RELATIONSHIP BETWEEN OTOADMITTANCE AND THRESHOLD MEASUREMENTS IN A TTS PARADIGM WITH PHONATION

by

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Abstract

This investigation studies the role of the middle ear muscles in the TTS reduction that occurs when phonation accompanies exposure to a high intensity low frequency pure tone. Changes in acoustic admittance (taken as a measure of middle ear muscle activity) were compared with changes in TTS, recorded under similar experimental conditions. The TTS paradigm consisted of measuring subjects' hearing thresholds before and after 5 minute exposure to a 500 Hz, 117.5 dB SPL tone, accompanied or not by phonation (humming). The paradigm was repeated with threshold measurement being replaced by otoadmittance measurement; in this case admittance changes were recorded before, during, and after the fatigue exposure.

The results show that TTS from the exposure tone with phonation was significantly less than TTS from the exposure tone with no phonation. The effect of phonation on TTS was most significant at early post-exposure times. No significant TTS differences between males and females were found.

Changes in the two admittance components at the beginning and at the end of exposure were significantly larger when phonation accompanied the exposure than when not. This finding suggests that more middle ear muscle activity occurs when phonation accompanies exposure than when no phonation is performed.

Most admittance measurements did not correlate significantly with any of the TTS measurements. The only significant
correlations indicated that the smaller the middle ear muscle activity resulting from the fatigue exposure alone, the larger the amount of protection provided by phonation, as measured by differences between TTS values at early post-exposure times between the two conditions. This finding suggests that most individuals may have middle ear muscles that contract weakly in response to intense acoustic stimulation alone but that these muscles contract significantly when phonation accompanies the acoustic stimulation. Thus, phonation provides considerable protection of the ear from the 500 Hz fatigue tone, as shown by the reduced TTS when phonation accompanies exposure. The results also suggest that the middle ear muscles are a major factor in reduced TTS with phonation but other mechanisms such as inefficient stapes vibration and attentional factors may also be involved. More research is necessary to determine the exact role each mechanism plays in the reduction of TTS with phonation.
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Chapter 1

Introduction

Each time a person talks aloud he is constantly dependent on his auditory system to monitor his vocal output. Thus speaking is influenced by hearing but, as recent evidence suggests, hearing is also influenced by speaking. It is known that if we speak while listening to a sound, the sound we hear is altered. But how does this occur? What mechanisms come into play during phonation and how do they change the sound that enters the ear?

When the human ear is exposed to any sound the acoustic energy of the sound travels from the external auditory meatus through the tympanic membrane, middle ear structures and cochlear fluid to the hair cells of the Organ of Corti. At the hair cells the acoustic energy is transformed into electrical energy which is transmitted along the auditory nerve and higher order neurons to the cortex. This transmission of sound energy is influenced by the frequency, intensity, and duration of the sound to which the ear is exposed.

It has been shown (Bell and Fairbanks, 1963) that a 60 second exposure to as low an intensity tone as 10 dB SL at 1, 2, or 4 kHz can significantly raise the post-exposure behavioural threshold for a tone of the same frequency. Such a post-exposure temporary threshold shift (henceforth TTS)
is a function of the intensity, duration, and frequency of the exposure tone. Thus, a high intensity exposure tone will produce a greater TTS than a low intensity exposure tone. A recent study (McBay, 1971) has shown that TTS produced by a five minute exposure to a 118 dB SPL 500 Hz tone is reduced if the listener phonates (hums) during the exposure. Such results indicate that if the TTS is decreased when phonation occurs during exposure, then phonation might attenuate transmission of the exposure tone to the inner ear. If less acoustic energy reaches the inner ear, less fatigue of the hair cells must occur, thus TTS due to exposure is reduced. It is not clear, however, what factors cause transmission of sound to be attenuated.

The sound may be attenuated by the contraction of middle ear muscles (henceforth MEM), which occurs during or just prior to phonation (Djupesland, 1964, 1967; Salomon and Starr, 1963; Shearer and Simmons, 1965), or the sound transmission may be altered by a change in the mode of stapes vibration, possibly resulting from a change in the direction of skull vibration that occurs during phonation (Békésy, 1960, p. 201; cf. sec. 2.22). If, during phonation, some or all of the attenuation of sound transmission is due to MEM contraction, how is the action of these muscles controlled? It is possible that the MEM are directly influenced by cortical control or it may be that the MEM are activated reflexively by activity of the larynx during and just prior to phonation.
The general objective of this study is to investigate one of the factors that may be responsible for reduction in TTS if phonation accompanies exposure to a high intensity tone. More specifically, the role of the MEM in the reduction of TTS will be investigated. Using acoustic admittance as a measure of MEM activity, changes in admittance and changes in TTS, recorded under similar experimental conditions, will be compared to reveal possible correlations between MEM activity and TTS.
Chapter 2

Review of the Literature

2.0 Introduction

Section 2.1 includes a discussion of the TTS phenomenon and a review of experiments that show some effects of phonation on TTS. Section 2.2 discusses the effect of phonation on sound transmission in the middle ear. Included are subsections on activity of the middle ear muscles and on vibration of the stapes. Although only indirectly relevant to this study a final section, which examines the possible control mechanisms involved in TTS reduction, is presented. Included in Section 2.3 are subsections on control of MEM activity and stapes vibration and on central factors influencing auditory fatigue.

2.1 Effect of Phonation on TTS

2.11 TTS If a listener is exposed to any sound of sufficient intensity and duration his ears' post-exposure sensitivity will be altered. This change in sensitivity may be measured in terms of a temporary shift in absolute hearing threshold (TTS). This TTS or post-stimulatory auditory fatigue is "usually, but not always, a decrease in threshold sensitivity." (Ward, 1963, p.241)

Measurement of TTS requires determination of pre-exposure threshold, followed by exposure of the same ear to the fatiguing stimulus, after which the post-exposure threshold
of that ear is measured. TTS is the difference, in dB, between the post- and pre-exposure thresholds. TTS that follows a pure tone fatigue stimulus generally increases with the duration and frequency of the stimulus until a limit in threshold shift is reached (Ward, 1963; Botsford, 1971). It is generally accepted that TTS varies directly with intensity of the pure tone fatigue stimulus (i.e., as intensity increases TTS becomes larger). This occurs even for intensities below 70 dB SL if TTS is measured within 5 seconds of exposure cessation (Bell and Fairbanks, 1963).

The frequency of the pre- and post-exposure test tone also influences TTS as does the post-exposure time at which threshold of the tone is measured. For exposure tones of less than 80 dB SPL the resulting TTS is maximum at the frequency of the exposure. TTS from such lower intensity stimuli is of short duration, thus measurement must be taken shortly after cessation of the exposure tone. Higher intensity stimulation (80 dB SPL and above) produces longer lasting TTS with a maximum value one-half octave or more above the exposure frequency (Davis, et al., 1950; Epstein and Schubert, 1957; Bell and Fairbanks, 1963; Rodda, 1964).

After cessation of the exposure tone TTS gradually decreases, in, roughly, an exponential fashion, rapidly in the first few seconds then gradually to zero (i.e., the threshold becomes equal to the pre-exposure value). This recovery occurs, for each subject, at a fairly constant rate which does not
seem to depend on the parameters of the fatigue stimulus (Ward, 1963).

There is great inter-subject variability in the magnitude of TTS, produced by a given exposure, which seems dependent on individual susceptibility to auditory fatigue and not related to differences in auditory threshold at the exposure frequency (Ward, 1963). Intra-subject variation in TTS magnitude produced by a specific exposure is, however, insignificant. Riach, et al. (1964) investigated individual susceptibility to auditory fatigue by giving 12 subjects the same high intensity pure tone exposure 20 times over a period of weeks. No significant change in the pre-exposure threshold (at 2800 Hz) was noted during the sessions but there was a "trend toward a smaller TTS at the one minute post-exposure point."

(Riach, et al., 1964, p.1195)

Nixon and Glorig (1962) also looked at susceptibility to auditory fatigue. They warned that TTS experiments must allow for the fact that if the ear does not have recovery time between exposures but is subjected to repeated fatiguing stimulation before recovery has occurred, cumulative effects may occur and lead to permanent shifts in hearing threshold.

2.12 Phonation and TTS Recent investigations (Karlovich and Luterman, 1969, 1970; Luterman and Karlovich, 1969; McBay, 1971; Benguerel and McBay, 1972) have shown that phonation appears to alter sound transmission in the auditory system. Karlovich and Luterman (1969) exposed four normal hearing
subjects to a 4000 Hz 90 dB SL fatiguing tone for three minutes. The subjects tracked their thresholds at 5656 Hz for two minutes before and three minutes after exposure. During exposure the subjects either read a set passage aloud or read it silently. Post-exposure TTS was found to be consistently greater when the subjects read aloud than when they read silently during exposure. Results suggest that, during the reading aloud activity, transmission of a 4000 Hz tone is enhanced. In a later study, Luterman and Karlovich (1969) found that when subjects, exposed to a 2000 Hz 90 dB SL tone, read aloud during exposure they obtained consistently less TTS than if they read silently, read silently while articulating, or engaged in reverie during exposure. These results suggest that, during the reading aloud activity, transmission of a 2000 Hz tone to the cochlea is reduced.

A third study by these experimenters exposed subjects to a 1000 Hz 110 dB SPL tone for three minutes during which the subjects either voiced or gestured-only the vowels /a/ or /i/ (Karlovich and Luterman, 1970). Post-exposure TTS at 1414 Hz was significantly less if voiced /a/ or /i/ accompanied the exposure than if non-voiced gestures were performed. As with the 2000 Hz tone, these results imply that, if voicing accompanies exposure, the transmission of a 1000 Hz tone is attenuated. Karlovich and Luterman suggest that attenuation of low frequency tones during phonation may result from MEM contraction, known to occur during phonation (Salomon and Starr, 1963; Shearer and Simmons, 1965; Djupesland,
and/or from inefficient stapes vibration during phonation (Békésy, 1960).

Most recently McBay and Benguerel (McBay, 1971; Benguerel and McBay, 1972) used TTS studies to investigate more closely the effect of phonation on sound transmission in the auditory system. They subjected listeners to a 500 Hz 118 dB SPL exposure tone for 5 minutes during which the listener hummed at specified fundamental frequency and intensity, approximated the vocal folds without voicing, listened to a recording of humming, performed activities to elicit (non-acoustically) the MEM reflexes, or sat quietly performing no task. Post-exposure TTS was measured by tracking thresholds at 700 Hz for 4 minutes after the exposure tone ended. They found that

"TTS from the exposure tone accompanied by phonation (humming) was consistently and significantly less than TTS from the exposure tone without any supplementary activity."

(McBay, 1971, p.107)

The most significant differences in magnitude of TTS occurred when post-exposure threshold was measured 10 to 15 seconds after exposure cessation. Slight decreases in TTS were noted when certain acoustic reflex eliciting movements accompanied exposure (ie. repeated turning of the head, chewing, smiling forcefully, and swallowing). No significant alterations in TTS occurred when subjects listened to recorded humming or approximated the vocal folds without humming during exposure. In addition, they found that phonation during exposure was
more effective in decreasing TTS for females than for males. This suggests that females may have more efficient mechanisms for attenuating low-frequency sound transmission to the cochlea during phonation than have males. This also supports the hypothesis that females may have more efficient MEM than males (Ward, 1966). For a more detailed discussion of the effect of phonation on TTS see McBay (1971).

2.2 Effect of Phonation on Sound Transmission in the Middle Ear

It has been established (cf. Section 2.1) that phonation during exposure to a fatiguing stimulus alters the post-exposure TTS and it is implied that phonation alters transmission of the fatiguing stimulus to the cochlea, the following discussion will consider the possible mechanisms by which this change in middle ear sound transmission occurs.

2.21 The Middle Ear Muscles (MEM)

**Anatomy** Of the two middle ear muscles, the larger is the tensor tympani which is about 25 mm in length and about 5.85 mm$^2$ in cross section. This muscle lies within a bony canal parallel with and superior to the Eustachian tube. The tendon of the muscle passes through the posterior opening of the canal and is inserted on the manubrium just below the neck of the malleus. (see Fig. 2.1) On contraction the tensor tympani moves the malleus medially and anteriorly, almost at right angles to the direction of rotation of the ossicles, thus increasing tension on the tympanic membrane. Innervation is supplied by a branch of the trigeminal nerve
Figure 2.1 Schematic diagram of the tensor tympani muscle.
(from Zenlin, 1968, p. 383)

Figure 2.2 Schematic diagram of middle ear ligaments and stapedius muscle.
(from Zenlin, 1968, p. 380)

The Stapedius muscle, 6.3 mm in length, is the smallest muscle in the human body. It occupies a bony canal on the posterior wall of the tympanic cavity and its tendon inserts at the posterior margin of the head of the stapes. (See Fig. 2.2) Contraction draws the stapes posteriorly, at right angles to the direction of movement of the ossicular chain, thus altering the movement of the stapes footplate against the oval window. Innervation is supplied by a branch of the facial nerve (Jepsen, 1963; Djupesland, 1967; Zemlin, 1968).

**MEM Activity** The two MEM contract in opposition to each other but the result of contraction is a dampening of ossicular movement and an increase of acoustic impedance at the tympanic membrane. Contraction can be elicited in a number of ways. A small percentage of individuals are able to voluntarily contract their MEM (Metz, 1951; Reger, 1960; Jepsen, 1963; Zemlin, 1968) but, for most individuals, activity usually results reflexively from acoustic or non-acoustic stimuli.

Acoustic elicitation of MEM reflex contraction occurs when the ear is presented with an acoustic stimulus of an intensity at or above the reflex threshold. This threshold is normally between 80 dB SL and 90 dB SL for pure tones of 125 Hz to 4000 Hz (Jepsen, 1963; Møller, 1961b; Jerger, 1970).
The acoustic reflex (henceforth AR) is bilateral, thus if a loud tone is presented to one ear, reflex contraction of MEM will occur in both ears. The reflex centre is thought to be the superior olivary nucleus of the pons, just ventral to the motor nucleus of the facial nerve, where efferent neurons of the reflex are located, while the afferent neurons are located in the dorsal and ventral cochlear nuclei (Jepsen, 1963).

Higher frequencies appear to elicit the AR at similar thresholds to lower frequencies (Jerger, 1970; Jepsen, 1963; Porter, 1972). Complex signals such as random noise, however, are more efficient than pure tones in eliciting the AR. Peterson and Liden (1972) found that narrow bands or full bands of white noise produced AR thresholds approximately 15 dB more sensitive than thresholds from pure tones.

The AR has a latency of about 45 to 150 msec depending on the frequency and intensity of the stimulus signal (Zemlin, 1968). As the intensity of the signal is increased the degree of contraction of the stapedius muscle, in particular, increases to a maximum. If the sound continues, the contraction of MEM gradually decreases to a resting level. If a sound of a different frequency is introduced a new contraction results (Metz, 1951). This finding suggests that reflex adaptation is due to processes other than muscular fatigue. Karlovich et al. (1972) have shown that MEM contraction, as measured by changes in acoustic impedance, is maintained if a tone or noise is presented pulsed 12 dB above
the AR threshold. The same tone or noise, if presented continuously, was found to result in a decrease in impedance (ie. an adaptation of the reflex). Such results suggest that a pulsed stimulus is a more effective activator of MEM than is a continuous stimulus. Frequency of stimulation may affect reflex adaptation as shown by Brasher et al (1969) who found that

"AR stimulated by the 1000 Hz (octave band) noise did adapt more slowly than that from the 4000 Hz (octave band) noise."

(Brasher, et al, 1969, p.583)

Several investigators have shown MEM reflexes to be elicited by non-acoustic procedures. Klockhoff and Anderson (1959) elicited reflex contraction of the stapedius muscle by pulsed electrical stimulation of the external auditory canal. An air blast directed toward the external meatus elicited tensor tympani response (Klockhoff and Anderson, 1960) or response of both muscles (Djupesland, 1964). A similar blast of air on the eyes resulted in tensor tympani contraction as part of a startle response (Klockhoff, 1961; Djupesland, 1967). Touching the skin of the auricles with a twist of cotton was found to produce stapedius muscle contraction (Djupesland, 1967). Djupesland (1967) also found that voluntary movements, such as tight closure of the eyes, swallowing, opening of the mouth, and clenching of the teeth, result in contraction of one or both tympanic muscles. Lifting or turning the head also appeared to result in such contractions

MEM Activity During Phonation

The occurrence of MEM contraction during speech activities has been found in a number of recent investigations. Salomon and Starr (1963) studied the electromyographic (EMG) activity of MEM in two human subjects during various motor activities. As one subject began to talk or hum increased activity of his tensor tympani was registered. Some contractions occurred at onset of phonation while others occurred 40 msec to 300 msec before onset of phonation. All contractions continued for up to 300 msec after cessation of phonation. Increased activity of the stapedius muscle during vocalization followed a similar temporal pattern. In an EMG study with cats Simmons found that

"in vocalization, middle ear muscle contractions begin about 100 msec before actual sound is produced and considerably outlast the speech (sic) sound; the contractions do not appear to habituate; their magnitude is proportional to the intensity of vocalization to be anticipated."

(Simmons, 1964, p.773)

Simmons investigated similar phenomena with human subjects; however, he defined stapedius muscle activity as occurring when the subject's acoustic impedance at the ear-drum showed a specified change. (Recall that when MEM contract, they stiffen the ossicular chain, thus increasing the transfer impedance of the middle ear.) When Simmons' subjects
said "one, two, three", impedance changes consistent with stapedius muscle activity were produced. In one ear, with a stapedius muscle paralysis, speech resulted in no impedance change (Simmons, 1964; Shearer and Simmons, 1965). Shearer and Simmons (1965) found acoustic impedance changes (MEM activity) to precede initiation of phonation by 65 msec to 100 msec or to coincide with onset of phonation. To determine whether head and jaw movements were responsible for some of the change in impedance the authors asked subjects to articulate words without producing voice. The negligible impedance changes that resulted indicate that such muscle activities did not interfere with measurement of MEM activity.

Djupesland (1967) recorded EMG activity from various muscles when his subjects spoke the words "ja" and "nei". All subjects showed increased activity in the orbicularis oculi, stapedius and tensor tympani muscles. "This activity seemed to increase directly with the intensity of the speech." (Ibidem, p.80) Activity of the tensor tympani began 30 msec to 450 msec before phonation was recorded and lasted up to 300 msec after phonation ceased.

**Effect of MEM Activity on Sound Transmission**

Evidence that MEM contraction has an effect on sound transmission through the middle ear is found primarily in animal studies. A number of investigators (Wersall, 1958; Weaver and Vernon, 1955; Simmons, 1959; and others cited in Jepsen, 1963, p.221) either measured MEM activity directly or observed
effects of the activity on cochlear microphonics. On the basis of such studies it is now accepted that MEM contraction attenuates sounds below 1000 Hz by up to 20 dB (Jepsen, 1963; Brasher et al, 1969), whereas it either does not effect or enhances slightly transmission of higher frequency sounds.

Simmons (1959), after cutting either the stapedius or tensor tympani of cats, measured the cochlear microphonic response of that ear to intense sounds. He found that the microphonic disappeared only when the stapedius had been cut, thus concluded that the stapedius has a more important role than the tensor tympani in sound transmission. Recently, however, Kevanishvili and Gvacharia (1972) measured the effect of tensor tympani contractions on sound transmission in cats and found transmission of 500 Hz, 800 Hz, and 1000 Hz tones to be attenuated. Higher frequencies were not attenuated and conduction of 1800-Hz to 2000-Hz tones may even have been increased. The authors concluded that, although tensor tympani contraction does not alter sound transmission to the same extent as does stapedius contraction, both muscles appear to act in a complementary fashion over the frequency range. Note, however, that findings in cats may not pertain to human ears.

Direct investigations of transmission changes cannot easily be accomplished with humans, thus indirect methods have been employed. Reger (1960) observed shifts in absolute hearing threshold before, during, and after subjects
voluntarily contracted their MEM. He found that MEM contraction increased the threshold of hearing for low frequency sounds (125 Hz to 1000 Hz) and that this threshold shift was greatest at 125 Hz and 250 Hz. Borg (1968) found, in one subject, that a 500 Hz tone 20 dB above acoustic reflex (AR) threshold was attenuated by 12 to 15 dB by stapedius contraction while a 1450 Hz tone 16 dB above AR threshold was attenuated by only 0 to 6 dB. The reflex had little or no effect at frequencies above 2000 Hz and at moderate (lower) sound intensities.

When MEM contract, the mobility of the ossicles changes, thus changing the acoustic impedance at the eardrum as well as the transfer impedance (transmission characteristics) of the middle ear. Measurement of impedance changes can, therefore, give information about concurrent changes in sound transmission. Metz (1951) observed that reduced sound transmission during human MEM contraction could be measured as a change in impedance of the external auditory canal, principally as a reduction in the absorption coefficient with little or no change in the phase (also cited by Jepsen, 1963; Møller, 1958).

Møller (1961b) investigated impedance changes in normal ears during acoustic elicitation of the MEM reflex. He found that a 500 Hz tone produced a greater change in impedance than a 1500 Hz tone, which supports the hypothesis that MEM contraction attenuates transmission of low frequency
sounds more than that of higher frequency sounds. A study, in which Möller (1965) investigated admittance (inverse of impedance) changes produced by MEM contraction in cats and rabbits, showed that, on elicitation of MEM contraction, these animals produced impedance changes similar to those produced by humans.

2.22 Stapes Vibration In addition to MEM contraction, a change in the vibration mode of the stapes may also occur during phonation. Békésy (1960) has shown that when a subject is exposed to moderate intensity air-conducted stimuli his stapes rotates around a vertical axis (as in Fig. 2.3a). He hypothesized that during phonation the stapes movement changes to a rotation around its long (horizontal) axis (as in Fig. 2.3b). This change would result in minimal displacement of the cochlear fluid which, in turn, would reduce efficiency of sound transmission to the cochlea (Békésy, 1960, pp.201-202.)

As discussed in Section 2.32, MEM contraction may result in such altered stapes vibration. Since MEM contraction occurs during phonation, both MEM contraction and altered stapes vibration may result in decreased efficiency of sound transmission to the cochlea. The role each mechanism plays in the reduction of sound transmission has, however, not yet been determined.
Figure 2.3 Movement of the stapes. a) Normal stapes motion in response to air-borne sound. b) Movement around the long axis of the stapes (possible during phonation) resulting in reduced displacement of cochlear fluid.

(from Békésy, 1960, p. 202)
2.3 Control of Possible Mechanisms Involved in TTS Reduction

2.3.1 Control of MEM Contraction During Phonation

The anatomy of the reflex arc through which the MEM are activated is incompletely known. One portion of the arc appears to involve activity from the cochlear nerve through the dorsal and ventral cochlear nuclei to the superior-olivary complex and finally to the motor nuclei of the facial and trigeminal nerves which innervate the MEM. Alternative pathways through the lateral lemniscus and the inferior colliculus may also be involved (Møller, 1972).

Since the MEM often contract just prior to the start of phonation, it seems likely that contraction is neurologically associated with laryngeal activity, such that the MEM are activated concurrently with the laryngeal musculature (Shearer and Simmons, 1965). McCall and Rabuzzi (1970, 1973) investigated the possibility that the MEM and laryngeal muscles are activated as part of a reflex during phonation. Their results with cats demonstrated reflex contractions of both MEM associated with contraction of the cricothyroid muscle of the larynx.

Approximation of the vocal folds has been suggested as the movement necessary to elicit reflex MEM contraction. This activity, however, performed during exposure to a fatiguing tone, resulted in TTS not significantly different from TTS after no activity during exposure (McBay, 1971). Karlovich and Luterman (1970) compared TTS results between
conditions in which vowels were 1) voiced or 2) whispered or gestured during the fatigue exposure. They found voicing to result in less TTS than the whispered or gestured condition. It, therefore, seems unlikely that vocal fold approximation elicits MEM contraction but rather that

"vocal-fold vibration is the necessary critical factor for eliciting the muscle contraction"  
(Karlovich and Luterman, 1970, p. 516)

In addition, higher areas of the central nervous system may direct the MEM to contract at about the same time as the laryngeal musculature but the neural pathways may not be organized as a direct reflex between MEM and larynx. As Carmel and Starr (1963) suggested, MEM contraction in association with phonation may simply be part of complex motor acts such as swallowing, yawning, etc. that involve many cranial nerves. Since it is known that certain individuals can voluntarily contract their MEM (Metz, 1951, Reger, 1960; Jepsen, 1963), it should be remembered that higher cortical influence over these muscles is one of the control mechanisms and must be considered along with any reflex control that occurs during phonation.

2.32 Control of Stapes Vibration During Phonation

Control of the mode of vibration of the stapes during phonation should also be considered. Békésy (1960) has shown that during exposure to moderate intensity air-conducted sounds, skull vibration is maximal in a direction parallel to the auditory meatus. During phonation, vibration in this direction
is minimal and skull vibration becomes maximal in the vertical direction. This alteration in skull vibration may change stapes vibration from that in Figure 2.3a to that in Figure 2.3b (Békésy, 1960). A similar shift of rotational axes, resulting in limiting transmission of excessive vibrations to the cochlea, is known to occur during stimulation by intense low frequency sounds, i.e. 130 dB SPL or greater (Ward, 1962, 1963).

It is also possible that contraction of MEM might shift the vibrational axis of the stapes. Møller explained that

"The stapes is assumed to rotate around its lower (posterior) ligament because it is much stiffer than the anterior ligament."

(Møller, 1961a, p.169)

Figure 2.2 shows the anatomical positions of these ligaments. Contraction of the stapedius muscle may, as Møller suggests, alter rotation of the stapes around the stiffer, posterior annular ligament to a rotation around a line through both anterior and posterior annular ligaments. Such a change in the axis of stapes vibration would, as previously discussed, reduce sound transmission to the cochlea.

Thus, both MEM contraction and altered skull vibration during phonation may cause inefficient stapes vibration which, in turn, may result in TTS reduction that occurs when phonation accompanies exposure.

2.33 Attention Factors and TTS Reduction A number of investigators have studied the effect variations of mental
activity might have on auditory fatigue (specifically TTS). Studies by experimenters such as Collins and Capps (1965) and Fricke (1966) suggest that certain types of mental activity might reduce or intensify the fatiguing effect of an exposure tone, however, at present, it is too difficult to delineate the mental task assigned to a listener. Thus, the effect of attention factors on TTS experiments must be considered, even though the control of such variables is not yet possible.
Chapter 3
Aims of the Investigation

The purpose of this research is to investigate the role of the MEM in the reduction of TTS that occurs if phonation accompanies exposure to a low frequency tone. Specifically, the aims are:

1) To investigate the effect on TTS (resulting from a 5 minute exposure to a 500 Hz tone) of phonation (humming) during the exposure, hence:
   a) to compare changes in TTS between humming and non-humming conditions.
   b) to compare the rate of TTS recovery between conditions.
   c) to determine if these effects are different in males and females.

2) To investigate the effect on middle ear admittance of a 5 minute 500 Hz exposure tone accompanied or not by a humming activity.

3) To compare and attempt to correlate TTS results with admittance measurements, in particular:
   a) changes in TTS and changes in admittance for each condition.
   b) rate of TTS recovery and rate of MEM relaxation (from admittance changes) for each condition.
   c) changes in TTS and rate of MEM relaxation (from admittance changes) for each condition.
Chapter 4

Experimental Apparatus and Procedures

4.1 Experimental Apparatus

4.11 TTS Instrumentation Figure 4.1 shows a block diagram of the equipment used in signal-generation and response-recording during TTS procedures. A Grason-Stadler Model E800 Békésy Audiometer was used for the pre- and post-exposure threshold tracking. The attenuation rate, controlled by the setting of the motor speed switch, was set at 5 dB/sec for sweep frequency audiograms and at 2.5 dB/sec for fixed frequency threshold tracings. Since all subjects had better than average hearing, the 20 dB fixed attenuation switch was used for each tracking procedure so the tracking record would remain on the graph. The continuous 500 Hz exposure tone was generated by Channel 1 frequency oscillator of a Madsen Model OB 60 Audiometer. In each experimental session, the 5 dB interval step attenuator was set at the maximum output setting of 110 dB (=117.5 dB SPL).

Outputs of both the Békésy and Madsen audiometers were sent to one set of earphones via an external switch box that allowed each output to be sent to either the right or the left earphone. The earphones were Madsen Model TDH-39 in MX-41/AR cushions, set in insulated plastic mountings on a light-weight headband.

In addition, a Brüel and Kjaer Type 2203 Precision Sound Level Meter with Type 1613 Octave Filter was set up in
Figure 4.1 Block diagram of instrumentation for TTS procedures.
the test room to provide subjects with visual feedback for maintaining constant intensity during the humming condition.

As shown in Figure 4.1, the signal-generating and response-recording equipment was in the control room, while the subject, control switch, and sound level meter were in the sound treated test room. A window permitted observation of the subject by the experimenter and a switch in the control room permitted external control of the light in the test room. The experimenter could monitor subject activity via a microphone in the test room connected to an amplifier and speaker in the control room.

4.12 Otoadmittance Instrumentation  The Grason-Stadler Model 1720 Otoadmittance Meter was chosen for this part of the study. (The reciprocal of acoustic impedance will henceforth be referred to as acoustic admittance.) One advantage of the Otoadmittance Meter is that it allows separate measurement of the two admittance components, the conductance G and the susceptance B. A second advantage is that it permits easier computation of ear drum admittance values than if impedance is used. For example, if we look at the equivalent electrical circuit of the combination "ear drum + ear canal," the latter is represented by a parallel branch. Knowing the value of the whole, one wants to obtain that of the ear drum alone. Using admittances, this can be done by a simple subtraction, whereas with impedances the calculation is more cumbersome. For a discussion of the principal components of the bridge and for a review of impedance and

The total G and B of the ear were amplified, low pass filtered and recorded on a H.P. 3960 Instrumentation Recorder. This was played back via an A to D converter into a PDP-12 Digital Computer for analysis. The signal was sampled at approximately 1 Hz, appropriately scaled, displayed on a Tetronix Type 564B Oscilloscope, and was photographically recorded with a Polaroid camera (See Fig. 4.2).

During otoadmittance procedures, the exposure tone was provided by an Interstate Electronics Function Generator Type F33. The exposure tone reached the ear via a TDH-49 earphone attached to the headband that also held the otoadmittance probe (See Fig. 4.2).

4.13 Calibration Before experimentation began the frequency responses of the earphones were determined using a Brüel and Kjaer Type 2203 Precision Sound Level Meter with Type 1613 Octave Filter, a Brüel and Kjaer Type 4152 Artificial Ear with a standard 6 c.c. NBS Coupler, a Brüel and Kjaer Type 1022 Beat Frequency Oscillator, and a Brüel and Kjaer Type 2305 Level Recorder. The acoustic outputs of the exposure tone producing oscillator-earphone units were also determined with the above sound level meter and artificial ear.

The intensity of the exposure tone at the earphone was recorded each day of data collection. The mean of daily
Figure 4.2 Block diagram of instrumentation for Otoadmittance procedures.
measurements (34) during the TTS sessions was 117.5 dB SPL (SD=0.28; Range=117.1 dB to 118.0 dB). The exposure tone of the otoadmittance sessions was manually adjustable thus was routinely set at 117.5 dB SPL. Other daily measurements included: intensity calibration of the Békésy audiometer (500 Hz reference); calibration of the circuit used to amplify G and B signals; and calibration of the Otoadmittance Meter using the 1720-1002 test cavities. The means of the daily test cavity measurements, using the 660 Hz probe tone, were:

<table>
<thead>
<tr>
<th></th>
<th>B (mmhos)</th>
<th>G (mmhos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Cavity</td>
<td>9.25 (SD=0.14)</td>
<td>0.62 (SD=0.07)</td>
</tr>
<tr>
<td>Small Cavity</td>
<td>1.58 (SD=0.02)</td>
<td>0.80 (SD=0)</td>
</tr>
</tbody>
</table>

Background noise in the test rooms, measured with the Bruel and Kjaer equipment before and after data collection, was found to be 29 dBA SPL in the room used for TTS procedures and 27 dBA SPL in the room used for otoadmittance procedures. Daily octave band analysis showed that frequencies below 250 Hz were the main components of this noise. The frequencies 500 Hz to 16,000 Hz never exceeded 28 dBA SPL and 22 dBA SPL in the TTS test room and the otoadmittance test room respectively.

4.2 Subjects

The subjects were 7 male and 7 female unpaid volunteers between 19 and 33 years of age. All subjects had normal hearing as shown by: no history of ear pathology; normal middle ear function and acoustic reflexes recorded from a Madsen Model
2070 Electraoustic Impedance Bridge; and normal pure tone air-conduction hearing thresholds (better than 25 dB ISO 1964) between 250 Hz and 8000 Hz as recorded by Békésy audiometry. Only those persons were to be included who, at one minute after cessation of the exposure tone during the condition requiring no activity, showed a TTS at 700 Hz of more than 1 dB (criteria of McBay, 1971). Two male and two female subjects did not fully meet these TTS criteria but were included to typify one extreme of the normal range of TTS and, possibly, otoadmittance results.

4.3 **Experiments**

For this investigation TTS is defined as the difference between a subject's mean pre-exposure threshold for a pulsed pure tone and his mean post-exposure thresholds for the same tone, measured after exposure cessation. The TTS paradigm was, largely, a replication of that used by McBay (1971). It was hypothesized that the otoadmittance values before, during, and after contralateral exposure to the fatigue stimulus would be a reasonable measure of the admittance values that occur during such a TTS paradigm.

4.31 **Experimental Design** The basic design and parameters of the experiments are shown in Figure 4.3. The TTS paradigm consisted of a 2 minute pre-exposure tracking at 700 Hz, a 5 minute exposure to a 117.5 dB SPL 500 Hz fatigue tone, and a 4 minute post-exposure tracking at 700 Hz. The otoadmittance paradigm was similar except that the
A. Design and parameters of TTS procedures.

B. Design and parameters of Otoadmittance procedures.

Figure 4.3 Experimental design and parameters.
recording of the tracked threshold during the pre-exposure and post-exposure periods was replaced by a recording of the admittance for the entire 11 minutes. During the 5 minute exposure period subjects performed one of the following activities:

1. \( N_T/N_0 \): Subject sat quietly and listened to the tone. He or she was instructed not to concentrate on anything specific while the exposure tone was on.

2. \( H_T/H_0 \): Subject hummed at 125 Hz (males) or 250 Hz (females) in cycles of 7-8 sec of humming and 2-3 sec of rest, as cued by the light in the test room (on=hum; off=rest and inhale). A "moderately loud" humming intensity of 65 dB SPL was monitored by the subject, who watched the sound level meter (plus filter corresponding to the frequency of humming) placed 54± 2 inches from his/her mouth.

The conditions \( N_T \) (non-humming TTS condition), \( H_T \) (humming TTS condition), \( N_0 \) (non-humming otoadmittance condition), and \( H_0 \) (humming otoadmittance condition) were mandatory for all 14 subjects. No two individuals were subjected to the same sequence of conditions as a partial control against possible cumulative and/or sequential effects. A Latin square design was not possible with 14 subjects and 4 conditions thus the sequence of conditions was randomized for each subject with the restriction that all subjects were to perform \( N_T \) or \( H_T \) condition during the first session. This permitted the TTS criteria (cf. Section 4.2) to be determined at the
beginning of experimentation. Data collection was scheduled to allow 24 hours or more between sessions for each subject.

4.32 Procedures After individuals were accepted as subjects, they were informed of the general outline of the experiments, and the purely voluntary nature of their cooperation was emphasized. Each subject then decided which ear was to be exposed to the fatigue tone; 8 left and 6 right ears were chosen. At each session the subject was seated comfortably, then given a set of instructions (See Appendix).

TTS Sessions All TTS sessions proceeded as follows:
1. Sweep-frequency (Békésy) threshold tracking from 250 Hz to 8000 Hz for the non-exposure ear;
2. 2-3 minutes of single-frequency (700 Hz) threshold tracking for the non-exposure ear;
3. Sweep-frequency threshold tracking from 250 Hz to 8000 Hz for the exposure ear.
4. 2 minutes of single-frequency (700 Hz) threshold tracking for the exposure ear (pre-exposure period of TTS paradigm);
5. 5 minute exposure to 117.5 dB SPL 500 Hz tone accompanied by specified activities (exposure period);
6. 4 minutes of single-frequency (700 Hz) threshold tracking for the exposure ear (post-exposure period).

Procedures 1 to 3 provided subjects with practice in Békésy tracking and served as a check for possible threshold fluctuations due to repeated intense exposure, practice, attentiveness, state of health, etc. No such fluctuations were
observed in the course of the experiments. The humming task was explained and practiced at the start of a session and instructions were repeated just prior to the exposure period. The humming activity was usually learned with 5 to 10 minutes of practice. With additional practice, even those subjects who initially experienced difficulty were able to hum acceptably.

**Otoadmittance Sessions** The exposure ear, for these sessions, was always the one contralateral to the TTS exposure ear. The probe tone used was 660 Hz. All otoadmittance sessions proceeded as follows:

1. Headset placed on subject with earphone on exposure ear. Probe placed in TTS exposure ear and an airtight seal obtained. Using ascending and descending air pressure, a tympanogram was obtained and the G (conductance) and B (susceptance) values read from the corresponding dials at 0 mmH₂O (drum loose) and +400 and -400 mm H₂O (drum tight);

2. Pre-exposure conductance and susceptance were recorded for 2 minutes;

3. 5 minute exposure to the 117.5 dB SPL 500 Hz tone was accompanied by specified activities while recording of conductance and susceptance continued;

4. Post-exposure conductance and susceptance were recorded for 4 minutes.

The tympanogram measurements provided a check of G and B
variability between sessions, allowed pre-exposure admittance values to be calculated, and provided a measure of the conductance and susceptance of the ear canal to be subtracted in the final calculation of conductance and susceptance at the eardrum. Since the exposure ear received a 500 Hz tone and the probe ear received a 660 Hz tone, some subjects found it somewhat more difficult to hum at the specified fundamental frequency for the $H_0$ condition than for the $H_T$ condition. With practice, however, all subjects were able to hum acceptably.

4.33 Data Measurement

TTS Measurement Figure 4.4 is a reproduction of the experimental record obtained from the pre- and post-exposure threshold tracking in the TTS procedures. Pre-exposure threshold was obtained by averaging dB values of the last 20 extrema in the pre-exposure tracing. The post-exposure tracking was averaged by marking the midpoint of each peak-to-trough or trough-to-peak excursion and fitting an average curve through these points. The ordinates of this curve at the post-exposure times of 7.5 sec, 15 sec, 30 sec, 1 min, 2 min, and 4 min were measured with respect to the subject's pre-exposure threshold. A series of French curves were used to extend the post-exposure threshold curve to time zero and to obtain an extrapolated TTS value at that time. Since all subjects were found to have thresholds that levelled off between 2 and 4 minutes post-exposure, an eighth TTS value was determined for this portion of the post-exposure
Figure 4.4 Record of a representative TTS procedure (condition $N_T$).
curve by averaging values the curve intersected at 2 min, 2.5 min, 3 min, 3.5 min, and 4 min. TTS, in dB, at each of the eight post-exposure times (0 sec, 7.5 sec, 15 sec, 30 sec, 1 min, 2 min, 4 min, and 2-4 min) was then obtained by subtracting the pre-exposure threshold. [Note: \( TTS_{N0} \) and \( TTS_{H15} \) refer to the value of TTS at the specified times for condition \( N_T \) and \( H_T \) respectively. \( TTS_{15} \), however, refers to the value of TTS at the specified time for either condition \( N_T \) or \( H_T \).]

Post-exposure threshold tracings revealed, for all subjects, a rapid initial TTS recovery in the first 1 to 2 minutes post-exposure followed by a slower secondary TTS recovery as evidenced, in part, by the threshold plateau between 2 and 4 minutes post-exposure. (This secondary TTS recovery may take several hours before the pre-exposure threshold is reached.) To investigate the rate of initial recovery a ninth measurement (\( I \)) was taken:

\[ \mathcal{I} \text{ (sec)} = \text{half-life of the initial TTS recovery period} \]

\[ \text{time, measured from the end of exposure, at which the TTS value has decreased by 50\%.} \]

\[ TTS_{\mathcal{I}} \text{ (dB)} = \frac{TTS_0 \text{ (dB)} + TTS_{2-4} \text{ (dB)}}{2} \]

\[ TTS_0 \text{ (dB)} = \text{TTS value at zero sec post-exposure} \]

\[ TTS_{2-4} \text{ (dB)} = \text{average TTS value between 2 and 4 minutes post-exposure.} \]

[Note: \( \mathcal{I}_N = \mathcal{I} \) for condition \( N_T \); \( \mathcal{I}_H = \mathcal{I} \) for condition \( H_T \).]

Ten TTS values from the threshold tracings of 5 randomly chosen subjects were remeasured to determine measurement
reliability. Standard deviation for the 50 pairs of values was 0.85 dB.

**Otoadmittance Measurement** The recorded conductance and susceptance values were fed from the A to D converter into the computer and there the (typed in) ear canal conductance and susceptance values were subtracted. The resulting values of conductance and susceptance at the eardrum were then plotted over time for each subject.

\[
\text{at the drum} = \text{G}_{\text{total}} - \text{G}_{\text{canal}}; \\
\text{at the drum} = \text{B}_{\text{total}} - \text{B}_{\text{canal}}.
\]

Figure 4.5 is an example of photographs obtained for each plot. A specially constructed transparency was used to measure each photograph. The measurements (as identified in the representative schematic of the plots, Fig. 4.6) were:

1. \(G_i\): pre-exposure conductance (in mmhos) measured 15 sec before the start of exposure.
2. \(\Delta G_i\): change in conductance (in mmhos) as the exposure tone came on.
3. \(\Delta G_f\): change in conductance (in mmhos) as the exposure tone ceased.
4. \(G_f\): post-exposure conductance (in mmhos) measured 225 sec. after the end of exposure. (ie. 15 sec before the end of the 4 minute post-exposure period.)

Four similar measurements (\(B_i, \Delta B_i, \Delta B_f, \text{ and } B_f\)) were taken from each susceptance plot. Although \(\Delta G_i, \Delta B_i, \Delta G_f, \text{ and } \Delta B_f\) values were much larger on the \(H_0\) plots than on the \(N_0\)
Figure 4.5 Example photograph of otoadmittance plots (condition $N_0$).

Figure 4.6 Representative schematic of otoadmittance plots.
plots, the same methods of measurement were used for both conditions.

[Note: $\Delta G_{N_i}$, $B_{Hf}$, etc. refer to the specified measurements in conditions $N_0$ and $H_0$ respectively. $\Delta G_i$, $B_f$, etc. refer to the specified measurements in either condition $N_0$ or $H_0$. $\Delta G$ and $\Delta B$ refer to changes in $G$ and $B$, respectively, at the beginning and/or end of exposure for either condition $N_0$ or $H_0$.]

Four otoadmittance values were remeasured from 5 otoadmittance plot photographs to determine measurement reliability. Standard deviation for the 20 pairs of values was 0.05 mmhos.
Chapter 5

Results

5.1 TTS Data

A three factor analysis of variance (ANOVA) for repeated measures (Winer, 1962, pp.298-349) was used to investigate possible systematic effect on TTS of the activity performed during exposure and to indicate if this effect was a function of time of TTS measurement and/or sex of the subject. This ANOVA followed a SEX (male, female) by TIME (0'', 7.5'', 15'', 30'', 1', 2', 4') by CONDITION (N_T, H_T) design in which 14 subjects (7 males, 7 females) were tested for each time and each condition. Table 1 is a summary of this analysis. Since TTS from a given exposure is known to vary greatly among individuals, the considerable variance associated with subjects was expected. Although SEX had a non-significant effect on TTS, CONDITION and TIME each had a highly significant effect, beyond the 0.01 level. The ANOVA revealed a highly significant interaction between TIME and CONDITION, however, no significant interactions between SEX and CONDITION, or SEX and TIME and no overall interaction between the three factors was found. Figure 5.1 shows the mean values of TTS for conditions N_T and H_T at six post-exposure times for all subjects.

The Neuman-Keuls method (Winer, 1962, pp.77-85) was used to probe the nature of the differences between treatment totals following a significant F in the ANOVA. A probe of the time effect was made to determine the significance of differences
Table 1: Summary of ANOVA. TTS as a function of sex, post-exposure time (0", 7.5", 15", 30", 1', 2', 4''), and condition (N_T, H_T) for 7 male and 7 female subjects.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>154.89</td>
<td>0.32</td>
</tr>
<tr>
<td>Subjects</td>
<td>12</td>
<td>487.02</td>
<td></td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td>182</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>6</td>
<td>964.28</td>
<td>101.62***</td>
</tr>
<tr>
<td>Sex x Subjects</td>
<td>.1</td>
<td>31.75</td>
<td>3.35</td>
</tr>
<tr>
<td>Time x Subjects</td>
<td>72</td>
<td>9.49</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>1</td>
<td>2,099.86</td>
<td>37.03***</td>
</tr>
<tr>
<td>Sex x Condition</td>
<td>1</td>
<td>26.97</td>
<td>0.48</td>
</tr>
<tr>
<td>Condition x Subjects</td>
<td>12</td>
<td>56.70</td>
<td></td>
</tr>
<tr>
<td>Time x Condition</td>
<td>6</td>
<td>37.73</td>
<td>10.51***</td>
</tr>
<tr>
<td>Sex x Time x Condition</td>
<td>6</td>
<td>4.76</td>
<td>1.33</td>
</tr>
<tr>
<td>Time x Condition x Subjects</td>
<td>72</td>
<td>3.59</td>
<td></td>
</tr>
</tbody>
</table>

* p < 0.05  
** p < 0.01  
*** p < 0.001
Fig. 5.1 Comparison of TTS (measured at 700 Hz) at six different post-exposure times for conditions $N_T$ and $H_T$. 
between all 7 post-exposure times for both conditions and all subjects. A summary is given in Table 2a. The results indicate that time had a highly significant effect on TTS, in particular; that TTS values for 0", 7.5", 15", and 30" times were significantly different from all other times except that TTS for 0" was not significantly different from TTS for 7.5", and that TTS values for 1', 2', and 4' times were, however, not significantly different from each other.

A probe of the condition effect confirmed that, as shown by the ANOVA, $H_T$ had a significantly different effect on TTS from $N_T$, for all times and subjects (see Table 2b). A final probe of the TIME X CONDITION effect was made to obtain more information on the effect of condition at specific post-exposure times. The effect of TIME X CONDITION on TTS for all subjects was shown to be significant at the 0.01 level by the ANOVA but the Neuman-Keuls probe revealed that the effect of condition was different at different times (See Table 2c). Specifically, condition $H_T$ had a significantly different effect on TTS from condition $N_T$ at 0", 7.5", 15" and 30" for all subjects but the effect of condition was not significantly different at 1', 2', and 4'.

A $t$-test for related measures (Bruning and Kintz, 1968, pp.12-15) was used to determine the relationship between conditions $N_T$ and $H_T$ for the values of TTS$_{2'-4'}$ (cf. Sec.4.2). It was shown that $H_T$ results in a significantly smaller average TTS value between 2' and 4' (0.01 level) than $N_T$. 
Table 2a: Results of Neuman-Keuls test for significance of differences between TTS for 7 post-exposure times (7 male and 7 female subjects).

<table>
<thead>
<tr>
<th>Time</th>
<th>4'</th>
<th>1'</th>
<th>2'</th>
<th>30''</th>
<th>15''</th>
<th>7.5''</th>
<th>0''</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.T.</td>
<td>202.35</td>
<td>234.64</td>
<td>240.55</td>
<td>317.55</td>
<td>428.12</td>
<td>550.57</td>
<td>615.10</td>
</tr>
<tr>
<td>4'</td>
<td>202.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1'</td>
<td>234.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2'</td>
<td>240.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30''</td>
<td>317.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15''</td>
<td>428.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5''</td>
<td>550.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q 0.99(r,72)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>xMSerror</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

** p < 0.01
Table 2b: Results of Neuman-Keuls test for significance of differences between TTS for $N_T$ and $H_T$ conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>$H_T$</th>
<th>$N_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.T.</td>
<td>973.67</td>
<td>1615.21</td>
</tr>
<tr>
<td>$H_T$</td>
<td>641.54**</td>
<td></td>
</tr>
<tr>
<td>q 0.99(r,12)</td>
<td>4.32</td>
<td></td>
</tr>
<tr>
<td>q 0.99(r,12)</td>
<td>322.01</td>
<td></td>
</tr>
</tbody>
</table>

Table 2c: Results of Neuman-Keuls test for significance of differences between TTS for conditions $N_T$ and $H_T$ at the specified post-exposure times.

<table>
<thead>
<tr>
<th>Time</th>
<th>$t=0''$</th>
<th>$t=7.5''$</th>
<th>$t=15''$</th>
<th>$t=30''$</th>
<th>$t=1'$</th>
<th>$t=2'$</th>
<th>$t=4'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>$H_T$</td>
<td>$N_T$</td>
<td>$H_T$</td>
<td>$N_T$</td>
<td>$H_T$</td>
<td>$N_T$</td>
<td>$H_T$</td>
</tr>
<tr>
<td>T.T.</td>
<td>245.29</td>
<td>369.81</td>
<td>216.84</td>
<td>333.73</td>
<td>151.38</td>
<td>276.74</td>
<td>108.84</td>
</tr>
<tr>
<td>$H_T$</td>
<td>124.52**</td>
<td>116.89**</td>
<td>125.38**</td>
<td>97.87**</td>
<td>68.96</td>
<td>60.87</td>
<td>47.07</td>
</tr>
<tr>
<td>q 0.99(r,72)</td>
<td>3.75</td>
<td>3.75</td>
<td>3.75</td>
<td>3.75</td>
<td>3.75</td>
<td>3.75</td>
<td>70.35</td>
</tr>
<tr>
<td>q 0.99(r,72)</td>
<td>70.35</td>
<td>70.35</td>
<td>70.35</td>
<td>70.35</td>
<td>70.35</td>
<td>70.35</td>
<td>70.35</td>
</tr>
</tbody>
</table>

** $p < 0.01$
Another analysis was done to investigate the effect of condition on the initial rate of TTS recovery (cf. Sec. 4.32). A t-test for related measures, performed on the half-life values $\tau_N$ and $\tau_H$ revealed that the $H_T$ condition results in a significantly shorter initial recovery rate (0.01 level), as defined by the half-life, than the $N_T$ condition.

5.2 Otoadmittance Data

Analysis of the otoadmittance data investigated the effect of condition on middle ear admittance before, during, and after the 5 minute exposure to a 117.5 dB SPL 500 Hz tone. The otoadmittance measurements ($G_i, \Delta G_i, \Delta G_f, G_f, B_i, \Delta B_i, \Delta B_f, B_f$; cf. Sec. 4.32) for condition $N_0$ were each compared with the corresponding measurement for condition $H_0$. t-tests for related measures were performed on the eight paired sets of values. It was found that condition had no significant effect on initial and final $G$ and $B$ values, as shown by non-significant $t$ values (non-significant at the 0.10 level). The other four $t$-tests, which were significant beyond the 0.001 level, revealed that changes in $G$ and $B$ at the beginning and end of exposure were significantly larger during condition $H_0$ than during condition $N_0$.

The changes in $G$ and $B$ at the beginning and end of exposure were then compared. When no phonation accompanied exposure the change in $G$ at the beginning of exposure was significantly larger (0.01 level) than the change in $B$ (ie. $\Delta G_{N_i} > \Delta B_{N_i}$) as shown by a $t$-test for related measures.
At the end of exposure the change in G was still larger than the corresponding change in B but not significantly larger. When phonation accompanied exposure, however, the change in B both at the beginning and at the end of exposure was significantly larger (0.01 level) than the corresponding change in G (ie. \( \Delta B_{Hi} > \Delta G_{Hi} \) and \( \Delta B_{Hf} > \Delta G_{Hf} \)). This finding suggests that the humming condition affected the susceptance significantly more than it affected the conductance.

5.3 **Comparison of TTS and Otoadmittance Data**

In an attempt to find some relationship between TTS and otoadmittance data, a number of Pearson product-moment correlations were calculated. Four of the \( N_0 \) condition measurements (\( \Delta G_{Ni} \), \( \Delta G_{Nf} \), \( \Delta B_{Ni} \), \( \Delta B_{Nf} \)) were first compared with TTS measurements at times 0", 7.5", 15", 30", 1', 2', 4', and 2'-4' and with the half life \( T \) for \( N_T \) and \( H_T \) conditions. The 72 Pearson \( r \) values obtained from these comparisons were all small and non-significant, not even at the 0.10 level. The two largest correlation coefficients were:

\[
\Delta G_{Nf} \times TTS_{N2}, \quad r = -0.31, \quad p = 0.10 \text{ if } r = 0.46
\]

\[
\Delta G_{Nf} \times TTS_{N1}, \quad r = -0.30
\]

The difference between TTS values for conditions \( N_T \) and \( H_T \) at 0", 7.5", 15", 30", and 1' were calculated as a measure of the protection given the ear by the humming condition. These 5 differences were compared with four \( N_0 \) measurements (\( \Delta G_{Ni} \), \( \Delta G_{Nf} \), \( \Delta B_{Ni} \), \( \Delta B_{Nf} \)). The only statistically
significant Pearson r correlation coefficient was:

\[
(TTS_{N7.5''} - TTS_{H7.5''}) \times \Delta G_{Ni} \quad r=-0.53 \quad *p=0.05
\]

(See Table 3)

The 5 TTS differences were then compared with the following ratios: \(\Delta G_{Ni}/G_{Ni}\), \(\Delta G_{Nf}/G_{Nf}\), \(\Delta B_{Ni}/B_{Ni}\), \(\Delta B_{Nf}/B_{Nf}\). All Pearson r correlations between the \(\Delta G\) ratios and the TTS difference values were larger than the corresponding non-ratio correlations, and, as shown in Table 3, four of the correlation coefficients were significant beyond the 0.05 level. Points corresponding to three of these correlations are graphed in Figures 5.2, 5.3, and 5.4.

The following admittance values from condition N0 were then calculated for each subject:

\[
\Delta Y_{Ni} = \frac{\sqrt{(\Delta G_{Ni})^2 + (\Delta B_{Ni})^2}}
\]

= change in admittance at the beginning of exposure.

\[
\Delta Y_{Nf} = \frac{\sqrt{(\Delta G_{Nf})^2 + (\Delta B_{Nf})^2}}
\]

= change in admittance at the end of exposure.

These values correlated weakly and negatively with the 5 TTS difference values. The largest correlation coefficient was:

\[
(TTS_{N7.5''} - TTS_{H7.5''}) \times \Delta Y_{Ni} \quad r=-0.51 \quad p<0.10
\]

(See Table 3)

The correlation coefficients were similar in magnitude to coefficients of the comparisons between the 5 TTS difference values and the values \(\Delta G_{Ni}\), \(\Delta G_{Nf}\), \(\Delta B_{Ni}\), and \(\Delta B_{Nf}\).
Table 3: Matrix of Results of Pearson Product-Moment Correlations between specified TTS and Otoadmittance values.

<table>
<thead>
<tr>
<th></th>
<th>$\Delta G_{Nf}$</th>
<th>$\Delta B_{Nf}$</th>
<th>$\Delta G_{Ni}/G_{Nf}$</th>
<th>$\Delta B_{Ni}/B_{Nf}$</th>
<th>$\Delta Y_{Ni}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$TTS_{N30}'' - TTS_{H30}''$</td>
<td>-0.35</td>
<td>-0.30</td>
<td>-0.47</td>
<td>-0.20</td>
<td>-0.31</td>
</tr>
<tr>
<td></td>
<td>-0.38</td>
<td>-0.30</td>
<td>-0.47</td>
<td>-0.20</td>
<td>-0.37</td>
</tr>
<tr>
<td>$TTS_{N7.5}'' - TTS_{H7.5}''$</td>
<td>-0.44</td>
<td>-0.29</td>
<td>-0.48</td>
<td>-0.20</td>
<td>-0.42</td>
</tr>
<tr>
<td></td>
<td>-0.53*</td>
<td>-0.40</td>
<td>-0.57*</td>
<td>-0.22</td>
<td>-0.51</td>
</tr>
<tr>
<td>$TTS_{N15}'' - TTS_{H15}''$</td>
<td>-0.43</td>
<td>-0.22</td>
<td>-0.56*</td>
<td>-0.15</td>
<td>-0.39</td>
</tr>
<tr>
<td></td>
<td>-0.41</td>
<td>-0.32</td>
<td>-0.63*</td>
<td>-0.07</td>
<td>-0.40</td>
</tr>
<tr>
<td>$TTS_{N0}'' - TTS_{H0}''$</td>
<td>-0.36</td>
<td>-0.20</td>
<td>-0.50</td>
<td>-0.18</td>
<td>-0.34</td>
</tr>
<tr>
<td></td>
<td>-0.35</td>
<td>-0.18</td>
<td>-0.57*</td>
<td>+0.15</td>
<td>-0.33</td>
</tr>
<tr>
<td>$TTS_{N1}'' - TTS_{H1}''$</td>
<td>-0.39</td>
<td>-0.40</td>
<td>-0.40</td>
<td>-0.35</td>
<td>-0.42</td>
</tr>
<tr>
<td></td>
<td>-0.37</td>
<td>-0.32</td>
<td>-0.47</td>
<td>+0.02</td>
<td>-0.36</td>
</tr>
</tbody>
</table>

*p<0.10  r=0.46  p<0.02  r=0.61  *p<0.05  r=0.53  **p<0.01  r=0.66
Fig. 5.2 Comparison of TTS difference values (15" post-exposure) with initial change in $G_N$ during exposure (in percentage).

* $p < 0.05$
Fig. 5.3 Comparison of TTS difference values (15" post-exposure) with final change in $G_N$ during exposure (in percentage).

$\text{Pearson } r = -0.56^\star$

$\Delta G_{NF} / G_{NF}$
Fig. 5.4 Comparison of TTS difference values (15" post-exposure) with initial change in $B_N$ during exposure (in percentage).

Pearson $r = -0.07$

Regression Line
Fig. 5.5 Comparison of TTS difference values (15" post-exposure) with initial change in $Y_N$ during exposure (in percentage).
The admittance values $\Delta Y_{Ni}$ and $\Delta Y_{Nf}$ were also converted into ratios, $\Delta Y_{Ni}/Y_{Ni}$ and $\Delta Y_{Nf}/Y_{Nf}$, and compared with the 5 TTS difference values. The largest of the negative, non-significant Pearson $r$ correlation coefficients was:

$$(TTS_{Ni5'} - TTS_{H15'}) \times \Delta Y_{Ni}/Y_{Ni} \quad r=-0.51 \quad p<0.10$$

(See Fig. 5.5)

A comparison of the rate of initial TTS recovery for condition $N_T$ (estimated by $T_N$) and the rate of MEM relaxation (estimated by $\Delta G_{Ni} - \Delta G_{Nf}$) was then undertaken. This difference between the initial and final change in $G_N$ during exposure was chosen as a measure of MEM relaxation since the change in $G_N$ ($\Delta G_N$) decreased significantly more, with respect to its baseline ($G_{Ni}$), than $\Delta G_H$, $\Delta B_N$, or $\Delta B_H$ decreased, relative to their respective baselines ($G_{Hi}$, $B_{Ni}$, and $G_{Hi}$), during exposure. The Pearson $r$ correlation coefficient between $(\Delta G_{Ni} - \Delta G_{Nf})$ and $T_N$ was small and non-significant ($r=0.15$). This same measure of the rate of MEM relaxation was also compared with TTS values for condition $N_T$ at times 0", 30", 1', 2', and 2'-4' but no significant Pearson $r$ correlations were found.
Chapter 6

Discussion

Most of the TTS results from the procedures that investigated the effect of phonation on TTS were in agreement with results of Karlovich and Luterman (1970), who used a 1000 Hz fatigue tone, and of McBay (1971), who used a 500 Hz tone. All these investigations showed that: 1) phonation during fatigue exposure consistently results in a significantly smaller post-exposure TTS than if no phonation accompanies exposure, for all post-exposure times and for both males and females; and 2) TTS is a function of the post-exposure time at which it is measured such that the TTS difference between phonation and non-phonation conditions is most significant at early post-exposure times. A minimal tendency, noted by Karlovich and Luterman and by McBay, for females to exhibit greater TTS differences than males between phonation and non-phonation conditions was not found in this study. Differences between procedures used in this study and those used by Karlovich and Luterman (1970) (ie. a 1000 Hz. tone was used; vocal effort was not controlled for; etc.) may explain why their finding was not repeated. McBay's (1971) study also differed in that three phonation conditions were used vs. one phonation condition in this study. She found the tendency for females to exhibit greater TTS differences to occur only during the "humming comfortably" conditions while the "humming loudly" condition, which most closely approximated this study's
HT condition, resulted in similar TTS differences for males and females. The results of this study, therefore, do not appear to conflict with previous findings concerning sex related TTS differences.

Examination of TTS recovery revealed that humming during the fatigue exposure results in a significantly shorter initial TTS recovery, indicated by the T values, than if no humming is performed. This shorter initial recovery rate for the humming condition would appear to support Karlovich and Luterman's (1970) prediction "that return to pre-exposure threshold levels would take longer for the non-voiced than for the voiced conditions." (Ibid., 1970, p.514). The data, however, seems to show a plateau of TTS recovery for the humming condition between 2' and 4' post-exposure (See Fig. 5.1), while the corresponding TTS curve for the non-humming condition is still decaying noticeably. Thus, it would be necessary to continue the post-exposure tracking until the pre-exposure threshold level is reached before the above prediction could be applied to a complete TTS paradigm.

The otoadmittance procedures revealed changes in conductance and susceptance at the beginning and at the end of the exposure period to be significantly larger when humming accompanied the exposure. It is known that 1) large changes in impedance (thus large changes in admittance) can result from a large degree of MEM activity (Metz, 1951; Möller, 1961a, 1965; Simmons, 1964; Shearer and Simmons, 1965; Karlovich, et al.)
1972) and 2) MEM contraction attenuates transmission of low frequency tones by up to 20 dB (Simmons, 1959; Reger, 1960; Jepsen, 1963; Borg, 1968; Brasher, et al., 1969; Kevanishvili and Gvacharia, 1972). From these facts, one might assume that the reduction of transmission of the exposure tone during the humming condition could be due to increased MEM activity. Such an assumption appears valid but should be regarded with caution because, although humming produced larger changes in G and B than no humming, these changes with humming appeared to become negative thus making interpretation difficult. A repetition of these otoadmittance procedures, possibly with technical improvements, would be desirable to resolve the above mentioned problem.

Karlovich and Luterman (1970, p. 513) "suspect involvement of a mechanism which increases the elastic reactance component of the impedance" to account for the reduction of TTS that occurs if phonation accompanies exposure. The "elastic reactance" is the negative part of the reactance or the capacitive component of the impedance. As the absolute value of this reactance increases, the absolute value of the susceptance component of admittance decreases. If Karlovich and Luterman's hypothesis is true one should find the negative reactance to become larger or, in this study, the positive susceptance to become smaller when phonation accompanies exposure. The latter result was found in the current study. In fact, a t-test for related measures showed susceptance to be reduced by the humming condition significantly more (0.01
level) than the conductance was. Such a finding suggests that the susceptance component of admittance is affected more than the conductance by whatever mechanism reduces TTS after phonation.

When no phonation accompanied exposure it was found that the change in conductance at the beginning of exposure was larger than the corresponding change in susceptance. This difference between changes in \( G \) and \( B \) was also present, though not significantly so, at the end of exposure (i.e., the change in \( G \) decreased during exposure). It is well known that MEM activity due to the acoustic reflex decays during continuous acoustic stimulation (Metz, 1951; Karlovich, et al., 1972). The fact that the change in \( G \) (but not the change in \( B \)) decreased during exposure seems to be an indication of such a reflex decay. It may be that \( G \) is the admittance component most affected by acoustic stimulation of the MEM.

On the other hand, when phonation accompanied exposure, the changes in susceptance during exposure were larger than the corresponding changes in conductance. Since we do not know which anatomical parts of the middle ear contribute which components of admittance, it is difficult to explain this finding. It is possible that the larger change in \( B \) results from an increased MEM contraction with phonation, from the change in stapes vibration thought to occur with phonation (Békésy, 1960), or from a combination of these and other, as yet undefined, mechanisms. Further research, such as that by
Møller (1961a), Onchi (1961), and Zwislocki (1965) on electrical or mechanical analogues of the middle ear, is needed.

Following otoadmittance data analysis, the apparently negative G and B values, during exposure in the humming condition, remained a problem. It was thought that acoustic feedback during the humming might have resulted in the negative values. Since the plotting of G and B had involved a relatively slow sampling rate (approximately 1 Hz), mingograms of the humming condition for each subject were made to determine if pertinent information had been missed in the between-sampling periods. The mingograms confirmed that, for all subjects, G and B, during exposure accompanied by humming, fell below the zero mmho baseline. G and B did not become positive, however, during the 2-3 sec pauses between two intervals of humming thus, the hypothesis of acoustic feedback resulting in negative G and B values was ruled out. A study investigating changes in G and B when no exposure is presented during a humming activity might help resolve this problem.

Since G and B did not become positive during the between-humming pauses it appeared that G and B do not change rapidly. It is known (Salomon and Starr, 1963; Djupesland, 1967) that MEM contractions continue up to 300 msec after phonation ends. Results of the current study suggest that mechanisms that alter G and B, when phonation accompanies an intense exposure, remain active much longer than 300 msec after phonation ends. The possible mechanisms involved were discussed
earlier (cf. Sec. 2.2 and 2.3) but it is not known which combination of mechanisms reduces admittance (and therefore reduces TTS) when phonation accompanies exposure or which mechanisms are responsible for separate changes in the two admittance components.

In the comparison of TTS and otoadmittance data only one significant trend was found. Figures 5.2 and 5.3 show that the larger the change in conductance, at the beginning and end of exposure with no humming, the smaller the TTS difference between humming and non-humming conditions (at early post-exposure times). In other words, the greater the amount of MEM contraction, reflected by the change in conductance with exposure (condition N₀), the smaller the protection given the ear by the humming, reflected by TTS difference values. This may mean that if the MEM are contracted strongly in response to an acoustic stimulus they may not contract much more during phonation thus humming provides little extra protection from the exposure. Figure 5.2 and 5.3 appear to substantiate this hypothesis i.e. individuals having the largest amounts of MEM contraction, as indicated by percentage changes in conductance, have the smallest amounts of extra protection from humming, as indicated by TTS difference values. The reverse also holds in that individuals with a weak MEM contraction in response to acoustic stimulation show considerable extra protection from the humming condition.

These results must be considered as preliminary. A repeat of these procedures with a larger population, of both
normals and subjects with certain middle ear abnormalities, might verify the above trend or even show more significant correlations. Such a study would help indicate the normal range of results from such procedures and might determine whether those not closely following the trend either fall within normal limits or possibly have some undiagnosed abnormality that was not apparent from accepted screening techniques. Changes in conductance and admittance (Fig. 5.5) were correlated with the TTS difference values but changes in susceptance did not show any such relationship (Fig. 5.4 and Table 3). Further research, hopefully, will indicate why this occurs. If EMG studies were possible with normal humans we might determine the levels of MEM contraction that result from acoustic stimulation and from acoustic stimulation accompanied by phonation. This could indicate whether changes in TTS and admittance during the humming condition are due to MEM contraction alone or whether other mechanisms, such as a change in stapes vibration (Békésy, 1960), are involved.

The results of this study indicate two basic types of MEM activity in response to acoustic and to acoustic plus phonatory stimulation. Some individuals show strong acoustic activation of their MEM with little further protection provided by phonation during the fatigue exposure. Most individuals, however, show some acoustic activation of their MEM while phonation during exposure provides considerable extra protection of the ear as evidenced by a significantly reduced TTS. The results do not, however, reveal how phonation protects
these ears from intense low frequency stimulation.

One could hypothesize that the MEM contract more strongly during phonation plus exposure than during acoustic exposure alone, however, this claim can be substantiated only through further research. Even if it is shown that the degree of contraction is the same for phonatory and auditory stimulation, MEM may still provide extra protection during phonation. Since we know that introduction of a new frequency during acoustic stimulation is sufficient to stimulate renewed MEM contraction (Metz, 1951; Brasher, et al., 1969) it would seem that, as shown by the current results, humming should keep the MEM maximally contracted throughout the exposure. We also know that continuous single frequency stimulation, as in the non-humming condition, results in a decrease of MEM activity (Metz, 1951; Karlovich, 1972). One might expect that the more rapid the decrease in MEM activity during the non-humming condition, the greater the TTS produced by exposure. Using a Madsen (Model ZO 70) electroacoustic impedance bridge with 6 subjects, McBay (1971) found this result for the non-humming condition. For the current group of subjects, however, no consistent pattern of decrease of MEM activity was found (as defined by $\Delta G_{N_i} - \Delta G_{N_f}$) thus it would appear that either MEM activity is different in the two conditions ($N_T$ and $H_T$) or that other mechanisms are involved during phonation to account for the larger change in admittance and thus reduced TTS with phonation.
Summary

This study was set up to investigate one of the factors that may be responsible for TTS reduction that occurs when phonation accompanies exposure to a 500 Hz 117.5 dB pure tone. Through the use of admittance measurements, the role of the MEM in TTS reduction was investigated. The results of the study indicated that:

1) TTS is a function of the post-exposure time at which the threshold is measured. The early post-exposure times (0", 7.5", 15", 30") resulted in the largest TTS values.

2) TTS from the exposure tone accompanied by phonation (humming) was consistently and significantly smaller than TTS from the exposure tone with no supplementary activity.

3) Differences between TTS from phonation (humming) during exposure and TTS from exposure with no supplementary activity were most significant at the early post-exposure times (0", 7.5", 15", 30").

4) The rate of initial TTS recovery when phonation accompanied exposure was significantly shorter than when no supplementary activity accompanied exposure.

5) There were no significant TTS differences between sexes.

6) Changes in the conductance and susceptance components of admittance at the beginning and end of exposure were significantly larger when phonation accompanied exposure than when no supplementary activity accompanied exposure.

7) When phonation accompanied exposure the changes in susceptance at the beginning and end of exposure were significantly larger than the corresponding changes in conductance. When no supplementary activity accompanied exposure, however, the changes in conductance at the beginning of exposure were significantly larger than the corresponding changes in susceptance.

8) Changes in conductance and susceptance at the beginning and end of exposure did not correlate significantly with TTS values measured at any of the post-exposure times.
9) The rate of MEM relaxation during exposure accompanied by no supplementary activity did not correlate significantly with the rate of initial TTS recovery or with TTS values measured at several of the post-exposure times (0", 30", 1', 2', 2'-4').

10) The degree of MEM activity at the beginning and end of exposure accompanied by no supplementary activity, measured by the percentage change in conductance at these times, correlated significantly with the amount of protection provided the ear by phonation (humming), measured by the differences between TTS values at early post-exposure times for the humming and non-humming conditions.

From the results, it was hypothesized that some individuals, who have MEM that contract strongly with intense acoustic stimulation, gain little extra protection from phonation (humming) during exposure, while the majority of individuals, who have MEM that contract weakly with intense acoustic stimulation, gain a significant amount of protection from phonation (humming) during exposure. The results suggest that the MEM play a major role in the attenuation of sound transmission that occurs when phonation accompanies exposure. Other mechanisms, however, including insufficient stapes vibration and attentional factors, also may be involved but more research is necessary before we can determine the exact role each mechanism plays in the reduction of TTS with phonation.
References


(1967). *Contractions of the Tympanic Muscles in Man* (Universitetforlaget, Oslo).


Appendix

Instructions to Subjects

A. TTS Procedures

1. You will first hear a pulsed tone of low pitch in your right (left) ear that will gradually become higher in pitch. Press the button as soon as you hear the tone, then let go as soon as the tone disappears.

2. You will now hear a pulsed tone in your right (left) ear that will remain at the same pitch. Press the button as soon as you hear the tone, let go as soon as it disappears.

3. Now in your left (right) ear Step 1 will be repeated, then Step 2. Press the button when you hear the tone, let go when you don't.

4. You will now hear a loud continuous tone in your left (right) ear for 5 minutes. You will be given instructions about what to do during this time and will get sufficient practice of the activities involved. During the 5 minutes refrain from excessive body movements or unnecessary clearing of the throat, coughing, yawning, or swallowing. About 10 seconds before the tone is turned off, I will jump on the floor to alert you to be ready for the next step.

5. As soon as the loud tone is turned off, listen for the pulsed tone that does not change in pitch. As
soon as you hear the pulsed tone, press the button until it disappears, then let go, etc. as before. This will continue for 4 minutes.

Do you have any questions?

B. Otoadmittance Procedures

When the probe is placed in one ear, you will hear a moderately loud tone that will remain on for the duration of the session. I will obtain an air-tight seal in that ear, then vary the pressure within the sealed cavity and make a number of measurements.

After this time, you must remain as still as possible. Do not move your feet, arms, hands, etc. and try not to swallow, cough or clear your throat until I tell you the session is over.

1. You will hear the probe tone only, for 2 minutes.
2. For the next 5 minutes you will also hear the loud exposure tone (same as in the TTS conditions) in the ear opposite to the probe. Sit very still or hum as directed.
3. When this loud tone is turned off remain very still for another 4 minutes. Probe tone will remain on. Wait until advised to move before doing so.

Do you have any questions?