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CHAPTER I

INTRODUCTION

The sensory systems provide the human body with information concerning its external and internal environment. Light patterns projected upon the retina assist us in making the decision whether or not to cross the street. The sound waves from an automobile horn, impinging upon the tympanic membrane, may be the warning of imminent danger. In addition to many externally originating stimuli, the organism receives sensory information from within itself. When an individual speaks, for example, he receives several kinds of monitoring information on the progress of his speech, e.g., auditory, kinesthetic, and cutaneous. This autostimulation is used to coordinate the muscular activity necessary to ensure the correct formation of the desired speech sounds. Afferent nerve impulses that result from self-stimulation are known as sensory feedback.

For decades, experimenters have been using spatially displaced sensory signals in an attempt to gain a better understanding of perception and perceptual-motor integration. However, the use of the displaced signals has been limited to techniques of reversals, inversions or distortions as in the case of visual signals. The advent of the magnetic tape recorder made the temporal displacement of visual and auditory signals possible. That is, it became possible to delay the self-stimulation or feedback that results from the performance of a motor act. When the intact sensory system is confronted with feedback information that is temporally displaced from the actual event, it becomes confused and the synchrony of the movement is lost.

The phenomenon of delayed sensory feedback, while probably observed many generations ago, has been studied systematically in the laboratory only for some twenty-five years. The effects of delayed visual feedback were first recognized as a human engineering problem during World War II when it was found that tracking accuracy was reduced when a power-assist device was incorporated into the steering system of a gun turret. The loss of accuracy was traced to the fact that the "power steering" unit caused a time lag between the time the turret control was activated and the time the turret actually began to turn. Delayed visual feedback experiments soon led to investigations of the effects of temporal delay in other sensory modalities.

The delayed auditory feedback (DAF) phenomenon was first described by Lee in 1950 (35). Since that time it has been studied in detail to determine its relevant parameters. In brief, if one's voice is returned to his ear delayed by a fraction of a second, he will prolong his words, increase his vocal intensity, raise his fundamental vocal frequency, make articulatory errors, show a tendency to repeat certain sounds in a stuttering-like manner, and finally he will show the effects of emotional disturbances, e.g., reddening of the face, changes in skin resistance, frustration and fatigue (4, 13, 21, 28, 35).

Speech auditory feedback is generally delayed by means of a magnetic tape recorder. The individual speaks into a microphone. The sound waves are transduced by the microphone into electrical impulses which are fed to the recording head where they are placed on the magnetic tape. Adjacent to the recording head is the playback head which picks up the magnetic impulses from the tape and delivers them to a loudspeaker or earphone where they are transduced back to sound waves and delivered to the individual's ear. The amount of delay is determined by the speed of the magnetic tape and the distance between the recording and playback heads.

It was soon discovered by Tiffany and Hanley (53) that normal-hearing subjects could not voluntarily overcome the effects of DAF when instructed to simulate a hearing loss. Several investigators (24, 28, 33) looked to DAF audiometry as a technique for detecting auditory malingering. The optimistic picture became clouded by the fact that there were wide differences among the responses of normal subjects.

In 1959, Chase *et al*. (13) utilized keytapping instead of speech to produce DAF of clicks and Ruhm and Cooper (44, 45, 46, 47) have investigated pure-tone DAF phenomena. The disruption of performance was analogous to that observed with speech DAF in that the key was pressed harder (measured intensity of motor act), held down longer (prolonged), and more taps were given than called for (repeated). There has been, however, a surprising lack of normative data concerning the variability of normal-hearing subjects on a keytapping task.

The literature yields only a few studies that deal with the otologically abnormal individual's reaction to DAF, and these mostly to the speech DAF task. Elliott (19) reports that her perceptively hard-of-hearing subjects tend to demonstrate more breakdown on a DAF task than do normal subjects. Harford and Jerger (31) report differences between otologically normal subjects and both conductively and perceptively-deafened hard-of hearing subjects. Gronas *et al*. (27) also indicate that normal-hearing persons differ from persons with a conductive hearing loss on a speech DAF task.

Gronas *et al*. and Harford and Jerger both report that otosclerotic subjects show more breakdown on a speech DAF task than do normal subjects. Neither study offers a tenable reason for this finding.

An important factor that has been overlooked in these preceding investigations of speech feedback in relation to otologically abnormal subjects is the occlusion effect. It is known that some type of hearing losses do not demonstrate the enhancement of bone-conduction thresholds at frequencies below 1 kHz when the ears are occluded with earphones whereas normal-hearing subjects do.

The purpose of this paper, therefore, is to determine whether or not the presence of the occlusion effect is a relevant variable in both speech and pure-tone DAF tasks and whether a plausible explanation for the results reported by Harford and Jerger and Gronas *et al*. can be found.

The following chapters contain a review of the pertinent literature on DAF, a discussion of the present experiment and test procedures, the presentation and discussion of the results of this experiment, and the implications of the findings.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

Sensory feedback is made up of afferent neural impulses that originate as a result of the functioning of an organism. These impulses inform the organism of how well or how poorly it accomplished an action or bodily function. All feedback information does not reach the level of consciousness. Vestibular impulses, for example, rarely reach consciousness, yet they inform the human body as to its position and location relative to gravity. An example of sensory feedback that does reach the level of consciousness is auditory feedback. When one speaks, his vocal output is monitored by the auditory system. After analysis by higher neurological centers, the information is utilized by the efferent system which sends commands to the vocal mechanism where vocal output may be modified. Kinesthetic and cutaneous feedback from the vocal mechanism also serve the same purpose but they are substantially less effective than the auditory feedback (39).

When a sensory system of an organism is confronted with feedback information that is temporally displaced from an actual event, the organism can become confused. Fortunately, delayed sensory feedback does not occur often in our environment. It does occur enough, however, to justify its study. Probably the most common example of natural delayed sensory feedback is the echo produced by the reflection of one's voice from a suitable surface some distance away. When an echo follows vocalization too closely, as in the case of a lecturer or vocalist in a reverberant hall, confusion on the part of the speaker may result.

Lee (35) is credited with the first report on DAF. Since that time this auditory phenomenon has been studied in considerable detail. The remainder of this chapter reviews the pertinent literature on auditory feedback using both speech and non-speech signals.

Speech Auditory Feedback

Method of Production

When one speaks, his voice is returned or fed back to him via two main pathways. One is the air-conduction route, and the other is the bone-conduction route. Although there is a slight time-lag between vocalization and perception of the air-conducted sound (1 msec) and bone-conducted sound (0.15 msec) (40), both routes of feedback may be considered to be synchronous. Synchronous feedback from the vocal mechanism is also present in the form of kinesthetic and cutaneous impulses but they are less important than the synchronous auditory feedback (SAF) (39). Speech feedback is produced in the laboratory usually by means of a magnetic tape recorder. The speech signal activity is recorded on tape and played back to the subject's ears almost immediately. The amount of delay is determined by the distance between the record and playback heads of the tape recorder and the speed of the magnetic tape. Fairbanks and Jaeger (22) published instructions for converting a conventional tape recorder into a DAF-producing device.

Much of the early literature on speech DAF concerns itself with the influence upon the magnitude of speech disturbance of two independent variables. These variables are the intensity of the feedback and the delay time. A brief description of these general effects follows.

Independent Variables

Delay time. Lee's original experiment (36) on DAF consisted of an investigation of the effect of different delay times on a speech task (the repetition of the speech sound /bu-bu-bu/). He observed that as the delay time was lengthened from 100 msec to 300 msec, the disturbances of the subject's speech patterns were increased. Black (4) and Fairbanks (21) reported that 180 msec is the optimum delay time for maximal speech disturbance. However, Butler and Galloway (7) and Spilka (50) reported that delay times of 85 to 340 msec are not significantly different from one another.

Intensity of presentation. The intensity level at which DAF is presented affects the amount and degree of speech disruption. Several investigators (7, 8, 31) seem in agreement that the degree of breakdown on a speech DAF task increases linearly with increasing intensity.

The absolute amounts of speech disruption or breakdown that occurs at a certain sensation level vary from investigator to investigator. This variation, in part, is due to the various reference levels that are employed. Some investigators (28, 31, 53) have used the subject's speech reception threshold (SRT) as the reference for their sensation levels. Butler and Galloway (7, 8) and Gronas et al. (27) have used speech detection threshold (SDT) for normal listeners for their reference point. Although the SRT and SDT have been the most popular reference levels for DAF experimentation, a variety of other reference levels have been used

(2, 4, 11, 21, 34, 51).

Dependent Variables

Duration of phonation. The degree of speech disruption, often called breakdown, in early DAF investigations was measured by the length of the reading time under no auditory feedback (NAF) or SAF compared to the reading time under DAF (4, 28, 51).

Another way to analyze the effect of DAF on reading time is to determine the percentage of phonation time and the average syllable duration time during the reading. Spilka (51) and Fairbanks (21) both reported that the percentage of phonation time and syllable duration both increase under DAF as compared to SAF.

Most of the speech materials used in DAF investigations possess various faults. Some have unstructured content, variable intensity levels within a passage and the need for a certain degree of reading proficiency while others demand specific knowledge of the material. To overcome these faults, Butler and Galloway (7) used as their speech stimuli the recitation of five pairs of flashing numbers presented at a rate of 2 per second. Their rationale was that the flashing numbers require minimal reading proficiency and carry with them no context on which the subject can concentrate. In addition, they say:

> In our experience with both types of visual presentations, *i.e.*, written paragraph and flashing numbers, the latter technique appears to create a more compelling task which serves to maintain a higher degree of motivation. By motivating subjects to perform at their highest level of proficiency, it is thought that greater stability of results can be obtained (p. 320).

The use of flashing numbers required another scoring method which is analogous to the determination of the reading time under SAF and

DAF. A presentation of from 40 to 80 pairs of numbers is delivered to the subject under an NAF or SAF condition, and the number of correctly repeated numbers is recorded. Then, the same or another randomized sequence of flashing numbers is presented under DAF. The correct responses are again tallied. The difference between the correct responses under NAF/SAF and DAF conditions is taken as the error score. It will usually be found that fewer numbers are repeated under the DAF conditions. Since the flashing numbers were presented at the same rate for each feedback condition, an increased error score is analogous to the increased reading time of a certain passage. Flashing numbers have been used by Butler and Galloway (7, 8), Harford and Jerger (31), and Gronas et al. (27).

Intensity of vocal output. In an attempt to overcome the confusion precipitated by DAF, the subject usually raises the intensity of his voice. There seems to be some disagreement, however, as to whether or not there is a critical delay time that produces a maximum of vocal output. Black (4) and Atkinson (2), using delay intervals of from 30 to 300 msec and Fairbanks (21), using delay intervals of from 100 to 800 msec noted a plateauing of vocal output for delays of about 200 msec and more. Spilka (51) used delay times ranging from 94 msec to 375 msec, but he failed to show the plateau function of vocal output intensity. He did find, however, that there was increased vocal output under all DAF conditions.

Articulation errors. Fairbanks (21) and Fairbanks and Guttman (23) have systematically analyzed the kinds of articulatory errors made under various delay times. In general they found that maximal articulatory disturbances (substitutions, omissions, distortions and additions) occurred when the delay is about 200 msec. It is interesting to note that while articulatory errors (syllable errors) were numerous, word errors were considerably fewer under DAF. In 1959 Chase et al. (13), in a similar analysis of articulatory errors using delays of from 138 to 394 msec, found that their data confirmed, in general, those of Fairbanks and Guttman. The delay that produced the maximum number of errors was 244 msec.

Fundamental vocal frequency. At least one investigator (21) has reported that one's fundamental vocal frequency is raised under DAF and seems to reach its highest value under a delay of about 200 msec. Smith (49) reported that since the relation of pitch elevation to delay is similar to the relation of elevation of vocal intensity to delay, vocal frequency is related to the magnitude of vocal output. It is typical that an increase in vocal output produces, concurrently, an increased pitch of the voice.

Adaptation and persistant after-effects of DAF. There have been a few studies that have examined whether or not subjects adapt to DAF (2, 3, 30, 54, 56). The general conclusion is that some adaptation occurs but that it is not complete and can be prevented either by changing the delay time or the intensity of the DAF, or by the interruption of the DAF.

The investigations of Tiffany and Hanley (53, 54) and Leith and Pranko (38) revealed that the effects of DAF do not persist in normal speech after removal of the DAF for most subjects. Exceptions were found in that some subjects, in whom breakdown was severe, tended to carry over speech disturbances after the DAF was removed.

In summary DAF causes the following speech disturbances:

1. An increase in vocal intensity.

2. An increase in phonation time.

3. An increase in reading time.

4. An increase in fundamental vocal frequency.

5. An increase in the number of articulatory errors.

Theories of DAF

Servomechanism analogies. Lee (36) presented a speech model with which he attempted to explain the effects of DAF upon speech behavior. He described a group of four successively smaller loops which have one point in common. The loops are named, from largest to smallest, the thought loop, the word loop, the syllable loop and the articulating or phoneme loop. The four loops contain all the building blocks essential to the expression of a complete thought or sentence. The organism must be satisfied with its performance at each loop before it proceeds to the next successively more general loop. If it is not, the organism stops and attempts to correct the error. Repetition of phonemes has not been observed on DAF tasks. The syllable loop, syllables being involuntarily or reflexively produced, is the level at which "artificial stutter" is produced by DAF. Few entire words are repeated incorrectly (20) and sentences are never repeated.

Fairbanks (20) has attempted to interpret the effect of DAF using a servomechanism analogy. A servomechanism system is one in which a sample taken at the output of the system is returned or fed back to the input where it is analyzed and then aids in the control of successive outputs. The output of the system is speech which is returned to the ear via bone-conduction and air-conduction pathways. From the ear the information is integrated in the brain for correctness. If the feedback information is correct, succeeding speech sounds will be produced. If not, the system tries to correct itself by repeating the speech sound until it is correct.

Chase (11) proposed the recirculation theory to explain the DAF phenomenon.

> ...normal utterance of a word involves successive discrete responses "A", "B", and "C", each of which is controlled in order by the feedback from the preceding unit. The completed word thus combines the three units in proper number and order. The effects of delayed hearing...is to cause recirculation of each speech unit, thus disturbing both the number and order of such units in a spoken word. (From 49, p. 53)

According to Smith (49) the three preceding servo-system analogies (Lee, Fairbanks, and Chase) are inadequate to explain the observed effects of DAF. These analogies do not account for the diverse results reported in the previous studies. If the simple feedback system were the only system operating, one would find a linear relationship between the degree of breakdown and duration of delay. As was pointed out earlier in the chapter, however, the effects on speech due to duration of delay are maximal at about 200 msec.

Another shortcoming of these analogies is that they do not take into account the infinite degree of coordination required by the various muscle groups of the abdomen, neck, larynx, jaw, tongue, etc. to produce smoothly articulated speech. All of the integration systems, operating at different levels, are not considered in the simple feedback system. Finally, the preceding analogies fail to recognize the role of kinesthetic and cutaneous feedback. Concentration upon these synchronous cues while trying to ignore the DAF may explain the wide variability found among individuals on DAF tasks.

Neurogeometric theory. Smith (49) put forth another theory for the explanation of the effect of DAF upon speech. Afferent nerve impulses originating in postural, transport and manipulative systems of the body are integrated continuously at various levels in the nervous system. This feedback is in addition to auditory feedback. Normally the integration process produces synchrony of all movements that results in freely flowing speech. When a main feedback channel receives delayed information, confusion and asynchrony result. This theory explains the peak breakdown at 200 msec in that maximal interference between auditory and other feedback occurs at that delay interval.

Non-Speech Auditory Feedback

Method of Production

The first citation of the effects of a non-speech DAF signal was made by Lee (35) in 1950 when he reported that a skilled telegrapher could not tap a coded message when the signal was returned to his ears after a brief delay. Also a skilled tympanist was unable to perform a rhythmic pattern under DAF. Hanley and Tiffany (29) showed that whistling was also disturbed under DAF. In 1955 Kalmus *et al.* (32) in a detailed analysis of hand-clapping activity reported pattern disruption when the subjects' claps were returned to their ears after a 250 msec delay. All of these procedures employed the use of a magnetic tape recorder in a configuration similar to that used in delayed speech feedback investigations.

In 1959, Chase *et al.* (13) used clicks generated by an electromechanical key as the auditory stimulus in an investigation of non-vocal DAF. Again, a tape recorder was used to effect the DAF. Chase *et al.* (16) later used an electromechanical tapping key in conjunction with a pulse generator which produced a square wave pulse. This pulse was recorded and played back from a tape recorder to the subject.

Ruhm and Cooper in 1962 (44) were the first to employ pure tones as the non-vocal stimulus in DAF studies. In essence, pressure on a silent electromechanical key initiated a pulse which, through a series of waveform and pulse generators, activated a conventional electronic switch. The electronic switch gated an audio signal from either a commercial audiometer or a variable oscillator.

Price and Wever (42) presented the plans for an apparatus that could work in conjunction with a standard audiometer to produce DAF for pure tones.

Variables

The same independent variables that were cited in the review on speech DAF hold for non-speech DAF. Ruhm and Cooper (45) assessed the effect of several additional dependent variables peculiar to keytapping procedures. They observed that (1) DAF effects are not frequency-sensitive (250, 1k, and 8k Hz); (2) short-term practice does not reduce the disturbing effects of the delay; (3) manual fatigue is of no consequence on short runs; (4) motivation and educational level may influence the degree of breakdown; (5) males and females are not affected differentially and (6) foreknowledge of the temporal relationships between the tapping pattern and the auditory signal has no appreciable effect at 5 dB sensation level (SL).

The effects of DAF upon a non-vocal tapping task are analogous to those of delayed speech feedback. On the speech task one finds that he speaks louder, decreases his reading rate and tends to repeat sounds in a stuttering-like manner. DAF produced by a tapping task causes a subject to press the key harder, increase the time between taps, and add additional taps (13, 15, 16, 17, 44, 45, 46, 47, 48, 58).

Theories of the Feedback Process

While there has been little literature concerning the feedback mechanisms in keytapping procedures, there seems to be some agreement that the feedback processes are similar for both speech and keytapping tasks (13, 44). Chase *et al.* (13) reported:

> The similarity of the changes in speech and keytapping with delayed auditory feedback may indicate that similar mechanisms operate to restore control in widely divergent motor systems (p. 904).

Ruhm and Cooper (44) in making the point that maximal disturbances on their keytapping procedure occurred at a delay of 200 msec noted:

> ...the results of the present study, in which no speech was employed, suggest that a parallel exists between the basic mechanism of speech DAF and pure-tone DAF (p. 191).

The DAF Phenomenon Used As An Auditory Test

Speech Auditory Feedback

Lee (35), in one of his first reports, suggested that the DAF phenomenon may be used to detect auditory malingering. Since that time, numerous investigators have sought to develop an objective auditory test that utilized DAF. Tiffany and Hanley (53) instructed normal-hearing subjects to simulate deafness. The subjects were unable to overcome the effects of DAF. Hanley and Tiffany (29) reported a medico-legal investigation which utilized a DAF test.

Gibbons and Winchester (24) using 70 subjects who were medically diagnosed as having unilateral organic hearing loss, presented DAF to the good ear with the opposite ear masked and vice versa. They report that DAF has less effect when it is presented to the poorer ear at a comparable SL.

In 1958 Hanley et al. (30) presented DAF to normal listeners while recording the galvanic skin response of the subjects. They concluded that DAF in conjunction with GSR is a valuable objective auditory test.

Butler and Galloway (8) reported that because of the large variability of normal-hearing subjects on speech DAF tasks, it may be difficult to interpret the results obtained on hearing-loss subjects. Factors such as the loudness recruitment phenomenon can cause some subjects with hearing loss to break down as much as subjects with normal hearing at comparable hearing levels.

To determine whether or not recruitment could affect a DAF speech task, Harford and Jerger (31), using the flashing numbers task (7), delivered DAF to five groups of subjects at comparable SLs. The five groups were: (1) normals, (2) patients with labyrinthine hydrops, (3) masked normals, (4) plugged normals and (5) otosclerotics. From their results, they concluded that recruitment can exaggerate the effects of DAF. A surprising result of Harford and Jerger's investigation was that otosclerotic subjects break down more than normals at the same sensation level. No explanation for this was given.

Gronas et al. (27), in an attempt to explain the results obtained by Harford and Jerger, conducted similar tests ~~upon norm~~als and plugged normals, and also upon operated and unoperated otosclerotics. Their hypothesis was that the inactivity of the stapedius muscle in the otosclerotics and the operated otosclerotics prevented normal stapes movement and thus altered the normal frequency characteristics of the ear. This would cause these subjects to break down more than normals or plugged-normals. The results of their investigation, however, indicated that the otosclerotics and the plugged normals broke down more than did either normals or the operated otosclerotics. Hence, they concluded that the activity of the stapedius muscle does not affect the results of a delayed speech task.

The speech DAF test has a number of limitations. According to Hanley and Tiffany (29), the levels at which breakdown occurs are not at auditory threshold but are somewhere in the range of from 25 to 45 dB SL. On the other hand, thresholds are reported by Causey (10) to be within 10 dB of the level at which breakdown occurs. Reading proficiency of the subjects may also influence test results.

The advent of keytapping methods in the early sixties, produced a number of investigations that assessed the feasibility of using non-speech procedures as a test to determine auditory threshold.

Non-Vocal Auditory Feedback

In non-vocal DAF tasks, the subject is often required to tap a rhythmic pattern (.... ..) with his finger. This key-tapping action produces the auditory signal that is returned to his ears either in synchrony with or delayed from his tapping. Using normal-hearing subjects, and a click as the signal, Chase _et al_. (15) found that significant rhythmic pattern disruptions occur at levels as low as 10 dB SL.

Ruhm and Cooper (44), using pure tones as the non-vocal signal, reported pattern disturbances at 5 dB SL and advocated the use of pure-tone DAF clinically. In 1964 Ruhm and Cooper (46) compared thresholds obtained by conventional pure-tone audiometry and electrodermal audiometry with those obtained using a pure-tone DAF task for two groups of subject — (1) those with organic losses, and (2) those with functional losses. They concluded that the pure-tone DAF task allows one to determine valid pure-tone thresholds on adults presenting organic and/or functional hearing losses.

Rapin *et al*. (43) found keytapping to be an appropriate procedure for use with children seven years of age and older. In most cases, DAF results agreed with conventional audiometric test results. In addition they found that there was no clear difference in performance between peripherally deaf and brain-damaged children.

It would appear at this time that the pure-tone DAF procedure is a useful addition to the audiologist's battery of objective test methods. Although performance on a speech DAF task appears to be affected by the subject's hearing sensitivity, performance on a pure-tone DAF task does not.

Rationale

A number of investigators have suggested that speech DAF might be employed as a means for assessing the auditory thresholds of those individuals who can not or will not give voluntary thresholds on conventional audiometric tests (8, 24, 29, 30, 52). Since functional hearing loss is usually accompanied by some organic loss, it would be useful to know what affect the organic loss has on the test results.

Harford and Jerger, in 1959 (31), published the results of an extensive investigation into the role of recruitment on the outcome of a speech DAF task. They found that subjects diagnosed as having labrynthine hydrops (recruiting ears), and masked normal subjects (recruiting-like ears with no discrimination difficulties) exhibited significantly more breakdown than did normal and plugged-normal subjects on a speech DAF task. They proposed that recruitment caused the DAF to be louder for the hydrops cases than for the normals, and thus caused the excessive breakdown. A completely unexpected and as yet unexplained finding in the study was the fact that an otosclerotic group also broke down significantly more than the normals and the plugged-normal subjects. "High error scores in the otosclerotic group were apparently due to reasons other than the recruitment phenomenon and remain unexplained." (31, p. 368)

Although Hanley and Tiffany (28) stated that the organic threshold of an individual is approximately 40 dB below the level at which breakdown occurs, the findings of Harford and Jerger (31) suggest that the presence of an organic hearing loss may modify this relationship.

In 1968 Gronas *et al.* (27) attempted to explain the increased breakdown of otosclerotics on a speech DAF task on the basis of stapedius muscle action. They were unsuccessful in doing so. Their results revealed that a plugged normal group and a group of unoperated otosclerotics broke down more than did the operated otosclerotics and normals. Because the operated otosclerotics and the normals performed the same on the task, they concluded that the presence or absence of the stapedius muscle is of no consequence on a speech DAF task. The question of why otosclerotics showed more breakdown than normals remained unanswered.

It was hypothesized (27) that in pure conductive losses of approximately 40 dB, the acoustic energy from the earphone was reaching the cochlea via air and bone conduction in almost equal amounts, and thus causing two times the amount of breakdown in otosclerotic subjects as compared to normals. This hypothesis is untenable in that even if there were perfect summation in the air-conduction (AC) and bone-conduction (BC) signals, it would not cause a doubling in loudness.

Table 1 presents pertinent procedural details taken from the

TABLE 1

A COMPARISON OF PROCEDURAL DETAILS FOUND IN TWO DAF INVESTIGATIONS

	Harford and Jerger Subjects			Gronas et al. Subjects		
Parameter	N	PN	O	N	PN	O
1. Spondee AC Threshold (dB)	-1.6	27.4	41.4	0	40	40
2. Occlusion Effect Present	Yes	Yes	No	Yes	No	No
3. More Breakdown Than Normal Subjects	-	No	Yes	-	Yes	Yes
4. Constant SAF/DAF Ratio	No	No	No	No	No	No

N = Normal Hearing PN = Plugged-Normal O = Otosclerotic

latter two investigations. A careful analysis of these details suggests possible explanations for the excess breakdown in otosclerotic subjects relative to normals.

One explanation to be considered in this paper is that the BC synchronous feedback stimulation is greater in normals than in otosclerotics due to the fact that otosclerotics lack the occlusion effect that is present in the normals. The net effect is that otosclerotics will break down more than normals because they receive less synchronous BC feedback. A second explanation is that the perceived magnitude of the AC synchronous feedback is less for otosclerotics than for the normals. Because they receive less synchronous AC feedback, the otosclerotics break down more than the normals.

Some support is given to the former explanation in that plugged normals responded differently in the two preceding investigations. The artificial hearing loss in the subjects employed in Harford and Jerger's study were created by placing wax-impregnated cotton plugs in the external auditory canals. No mention was made of how deeply the plugs were placed. It is assumed by this investigator that they did not reach medially to the bony portion of the canal. Prior to the present investigation, in a preliminary informal study, it was found that bilaterally placed plugs of petroleum jelly-impregnated cotton inserted into the external auditory canals created a conductive hearing loss of approximately 25 to 30 dB in a normal-hearing subject. Bone conduction thresholds in this plugged normal subject revealed that there was an occlusion effect when the ears either were or were not covered with the standard headset (TDH-39 phones with MX-41/AR cushions).

Gronas et al. plugged the canals of their normal-hearing subjects with a cotton wad impregnated with petroleum jelly. In addition, they stated: "The wad was placed close to the ear drum and the ear canal filled with model wax." (p. 243). In a preliminary investigation at this center, a similar procedure was carried out. A quantity of earmold impression material was injected by a physician into the external auditory canals of a normal-hearing subject. Care was taken to ascertain that the material was packed as close to the tympanic membranes as possible. With the canals thus plugged, a hearing loss of from 35 to 40 dB was demonstrated. The occlusion effect was absent whether the ears were either covered with the earphones or not.

It is known that otosclerotic subjects do not demonstrate the occlusion effect when their ears are covered with earphones. One might hypothesize then, that the reason otosclerotics break down more than normals is due to a reduction of BC synchronous feedback as compared to normals. This hypothesis explains why Harford and Jerger's plugged normals (with occlusion effect) broke down only as much as normals and why the Gronas _et al_. plugged normals (without occlusion effect) broke down as much as the otosclerotics.

There is support for the second explanation. In both investigations the magnitude of the hearing loss for the otosclerotics was approximately 40 dB. The attenuation provided by the earphones is about 20 dB in the speech frequencies. It can be seen that the combination of a hearing loss and the attenuation characteristics of the earphones provides more attenuation of the air-borne signal for the otosclerotic subjects than it does for the normal subjects. There is a difference in the magnitude of the AC synchronous feedback in favor of the normals. Therefore, otosclerotics might show more breakdown than normals because they have less synchronous AC auditory feedback.

Again, Gronas _et al_. reported that their plugged-normal group had the same amount of hearing loss as did their otosclerotic group (35 to 45 dB) and the two groups broke down similarly. The plugged normals in Harford and Jerger's study (hearing loss for speech of 27 dB) broke down slightly more—than the normal subjects and considerably less than the otosclerotic subjects.

The two previously cited studies are confounded by the fact that the SAF/DAF ratios were probably not kept constant because the experimenters "rode the gain" on each DAF condition. That is, in order to keep the delayed signal at a relatively constant level at the ear, the gain was reduced under the DAF conditions to nullify the results of increased vocal output. By so doing, the SAF/DAF ratios were changed in uncontrolled amounts over the experimental conditions thus injecting another variable into the study.

Two possible explanations are suggested as to why otosclerotics show more breakdown than normals on a speech DAF task:

1. The lack of the occlusion effect in otosclerotic subjects decreases the amount of synchronous BC feedback and causes increased breakdown.
2. The reduction in the amount of synchronous AC feedback in otosclerotic subjects, due to the magnitude of the hearing loss itself, causes increased breakdown.

In order to determine whether or not the "bone-conduction" hypothesis better explains the behavior of otosclerotic subjects, an investigation was designed that would hold the SAF/DAF ratios constant, provide that the AC synchronous pathway is held constant, and allow an independent determination of the role of BC synchronous auditory feedback during a delayed speech feedback task.

CHAPTER III

INSTRUMENTATION AND PROCEDURES

Introduction

The purpose of this investigation was to test the hypothesis that the presence or absence of the occlusion effect causes differential effects upon two DAF tasks, namely, speech and keytapping. The speech DAF procedure was a modification of the flashing numbers task developed by Butler and Galloway (7). In this procedure, the subject was required to identify verbally a series of two-digit numbers that were illuminated at the rate of two per second under a SAF condition and a DAF condition. In the keytapping procedure described by Ruhm and Cooper (44), the subject tapped a rhythmic pattern (.... ..) on a special touchplate. Each tap generated a pure-tone signal that was returned to the subject's ear either in synchrony with the tap or delayed from it.

Subjects

Subjects for this investigation were eight individuals with normal hearing as demonstrated by pure-tone air-conduction and bone-conduction thresholds of no more than 10 dB hearing level (HL) re: ISO-1964 standard at the frequencies of 500, 1000, and 2000 Hz. Persons with an air-bone gap of more than 5 dB were not employed in the study. Further, each subject demonstrated a speech reception threshold (SRT) of no more than 10 dB HL as determined by a recorded presentation of the CID Auditory Test W1.

Test Environment

All test procedures and threshold measurements were carried out in a sound treated test booth (IAC, model 400) located at the Veterans Administration Hospital, Oklahoma City, Oklahoma. Sound levels were measured with a sound-level meter (General Radio, Type 1551-C) in conjunction with an octave-band noise analyzer (General Radio, Type 1558-AP) located at the approximate position of the subject's head. These levels were below the limits required for air and bone conduction threshold testing (ISO-1964).

The test room contained a headset consisting of TDH 39-10Z earphones set in MX-41/AR cushions mounted on a standard headband, the non-occluding enclosures, a microphone (Altec, Type 682A), a bone-conduction transducer (Radioear B70), the signal panel for the speech DAF test, and a special touchplate mounted upon a conventional tablet-arm chair. Other associated apparatus was located outside the test room.

Apparatus

Preliminary Threshold-Finding and Control Equipment

Preliminary pure-tone AC and BC thresholds were determined with a commercial clinical audiometer (Beltone 15C). A 15 dB attenuation pad was inserted between the output of the audiometer and either the earphones or the bone-conduction vibrator so that thresholds below 0 dB HL could be measured.

A Tektronix oscilloscope (model 561A) and an ac Voltmeter (Balantine, model 300) were employed to ascertain and maintain the specified signal parameters. All time intervals and signal frequencies were measured with an accurate counter-timer (Transistor Specialities Incorporated, model 361).

Non-Occluding Headset

Two custom-designed sound enclosures were constructed. Their purpose was to direct an auditory signal to each ear separately without producing an occlusion effect. The occlusion effect is an auditory phenomenon which results in an enhancement of bone-conducted signals at frequencies below 1000 Hz when the ears are covered or occluded in certain ways. For example, one will obtain a better bone-conduction threshold at a frequency of 500 Hz when one or both external ears are occluded with TDH 39-10Z earphones set in MX-41/AR cushions (the standard headset). For two experimental conditions (to be discussed in a subsequent section) it was necessary that the occlusion effect be eliminated while still presenting the signal to each ear separately. The special sound enclosures (hereafter called non-occluding headset) described in the following paragraphs served this purpose.

Since both sections of the non-occluding headset are identical, only one will be described here. The enclosure is essentially a box made of 3/4 inch white pine with inside dimensions of 12" x 9" x 9". Approximately 3 inches from one end and parallel to the ends was mounted a piece of 1/4 inch plywood 9" x 9" in which there was centered a circular 5" diameter cutout. A 6" diameter permanent-magnet speaker was mounted centrally on the back of this square of plywood facing the larger section of the enclosure.

The enclosure was lined with acoustical fiberglass, 1 inch thick and had a total volume of approximately 15,000 cc less the fiberglass lining. This volume was in excess of the 6700 cc reported by Watson and Gales (55) to preclude the occlusion effect at any frequency down to 125 Hz.

At the end of the enclosure opposite the speaker was a hole 2 inches in diameter. Centered over this hole on the outside of the enclosure was cemented a layer of 1 inch foam rubber also with a 2 inch diameter hole. An MX-41/AR cushion was in turn cemented to the foam rubber.

Both enclosures with the cushions facing each other, were suspended from hooks which allowed the enclosures to slide in a horizontal plane on a 1 inch diameter piece of thin-wall electrical conduit mounted on two microphone stands four feet apart. The two enclosures were connected by an elastic band that served to pull them together and thus provided a firm but flexible fit when the subject's head was place between them.

Keytapping Equipment

The keytapping apparatus employed in this investigation consisted of a custom-made capacity-operated switch, an electronic timing network, a stripchart recorder (SCR) (Techni-rite, model TR 711), a puretone audio oscillator (Hewlett-Packard, model 200 ABR) an electronic switch (Grason-Stadler, model 829C) and the earphones and cushions described in the preceding section. Figure 1 shows a block diagram of the apparatus.

The capacity-operated switch. A silent capacity-operated

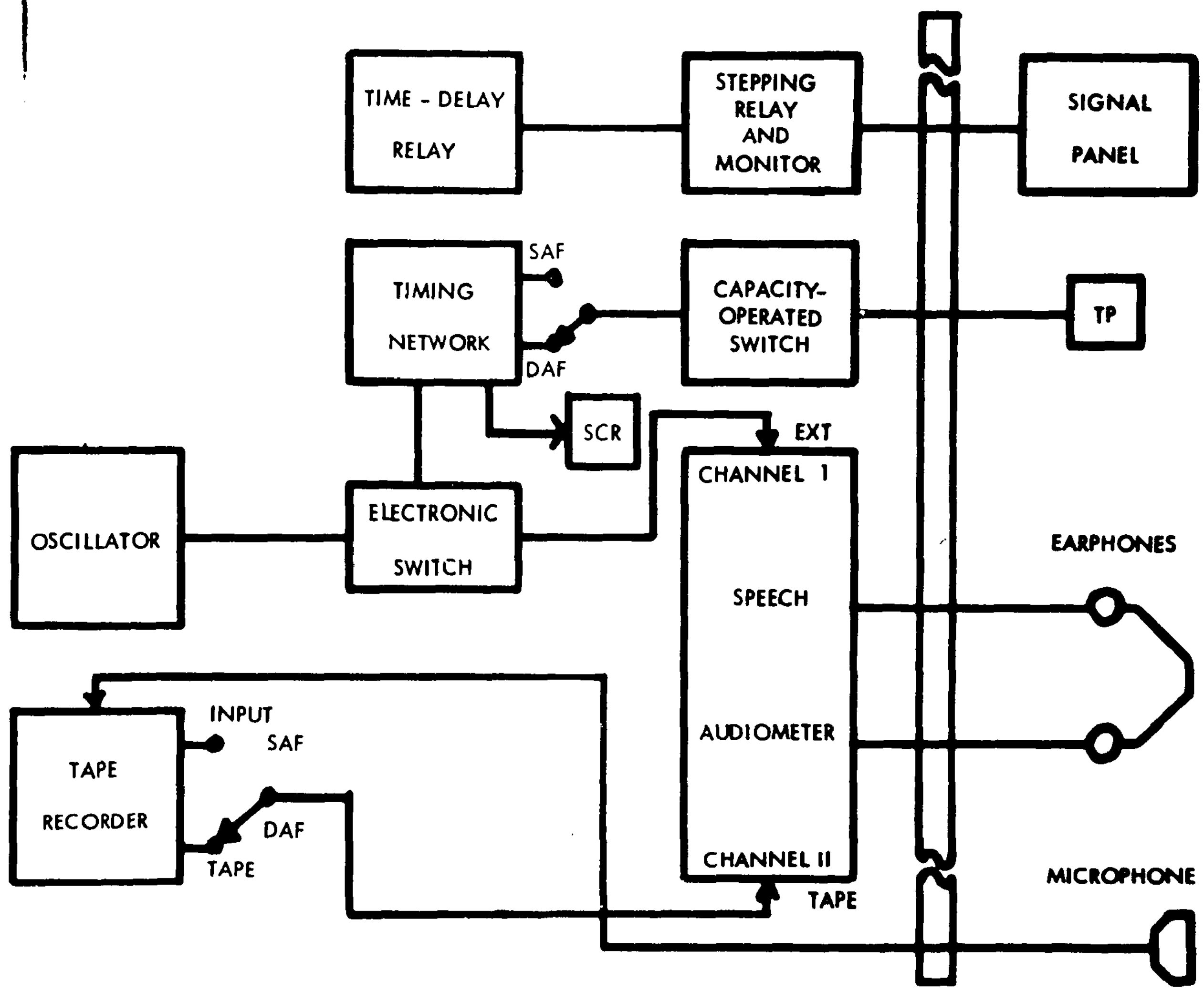

FIGURE 1. BLOCK DIAGRAM OF SPEECH AND PURE - TONE FEEDBACK APPARATUS.

switch (CS) was constructed in order to insure that the subject would receive no synchronous auditory feedback (SAF) when his finger tapped the touch-plate. The silent properties of the switch were demonstrated to the satisfaction of the experimenter and normal-hearing listeners. Briefly, the switch can be described in the following manner: the touch-plate (TP) is fabricated from a two inch-by-two inch piece of aluminum and has no moving parts or contacts. The plate is cemented to a piece of foam rubber which in turn is cemented to the tablet-arm chair. The active circuit of the switch consists of an rf oscillator whose output serves to hold the contacts of a sensitive relay in their open position. The TP is connected to this circuit so that when it is touched, the increased capacity thus injected into the circuit disables the oscillator and causes the sensitive relay to drop out. When this happens, the two relay contacts close and send a positive pulse to the appropriate waveform generator in the timing network.

The timing network and the stripchart recorder. Three Tektronix waveform generators (Type 162), four pulse generators (Type 161), and one power supply (Type 160A) were utilized in the timing network to effect the synchronous and delayed pure-tone feedback conditions. The network consisted of waveform generators W1, W2 and W3 and pulse generators P1, P2, P3, and P4. Figure 2 shows the interconnections of this equipment.

When the "Delay-Synchronous" function switch was in the "Synchronous" position, the positive pulse initiated by the closure of CS was directed to W3. W3, P3, and P4 comprised the part of the timing network that activated the electronic switch. P3 in conjunction with W3 turned channel A of the electronic switch on in synchrony with the sub-

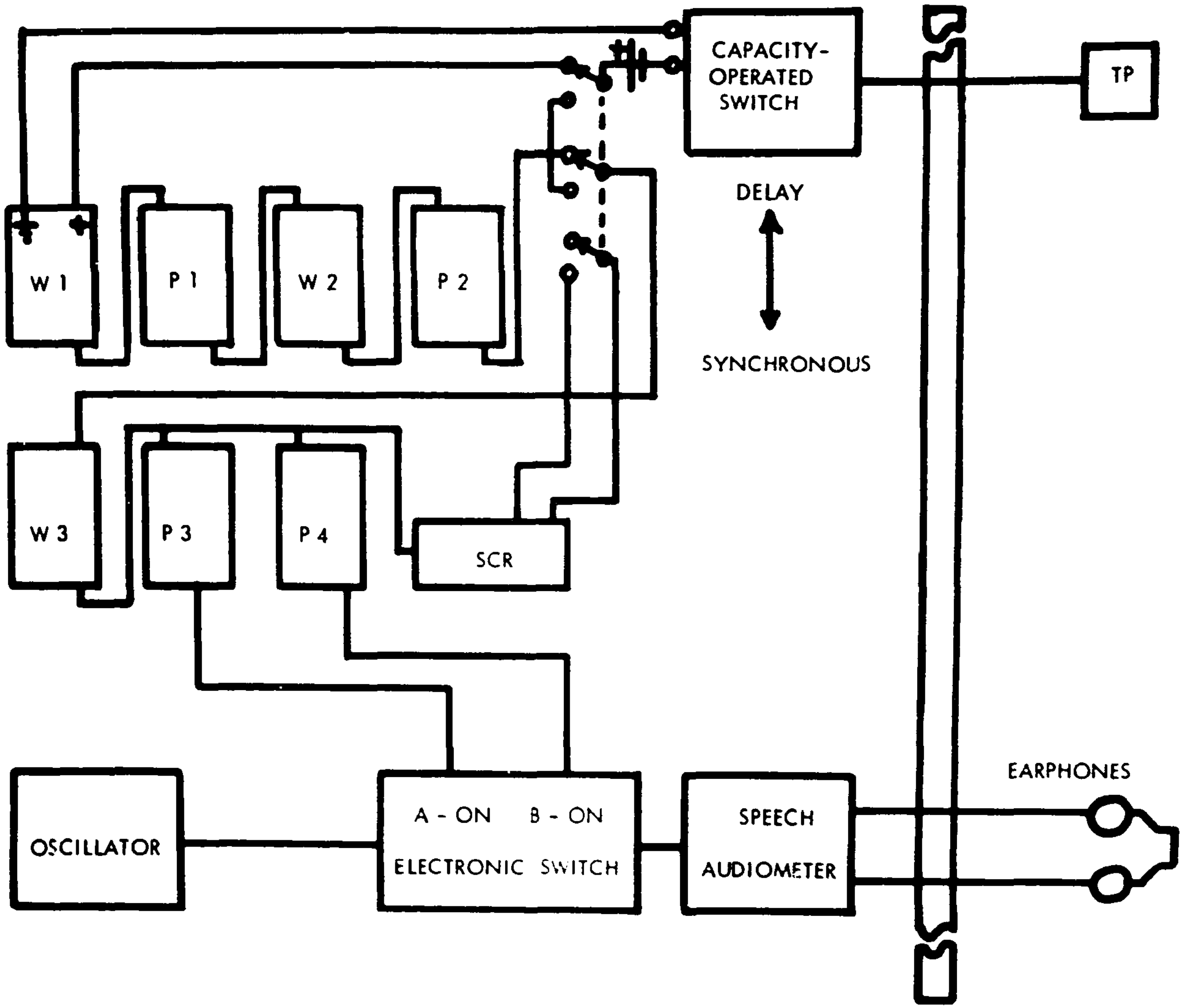

FIGURE 2. BLOCK DIAGRAM OF PURE - TONE FEEDBACK APPARATUS.

ject's tapping performance and the output of P4 served to turn off channel A after an interval of 60 msec.

With the function switch in the "Delay" position, a positive pulse initiated by the closure of CS caused W1 to generate a negative going sawtooth waveform of 86 msec duration. After 85 msec of this duration had elapsed, P1 generated a positive pulse that triggered W2 which initiated another sawtooth waveform also of 86 msec duration. After another 85 msec, P2 produced a positive pulse at its output. It is clear that there was a time-delay of 170 msec (85 msec plus 85 msec) between the initial positive pulse originating from the closure of CS and the positive pulse occurring at P2's output. The pulse from P2 was directed through a section of the function switch to W3 where the electronic switch was activated as discussed above. It was necessary to break up the total desired delay time into two intervals because some subjects were able to tap a pattern whose individual components were less than 170 msec apart. If the total delay duration were determined by only one waveform generator, it would be possible for a subject to tap the touchplate more than once during a single cycle of the waveform. Since only the first tap would initiate the cycle and generate a pure-tone burst, the effect of the second tap would be lost. By splitting the delay time into two segments, W1 will have completed its cycle before the subject's second tap.

A stripchart recorder (SCR) was utilized to make a permanent record of the subject's tapping performance. The sawtooth output of W3 was connected to the SCR input. Each tap, under either the delayed or synchronous condition produced a deflection of the hot-wire stylus which marked the chart paper. In addition, when the function switch was in the

"Synchronous" position, a secondary "marker" stylus on the SCR was activated and thus provided a means of differentiating the "Synchronous" and "Delayed" patterns on the chart paper.

In summary, the timing network provided 170 msec of delay when the switch was in the "Delay" position and 00 (zero) msec when it was in the "Synchronous" position. Also, a stripchart recorder furnished a permanent record of tapping performance.

Oscillator, electronic switch, and speech audiometer. The oscillator was adjusted to produce a pure tone of 500 Hz that was directed to the input of the electronic switch (ES). The rise-decay times of the electronic switch were set at 10 msec and were verified by viewing the signal envelope on the oscilloscope. The decay time of 10 msec in conjunction with the 60 msec interval between P3 and P4 (which includes the 10 msec rise time) produced an overall signal duration of 70 msec. With ES in the "A-on" position, the voltage at its output terminal was set at 1 volt into a 600 ohm load.

The speech audiometer was common to both the keytapping apparatus and the speech feedback apparatus. The channel I "external" input accepted the output signal from the electronic switch, associated with the keytapping procedure, and the channel II "tape" input accepted the output signal from the tape recorder that was used in the speech feedback procedure. Two separate channels of the speech audiometer were utilized so that the input gain controls could be adjusted independently. The signal from either channel was split and sent through both the "grey" and the "black" attenuators. This procedure allowed the intensity at each earphone to be varied independently thereby providing a means to adjust for minor threshold differences between the subject's ears. The attenuators were adjusted to provide the appropriate sensation levels of the signal under each test condition. The output of the speech audiometer was connected to either the standard headset or to the non-occluding headset located in the test room.

Speech Feedback Equipment

Synchronous and delayed speech apparatus. A magnetic tape recorder (TR) (Concertone Series 30) with a movable playback head was utilized to provide speech feedback. The microphone, located in the test room, was connected to the magnetic recorder. The TR had a monitor-selector control which was labeled "Input-Tape". In the "Input" position one could monitor the input signal. This position was used for the synchronous feedback condition. In the "Tape" position, the incoming signal was monitored from the playback head after it had been recorded on the magnetic tape, just a fraction of a second after it entered the machine. The amount of delay introduced when the switch was in this position was measured in the following manner: A single square wave, 1 msec wide, was introduced at the microphone input of the tape recorder. At the same time it triggered "on" the counter-timer. With the monitor switch in the "Tape" position, the recorded signal was monitored and triggered the counter-timer "off". The delay interval produced by this recorder was adjusted, by moving the tape head, to be 170 msec.

Flashing numbers apparatus. This apparatus is similar to that described by Butler and Galloway (7), and Harford and Jerger (31). The apparatus consisted of a modified Time-delay Relay (TD) (Potter-Brumfield, Type CHB 38-70003) connected so that its contacts closed and opened at the rate of two times each second. Connected in series with these contacts was a telephone-type stepping relay (52 positions, "round and round"; 12 decks; 6 poles), and a 24 volt dc power supply. Each closure of TD advanced the stepping relay one step. Each of the first 50 positions of the stepping relay completed the circuit that caused the appropriate set of lights in the signal panel to illuminate a pair of numerals. The signal panel (Figure 3) consisted of a box (30" x 4" x 3") that was divided into five equally-spaced, aluminum-foil-lined compartments. On the back wall of each compartment were mounted four #47 pilot lamps connected in parallel (20 bulbs). Each bulb had two leads. One lead from each of the 20 bulbs was connected to a common ground. The remaining leads were grouped by compartment. A common lead from each compartment was then connected to one pin of an octal socket mounted on the back of the box.

The front of the signal panel was covered with a piece of translucent white plastic. Mounted on the plastic in front of each compartment were five pairs of adhesive-backed, plastic numberals two inches high. Reading from the viewer's left the numbers were: 24, 31, 58, 63 and 92. The stepping relay was wired in such a way that in each run of fifty steps, each of the above numbers was back-lighted ten times in a quasi-random sequence.[1] An 11-position switch was provided so that the numbers could be presented in ten additional quasi-random sequences. The signal panel was mounted on a wall of the test room approximately six feet in front of and slightly above the subject. Also, a monitor panel connected in parallel with the signal panel was provided for the experi-

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[1]The stipulation was made that a number did not appear twice in succession.

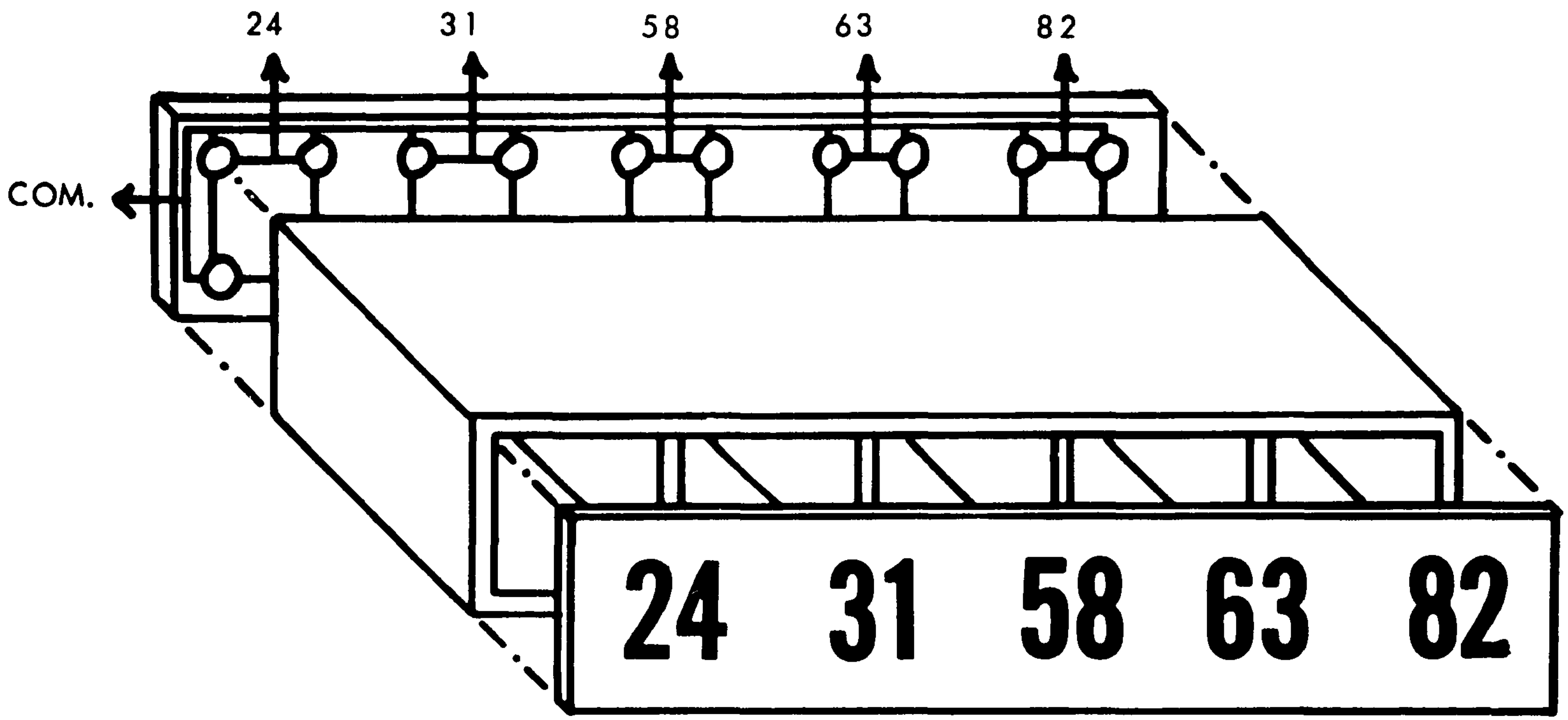

FIGURE 3. FLASHING NUMBERS PANEL

menter and located in such a way so that it could not be seen by the subject.

Procedure

Subject Selection

Before being accepted as a subject, each volunteer was required to meet the criteria set in a preceding section. The method used for the determination of pure-tone thresholds was that advocated by Carhart and Jerger (9). SRTs were determined using a standard clinical method.

The Experimental Conditions

The present investigation consisted of the evaluation of the data derived from four experimental conditions. The four conditions were:

1. Delayed speech feedback with the standard headset.
2. Delayed speech feedback with the non-occluding headset.
3. Delayed pure-tone feedback with the standard headset.
4. Delayed pure-tone feedback with the non-occluding headset.

Each of the four conditions was counterbalanced to account for order effects. Table 2 presents the counterbalanced schedule of conditions for each subject. Subjects were assigned a subject number randomly.

Collection of the Data

General procedures. Prior to the experimental conditions, certain baseline data were collected. The subject's AC threshold for the right and left ear was determined using the pure-tone feedback apparatus as described in the apparatus section. The thresholds obtained during subject selection were not adequate for baseline data because they were

TABLE 2

PRESENTATION SCHEDULE OF EXPERIMENTAL
CONDITIONS FOR EACH SUBJECT

Subject	1st Condition	2nd Condition	3rd Condition	4th Condition
1	ES	ET	HS	HT
2	ET	ES	HT	HS
3	ES	ET	HT	HS
4	ET	ES	HS	HT
5	HS	HT	ES	ET
6	HT	HS	ET	ES
7	HS	HT	ET	ES
8	HT	HS	ES	ET

E = Enclosures S = Speech
H = Headset T = Tapping

determined using different apparatus. The shorter duration of the signal generated by the keytapping equipment resulted in poorer threshold as compared to the thresholds obtained with the commercial audiometer. A BC threshold at 500 Hz was also obtained with the keytapping apparatus. The BC threshold did not agree with the AC threshold on a dial-reading basis because of the greater power required to drive the bone vibrator. However, the BC thresholds served as a baseline reference. Monaural SRTs by AC and BC were also obtained at this time.

Care was taken to ensure that the sequence of events in the speech feedback and the pure-tone feedback procedures were analogous. Each condition was preceded by a demonstration by the investigator of the task that the subject was to perform. The demonstration was followed by a very brief practice session by the subject during which the investigator observed and "shaped" the subject's performance until a satisfactory level of performance was achieved.

In any experimental series, the subjects were required to finish the task completely. This meant that no fewer than fourteen patterns were to constitute a complete and acceptable performance for the keytapping task. Also, only a continuous recitation of the flashing numbers (save short pauses for breath) was to constitute a complete and acceptable performance for the speech feedback task. All subjects were able to perform the task.

The keytapping procedure. The subject was seated comfortably in the test room at a tablet-arm chair on which the touchplate was mounted. The investigator demonstrated the keytapping task and then ascertained that the subject was able to do it. The investigator then placed a shield (a piece of cloth suspended from a horizontal bar which is connected to a microphone stand) in such a way that the subject was not able to view his hand during the tapping task. The shield prevented synchronous visual feedback. The instructions (Appendix A) were then read to the subject. If there were no questions, the appropriate headset was placed on the subject's head and the experimenter left the room. After a final check of the equipment, the subject was instructed to begin the tapping sequence. He was required to tap the full pattern (.... ..) fourteen times with no auditory feedback, synchronous or delayed, presented to his ears. When fourteen patterns were recorded on the SCR, the first series of the keytapping condition was terminated.

The second series of the keytapping condition was identical to the first except that SAF was presented bilaterally to the subject at 50 dB sensation level (SL) re: The AC threshold for each ear obtained with the keytapping apparatus described previously. Again, fourteen patterns were required of each subject.

The final series of the keytapping condition followed the format of the two previous series except that DAF was presented to the subject bilaterally at 50 dB SL. After the subject had tapped fourteen patterns under DAF, the keytapping task was terminated.

The flashing numbers procedure. Each subject was seated in the tablet-arm chair and his attention directed to the signal panel that was mounted on the wall of the test room in front of and slightly above him. The investigator activated the flashing numbers apparatus and demonstrated to the subject the manner in which he was to say the numbers. The subject was then allowed to try the task himself. The subject practiced repeating the flashing numbers until his performance appeared satisfactory to the investigator. The instructions for the task (Appendix A) were then read to the subject. If there were no questions, the appropriate headset was placed on the subject's head and the microphone placed nine inches from his lips. The investigator then left the room and initiated the testing sequence.

The first series of the speech condition required that the subject repeat a quasi-random series of 50 flashing numbers without SAF or DAF presented through the earphones. During this series, the investigator adjusted the calibration control on Channel II of the speech audiometer so that the subject's voice peaked the needle of the VU meter at a pre-determined point. This calibration control, once set, was not readjusted for the subsequent conditions. Some investigators (1, 4, 7) have attempted to compensate for the Lombard Effect and other allied phenomena under SAF and DAF conditions by decreasing the intensity of the feedback signal presented to the subject's ears by an amount equal to the increase in the vocal output. It is felt by the present investigator that "riding the gain" during feedback conditions would introduce more variability into the data than it was meant to reduce. In this investigation, the calibration control was not adjusted for each speech experimental condition. Hence, the same SAF/DAF ratio was maintained for all the conditions. The first series was terminated automatically when the stepping relay reached its 51st position.

In the second series of the speech condition, the subject repeated another quasi-random sequence of flashing numbers while SAF was presented to him bilaterally at an SL of 50 dB re: The AC SRT for each ear. The series was terminated automatically after 50 numbers were presented.

The third and final series of the speech condition consisted of a recitation of a different quasi-random sequence of the flashing numbers while DAF was presented bilaterally at 50 dB SL. The series again was terminated automatically after 50 numbers had been presented.

Summary

Each subject was assigned a subject number at random. The order of presentation of the experimental conditions for all subjects was determined by Table 2. The four experimental conditions consisted of a speech and pure-tone (keytapping) feedback task carried out under the standard headset and the non-occluding headset. Table 3 summarizes the procedure for each condition.

Scoring the Data

Keytapping Data

The data collected from the keytapping experiment was in the form of marked chart paper from the SCR. The subject's tapping performance was recorded as a series of spikes, one for each tap of the touchplate. Ruhm and Cooper (46) have found that the duration of the tapping pattern in SAF and DAF conditions is a sensitive index of tapping performance. In this investigation the data for the keytapping task is expressed as the mean time (duration) per pattern (.... ..) or the mean pattern time (MPT).

The MPT was derived in the following way: As previously described, a single series of a pure-tone experimental condition consisted of fourteen patterns. The chart paper containing the patterns was identified as to the experimental condition and series number. The beginning two patterns and the final two patterns were discarded leaving only

TABLE 3

TESTING SEQUENCE FOR THE SPEECH AND KEYTAPPING TASKS

Occluding Headset or Non-Occluding Headset	
Speech Feedback	**Pure-Tone Feedback**
1. Demonstration (Investigator repeats FN)	1. Demonstration (Investigator taps pattern)
2. Practice by subject (subject repeats FN)	2. Practice by subject (subject taps pattern)
3. Modification of performance if necessary	3. Modification of performance if necessary
4. Placement of earphones	4. Placement of earphones
5. The experimental runs a. Repeat FN under NAF b. Repeat FN @50 dB SL SAF c. Repeat FN @50 dB SL DAF	5. The experimental runs a. Tap patterns under NAF b. Tap patterns @50 dB SL SAF c. Tap patterns @50 dB SL DAF

FN = Flashing Numbers

SL = Sensation Level

NAF = No Auditory Feedback

SAF = Synchronous Auditory Feedback

DAF = Delayed Auditory Feedback

the middle ten patterns for analysis. The task remained to convert the ten patterns into the MPT. The chart speed of the SCR was verified to be 25mm/second. The length of the chart paper from the first spike of the third pattern to the first spike of the thirteenth pattern was measured with a millimeter rule to the nearest millimeter. This measurement was divided by 25 to convert the total length of the patterns into seconds per 10 patterns which were then divided by 10 to give the MPT in seconds. In practice, the length of the ten patterns was divided by 250 to give the MPT. Therefore, MPT = Length (mm) for 10 patterns divided by 250. The MPTs obtained under NAF, SAF and DAF were recorded on a master data sheet.

Speech Feedback Data

The utilization of a magnetic tape recorder has been discussed as a means for effecting the speech feedback task. The recorder's prime function was to provide a time delay of the speech signal in the DAF condition. A secondary function of the recorder was to provide a permanent record of the subject's speech feedback performance which was used in the scoring of these conditions.

The maximum possible number of correct responses on a speech feedback run was fifty. The data for these runs consisted of the number of errors made on a NAF run, SAF run and a DAF run. After a subject finished the four experimental conditions, the investigator played back the tape and tallied the number of correct responses for each run. Strict criteria were used to determine exactly what constituted a correct response. The criteria were:

1. Only numbers on the signal panel were accepted.

2. Numbers must have been intelligible to the investigator.

3. The investigator must have arrived at the same number of correct responses on two successive listenings of the tapes.

Having met the above criteria, the correct responses were subtracted from 50 and the error score was recorded on a master data sheet.

Analysis of the Data

The data were analyzed by the use of two analyses of variance (AOV) 2 x 2 factorial designs. The factors were standard headset vs. special headset and synchronous vs. delayed auditory feedback for both the speech feedback task and the pure-tone feedback task.

CHAPTER IV

RESULTS ANALYSIS AND DISCUSSION

Introduction

Harford and Jerger (31) and Gronas et al. (27) have shown that otosclerotic subjects break down more on a speech DAF task than do normal subjects. These investigators have not offered a tenable explanation for this result. The present investigation has sought to explain the findings of these two studies. The purpose of this investigation was to determine whether or not changes in the level of synchronous bone-conducted auditory feedback have an influence upon the degree of breakdown obtained on a delayed speech feedback task. Speech and pure-tone feedback tasks were performed on eight normal-hearing subjects while the level of the bone-conducted signal was changed systematically.

The level of the BC signal was varied through the use of occluding and non-occluding headsets. Each headset provided the same amount of attenuation to air-borne sounds. The occluding headset produced an enhancement of BC thresholds for spondee words of approximately 10 dB.

Prior to the actual running of the experimental conditions, AC pure-tone and speech thresholds were obtained under the standard headset and under the non-occluding headset. These thresholds were used as the reference points from which all sensation levels were determined. BC thresholds were also obtained under both headsets. It was found that the standard headset produced a median enhancement of the SRT of 9 dB and of the pure-tone threshold at 500 Hz of 21 dB. Under the non-occluding enclosures the SRT and pure tone thresholds were better than unoccluded BC thresholds by median values of 1 dB and 5 dB respectively.

It was desirable to ascertain that both headsets provided approximately the same amount of attenuation to air-borne signals. If the headsets had similar attenuation characteristics, any differences between the data obtained under the different headsets could not be attributed to differing levels of air-borne synchronous auditory feedback present at the ears. The occluding and non-occluding headsets differed in the amount of attenuation they provided by a median value of only 3 dB at the octave frequencies of from 250 Hz to 2 kHz with the occluding headset providing greater attenuation.

Eight normal-hearing subjects performed the flashing numbers speech task (7) under both headsets and under conditions of NAF, SAF at 50 dB SL, and DAF at 50 dB SL. In addition, each subject performed a keytapping task under both headsets and under the same feedback conditions. The keytapping task served as a control in that no synchronous bone-conducted auditory feedback was produced. This prevented modification of the BC signal by the occlusion effect.

Results

Data for the speech and keytapping tasks are expressed in number of errors and the mean pattern time (MPT) respectively. Table 4 presents the mean data and the standard deviations obtained from the twelve experimental conditions for the eight subjects. It can be seen that there is a considerable difference between the number of errors

TABLE 4

MEAN DATA FOR OCCLUDING AND NON-OCCLUDING HEADSETS

Headsets	Speech			Kaytapping		
Occluding	NAF	SAF	DAF	NAF	SAF	DAF
Mean	3.75	3.38	20.13	1.581	1.583	1.935
S.D.	2.22	1.68	7.57	.181	.116	.227
Non-Occluding						
Mean	5.00	5.25	17.13	1.608	1.598	2.173
S.D.	4.90	5.61	7.59	.235	.187	.387

Speech means expressed in number of errors.
Keytapping means expressed in MPT (seconds).

made under NAF and SAF as compared to those made under DAF on the speech feedback task. This difference is not so dramatic on the keytapping task. A comparison was made to determine whether, on the average, subjects that tended to break down more than others on the speech task performed similarly on the keytapping task. The Spearman's coefficient of rank correlation (52, p. 409) was calculated from the present data. The coefficient was found to be -0.12. There appears to be little correlation between performance on the two feedback tasks. The conclusion is drawn that one's performance on a speech feedback task is not related to his performance on the keytapping task and vice versa. Appendix B shows the individual subject data for the speech and keytapping tasks.

Analysis

The data obtained from the six treatments (2 headsets for each of 3 conditions of feedback) were arranged in a factorial design with the subjects considered as a random factor. Speech and keytapping data were analyzed separately by the analysis of variance (AOV) described by Steele and Torrie (52, p. 199). Duncan's New Multiple Range Test (DNMRT) (52, p. 107) was utilized to make meaningful comparisons among means within the feedback factor.

Speech Data

The results of the AOV for the speech task are found in Table 5.

TABLE 5

ANALYSIS OF VARIANCE FOR THE SPEECH TASK

Source	df	SS	MS	F
Treatments	5	2231.86	446.37	16.04 *
A (Feedback)	2	2175.54	1087.77	39.10 *
B (Headset)	1	16.02	16.02	$<$1.0 N.S.
A x B	2	40.30	20.15	$<$1.0 N.S.
Error	42	1168.62	27.82	

* Significant at the .01 level of confidence.

These results reveal a significant difference among the three feedback conditions. The DNMRT reveals that the significant difference is between DAF and both NAF and SAF and further, that NAF is not significantly different from SAF.

Of prime interest is the B factor - the occluding and non-occluding headsets. The purpose of these headsets was to change the level of synchronous BC feedback. If they produce significant changes in performance, their effect will be seen in the analysis of the B factor. The results indicate that there is no significant difference in performance under the two different headsets on this speech feedback task. That is to say that an enhancement of synchronous BC auditory feedback of 10 dB does not substantially alter the results of this speech DAF task.

The A x B interaction (condition of feedback x headset) was not significant. This means that performance under any feedback condition (NAF, SAF, DAF) is not influenced differentially by the occluding or non-occluding headsets.

In summary, a statistical analysis of the data derived from the speech feedback task reveals that:

1. There is a significant difference between DAF and both NAF and SAF.
2. There is no significant difference between NAF and SAF.
3. There is no significant difference in performance between the occluding and non-occluding headsets.
4. There is no significant interaction among any of the conditions of feedback and either of the headsets.

Keytapping Data

The data obtained from the keytapping procedure were also subjected to an AOV. The results are shown in Table 6. Again, it is seen that there is a significant difference among the feedback conditions. The DNMRT shows that the difference is between DAF and both NAF and SAF with no significant difference being found between NAF and SAF.

As expected, there was no significant difference between the keytapping performance under either of the headsets. Because there was no BC feedback produced when one tapped the key, the presence or absence

TABLE 6

ANALYSIS OF VARIANCE FOR THE KEYTAPPING TASK

Source	df	SS	MS	F
Treatments	5	250.23	50.05	9.63 *
A (Feedback)	2	227.19	113.60	21.85 *
B (Headset)	1	10.45	10.45	2.01 N.S.
A x B	2	12.59	6.30	1.21 N.S.
Error	42	218.51	5.20	

* Significant at the .01 level of confidence.

of an occlusion effect should not have and did not affect tapping performance.

The A x B (feedback condition x headset) interaction, again, was not shown to be significant on the keytapping task. That is, performance under the feedback conditions did not change significantly when the feedback was presented through the occluding or non-occluding headset. To summarize, the AOV performed on the data obtained from the keytapping task reveals that:

1. There is significant difference between DAF and both NAF and SAF.

2. There is no significant difference between NAF and SAF.

3. There is no significant difference in performances between the occluding and non-occluding headsets.

4. There is no significant interaction among any of the conditions of feedback and either of the headsets.

Discussion

The analysis of the present data revealed that there is no significant difference between NAF and SAF on either feedback task. It would seem that in future DAF investigations either NAF or SAF could serve as the baseline from which the degree of breakdown under DAF could be measured.

As expected, there was a significant difference in performance between DAF and both NAF and SAF on the speech and keytapping tasks. Again, the present results confirm the presence of disruptive effects of suprathreshold DAF found by preceding investigators.

Analysis of the data fails to show any significant difference in the magnitude of DAF breakdown between the occluding and non-occluding headsets on the speech or pure-tone task. It was not surprising that there was no significant difference in performance between the two headsets on the keytapping task. The purpose of the non-occluding headsets was to eliminate the enhancement of BC signals caused by the occlusion effect. Because BC feedback signals are not present in the keytapping task, they cannot be modified by either headset.

With regard to the speech feedback task, it must be concluded that, at a sensation level of 50 dB, a difference of 10 dB in the level of the synchronous BC feedback does not differentially affect the degree of breakdown. One possible explanation for this finding is that at 50 dB SL, the AC DAF is of a sufficient magnitude to override the synchronous AC and BC feedback.

It may be useful to determine for each subject the level of DAF that just begins to produce significant amounts of breakdown. At each subject's threshold of breakdown the difference between the occluding and non-occluding headsets could be assessed. The effects of small differences in the level of BC signals would possibly be apparent more readily near the threshold of breakdown than at suprathreshold levels. It is possible that in the present investigation the DAF was presented at a level greatly above the breakdown threshold of the subject. The effects on performance caused by small changes in the level of the BC signals were probably obscured by the large DAF/SAF ratio which produced a large amount of breakdown under both headsets.

The conclusion is reached that, under the conditions of this study, a change of 10 dB in the level of the bone-conducted signal has no differential effect upon the degree of breakdown on a speech DAF task. This conclusion leads to a rejection of the hypothesis that the occlusion effect influences breakdown under DAF. The results of Harford and Jerger (31) and Gronas et al. (27) may yet be explained on the basis of the occlusion effect. However, other factors may aid in explaining their findings. One such factor is that there was less synchronous AC feedback present for their otosclerotic subjects than for their normals. Another factor to be considered is that in the present investigation an attempt was made to control the SAF/DAF ratio. It does not appear that Harford and Jerger and Gronas et al. controlled this factor.

The plugged-normal subjects of Harford and Jerger and Gronas et al. behaved differently from each other on a similar speech DAF task. In Harford and Jerger's investigation, otosclerotic subjects broke down more than normals. On the contrary, plugged-normal subjects, who had a minimal (27 dB) air-conduction loss, did not differ significantly in performance from normal subjects at comparable SLs. The otosclerotic subjects of Gronas et al. broke down more than normals. Their plugged-normal subjects' performance, however, did not differ significantly from the otosclerotic subjects. It will be recalled that the hearing loss for the plugged normals and otosclerotic subjects was the same (approximately 40 dB) in the Gronas et al. study. The difference in performance between the plugged-normal subjects of these two investigations is probably due to the degree of AC loss they present. When these subjects have a minimal AC loss, they perform as normals. When they have an AC loss similar to that presented by the otosclerotic subjects, they perform as otosclerotics.

It seems reasonable to conclude that the synchronous AC pathway plays an important role in the determination of the magnitude of breakdown on a speech DAF task when the DAF is presented at a 50 dB sensation level. It has been shown by Black and Tolhurst (6) that a speaker depends upon the air-borne synchronous feedback rather than the BC feedback in order to monitor the intensity of his speech. Further, Lawrence (34) showed more breakdown for subjects who whisper than for those who vocalize normally. He showed that at the two levels (20 dB and 30 dB SL) where there was a significant difference between whispered and voiced speech, the level of vocal output was approximately 10 dB less for the whispered speech. Lawrences' 20 dB SL (re: equal loudness of speech and feedback) is probably equivalent to the level used in the present study. Again, it appears that there is a trend for more breakdown to occur when the air-borne synchronous signal is decreased.

The conclusion reached by Harford and Jerger that the increase in loudness due to recruitment is responsible for excessive breakdown is open to question. In light of the above discussion, the degree of breakdown found in subjects with recruiting losses and masked normal subjects may not be due to the recruitment phenomenon but in reality to a reduction in the amount of synchronous AC feedback present for these subjects. The three experimental groups, (1) hydrops, (2) masked normal, and (3) otosclerotic, had mean binaural spondee thresholds of 44 dB, 42.2 dB, and 41.4 dB respectively and all three broke down an equivalent amount.

One of the most important variables that was held constant in this investigation was that of the SAF/DAF ratio. As was previously discussed, several investigators adjusted the gain of their recording systems in order to keep the level of the DAF constant at the subject's ears. By so doing, they injected into their investigations the variable of differing SAF/DAF ratios. Since the purpose of the two headsets in the present investigation was to change the SAF/DAF ratio by changing the level of the synchronous BC signals, it was imperative that the SAF/DAF ratio not be changed by any other means. Adjusting the gain of the recording system to nullify the increased vocal output caused by the DAF does just that. If the gain is adjusted on a SAF condition, the experimenter has determined a certain SAF/DAF ratio. If, on a DAF condition in which the subject usually raises the intensity of his voice, the experimenter reduces the gain to compensate for the intensity increase, he changes the SAF/DAF ratio. Changing the SAF/DAF ratio in this way results in more SAF being produced by and presented to the subject thus inhibiting breakdown. That is, when the subject speaks louder, he increases his SAF by AC and BC; if the gain of the system is reduced, the level of the DAF remains the same but the level of the SAF is increased. The more SAF that is present, as compared to DAF, the less the subject should break down. A comparison of the results obtained from the present investigation and those of Harford and Jerger and Gronas _et al_. are presented in Table 7. It can be seen that the amount of breakdown, ex-

TABLE 7

A COMPARISON OF THE AMOUNT OF BREAKDOWN FOR NORMAL SUBJECTS AT 50 dB SL ON THREE INVESTIGATIONS - STANDARD HEADSETS

Investigation	Average Errors	Possible Errors	% Errors
Present	20.12	50	40.25
Harford and Jerger	17.00	80	21.25
Gronas _et al_.	7.75	40	19.38

pressed in percentage of errors, for normals is similar on the Harford and Jerger and Gronas _et al_. investigations. In the former investigation, the gain of the recording system was varied to compensate for the increase in the level of vocal output under DAF conditions. Although it is not mentioned, it is assumed that the latter investigators also adjusted the gain of their system. The present investigation yields breakdown results that are considerably greater than the results obtained in the two previous studies. In light of the preceding discussion, it is felt that this increased breakdown is caused by the fact that the gain of the recording system was not changed under the DAF conditions in the present study. Expressed differently, changing the gain setting on a DAF condition results in an increase in the SAF relative to the level of the DAF, which then limits the amount of breakdown.

CHAPTER V

SUMMARY AND CONCLUSIONS

Introduction

The delayed auditory feedback phenomenon has been investigated for some twenty years. During this time many of its relevant parameters have been delineated. Experimenters are in general agreement that the disruptive effects of DAF are related to the delay time and the intensity of the feedback signal. Disruption is present in the form of increased phonation time and stuttering-like behavior on a speech DAF task. Increased pattern time and the addition of extra taps on a keytapping, non-speech DAF task are also described.

Harford and Jerger (31) and Gronas et al. (27) have presented data that show that otosclerotic subjects break down more than normals on a speech DAF task. Two hypotheses that could explain these results were presented. The hypothesis tested by this investigator was that otosclerotics show excessive breakdown because of a decrease in the amount of synchronous BC feedback they receive due to the absence of the occlusion effect.

The purpose of the present investigation was to determine whether or not the presence of the occlusion effect influences the amount of breakdown on a speech and pure-tone DAF task.

The speech task employed was the flashing numbers task described by Butler and Galloway (7). The pure-tone task was the one first used by Ruhm and Cooper (44). Special non-occluding headsets were constructed and utilized to eliminate the occlusion effect. For both the speech and the 500 Hz pure-tone tasks, DAF was presented binaurally at a 50 dB sensation level under both the standard headset and the non-occluding headset.

The delay time utilized for both tasks was 170 msec. A constant SAF/DAF ratio was maintained throughout the speech conditions. Prior to each DAF condition, data were collected under NAF and under SAF at 50 dB SL. Eight normal-hearing persons served as subjects.

Results

The present investigation yielded the following results:

1. There was no significant difference between NAF and SAF on the speech and pure-tone tasks.
2. There was a significant difference between DAF and both NAF and SAF on the speech and pure-tone tasks.
3. At a sensation level of 50 dB, there was no significant difference in the amount of breakdown on the speech DAF task due to the improvement of the bone-conduction threshold produced by occluding the subject's ears with the standard headset.

Conclusion

Two possible hypotheses were presented by the present investigator that could account for the excessive breakdown of otosclerotics found in the investigations of Harford and Jerger and Gronas et al. One hypothesis stated that otosclerotic subjects broke down excessively because the lack of an occlusion effect reduced the level of synchronous BC feedback. The other hypothesis stated that in otosclerotic subjects, the level of synchronous AC feedback is decreased, as compared to normals due to the magnitude of the hearing loss, *per se*.

In light of the results of the present investigation, the second hypothesis is supported. This would explain not only the results on the otosclerotic subjects but also the results on subjects with a sensorineural hearing loss. Acceptance of this hypothesis does not imply, however, that changing the level of synchronous bone-conducted feedback at some other sensation levels will not produce differences in subject performance on a speech DAF task.

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Appendix A

Instructions for the Speech and Keytapping Tasks

INSTRUCTIONS FOR THE SPEECH TASK

When I point to you, I will start the numbers flashing. Repeat the numbers in a natural voice and be as accurate as you can. Remember, it will be helpful if you take short small breaths rather than big long ones. If you get behind in saying the numbers, it is permissable to omit any numbers in order to catch up. Once we have started the run, do not stop trying to say the numbers or give up. If you do, we will have to start over again. Be sure to stay the same distance from the microphone during all the runs.

At times you may hear your voice in the earphones; try to disregard it and concentrate on saying the numbers. Do you have any questions?

INSTRUCTIONS FOR THE KEYTAPPING TASK

When I point to you, I want you to start tapping the pattern. Remember to be sure and use only your index finger and not your whole hand. Tap the pattern as fast and as consistently as you can.

When I point to you, start tapping the pattern. You may hear a sound in the earphones when you tap the touchplate. Disregard it and concentrate on tapping the pattern at your own rate. When I motion to you, stop tapping.

Under no circumstances will you stop tapping or give up during a run. If you do, the data collected from that run will be discarded and we will have to repeat the run. Do you have any questions?

Appendix B

Individual Subject Data for the Speech
and Keytapping Tasks

TABLE 8

INDIVIDUAL SUBJECT DATA FOR THE SPEECH AND KEYTAPPING TASKS

	Non-Occluding Headset						Occluding Headset					
	Speech (Errors)			Tapping (MPT)			Speech (Errors)			Tapping (MPT)		
SUBJECT	NAF	SAF	DAF	NAF	SAF	DAF	NAF	SAF	DAF	NAF	SAF	DAF
1	15	8	18	1.54	1.59	1.71	6	4	22	1.57	1.58	1.79
2	9	14	27	1.85	1.77	2.35	6	4	25	1.61	1.57	1.94
3	6	8	13	1.81	1.79	2.73	6	5	28	1.54	1.72	2.40
4	2	1	21	1.62	1.67	1.74	1	1	17	1.50	1.60	1.82
5	1	1	4	1.09	1.20	2.50	2	2	5	1.24	1.37	1.70
6	2	3	10	1.60	1.50	1.79	2	3	17	1.64	1.50	1.76
7	1	5	23	1.65	1.72	2.29	2	6	23	1.65	1.58	2.09
8	4	2	21	1.70	1.56	2.31	5	2	25	1.90	1.74	1.99
TOTAL	40	42	137	12.86	12.80	17.42	30	27	162	12.65	12.66	15.49