the above questions, the procedures outlined in the following chapter were developed. In brief, it is the goal of the present investigation to provide answers to the questions specified above regarding the use of the master hearing aid as a tool in hearing aid evaluation procedures.

CHAPTER III

SUBJECTS, APPARATUS, AND PROCEDURES

Introduction

The previous chapter has illustrated the need for investigation into the usefulness of the master hearing aid procedure in use at Utah State University. The literature reviewed in the previous chapter reflects significant variance in results and conclusions and suggests a need for further research in the area of hearing aid evaluation. Also, until the present, usefulness of the procedures currently in use at U.S.U. were unresearched. As a result, a need existed for investigation of results obtained through use of the master hearing aid.

The present study was designed to research the utility of master hearing aid use in predicting the speech reception threshold and speech discrimination scores achieved by a particular patient with a wearable hearing aid procured on the basis of master hearing aid data. Basically, the research involved the testing of 20 subjects who had previously obtained hearing aids under the U.S.U. procedures. A speech reception threshold (SRT), a speech discrimination score in quiet, and a speech discrimination score in noise was obtained from each subject in each of the four following conditions: (1) without amplification, (2) with the subjects own wearable hearing aid, (3) with the headset, or yoke system of the master hearing aid, and (4) with the ear-level attachment of the same master hearing aid (See Figure 1).

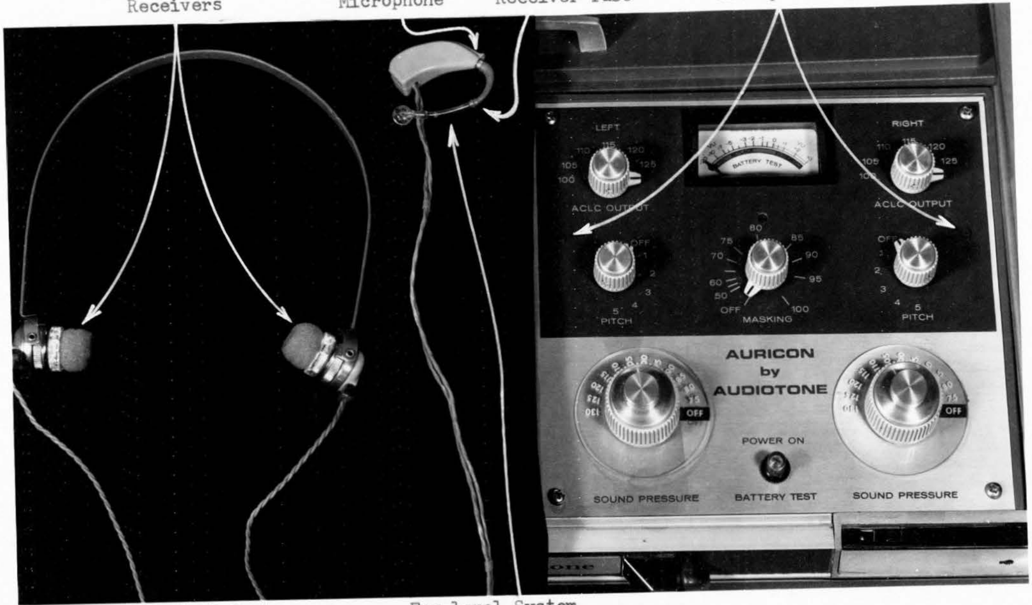


Figure 1. Control panel of master hearing aid

Subject characteristics, experimental apparatus, and procedures are detailed further in the following sections.

Experimental Subjects

Sample Description

Subjects comprising the experimental sample of the present study were selected from the population of individuals who were evaluated audiologically by the Utah State University audiological staff after having been examined medically by an otolaryngologist. Each subject received a hearing aid evaluation using the master hearing aid technique as outlined in the previous chapters, and subsequently obtained a hearing aid on either a permanent or trial basis. The data used in ordering specific hearing aids was that generated using the master hearing aid. The sample included 20 hearing aid candidates ranging in age from seven to 86 years, with a mean age of 58.2 years, and a standard deviation of 21.6 years. Seven of the 20 subjects were female. Of the 20 subjects, 13 had hearing losses diagnosed as primarily sensorineural and the remaining seven possessed mixed hearing losses. The mean pure-tone average for the sample was 46.4 dB HL.

Subject Invitation

A form letter, shown in Appendix A, was mailed to prospective subjects. The letter explained the purpose of the proposed testing and asked for the cooperation of the letter recipient. Subsequently, an appointment was arranged by telephone for the required testing. Most of the possible subjects agreed to the proposition that additional research was needed in the area of hearing aid evaluation and submitted to testing. Of 30 people contacted, 20 subjects responded affirmatively, two could not come due to illness, one was out of town, and one person was dissatisfied with his hearing aid to the extent that he did not wish to participate. In all, 67 percent of the possible hearing aid candidates responded positively, in that they submitted to testing.

Preparation of Test Materials

It was necessary to prepare a magnetic tape with eight phonetically balanced monosyllabic word lists for the discrimination testing required in the present study. The 50-word lists were prepared using the apparatus and procedures outlined below.

Apparatus

Equipment and materials used in the preparation of the speech discrimination test materials utilized in the present study included the following: a sound-treated test booth (Industrial Acoustics Corporation, Model 1202); stereo tape recorder (Sony, Model TC-630); condenser microphone (Sony, Model ECM-22) with associated cathode follower; magnetic recording tape (Sony, Type SLH-180); audio oscillator (Hewlett-Packard, Model 200 AB); universal counter-timer (Computer Measurements Company, Model 605A); graphic level recorder (Bruel and Kjaer, Type 2305); and the phonetically balanced monosyllabic word lists as revised by Peterson and Lehiste (1967).

Recording of Test Materials

Before recording the Peterson and Lehiste word lists, it was necessary to record a calibration tone at the beginning of the tape.

Recording of the calibration tone on the tape was accomplished in the following way. The intensity of the 1000 Hz pure tone produced by the audio oscillator was adjusted using the graphic level recorder. The intensity was set so that the level on the tone could be matched to the level of the carrier phrases in the recorded speech material. The 1000 Hz pure tone was recorded at a -2 dB VU meter reading for a time period of 10 seconds at the beginning of the tape. A graphic illustration of the relationship between the pure tone and the speech material is contained in Figure 2. The frequency accuracy of the 1000 Hz pure tone was monitored continuously using a universal counter-timer.

The CNC test lists prepared by Peterson and Lehiste (1967) were recorded in the following way. The microphone was placed in the test room of the sound-treated test suite. The microphone cord led through the walls of the audiometric suite to the microphone input jack of the tape recorder located in the control room of the audiometric suite. The arrangement is shown in Figure 3. Monitoring of the VU meter continued throughout the recording of the eight CNC word lists used in the present study to insure a variance of no more than $\pm$ 2 dB in the peaks of the carrier phrase "say the word". No attempt was made to peak each individual CNC word to a particular level. As can be seen in Figure 2, the signal-to-noise ratio of the recording is at least as good as 40 dB. A time lapse of five seconds was used between the onset of each successive carrier phrase to allow sufficient time for subjects to respond to the stimulus word.

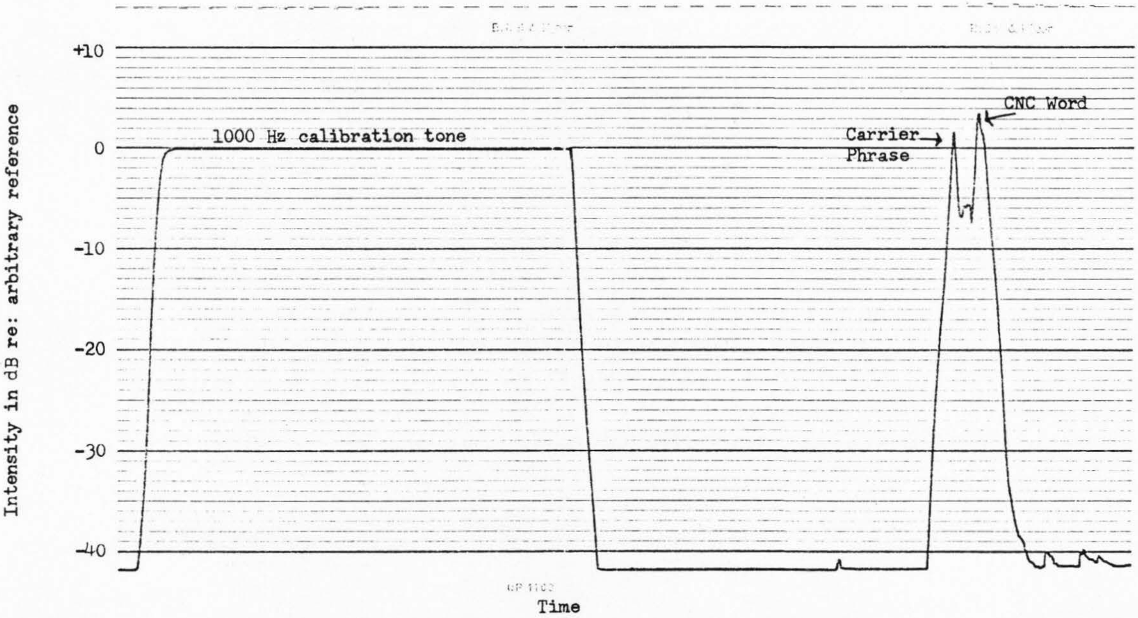


Figure 2. Recording of the relation between the level of the calibration tone and the level of the first carrier phrase and CNC word.

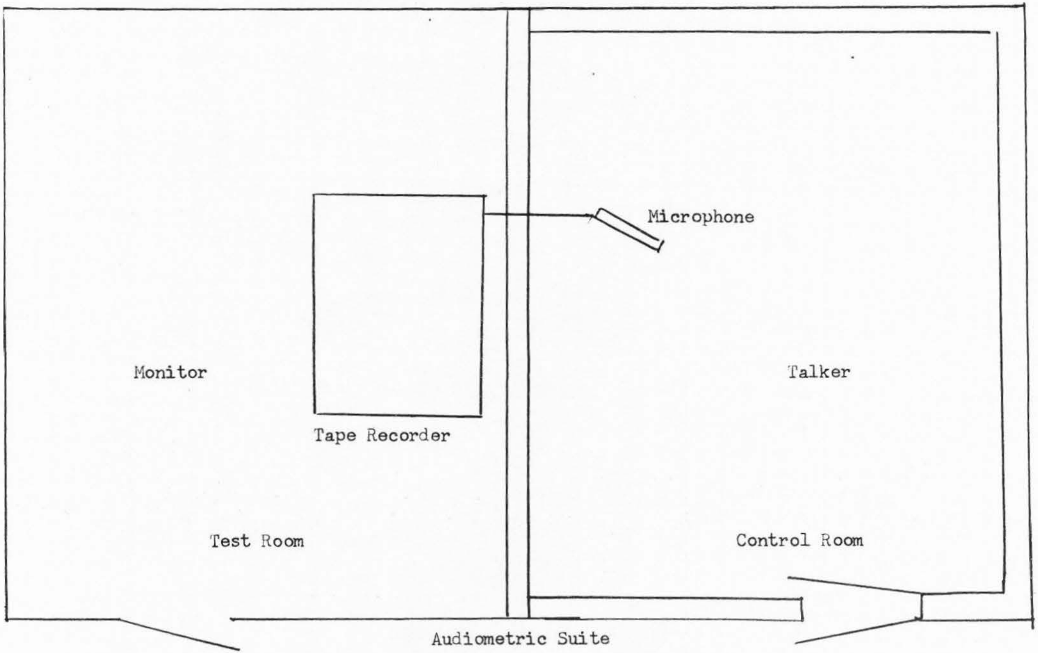


Figure 3. Equipment arrangement for speech material preparation

Test Situation

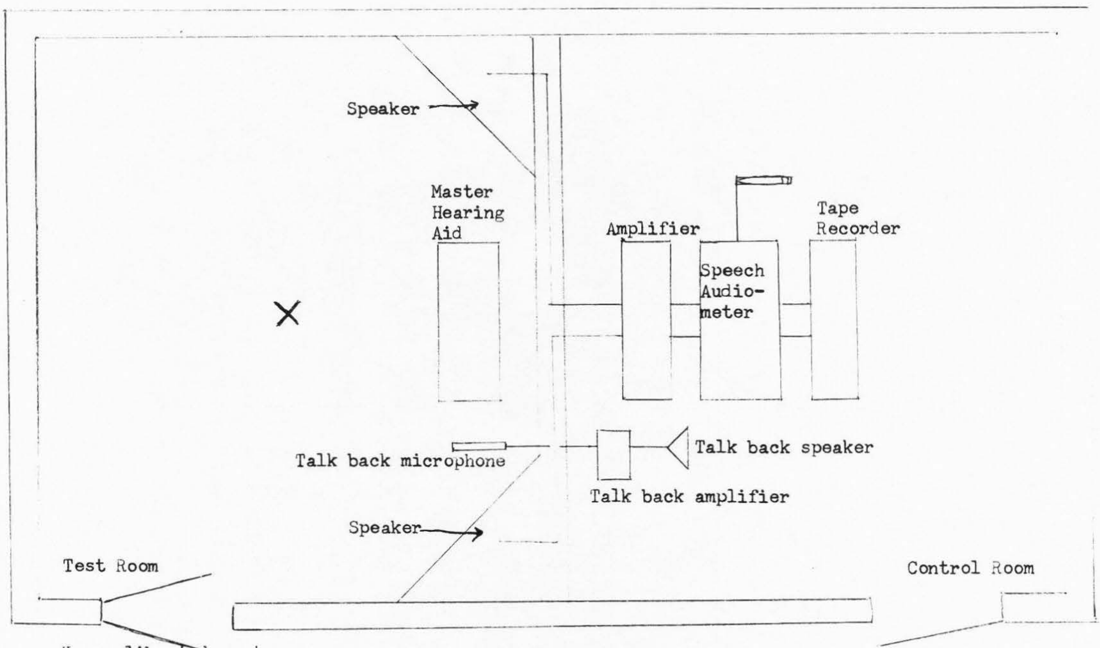
Apparatus

Equipment and materials used in the actual experimental portion of the present study included the following: a sound-treated test suite (Industrial Acoustics Corporation, Model 1603A); stereo tape recorder (Sony, Model TC-252D); speech audiometer system (Grason-Stadler, Model 162-4) with associated microphone (Altec, Model 628A), amplifier (McIntosh, Type M224), and Altec speakers; master hearing aid (Audiotone, Model AA-5); Peterson and Lehiste Revised CNC Word Lists as recorded in the manner previously discussed; spondee word list; and each subject's personal hearing aid.

Equipment Arrangement

The equipment specified above was arranged in the following ways in obtaining experimental data. The two channels of the stereo tape recorder were connected to the right and left channels of the speech audiometer and both were located in the control room of the sound-treated test booth. The associated speakers of the speech audiometer were located in the test room. The equipment arrangement is shown in Figure 4. The master hearing aid shown in Figure 1 was situated in the test room of the audiometric suite so that the microphone of the test instrument (master hearing aid or subject's own hearing aid) being utilized by the subject was situated one meter from the center of each speaker (See Figure 4). Specifically, in one condition involving the use of the master hearing aid, the microphone was placed on the ear of the subject and connected by wire to the chassis of the master hearing aid. In the other condition involving the use

Audiometric Suite



X = calibrated spot

Figure 4. Equipment arrangement in test situation

of the master hearing aid, the microphone was situated on the chassis of the master hearing aid, while the receiver was mounted in a headset (See Figure 1). Because of the two locations of the microphones, movement of the master hearing aid was necessary in order to position the microphones at the calibrated test point in the test room.

Calibration

Calibration of the equipment arrangement described above was necessary to insure that each subject was tested with the same intensity of stimulus in the test room of the audiometric suite. Calibration of the above named experimental apparatus as connected and used involved use of a sound level meter (Bruel and Kjaer, Type 2203) with associated octave band filter set (Bruel and Kjaer, Type 1613). The sound level meter was placed in the approximate position of the head of the experimental subjects. This was exactly one meter from each speaker. The taped calibration tone and speech material was then presented alternately through each channel of the speech audiometer at a 50 dB hearing level, and the sound pressure level (SPL) was noted. Initial calibration revealed the HL dial settings of 50 dB yielded 69.5 (±2) dB SPL at the calibrated spot in the test booth. Periodic calibration during and after the data gathering process yielded the same results. No corrections were necessitated at any time in the data gathering period.

Test Procedures and Test Sequence

The subjects involved in the present study were given a speech reception threshold test and speech discrimination tests in quiet and in noise. The testing was accomplished in the test booth of the audiometric suite without benefit of amplification and under three conditions involving the use of an amplification system. Specifically, each subject was tested: (1) without benefit of amplification; (2) using his own hearing aid; (3) using the master hearing aid with the ear-level microphone and receiver system; and (4) using the master hearing aid with the external hearing aid receivers mounted in a yoke and microphones mounted on the chassis of the master hearing aid.

Under each of the four conditions outlined above, each subject was given three tests: (1) Speech Reception Threshold; (2) speech discrimination as obtained at 50 dB HL in quiet; and (3) speech discrimination as obtained at 50 dB HL in the presence of white noise presented at a speech-to-noise ratio of 6 dB. The speech ratio of 6 dB was chosen to make the listening task considerably difficult and, consequently, more sensitive to differences in the amplification systems, according to Viehweg, (1968).

The order of presentation of the speech discrimination test lists was quasi-counterbalanced to avoid systematic order effects. Table 4 contains the actual order of presentation of the CNC word lists under the various conditions to each of the 20 subjects involved in the present investigation.

All speech materials, i.e., spondee words presented by the monitored live voice technique, and the taped CNC word lists, were presented to the subject from the monaural direct speaker, while the noise was presented from the alternate, or monaural indirect speaker. All CNC word lists were presented at a hearing level of 50 dB HL, which represents the approximate level of normal conversational speech. There were two exceptions where tolerance problems required the use of

Table 4. Order of presentation of discrimination test lists for the various test conditions*

Test Lists	Subjects 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	WQ	HQ	EQ	WQ	HQ	WQ	WQ	WQ	WN	WQ	WQ	UQ	WN	HN	UN	UN	HN	UN	EN	UQ
2	WN	HN	EN	WN	HN	WN	WN	WN	WQ	WN	WN	UN	WQ	HQ	UQ	UQ	HQ	UQ	EQ	UN
3	UQ	UQ	HQ	UQ	EQ	HQ	UQ	HQ	UQ	EN	EQ	HN	UN	WN	EN	HN	EN	WN	WQ	WQ
4	UN	UN	HN	UN	EN	HN	UN	HN	UN	UQ	EN	HQ	UQ	WQ	EQ	HQ	EQ	WQ	WN	WN
5	HQ	WQ	UQ	EQ	WQ	EQ	HQ	EQ	EQ	UN	UQ	EQ	HN	UN	HN	WN	UN	HN	HN	EN
6	HN	WN	UN	EN	WN	EN	HN	EN	EN	HQ	UN	EN	HQ	UQ	HQ	WQ	UQ	HQ	HQ	EQ
7	EQ	EQ	WQ	HQ	UQ	UQ	EQ	UQ	HQ	HN	HQ	WN	EN	EN	WN	EN	WN	EN	UN	HN
8	EN	EN	WN	HN	UN	UN	EN	UN	HN	EQ	HN	WQ	EQ	EQ	WQ	EQ	WQ	EQ	UQ	HQ

*WQ = Subject tested in quiet with wearable hearing aid
WN = Subject tested in noise with wearable hearing aid
EQ = Subject tested in quiet with ear-level receiver, master hearing aid
EN = Subject tested in noise with ear-level receiver, master hearing aid
HQ = Subject tested in quiet with headset receiver, master hearing aid
HN = Subject tested in noise with headset receiver, master hearing aid
UQ = Subject tested in quiet without amplification, unaided
UN = Subject tested in noise without amplification, unaided

a lower level. In these two cases, a hearing level of 40 dB HL was used in the aided condition in noise.

In review, each subject was given the following tests: SRT, speech discrimination in quiet at 50 dB HL, and speech discrimination at 50 dB HL in the presence of white noise at a 6 dB speech-to-noise ratio under each of the following conditions:

(1) without the benefit of amplification;

(2) with the headset attachment of the master hearing aid;

(3) with the ear-level attachment of the master hearing aid; and

(4) with his own wearable hearing aid.

Under each of the conditions involving the use of an amplification system, the "comfort level" approach was used to determine the appropriate level of gain to use on the instrument. Specifically, while the experimenter talked at normal conversational intensity, the subject selected the gain setting which was "most comfortable". The subjects were instructed to choose a gain setting under each condition of amplification which approximated the gain produced by their wearable hearing aid.

The present chapter has described procedures used to test the research questions posed in the second chapter of the present investigation. The next chapter will describe and discuss the results of testing the 20 subjects under the conditions outlined in the present chapter. Specifically, the average SRT, speech discrimination score in quiet, and speech discrimination score in noise obtained by the subjects under three aided conditions and without amplification will be reported and discussed.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The procedures and materials specified in the previous chapter were designed to test the feasibility of the master hearing aid procedure of hearing aid evaluation used at Utah State University as described in Chapter II. The 20 subjects were each tested to obtain the speech reception threshold and speech discrimination scores in quiet and noise. The above measures were obtained without amplification, with the subjects' wearable hearing aid, with the headset system of the master hearing aid, and with the ear-level system of the master hearing aid. Clawson (1972), a co-study, obtained sound field pure tone thresholds of the same 20 subjects under the four conditions listed above, and assessed subject satisfaction versus subject need by means of questionnaires.

The results of the present study will be reported according to the following format. The results of testing the subjects without amplification will be reported and described first for later comparison with results from the aided conditions. The results obtained from testing subjects with the headset, or yoke, system of the master hearing aid will follow. The results of testing the subjects with the ear-level system of the master hearing aid will be reported third, and finally, the results obtained from testing the subjects using their own wearable hearing aid will be presented. The reason for the above ordering relates to the fact that the results generally improve from system to system in the above order and presentation in the above manner will facilitate comparison somewhat.

The data was treated to provide central tendency data in the form of a mean speech reception threshold, a mean speech discrimination score in quiet, and a mean speech discrimination score in noise at a 6 dB speech-to-noise ratio under each of the four test conditions specified above. Ranges of scores and standard deviations from the means were calculated to provide data relative to variance or dispersion. In order to answer the basic research questions, the data was analyzed using the analysis of variance (ANOV) technique.

ANOV tests were completed involving the SRT, the speech discrimination score in quiet, and the speech discrimination score in noise obtained by testing the subjects with: (1) the headset system of the master hearing aid, (2) the ear-level system of the master hearing aid, and (3) the subjects' wearable hearing aids.

The test condition involving non-use of an amplification system was included for comparison purposes only, and was not included in the ANOV tests.

Comparison of Mean and Variance Data in Four Experimental Conditions

Speech Audiometric Testing Without Amplification

Speech Reception Threshold (SRT)

Data relating to SRT's obtained with the subjects in the unaided condition were as follows: Mean = 29.4 dB; standard deviation = 10.2

dB; range = 40.0 dB (from 10 to 50 dB). These values are shown graphically in Figure 5, column 2, and numerically in Table 5, column 2.

The above data illustrate that the average subject involved in the present study had a mild loss for speech, as measured using the speech reception threshold test. The grouping of the unaided SRT's was fairly homogeneous, as evidenced by the standard deviation of 10.2 dB, but variance within the sample was noted by the range of 40.0 dB.

Speech Discrimination in Quiet

Speech discrimination testing at normal conversational intensity (70 dB SPL) in a quiet atmosphere without amplification yielded the following results: Mean = 78.0%; standard deviation = 23.9% and range = 100% (from 0 to 100%). This data is graphically illustrated in Figure 6, column 2 and is tabulated in Table 6 under column 2.

The above description of the averaged discrimination results can be interpreted to mean that, under optimum conditions, the average subject in the present study had considerable difficulty understanding speech at normal conversational intensity. However, an analysis of the range illustrates that some subjects experienced little or no difficulty understanding speech at normal conversational intensity, while other subjects experienced severe difficulty or total failure at the discrimination task.

Speech Discrimination in Noise

Speech discrimination scores obtained at normal conversational intensity (70 dB SPL) in the presence of white noise at a 6 dB speech-to-noise ratio without amplification is described as follows: Mean = 72.3%; standard deviation = 22.9%; and range = 100.0% (from 0 to

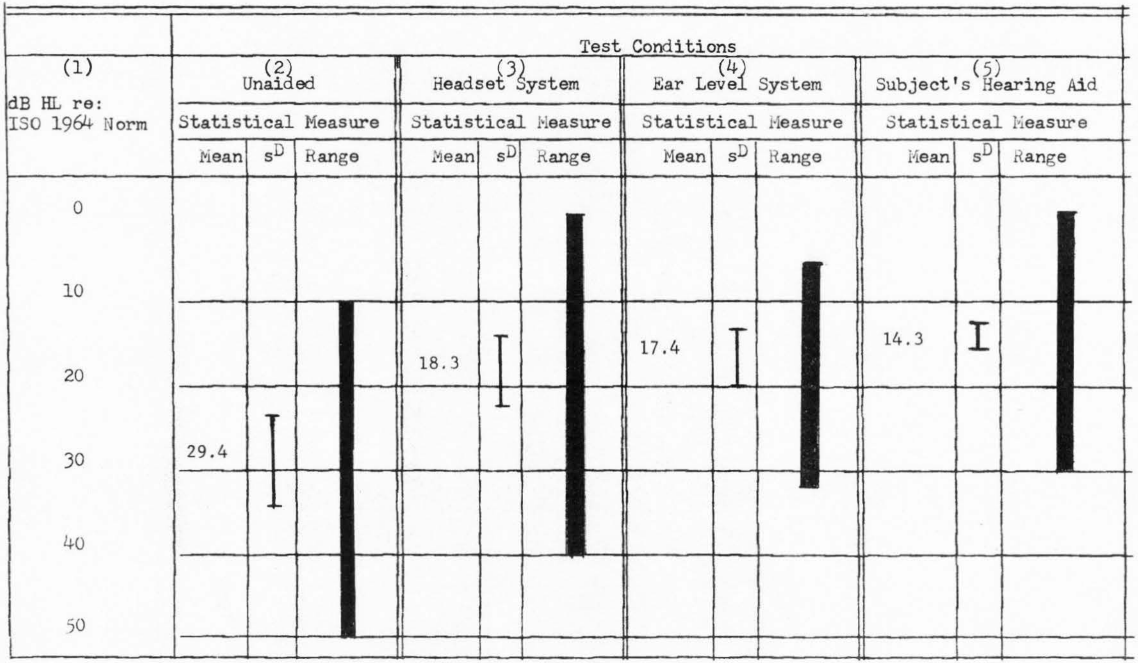


Figure 5. Data relating to speech reception thresholds under four experimental conditions

Table 5. Data relating to speech reception thresholds under four experimental conditions

(1) Statistical Measure	Experimental Condition			
	(2) Unaided	(3) Headset System	(4) Ear-level System	(5) Wearable Hearing Aid
Mean ($\overline{x}$)	29.4 dB	18.3 dB	17.4 dB	14.3 dB
Standard Deviation (s^D)	10.2 dB	8.4 dB	6.4 dB	2.4 dB
Range	40.0 dB	32.0 dB	22.0 dB	28.0 dB

Table 6. Data relating to speech discrimination scores obtained in quiet at 50 dB HL

(1) Statistical Measure	Experimental Condition			
	(2) Unaided	(3) Headset System	(4) Ear-level System	(5) Wearable Hearing Aid
Mean ($\overline{x}$)	78.0%	86.8%	87.5%	89.2%
Standard Deviation (s^D)	23.9%	9.1%	11.9%	11.8%
Range	100.0%	36.0%	50.0%	44.0%

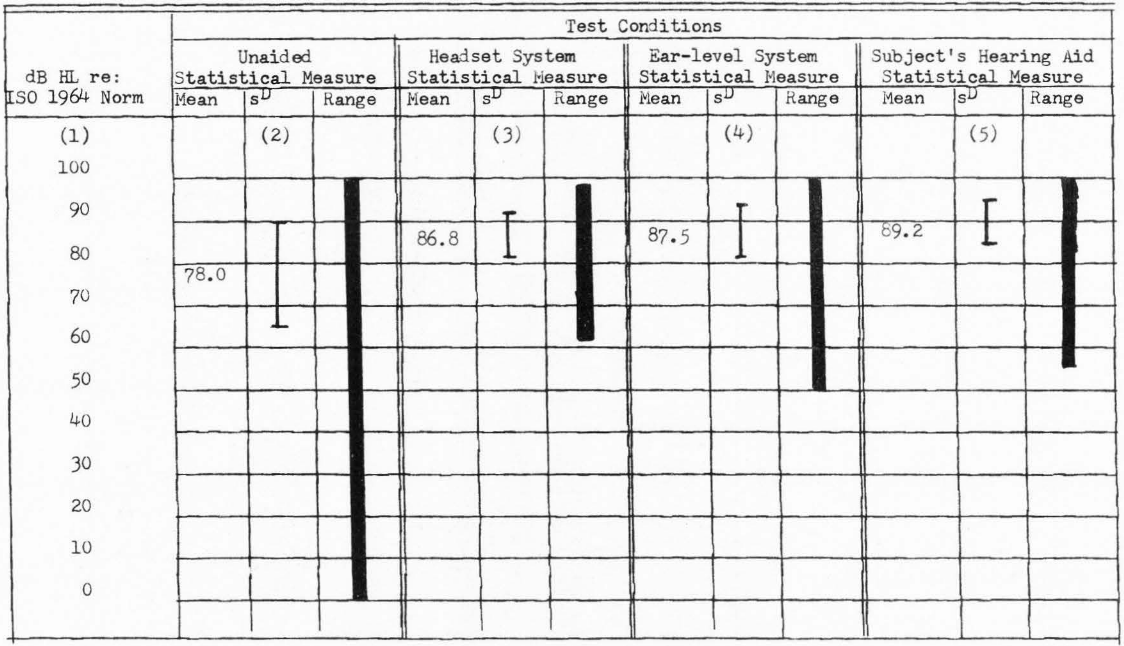


Figure 6. Data relating to speech discrimination scores obtained in quiet at 50 dB HL

100%). This data is contained in Figure 7, column 2, and is tabulated in Table 7 under column 2.

Upon comparing the mean unaided speech discrimination score obtained in quiet with the mean unaided discrimination score obtained in noise, a decrease of 5.7 percent is noted. This data indicates that, even with a fairly severe speech-to-noise ratio, the average subject suffered only a slight (5.7 percent) decrease in speech discrimination.

Analysis of the above data again illustrates the wide variance of speech discrimination ability possessed by the subjects involved in the present study. The large standard deviation and range of 100 percent show that some subjects had no difficulty with the speech-in-noise task, while other subjects experienced considerable or total frustration in attempting to understand speech at 70 dB SPL at a +6 dB speech-to-noise ratio.

Speech Audiometric Testing with Headset of Master Hearing Aid

Speech Reception Threshold (SRT)

SRT's obtained by testing the subjects with the headset containing the external receivers and using the remote microphones, as shown in Figure 1 were as follows: mean = 18.3 dB; standard deviation = 8.4 dB; and range = 32.0 dB (from 2 to 34 dB). The above data are illustrated in Figure 5, column 3, and is numerically presented in Table 5, column 3.

The data listed above show that the average subject tested received 11.1 dB of gain, or improvement, over the unaided SRT when using the headset or yoke system of the master hearing aid.

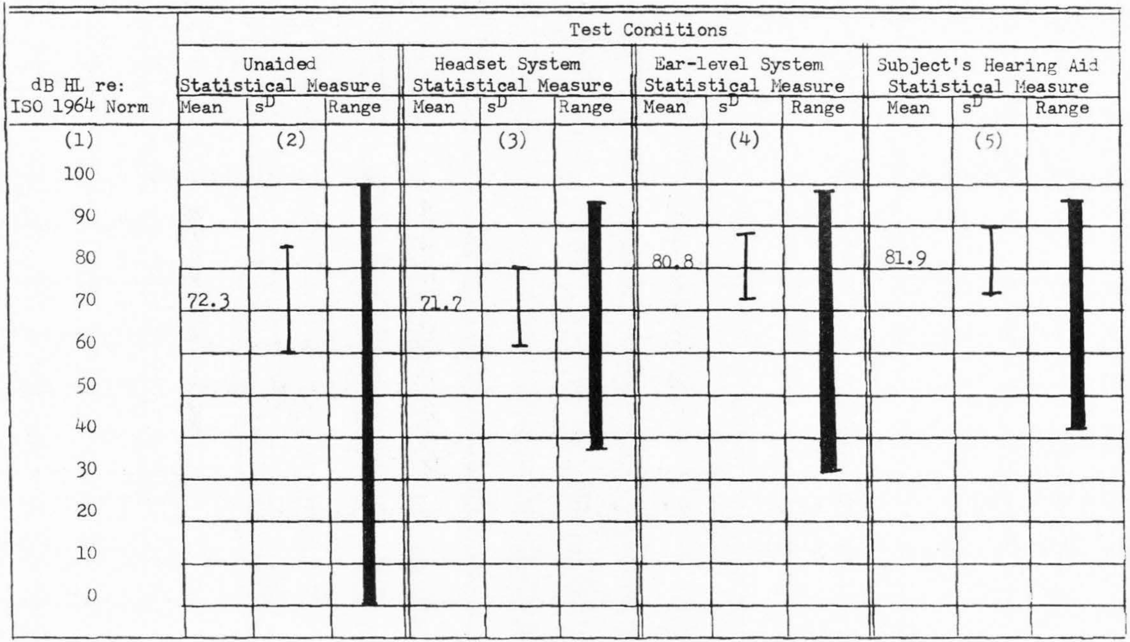


Figure 7. Data relating to speech discrimination scores obtained at 50 dB HL, 6 dB speech-to-noise ratio

Table 7. Data relating to speech discrimination scores obtained in noise at a speech-to-noise ratio of +6 dB

	Experimental Condition			
(1) Statistical Measure	(2) Unaided	(3) Headset System	(4) Ear-level System	(5) Wearable Hearing Aid
Mean ($\bar{x}$)	72.3%	71.7%	80.8%	81.9%
Standard Deviation (s^D)	22.9%	17.1%	13.6%	15.4%
Range	100.0%	54.0%	66.0%	54.0%

Speech Discrimination in Quiet

Group data relating to speech discrimination scores of experimental subjects obtained through the headset arrangement of the master hearing aid in quiet were as follows: mean = 86.8 percent; standard deviation = 9.1 percent; and range = 36.0 percent (from 62 to 98 percent). The data specified is illustrated in Figure 6, column 3, and is tabulated in Table 6, column 3.

The above data illustrate that the mean speech discrimination score obtained using the headset system is better than the mean unaided discrimination score by 8.8 percent. Also, the standard deviation associated with the mean discrimination score obtained in the headset condition is about one-half the size of the standard deviation associated with the mean discrimination score obtained in quiet without amplification. The ranges differ substantially in the same manner, as shown in Figure 6, columns 2 and 3.

Speech Discrimination in Noise

Speech discrimination scores obtained at conversational intensity (70 dB SPL) in a background of noise at a speech-to-noise ratio of 6 dB when the subjects were required to listen through the headset system of the master hearing aid are as follows: mean = 71.7 percent; standard deviation = 17.1 percent; range = 54.0 percent (from 38 to 96 percent). The above data is illustrated in column 3 of Figure 7, and tabulated in column 3 of Table 7.

The above data show that the average subject in the present study obtained a slightly poorer (0.6 percent) speech discrimination score under the headset amplification system of the master hearing aid than under the unaided condition when tested for speech discrimination in noise.

Speech Audiometric Testing With Ear-Level System of Master Hearing Aid

Speech Reception Threshold (SRT)

SRT's obtained from experimental subjects through use of the ear-level microphone system of the master hearing aid are described as follows: mean = 17.4 dB; standard deviation = 6.4 dB; and range = 22.0 dB (from 8 to 30 dB). These results are graphically represented in column 4 of Figure 6, and are tabulated in column 4 of Table 6.

The data listed above indicate that the mean SRT obtained using the ear-level microphone and receiver is slightly better (0.9 dB) than the average SRT obtained with the headset system of the master hearing aid. Also, the standard deviation and range associated with the SRT obtained with the ear-level system are smaller than the corresponding data associated with the mean SRT obtained under the headset system of the master hearing aid.

Speech Discrimination in Quiet

Speech discrimination scores obtained at normal conversational intensity (70 dB SPL) in a quiet environment from subjects tested with the ear-level microphone system are as follows: mean = 87.5 percent; standard deviation = 11.9 percent; range = 50.0 percent (from 50 to 100 percent). This information is shown graphically in column 4 of Figure 6. The data is listed numerically in column 4 of Table 6.

The data listed above can be interpreted in the following manner. The average subject improved in speech discrimination by 9.5 percent when using the ear-level system of the master hearing aid as opposed to no amplification. A very slight difference (0.7 percent) was noted favoring the ear-level system of the master hearing aid over the headset system of the master hearing aid.

Speech Discrimination in Noise

Data relative to discrimination of speech at conversational intensity (70 dB SPL) in a background of noise (speech-to-noise ratio of 6 dB) using the ear-level system of the master hearing aid are as follows: mean = 80.8 percent; standard deviation = 13.6 percent;

range = 66.0 percent (from 32 to 98 percent). Figure 7, column 4, contains a graphical representation of data, and tabulation of the data occurs in column 4 of Table 7.

The above data indicate that noise affected the subjects' average speech discrimination less with the ear-level system of the master hearing aid (8.4 percent) than with the headset system of the master hearing aid (15.1 percent). The average improvement in discrimination over the unaided condition was 8.5 percent with the ear-level system of the master hearing aid, which is approximately the same as the improvement noted in quiet.

The standard deviation associated with the mean speech discrimination score obtained under the ear-level condition in noise is smaller than the standard deviation associated with the mean speech discrimination score obtained with the headset system in noise. The range associated with the headset system in noise is smaller than the range associated with the ear-level system in noise. These data indicate that, as a group, subjects perform more homogeneously with the ear-level system, but that some individual subjects' discrimination was affected more by noise with the ear-level system of the master hearing aid than with the headset system.

Speech Audiometric Testing With Wearable Amplification

Speech Reception Thresholds (SRT)

SRT data obtained by testing experimental subjects with their own wearable hearing aid are described as follows: mean = 14.3 dB; standard deviation = 2.4 dB; range = 28.0 dB (from 2 to 38 dB). The information is illustrated graphically in column 5 of Figure 5 and is shown numerically in column 5 of Table 5.

The average improvement in the SRT supplied by the wearable hearing aids was 14.9 dB over the SRT obtained in the unaided condition. Note that mean unaided SRT was 29.4 dB, which falls into the range of mild hearing loss, while the mean SRT, with wearable hearing aids, is within normal limits. The mean SRT obtained under the wearable hearing aid condition is better than the SRT's obtained under the ear-level system of the master hearing aid (by 2.9 dB) and the headset system of the master hearing aid (by 4.0 dB). Table 8, row 1, shows the SRT's obtained under the four experimental conditions and the differences, or improvements noted between the conditions, from left to right.

The above information indicates that, though variation exists within the sample, most of the subjects exhibited an SRT considerably closer to the mean SRT of 14.3 dB than in the other conditions (See Figure 6 and Table 5).

The standard deviation associated with the wearable aids is smaller than the standard deviations associated with the unaided condition or the headset system condition or the ear-level system condition. The range of scores (28.0 dB) is smaller than the range found under the unaided condition (40.0 dB) or the headset system condition (32.0 dB), but not as small as the range associated with the ear-level system condition (22.0 dB).

Speech Discrimination in Quiet

Speech discrimination scores obtained by testing experimental subjects with wearable amplification in a quiet environment are

Table 8. Mean speech reception thresholds, mean speech discrimination scores in quiet, mean speech discrimination scores in noise, and differences in quiet and noise under unaided condition, headset system condition, ear-level system condition, and wearable hearing aid condition, with improvements noted between conditions

	Scores and Improvements Noted									
(1) Type of Score*	(2) Mean Score Under Unaided Cond.	(3) Mean Score Under Headset Cond.	(4) Col. 2 vs Col. 3	(5) Mean Score Under Ear-level Cond.	(6) Col. 2 vs Col. 5	(7) Col. 3 vs Col. 5	(8) Mean Score Under Wearable Cond.	(9) Col. 2 vs Col. 8	(10) Col. 3 vs Col. 8	(11) Col. 5 vs Col. 8
SRT (dB)	29.4	18.3	11.1	17.4	12.0	0.9	14.3	14.9	4.0	2.9
%DQ	78.0	86.8	8.8	87.5	9.5	0.7	89.2	11.2	2.4	1.7
%DN	72.3	71.7	-0.6	80.8	8.5	9.1	81.9	9.6	10.2	1.1
DQN	5.7	15.1		6.7			7.3			

*SRT = Mean speech reception threshold by condition
%DQ = Mean speech discrimination score obtained in quiet by condition
%DN = Mean speech discrimination score obtained in noise by condition
DQN = Differences between speech discrimination scores by condition in quiet and in noise

described as follows: mean = 89.2 percent; standard deviation = 11.8 percent; range = 44.0 percent (from 56 to 100 percent). This data is shown graphically in column 5 of Figure 6 and numerically in column 5 of Table 6.

The data can be analyzed to illustrate an average improvement in discrimination of 11.2 percent over the mean score obtained in the unaided condition, 2.4 percent over the mean score obtained in the headset system condition, and 1.7 percent over the mean discrimination score obtained under the ear-level system condition. Note Table 8, row 2, which compares speech discrimination scores in quiet. The mean score obtained under the headset system (column 3 of Table 8) shows an improvement of 8.8 percent (column 4) over the unaided mean speech discrimination score (column 2). The mean score under the ear-level system condition is 87.5 percent, which is an improvement of 9.5 percent (column 6) over the unaided condition and an improvement of 0.7 percent (column 7) over the headset system condition. The discrimination score obtained under the wearable hearing aid condition is 89.2 percent (column 8) which represents an improvement over the score in the unaided condition of 11.2 percent, over the headset system condition (column 10) by 2.4 percent, and over the ear-level system condition (column 11) by 1.7 percent.

The smaller standard deviation (11.8 percent) using the wearable hearing aid suggests that the subjects performed more alike with the wearable amplification than in the unaided condition where the standard deviation was 23.9 percent. However, the standard deviation associated with the headset system condition was 9.1 percent, showing that the sample was more homogenous under the headset system condition than under the wearable aid condition, the unaided condition, or the ear-level system condition using the speech discrimination test in quiet. The range associated with the headset system was 36.0 percent, which again implies more homogeneity than the other conditions listed. See Figure 6 for a graphical comparison of the standard deviations and ranges

Speech Discrimination in Noise

Speech discrimination scores obtained by testing the subjects with wearable amplification in the presence of noise at a speech-to-noise ratio of 6 dB are as listed: mean = 81.9 percent; standard deviation = 15.4 percent; range = 54.0 percent (from 42 to 96 percent). Graphical presentation of the data is found in column 5 of Figure 7. The data is tables in column 5 of Table 7. See row 3 of Table 8, column 8, also.

Analysis of the data indicates that noise delivered at a 6 dB speech-to-noise ratio resulted in a decrement of 7.3 percent in speech discrimination under the wearable hearing aid condition. A decrement of only 5.7 percent in speech discrimination was evidenced in the unaided condition when noise was introduced.

An increase occurred in the range of 10 percent (from 44 to 54 percent) when the noise was introduced, and an associated increase in the standard deviation occurred (from 11.8 percent in quiet to 15.4 percent in noise).

The above data indicate that noise had a tendency to spread the scores over a wider range such that some subjects' performance with their wearable hearing aid was affected more by the noise than other subjects' performance.

At the same time, however, an average increase of 9.6 percent in speech discrimination was obtained by testing the subjects with their wearable hearing aid over testing the subjects without amplification under the same conditions of stimulus presentation, namely, with the speech material at normal conversational intensity (70 dB SPL) and white noise at a speech-to-noise ratio of 6 dB (See Figure 7, columns 2 and 5). Also improvements of 10.2 percent over the headset system condition and 1.1 percent over the ear-level system condition can be noted on Table 8. See row 3, columns 10 and 11.

A comparison of the standard deviations shows (Figure 7) that the standard deviations of 17.1 percent (headset), 13.6 percent (ear-level) and 15.4 percent (wearable hearing aid) are all very similar. The associated ranges under the wearable hearing aid condition and under the headset system condition are also similar, both being smaller than the range of scores.

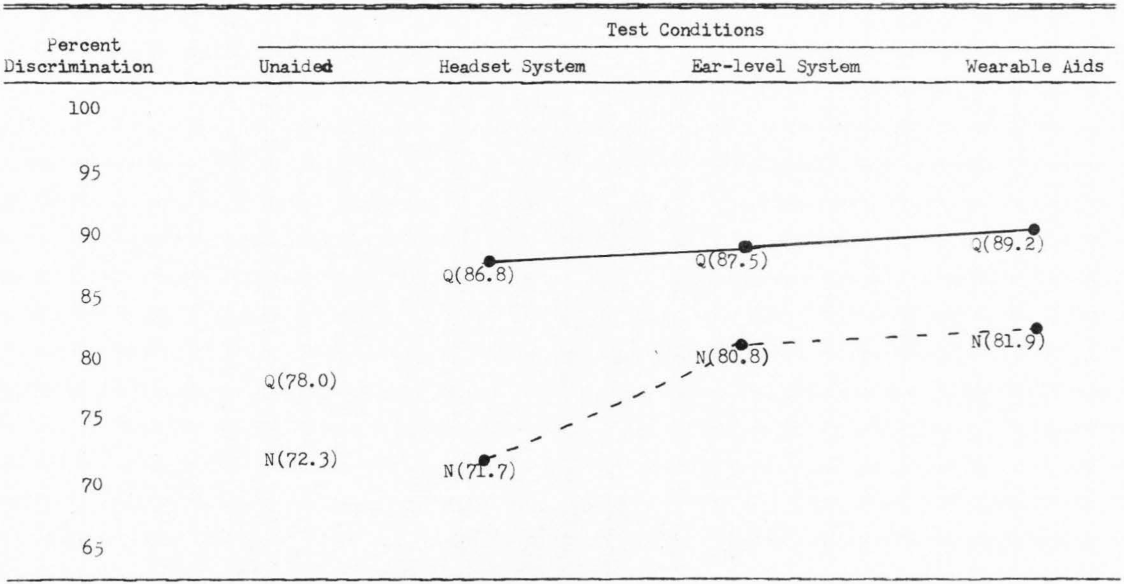
When referring to Table 8, row 3, it is evident that the speech discrimination score obtained in noise under the unaided condition was 72.3 percent (column 2). In column 3, it is evident that the speech discrimination score obtained in noise under the headset system of the master hearing aid was 71.7 percent. This amounts to a decrease of 0.6 percent (column 4) from the unaided condition. Column 5 shows the speech discrimination score (87.5 percent) obtained under the ear-level system of the master hearing aid. This discrimination score represents a mean improvement in speech discrimination of 8.5 percent over the unaided condition (See column 6, row 3), and a mean improvement of 9.1 percent in speech discrimination over the headset system condition (See column 7, row 3). The speech discrimination score obtained under the wearable hearing aid condition was 81.9 percent (column 8, row 3), and represents the following improvements in speech discrimination: over unaided condition, 9.6 percent (column 9); over headset system condition, 10.2 percent (column 10); and over ear-level system condition, 1.1 percent (column 11). To further understand the differences in scores between systems, the reader should refer to row 4 of Table 8. Column 2 shows the mean decrease in speech discrimination found when noise was introduced into the unaided condition, which is 5.7 percent. This value shows that the subjects, on the average, experienced a 5.7 percent decrement in speech discrimination as a consequence of listening in the presence of noise. Column 3, row 4 shows the mean decrease in speech discrimination found when noise was introduced into the test situation. The decrease is 15.1 percent. This value shows that, when required to listen through the headset system of the master hearing aid, subjects seem to function very poorly in noise. The subjects obtained only a mean speech discrimination score which is actually poorer by 0.6 percent, than the mean unaided speech discrimination score obtained in noise. Obviously the headset system cannot be said to predict, for the average subject, the ability to discriminate speech in a noisy environment as well as the ear-level system of the master hearing aid. The mean decrease under the ear-level system condition was 6.7 percent when noise was introduced. That is, when comparing the mean speech discrimination scores of the quiet and noise conditions, the difference was 6.7 percent (See row 4, column 5). The difference in speech discrimination caused by the addition of noise under the ear-level condition (6.7 percent) compares very well with the decrease found under the wearable hearing aid condition when noise was presented at a 6 dB speech-to-noise ratio, which was 7.3 percent (See column 8, row 3). See Figure 8 for graphical speech discrimination score comparison.

Comparison of Test Results Using Inferential Statistics

The data obtained under the four test conditions outlined previously in the chapter are inter-related in several ways. One purpose of the present study was to investigate the efficacy of using the data obtained by testing a prospective hearing aid wearer with the master hearing aid to order a wearable hearing aid. Thus, the data outlined previously will be discussed in relation to the various questions posed in the second chapter of the present study.

Analysis of SRT Differences

The speech reception thresholds obtained under the three aided conditions differ from each other somewhat, as is evident in Figure 6, and in Tables 5 and 8. Table 9 contains data relative to an analysis of variance (ANOV) test involving the three mean SRT scores obtained in the present study. Column 5, row 3 shows a computed F score of 4.8, which is significant at the .05 probability level. The tabular F value at the .05 alpha level is 3.25. In view of the fact that the ANOV test revealed significant differences among the means, the Tukey post-hoc comparison test was used to isolate the specific areas of difference. The critical Tukey value is 2.7 dB and any difference between two means greater than 2.7 dB may be interpreted to mean that the two means involved are significantly different at the .05 probability level. The data relative to the Tukey test is shown



Q = speech discrimination score obtained in quiet
N = mean speech discrimination score obtained in noise

Figure 8. Comparison of speech discrimination scores obtained under four conditions in quiet and in noise

Table 9. Aided speech reception threshold analysis of variance

Source	df	SS	MS	Computed F.	Tabular F. $\alpha = .05$
Total	59	3521.9333			
Block	19	2641.9333			
Treatment	2	177.6333	88.81667	4.80523	3.25
Error	38	702.3666	18.48333		

in Table 10. Under comparison #2, column 3 contains the value of 4.0 dB. Thus the difference between the SRT obtained under the headset system condition and the wearable aid condition is significant to the .05 level. In other words, considering the direction of difference, the SRT obtained under the wearable hearing aid condition is significantly better than the SRT obtained under the headset system condition.

Table 10. Results from Tukey test involving various post-hoc comparisons of aided SRT data

Comparison Number	Comparison Conditions	Difference Between Means	Tukey's Critical Value $\alpha = .05$
#1	Headset vs. Ear-level	0.9	2.749
#2	Headset vs. Wearable aid	4.0	2.749
#3	Ear-level vs. Wearable aid	2.9	2.749

Under comparison #3, column 3 contains the value of 2.9 dB. Thus, the SRT obtained under the ear-level system condition also differs significantly from the SRT obtained under the wearable hearing aid condition. In other words, the wearable hearing aid systems allowed the subjects to obtain a significantly better SRT than either of the systems of the master hearing aid.

Analysis of Speech Discrimination Score Differences

The speech discrimination scores obtained in quiet and in noise under the three conditions involving amplification exhibit differences noted graphically in Figure 8, and numerically in Table 8. The six mean speech discrimination scores were included in a two-way ANOV test, and the results are tabulated in Table 11. As can be readily noted, certain of the comparisons involved are highly significant. For purposes of the present study, compare the computed F's with the tabular F's for the following rows. Row 2 column 5 contains the computed F score for the comparison of the mean speech discrimination scores obtained under the aided conditions. The value is 8.02, which is significant at the .05 probability level when compared to the tabular value of 3.12. Thus, statistically, the means among the aided conditions are not equal. Row 3 represents the second variable which was discrimination in quiet vs. discrimination in noise. The computed "F" value is 51.68 and exceeds the tabular "F" value of 3.97. Thus, the mean discrimination scores obtained in quiet are significantly different from the mean discrimination scores obtained in the present of noise.

Table 11. Analysis of variance data relating to aided speech discrimination in quiet and noise

Source (1)	df (2)	SS (3)	MS (4)	Computed F. (5)	Tabular F. = .05 (6)
Subjects	19	16619.30	874.70	16.02	1.72
Aided Condition	2	875.47	437.73	8.02	3.12
Discrim.	1	2822.70	2822.70	51.68	3.97
Aided Cond. x Discrim.	2	439.20	219.60	4.02	3.12
Error	95	5187.30	54.60		
Total	119	25943.97	218.02		

Row 4 of Table 11 indicates that the interaction between the aided condition (headset, ear-level, and patient's own hearing aid) and the discrimination test environments (in quiet and in noise) is also significant. The computed "F" value is 4.02 while the tabular "F" value is only 3.12. Reference to Figure 8 will show that the source of interaction is in the difference in the way the subjects performed in noise between the headset system and the ear-level system.

In an attempt to discover the source of the significant differences, the Tukey post-hoc procedure was applied to the mean speech discrimination scores. Table 12 contains results of six meaningful comparisons made possible by the Tukey procedure. A critical Tukey value of 6.83 percent represents significance at

Table 12. Results from Tukey test involving various post-hoc comparisons of discrimination scores in quiet and in noise

Comparison Number	Comparison Conditions	Difference between Means	Critical Tukey Value = .05	Significance*
1	HQ vs. EQ	0.9%	6.83%	
2	HQ vs. WQ	3.8%	6.83%	
3	EQ vs. WQ	2.9%	6.83%	
4	HN vs. WN	10.2%	6.83%	*
5	HN vs. EN	9.1%	6.83%	*
6	EN vs. WN	1.1%	6.83%	

HQ = Subject tested in quiet with headset system, master aid
HN = Subject tested in noise with headset system, master aid
EQ = Subject tested in quiet with ear-level system
EN = Subject tested in noise with ear-level system
WQ = Subject tested in quiet with wearable hearing aid
WN = Subject tested in noise with wearable hearing aid

the .05 probability level. Note from the comparisons in Table 12 that none of the mean scores obtained in quiet were significantly different. Significant differences between conditions were found only in the presence of noise. Specifically, when the testing was conducted in a background of noise. Specifically, when the testing was conducted in a background of noise, the mean discrimination score obtained using the headset system was significantly different from the mean score obtained with the ear-level system and from the mean score obtained using the patient's own hearing aid. These data are shown in comparisons 4 and 5. Subsequently, the summary and recommendations to follow the present section will reflect the findings regarding the obvious difference found in the headset system of the master hearing aid from the other amplification systems involved in the present study

Recommendations

In view of the data generated and analyzed in the present study, certain recommendations are proposed. The procedure of hearing aid evaluation at Utah State University functions well at the present time, but the following suggestions are intended to improve the validity of the procedures involving use of master hearing aid, and to improve confidence in the present hearing aid evaluation procedures as reported in the present study.

1. It is recommended that the ear-level system of the master hearing aid be given preference over the headset system of the master hearing aid when attempting to predict the speech reception threshold the average hearing aid candidate will obtain with a wearable hearing aid ordered from the master hearing aid data.

2. Since no real difference existed between the speech discrimination scores obtained under the headset system of the master hearing aid, the ear-level system of the master hearing aid, and the wearable hearing aid conditions, either of the master hearing aid systems is recommended to be used to ascertain the probable benefit to be expected from a particular patient with a wearable hearing aid.

3. It is recommended that when discrimination testing is conducted in the presence of noise, the headset system of the master hearing aid not be used in attempting to predict a given patient's success with a wearable hearing aid. Rather, the ear-level system of the master hearing aid should be used in speech discrimination testing in noise.

In all, the master hearing aid data, especially that obtained under the ear-level system of the master hearing aid, seems to agree well with the data obtained under the wearable hearing aid condition. It is the general recommendation of the present author that use of the master hearing aid, as outlined in the present study, can be used with confidence in predicting speech audiometric results with a hearing aid ordered from master hearing data.

Summary

Statistical analysis of mean SRT's, mean speech discrimination scores obtained in quiet, and mean speech discrimination scores obtained in noise under the three aided conditions; namely, with the headset system of the master hearing aid, with the ear-level system of the master hearing aid, and with wearable hearing aids possessed by the subjects show that statistically significant differences exist among the means of the three measures. Post-hoc analysis, by the Tukey procedure, favors the ear-level system over the headset system of the master hearing aid as a predictor of subject success on the speech measures with a wearable hearing aid. Both the ear-level system and the headset system of the master hearing aid predicted the SRT obtained under the wearable aid condition by small but statistically significant amount.

Two reasons are postulated for the under-prediction found: (1) a majority (75%) of the subjects utilized custom fitted acoustic modifier earmolds with their wearable hearing aids. The remainder of the patients used standard perimeter custom fitted earmolds. Custom fitted earmolds were not used with the master hearing aid. The exact nature of discrepancies arising from earmold variables, if any, are unknown at the present time. (2) All of the subjects had received their wearable hearing aids no later than three weeks prior to participating in the present investigation. Thus, the element of practice with the particular amplification system may have assisted the subjects in obtaining the significantly better average scores noted. (3) The method of limits was used to set the gain of the master hearing aid systems, while the method of adjustment was used to set the gain utilized with the wearable hearing aid. (4) Possibly the positioning of the microphone on the chassis of the master hearing aid accounts for the poorer performance of the subjects in connection with the headset system of the master hearing aid in speech discrimination in noise.

While some of the differences are statistically significant, clinically, most of the results obtained under the aided condition are not significantly different. The speech reception thresholds were all within 5 dB of one another and the speech discrimination score differences in quiet were not statistically significant. However, the differences between the speech discrimination scores obtained in noise under the headset system of the master hearing aid condition and the speech discrimination scores obtained in noise under conditions involving the ear-level system of the master hearing aid and the patients' wearable hearing aid were statistically and clinically different.

CHAPTER V

SUMMARY AND CONCLUSIONS

The present study had, as a goal, the testing of the systems of the master hearing aid, and in effect, the testing of the entire hearing aid evaluation program in operation at Utah State University (U.S.U.). The philosophy and procedures used at U.S.U. were explained in the second chapter following a review of various philosophies of hearing aid evaluation in use in the United States today. Many of the philosophies reviewed have helped to shape the procedures utilized at U.S.U.

Subjects, materials, apparatus, and procedures, as outlined and explained in Chapter III, were designed to provide answers to the basic questions posed in the second chapter which had developed as a result of more than a years use of the U.S.U. procedures. Specifically, one question concerned the accuracy of master hearing aid use in predicting speech reception thresholds and speech discrimination scores obtained from subjects using the wearable hearing aid procured on the basis of master hearing aid data. In other words, it was the purpose of the present study to obtain speech reception thresholds and discrimination scores in quiet and in noise from subjects using their own wearable amplification system which ordered from master hearing aid data, and to compare the same scores with two microphone-receiver systems of the master hearing aid. The subjects, apparatus, materials, and conditions used to accomplish the goal of the present study are described in the third chapter.

The results obtained through the procedures of the present study seem to indicate that the ear-level system of the master hearing aid is superior to the headset system of the master hearing aid as a predictor of scores obtainable with a wearable hearing aid ordered from the master hearing aid data.

Specifically, the average SRT obtained under the wearable hearing aid condition compared more closely with the SRT obtained under the ear-level system of the master hearing aid than with the SRT obtained under the headset system condition. Although the SRT obtained under the wearable hearing aid was significantly better ($\alpha = .05$) than either of the SRT's obtained under the systems of the master hearing aid, the SRT obtained under the ear-level system was closer (dB) than the SRT obtained under the wearable hearing aid condition. The result is that the ear-level system of the master hearing aid seems to predict the SRT obtainable with wearable hearing aids statistically better than the headset system of the master hearing aid, but the differences were not clinically significant.

The mean speech discrimination scores obtained in quiet and in noise under the wearable hearing aid condition were also approximated better under the ear-level system condition than under the headset system condition. Actually, no statistical difference existed between the speech discrimination scores obtained in quiet under the aided conditions. However, in noise, the mean discrimination score obtained using the ear-level system of the master hearing aid was much closer to the mean speech discrimination score obtained under the wearable hearing aid condition than was the mean discrimination score obtained using the headset system.

The results discussed above and in the previous chapter have led the author to draw the following conclusions from the present study. (1) The master hearing aid, utilizing the ear-level system is a valid predictor of hearing aid candidate's performance with a wearable hearing aid ordered from the data obtained using the master hearing aid procedures outlined above. (2) The headset system of the master hearing aid does not seem to warrant the same recommendations when the testing is conducted in the presence of noise.

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Appendix A

Form Letter of Invitation to Prospective

Subjects in the Present Study

UTAH STATE UNIVERSITY · LOGAN, UTAH 84321

COLLEGE OF EDUCATION

DEPARTMENT OF
COMMUNICATIVE
DISORDERS

The Department of Communicative Disorders at Utah State University is presently engaged in research to assess hearing aid evaluation and fitting procedures, and to improve use of hearing aids by persons who have been evaluated by the Utah State University Audiological staff.

We are anxious to increase our knowledge concerning hearing aid use with hearing problems of your type. Continually improving hearing tests help us in this endeavor. At present we have a new set of tests ready, and would like to extend to you an invitation to assist us in this project. Of course there will be no charge for your visit.

In a few days a member of our research staff will telephone you and make arrangements for an appointment which will be convenient for you. The details can be discussed at that time. I am writing to you today so that you will know about the plan in advance. Your cooperation will assist us in carrying forward an important project.

Sincerely yours,

P.S. Please complete the enclosed questionaires and bring them with you on the day of your appointment.

Appendix B

Eight CNC Lists of Peterson and Lehiste

As Used in the Present Investigation

	List I	List II	List III	List IV
1.	tough	goal	gap	net
2.	make	nose	toll	pack
3.	ripe	rail	faith	till
4.	fall	dire	what	wail
5.	home	choice	with	foot
6.	knife	tall	gull	shut
7.	rose	puff	hut	hire
8.	loop	moon	rouge	take
9.	yearn	late	life	war
10.	boil	vine	rat	hoof
11.	shore	nurse	lake	mop
12.	merge	ring	kid	date
13.	kite	love	soon	dose
14.	ditch	coat	toss	mill
15.	sob	hide	rig	nice
16.	chore	ship	perch	when
17.	thin	fake	mate	sock
18.	jug	this	bush	said
19.	seize	suck	dab	shake
20.	toad	germ	head	chum
21.	wood	hill	dike	void
22.	rout	should	numb	mirth
23.	shirt	beg	sheep	read
24.	king	cob	vote	loan
25.	lag	south	piece	him
26.	wish	choose	shine	phone
27.	tooth	weep	work	job
28.	bean	dam	yam	tower
29.	fit	bought	bell	keep
30.	boat	jet	size	wig
31.	pad	soul	bar	chief
32.	dime	met	dip	loud
33.	mess	talk	chin	rage
34.	van	fern	keen	give
35.	lease	hash	four	thumb
36.	cape	wag	leave	deal
37.	patch	pave	jail	birch
38.	jar	gain	noise	cash
39.	goose	which	more	pause
40.	salve	tire	fade	lap
41.	name	dodge	house	can
42.	gale	lead	purge	write
43.	hull	pan	man	serve
44.	pick	red	room	youth
45.	dead	root	well	pool
46.	hate	much	joke	rice
47.	sun	beam	peg	bone
48.	check	car	pod	long
49.	wheel	leak	tone	gas
50.	wreck	sap	sung	bug

	List V	List VI	List VII	List VIII
1.	chalk	web	cheek	hail
2.	light	sit	face	poor
3.	gaze	cheese	gem	daze
4.	thought	birth	gun	thing
5.	veil	fire	bun	wet
6.	wire	raize	pine	wake
7.	match	niece	shore	hoop
8.	nudge	cat	pass	guide
9.	five	move	reach	pose
10.	food	chain	talk	week
11.	lean	whip	ridge	vowel
12.	beach	live	young	seek
13.	hack	search	far	hurl
14.	juice	tube	laugh	jerk
15.	nag	jam	call	cheap
16.	boot	lawn	heat	sad
17.	shop	pace	rib	cough
18.	dawn	rug	join	calm
19.	luck	get	caught	gag
20.	sore	shone	third	touch
21.	sail	gone	nap	near
22.	purse	sour	lose	phone
23.	zeal	hiss	doom	bag
24.	myth	rush	loot	rode
25.	raid	pole	shall	rain
26.	knit	bad	wit	shawl
27.	hush	turn	save	moss
28.	dim	map	have	gin
29.	then	door	dumb	moose
30.	yoke	veal	big	muff
31.	coal	wing	mole	dive
32.	peg	shock	neck	there
33.	tease	cool	note	bath
34.	half	bud	moth	den
35.	care	knock	side	bite
36.	cab	wife	mine	lock
37.	tell	dig	fish	rot
38.	dock	howl	geese	sum
39.	pool	hike	coke	learn
40.	sing	pope	was	page
41.	good	jot	such	gear
42.	town	cage	sack	tip
43.	hot	dull	hole	lash
44.	worm	bed	vague	fuss
45.	rough	night	bet	tin
46.	limb	calf	did	shoot
47.	mean	look	led	real
48.	bathe	team	tar	wheat
49.	robe	fan	pearl	cub
50.	cup	mode	tape	loath

Appendix C

Raw SRT and Discrimination Scores of 20 Experimental Subjects Under Four Listening Conditions

Table 13. Subjects' scores by conditions

No.	Name	Unaided			Headset			Ear-level			Wearable		
		SRT	%D.Q	%D.N	SRT	%D.Q	%D.N	SRT	%D.Q	%D.N	SRT	%D.Q	%D.N
1.	A.J.	32	94	84	34	98	72	30	92	90	26	98	96
2.	V.W.	30	94	84	24	96	76	20	98	86	20	98	92
3.	E.A.	42	72	62	30	90	68	30	96	88	30	82	64
4.	C.M.	30	70	66	24	78	66	22	84	84	20	76	84
5.	S.D.	22	100	100	5	98	92	8	100	96	10	100	94
6.	C.W.	50	0	0	30	76	38	26	64	80	5	56	42
7.	E.P.	24	94	86	18	92	96	12	90	88	14	96	92
8.	K.V.	20	80	50	2	82	46	18	84	54	2	86	72
9.	A.S.	38	76	66	26	80	64	22	86	82	20	94	82
10.	N.C.	40	54	54	18	90	70	10	92	92	8	100	92
11.	W.P.	44	40	52	24	86	68	16	82	80	18	82	88
12.	M.B.	22	98	96	12	96	82	14	94	90	16	96	94
13.	L.S.	30	68	80	22	74	74	18	84	84	24	86	80
14.	R.C.	24	94	82	20	86	84	20	80	74	18	92	84
15.	R.W.	30	96	90	10	86	52	18	90	68	10	86	66
16.	D.G.	40	90	76	14	90	84	12	92	84	6	100	94
17.	C.A.	12	92	80	10	92	76	12	94	76	6	96	88
18.	F.W.	18	58	50	16	62	42	16	50	32	16	66	48
19.	P.B.	16	90	90	16	96	92	16	98	90	10	96	90
20.	R.S.	10	100	98	10	88	92	8	100	98	6	98	96

SRT = Speech reception threshold
%D.Q = Percentage speech discrimination score in quiet
%D.N = Percentage speech discrimination score in noise

VITA

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