EFFECTS OF COLD AIR TEMPERATURE ON THE HUMAN PERIPHERAL AUDITORY SYSTEM

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ABSTRACT

EFFECTS OF COLD AIR TEMPERATURE ON

THE HUMAN PERIPHERAL AUDITORY SYSTEM

By

Judith F. Borus

Earlier research by this writer suggested that when normal hearing human subjects spent approximately 15 minutes out of doors in cold weather prior to pure-tone audiometric testing, the test results deviated from the expected normal and a conductive type stiffness tilt was observed. The major purpose of this research was to determine the effects of cold air temperatures on the human peripheral auditory system. In most audiology clinics, audiometric testing begins very shortly after the client arrives at the testing suite. It is not unusual for clients to spend ten or fifteen minutes out of doors in temperatures below 0° F. The problem presented here is, assuming that this exposure takes place immediately before the client arrives at the clinic, what effects will it have on the pure-tone thresh-holds obtained? In addition, recovery from the effects found and possible explanations for these effects were also investigated.

Forty-six students with normal hearing served as the subjects for this study. Each of the subjects had their air and bone conduction thresholds determined bilaterally using 2 dB steps. Tympanic temperature and various impedance measurements were also made. Following these measurements, each subject was allowed to dress as warmly as he wished, leaving the head and ears exposed, and then entered a cold room where the temperature varied from -3° to -10° F., with a mean of -7.07° F. Following 20 minutes of this cold exposure, all of the pre-exposure tests were repeated.

No significant shifts were found by bone conduction following this exposure, however air-conduction thresholds were depressed at 125 Hz by +3.17 dB, at 250 Hz by +2.52 dB, at 500 Hz by +1.83 dB, and at 1000 Hz by +0.91 dB. The shifts found at frequencies above 1000 Hz were not statistically significant, but were all in the opposite direction, i.e., improved hearing following the exposure.

The subjects were divided into two groups, "shifters" and "non-shifters." Subjects were classified as shifters if two of their three low frequency thresholds (125 Hz, 250 Hz and 500 Hz) shifted by +4 dB or more and the third shifted by at least +2 dB. Twenty subjects, classified as shifters, showed mean air-conduction threshold shifts at 125 Hz of +6.10 dB; at 250 Hz, +5.40 dB; at 500 Hz, +5.20 dB; at 1000 Hz, +1.20 dB; at 2000 Hz, +0.30 dB; at 4000 Hz, -0.50 dB; and at 8000 Hz, -0.10 dB. The group of 26 non-shifters showed mean air-conduction threshold shifts within $\pm$ 1 dB at all frequencies.

The mean pre-exposure tympanic temperature of all subjects was 98.00° F. and the mean shift following the cold exposure was -0.72° F. There was no significant difference in the size of the temperature shift between the shifters and non-shifters, nor was there any significant relationship between the size of the temperature shift and the size of the threshold shift.

The various impedance measurements made (acoustic impedance in the plane of the eardrum, middle ear pressure readings, and compliance measurements at various pressure settings) all indicated that those subjects classified as shifters had more compliant ears to start with but the cold exposure caused an increase in stiffness (reduced compliance) in the ears of shifters and non-shifters alike.

In the second phase of the study, nine of the 20 shifters returned for three additional testing sessions. The same tests were administered but the length of the cold exposures was varied and the recovery from air-conduction thresholds shifts found was tracked. When the length of the exposure duration was reduced, the size of the air-conduction threshold shifts was likewise reduced. A ten minute exposure duration resulted in statistically significant low frequency shifts of approximately 3 dB and a five minute exposure duration did not affect thresholds significantly. Recovery from the air-conduction threshold shifts appeared to be quite constant. For most subjects recovery from the 20 minute exposure took place within 60 minutes and recovery from the 10 minute exposure occurred within 40 minutes.

Exposure to cold air apparently increased middle ear pressure and affected the tympanic membrane's vibratory capacity in some of the subjects, resulting in a slight conductive-type hearing loss (displayed audiometrically as an air-conduction "stiffness tilt"). Given the fact that this type of audiogram is similar to that found in patients with adhesive otitis media and pre-clinical otosclerosis, great care should be taken to determine how long the patient being tested was outdoors in cold air temperatures immediately preceding an audiometric evaluation. Sufficient time should be allowed for threshold shifts caused by the cold air outdoors to fully recover before the actual pure-tone testing is begun to help insure valid pure-tone test results and to aid in avoiding mis-diagnoses of middle ear pathology.

EFFECTS OF COLD AIR TEMPERATURE

ON THE HUMAN PERIPHERAL AUDITORY SYSTEM

By

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CHAPTER I

INTRODUCTION

In most audiology clinics audiometric testing begins very shortly after the client arrives at the testing suite, perhaps following a five or ten minute interview. Almost always the first procedure carried out is pure-tone air-conduction testing. In previous research by this writer, which required obtaining pure-tone thresholds for over 50 college students, it was felt that in some cases the low frequency thresholds varied depending on whether hearing testing was done immediately upon the subject's arrival at the clinic or after a lengthy questionnaire had been filled out (which took over half an hour). In most cases the students walked for 10 to 20 minutes from their dormitories to the testing suite in outdoor temperatures ranging from -15° to +15° F. Subsequent to the conclusion of that research an attempt was made to explore further the effects of extreme cold on low frequency hearing thresholds in a series of pilot studies. The results of these preliminary studies further suggested that cold exposure might be a factor affecting air-conduction thresholds in the low frequencies.

The phenomenon to be discussed here can be accounted for on a physiological basis. The hypothesized post-exposure pure-tone air-conduction audiometric curve would show depressed thresholds in the low frequencies whereas the bone-conduction curve would remain normal. This type of audiometric configuration, sometimes referred to as a "stiffness tilt," is believed to be due to changes in impedance in the middle ear caused by increased stiffness in the action of the auditory ossicles.[1] The theory being proposed is that the exposure to cold air will cause increased stiffness in the movement of these ossicles due to one of a variety of possible reasons.

Purpose of the Study

The major purpose of this research was to determine what effect extremely cold air temperatures have on hearing thresholds. Several aspects of this question were explored including the frequencies that were affected and by what amount, what proportion of the subjects showed a threshold shift and whether the subject's sex was a variable to be considered. In addition, an effort was made to determine how long the subjects had to be exposed to the cold air for the shift to occur. A study of recovery patterns was also made. Also, an attempt was made to determine what caused this shift in hearing thresholds through the use of a tympanic thermometer and an acoustic impedance bridge.

Significance of the Study

In the pilot studies discussed below more than half of the subjects involved exhibited low frequency air-conduction threshold shifts (in the direction of poorer hearing) following exposure to extreme cold. In the study where bone-conduction thresholds were also tested no shifts in bone-conduction thresholds occurred in any subject. The significance of this is at least two-fold. A primary consideration is the diagnostic importance. It is not unusual in many parts of this country and the rest of the world

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[1] P. Campbell, "The Importance of the Impedance Formula in the Interpretation of Audiograms," Transactions of the American Academy of Ophthalmology and Otolaryngology, 54 (1950), pp. 245-252.

for individuals to spend 15 minutes out of doors in temperatures below 0° F. If this exposure should occur just prior to an audiometric examination, spurious low frequency conductive type hearing losses could be found. There are many middle ear disorders which are routinely diagnosed at least partially on the basis of this type of audiometric configuration (such as middle ear muscle contractions, adhesions, and stapes fixation, whether due to adhesive otitis media or early otosclerosis). The importance of adequate and accurate audiometric testing is obvious.

In addition, this study should yield new information concerning the aural mechanism; that is, that exposure to cold air does affect the activity of the middle ear system which is reflected audiometrically in a low frequency conductive type hearing loss.

The Pilot Studies

Four pilot studies were carried out prior to the beginning of this study. The first one involved ten college students from the University of Maryland who were taken to a very large commercial freezer similar to the one which was used in the present research. The testing was carried on during the working day and the results, while indicating the possibility of threshold shifts, were inconclusive due to the excessive street traffic and other ambient noise which made testing extremely difficult.

The second pilot study was carried out at the University of Maryland in much smaller freezers (about 15 feet square) located inside of a warehouse. Conditions there were much more favorable since the testing was done only when the warehouse itself was not in use. It was not possible to make ambient noise measurements at this location. This pilot study involved twelve college students. The procedure followed was: each student had his hearing tested by air and bone conduction in both ears, from 250 Hz through 8000 Hz by air conduction and from 250 Hz through 4000 Hz by bone conduction, using the Hughson-Westlake ascending technique as described by Carhart and Jerger.[1] All of the testing was done in the empty warehouse in an area just a few feet away from the freezer.

Two subjects exhibited air-bone gaps and were eliminated from the sample. The remaining ten subjects then had their thresholds obtained by air and bone conduction in both ears twice more. One subject was extremely difficult to test (her thresholds varied greatly during pre-exposure testing sessions) and she, too, was eliminated from the sample. A fourth subject dropped out of school before the pre-exposure testing had been completed and was therefore not included in the study.

The eight remaining subjects were allowed to dress as warmly as desired (leaving the head and ears exposed) before entering the freezer. They were instructed to keep their physical activity in the freezer moderate and to come out if they became uncomfortable in any way. The temperature in this freezer ranged from -4° to -18° F. The subjects were in the freezer for ten minutes. Following this, air and bone-conduction thresholds were obtained again as described above, and then air-conduction thresholds were obtained once more one hour later. Most of the subjects went through this procedure twice.

Of the eight subjects used, five (three males and two females) exhibited depressed low frequency thresholds following the cold exposure and three (one male and two females) did not. In every instance those who

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[1]R. Carhart and J. F. Jerger, "Preferred Method for Clinical Determination of Pure-Tone Thresholds," Journal of Speech and Hearing Disorders, 24 (1959), pp. 330-345.

did not show a shift following the first exposure did not show a shift following the second exposure session. Following are the average thresholds obtained for these two groups before and after exposure and the shifts found for the right and left ears combined for the shifters (Table I)[1] and non-shifters (Table II).

None of the subjects objected to the cold exposure or found it to be particularly uncomfortable. When thresholds were obtained one hour following the cold exposure they were found, without exception, to have returned to the pre-exposure levels. To summarize, of the eight subjects included in this pilot study, five demonstrated pure-tone air-conduction threshold shifts at 250 Hz, 500 Hz, and possibly 1000 Hz in the direction of poorer hearing following a ten minute exposure to -4° to -18° F. with no accompanying shift in the bone-conduction thresholds. All threshold shifts returned to pre-exposure levels within one hour following the conclusion of the exposure period. The other three subjects demonstrated no threshold shifts by air or bone conduction following the same exposure. No subject, then, exhibited a post-exposure shift in bone-conduction thresholds.

In order to determine whether the shift in hearing thresholds might have been due to an overall muscular reaction to the entire body's being chilled or to an overall lowering of the body's internal temperature, three subjects were exposed for longer periods at somewhat higher air temperatures. Here a specific attempt was made to thoroughly chill the subjects. This third pilot study was carried out at the University of Maryland in a small walk-in refrigerator (about eight feet square) located in the basement of a

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[1]In all of the tables where shifts are presented the negative sign indicates that the post-exposure threshold was better than the pre-exposure threshold.

Table I.--Mean Air and Bone-Conduction Thresholds* of Five Subjects with Threshold Shifts Following Cold Exposure. Pre and Post-Exposure Readings.**

	Pre-exposure	Post-exposure	Shift
250 Hz			
Air Conduction	10.0	16.9	+6.9
Bone Conduction	21.6	18.3	-3.3
500 Hz			
Air Conduction	13.1	17.5	+4.4
Bone Conduction	20.0	20.0	0.0
1000 Hz			
Air Conduction	6.9	10.0	+3.1
Bone Conduction	11.7	15.0	+3.3
2000 Hz			
Air Conduction	1.3	1.9	+0.6
Bone Conduction	6.7	6.7	0.0
4000 Hz			
Air Conduction	0.9	2.8	+1.9
Bone Conduction	6.7	3.3	-3.4
8000 Hz			
Air Conduction	4.1	4.1	0.0

*In dB re 0 Hearing Level (ISO 1964)
**Post-exposure bone-conduction thresholds were obtained for only three subjects.

Table II.--Mean Air and Bone-Conduction Thresholds* of Three Subjects without Threshold Shifts Following Cold Exposure. Pre and Post-Exposure Readings.

	Pre-exposure	Post-exposure	Shift
250 Hz			
Air Conduction	15.0	15.0	0.0
Bone Conduction	20.0	20.0	0.0
500 Hz			
Air Conduction	17.0	18.5	+1.5
Bone Conduction	16.7	18.3	+1.6
1000 Hz			
Air Conduction	9.5	10.5	+1.0
Bone Conduction	11.7	13.3	+1.6
2000 Hz			
Air Conduction	2.5	2.0	-0.5
Bone Conduction	6.7	8.3	+1.6
4000 Hz			
Air Conduction	-1.0	0.0	+1.0
Bone Conduction	6.7	8.3	+1.6
8000 Hz			
Air Conduction	-1.5	-1.5	0.0

*In dB re 0 Hearing Level (ISO 1964)

campus dining hall. Conditions were favorable for testing since the dining hall was not open to the students at the time of testing. The pure-tone testing was done in an empty office and again it was not possible to make ambient noise measurements. The procedure followed was exactly the same as in the prior pilot study except that the subjects were sent into the refrigerator (where the temperature was kept at +35° to +40° F.) lightly dressed and asked to remain there until they were thoroughly chilled (shivering, goose bumps, etc.). All of the subjects remained in this environment for 30 to 40 minutes and signs of chilling as described above were observed in all of them when they came out. Following the cold exposure, pure-tone air-conduction thresholds were once again obtained. The average thresholds obtained for these subjects before and after exposure and the shifts found for the right and left ears combined are shown in Table III. Only air-conduction thresholds are reported because the ambient noise levels in the testing area were too high for accurate bone-conduction testing to be done.

None of these subjects showed any threshold shifts at any frequencies in either ear following this exposure. This would tend to indicate that the threshold shifts found in the pilot study discussed previously were due to factors other than changes in overall internal body temperature and/or muscular contractions throughout the body as a reaction to chilling.

The fourth pilot study involved two college students who were tested using the Michigan State University facilities that were used in the thesis research. In addition to pure-tone thresholds, pre and post-exposure impedance measurements were also made. These subjects' pure-tone thresholds also shifted in varying amounts in the low frequencies (and not at all above 1000 Hz)

Table III.--Mean Air-Conduction Thresholds* of Three Subjects Exposed to +35° to +40° F. for 30 to 40 Minutes. Pre and Post-Exposure Readings.

	Pre-exposure	Post-exposure	Shift
250 Hz	25.0	23.3	-1.7
500 Hz	21.7	23.3	+1.6
1000 Hz	10.0	9.2	-0.8
2000 Hz	2.5	0.8	-1.7
4000 Hz	0.8	-0.8	-1.6
8000 Hz	-2.5	-0.8	+1.7

*In dB re 0 Hearing Level (ISO 1964)

following a cold exposure of 20 minutes at -10° F. In addition, the maximum variation in three pre-exposure impedance readings in one ear was 69 ohms. The shift from pre-exposure impedance to post-exposure impedance was 186 ohms in one of the subjects and 216 ohms in the other subject, both shifts being in the direction of increased stiffness.

The Experimental Questions

It was hoped that this research would permit the following questions to be answered:

1. What effect, if any, does exposure for 20 minutes to temperatures ranging from -3° to -10° F. have on pure-tone air and bone-conduction thresholds?

2. Will pre-exposure tympanic temperature readings be within the normal range and how will they be affected by the cold exposure? What will the relationship be between tympanic temperature and air and bone-conduction threshold shifts?

3. Will pre-exposure impedance measurements be within the normal range and how will they be affected by the cold exposure? What will the relationship be between various impedance measurements and tympanic temperature and air and bone-conduction threshold shifts?

4. What is the replicability of the twenty minute exposure experience? When the length of the exposure time is less than 20 minutes (5 or 10 minutes) will the same effects be found with regard to air-conduction thresholds shifts, tympanic temperature, and impedance measurements? What is the relationship between varying the length of the exposure and all of the variables discussed?

5. How long will the recovery from these shifts take following each of the exposure durations (20 minutes, 10 minutes, and 5 minutes) and what will the pattern of the recovery be?

CHAPTER II

REVIEW OF THE LITERATURE

The review of the literature is divided into three sections. The first deals with the physiology involved. The literature in the area of thermal homeostasis in man will be briefly reviewed in addition to how muscle tissue responds to cold stimulation and with how the body in general responds to chilling. Also, the existing body of literature concerning the effects of cold on the auditory systems of various animals as well as man will be reviewed. The second section will deal with the theory of impedance and research which has employed the Madsen Acoustic Bridge, used in this study. The third section is concerned with the development of the tympanic thermometer and its application to this research.

Physiology

There is a large body of research concerned with how the body compensates for cold exposure and much has been written concerning the thermal homeostasis of man (i.e., body core temperature will remain quite constant when the outside temperature is varied within limits). This may be summarized as follows: Normal body functions depend upon a constant body temperature. Man possesses a group of reflex responses integrated in the hypothalamus which together operate in such a way as to control body temperature within a narrow range in spite of relatively wide fluctuations in environmental temperature. Normal oral body temperature in healthy young adults has been found to average

98.1° F. The oral temperature of 95% of this group falls within the range of 97.3° F. to 98.9° F.[1] When the body is exposed to a cold environment certain mechanisms are activated in order to increase heat production and decrease heat loss. Heat production may be increased through shivering, increased voluntary activity, and increased secretion of certain substances such as norepinephrine and epinephrine. Heat loss may be decreased through cutaneous vasoconstriction, curling the body up in order to reduce the amount of exposed body surface, and horripilation.[2] The purpose of these activities is to maintain the normal body temperature. The ability of the body to do this successfully is called thermal homeostasis.

Benzinger stated conclusively: "In warm blooded animals and man, homeostasis of internal temperature is maintained against wide variations of thermal flux from external or internal sources. The thermal _milieu interieur_ is closely guarded. Gains of heat (in warmth) are answered by equivalent physiological losses. Forced losses of heat (in cold) are balanced by equivalent internal gains. The principal effector mechanisms of thermoregulation are evaporative loss of heat by sweating and metabolic gain of heat by food combustion. . . . A third kind of thermoregulatory response (is) vasomotor action."[3]

Given the fact that in this study the subjects were warmly dressed and only their heads exposed there is no reason to believe that their body core temperatures would be affected by the length of exposure used. Benzinger and

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[1]William F. Ganong, _Review of Medical Physiology_ (Los Altos: Lange Medical Publications, 1967), p. 183.

[2]More commonly known as "goose bumps."

[3]T. H. Benzinger, "The Thermal Homeostasis of Man," _Les Concepts de Claude Bernard Sur Le Milieu Interieur_ (Paris: Masson & Co., 1967), p. 325.

Kitzinger found that: "The relations between the influence of temperature upon certain specific tissues of the body as a stimulus or cause and the thermoregulatory production or loss of heat as a response or an effect . . . cannot be demonstrated."[1] It is extremely unlikely that cooling the head alone would result in lowering the body temperature, and this is not proposed here. Since the ears were not covered, however, and since the cold air was also being breathed in directly, it is possible that a direct cooling effect of the cold air on the tympanic membrane and/or middle ear muscles might have occurred.

Next, we need to consider what sort of effect cold can produce in the ear. The research seems to conclude that the cochlea may be affected by changes in body temperature or by changing the temperature in the cochlea directly. Kahana, Rosenblith, and Galambos used hamsters[2] and reduced their body temperatures from normal (32° C.) to 18° C. by using copper coils through which ran hot and cold water as required. Photographic records were kept of the cochlear response produced by clicks of 0.1 msec duration. They found that when the body temperature was reduced the latency of the cochlear response remained constant but the amplitude of the response fell significantly. When body temperature returned to normal the cochlear response did also.[3] Gulick

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[1] T. H. Benzinger and C. Kitzinger, "The Human Thermostat," Temperature - Its Measurement and Control in Science and Industry (New York: Reinhold Corp., 1963), p. 637.

[2] It is interesting to note that it was necessary to select an animal whose body temperature drops when the environmental temperature drops. Hamsters are ideal because, although they are homeothermic when awake, they do not adapt their body temperature to compensate for cold environmental conditions; instead they hibernate.

[3] L. Kahana, W. A. Rosenblith, and R. Galambos, "Effect of Temperature Change on Round Window Response in the Hampster," American Journal of Physiology, 163 (1950), pp. 213-223.

and Cutt, using guinea pigs, found that when body temperature was reduced below normal the magnitude of the cochlear potential was reduced and a hearing loss was created. They hypothesized that cooling may have slowed down the metabolic processes which are responsible for generating the electrical response in the cochlea or that the body cooling may have damaged some of the hair cells by altering the structure of the cell membrane or by producing excessive mechanical strain during the deformation of the membrane under stimulation. They concluded that when body temperature is decreased the magnitude of the cochlear response is likewise decreased. They found that the cochlear response returned to normal when the body temperature returned to normal unless body temperature was allowed to fall below 30° C. When body temperature was reduced to 28° C. (82.4° F.) for 20 minutes hearing losses of up to 10 dB that lasted for one hour or more were produced.[1]

Patterson, et al., found that, in turtles, body temperature did not affect the cochlear response whereas cochlear temperature did. They suggested that "the conductive impedance . . . of the turtle ear may vary with temperature."[2]

Wever and Bray, on the other hand, found no changes in cochlear potential when a decerebrate cat was placed in an ice pack.[3] Chambers and Lucchina cooled the cochlea of a cat locally with a probe of -40° C. and induced a 6 dB loss at 1000 Hz. Full recovery took place within 20 minutes after the

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[1]W. L. Gulick and R. A. Cutt, "The Effects of Abnormal Body Temperature Upon the Ear: Cooling," Annals of Otology, Rhinology, and Laryngology, 69 (1960), pp. 35-50.

[2]W. C. Patterson, et al., "The Relationship of Temperature to the Cochlear Response in a Poikilotherm," The Journal of Auditory Research, 8 (1968) p. 437.

[3]E. G. Wever and C. W. Bray, "The Nature of Cochlear Activity After Death," Annals of Otology, Rhinology, and Laryngology, 50 (1941), pp. 317-329.

probe was removed.[1] In general, it may be concluded that extreme cold does have an effect on the cochlea and on hearing.

With regard to the middle ear, it has been noted that there is increased otitis media and other middle ear disorders among Eskimos and other groups who live in cold environments.[2] In addition, the United States Public Health Service has published hearing survey test results (gathered in 1960-1962) which give hearing thresholds at various frequencies by area of residence (as well as by sex and race).[3] When the data were examined for hearing thresholds at 500 Hz (the lowest frequency tested) by region of the country -- northeast, south, or west -- it was found that thresholds were poorest in the northeastern region. Of the 6,673 adults tested, 5.6% of those in the southern region, 5.6% of those in the western region, and 6.0% of those in the northeastern region had hearing levels of +16 dB or worse (ASA).[4] These differences, though small, appear to be significant, especially when the other frequencies tested are also examined. At 1000 Hz, for example, the percentage of subjects with thresholds of 16 dB or more are 5.6% for the south and west and 4.8% for the northeast. But the direct effect of cold on the middle ear specifically has apparently not been examined.

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[1] A. H. Chambers and G. G. Lucchina, "Reversible Frequency Selective Reduction by Cold of Round Window Potentials," Federation Proceedings, 15:1 (1956).

[2] J. A. Brody, et al., "Draining Ears and Deafness Among Alaskan Eskimos," Archives of Otolaryngology, 81 (1965), pp. 29-33.

[3] United States Public Health Service, Publication Number 1000, Series 11, No. 26, p. 22.

[4] One might expect to find thresholds for higher frequencies to be depressed in the northeast because of the greater industrialization there and the resultant increase in noise-induced type hearing losses, but this does not account for poorer hearing in the lower frequencies.

When specific human muscle tissue is exposed to cold, however, its activity is demonstrably diminished due to the generalized stiffness of the muscle which is associated with the constriction of arteries, veins, and capillaries and the resultant general reduction of blood supply to the muscles involved.[1] All human muscle tissue reacts similarly to being thus chilled. In the middle ear are two muscles, the tensor tympani and the stapedius and it would be expected that, were these muscles exposed to cold, they, too, would respond by stiffening. At this time an hypothesis will be presented as to what would happen to the physiology of the middle ear should these two muscles be chilled.

The tensor tympani is attached to the handle of the malleus. When it contracts it draws the malleus inward with the result that the tension in the tympanic membrane is increased. The stapedius, on the other hand, attaches to the head of the stapes and when it contracts it pulls the stapes laterally thereby impairing its ability to vibrate freely. The two muscles are antagonistic in their action and when both are contracted the three ossicles in the middle ear are brought into closer approximation to one another, the tympanic membrane is drawn inward with an accompanying increase in tension in the membrane and the footplate of the stapes is forced inward.[2] The end result is that neither the tympanic membrane nor the auditory ossicles are able to move as freely as in a non-contracted state. In addition, it is possible that the tympanic membrane might stiffen as a direct reaction to becoming

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[1]P. Bard, Medical Physiology (St. Louis: C. V. Mosby Co., 1956), pp. 154-158.

[2]W. Hughson and S. Crowe, "Experimental Investigation of Physiology of the Ear," Acta Oto-Laryngologica, 18 (1933), p. 291.

chilled (reduced blood supply, etc.). Although this has not apparently been specifically examined there is no reason to believe that the tympanic membrane would react any differently to cold exposure than any other body tissue.

It is not proposed here that body core temperature (or internal body temperature as it is sometimes referred to) is significantly affected by such short term exposures to extreme cold when the individuals are warmly dressed. Instead, it is suggested that the cold air reaches and affects the action of the tympanic membrane directly (via the external auditory meatus) and/or the middle ear muscles indirectly (through the venal blood supply and the mucosal lining of the nasopharynx). It should be noted that head temperature (temperature measured at the back of the nasal cavity and the interior of the ear) does not always correlate with body core temperature.[1] Benzinger believed that this was possibly due to the passing of cooler blood returning from the ear "lobe and surrounding skin in descending veins adjacent to some of the ascending arteries which supply the tympanic membrane."[2]

It is possible to take an individual's temperature on the tympanic membrane. Under ordinary environmental conditions this temperature reading agrees very closely with body temperature readings taken elsewhere (such as rectally). Under these special conditions, where middle ear and body temperature may differ, however, it is felt that body temperature probably does not change and that the tympanic temperature in this case is a measure of the temperature shifts at the tympanic membrane only and does not reflect internal body temperature changes.[3]

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[1]William F. Ganong, Review of Medical Physiology, p. 186.

[2]T. H. Benzinger and G. W. Taylor, "Cranial Measurements of Internal Temperature in Man," Temperature--Its Measurement and Control in Science and Industry (New York: Reinhold Corp., 1963), pp. 111-120, and personal communication with T. H. Benzinger.

[3]Unfortunately, it was not possible to prove this theory since oral temperature could also be affected by breathing the cold air and the testing environment did not allow for rectal temperatures to be taken.

Therefore, although the subjects in this study may be dressed warmly and experience no discomfort, shivering, or other signs of chilling during the cold exposure, and although their body core temperature may not vary from normal, the temperature at the tympanic membrane may be depressed: the result being increased stiffness in the action of the tympanic membrane and middle ear ossicles. This increased stiffness might be expected to affect the impedance characteristics of the middle ear along with the air-conduction hearing thresholds. On the basis of the research reviewed, one might conclude that bone-conduction thresholds might also be affected if the cold air were reaching the cochlea. This would only happen if the cold were passed to the inner ear through the middle ear (local cooling) since overall body core temperature is not affected.

Impedance

In a normal ear, when a sound wave enters the external auditory canal it travels to the tympanic membrane where some of the acoustic energy is reflected back out and the rest causes the membrane to vibrate. The size of the reflected portion of the wave is affected by the condition of the ear's mechanical components: the tympanic membrane, middle ear ossicles, tensor tympani and stapedius muscles, tendons and ligaments, and the oval and round windows. The amount of energy in the reflected wave may be determined by measuring the sound pressure in the external meatus and subtracting from the total the (known) sound pressure of the incoming sound wave. When the middle ear mechanism is stiff, less energy would be transmitted to the inner ear and more of the incoming wave would be reflected back out of the external meatus. This stiffness or resistance, or lack of it, that the middle ear system presents to the incoming sound waves is referred to as impedance.

Total impedance is determined by the combined reactance and compliance of the ear. The reactance of the ear may be defined as the amount of resistance the middle ear (membrane, ossicles, etc.) presents to the incoming sound waves. Compliance is, of course, just the opposite. It refers to the decrease in stiffness of the middle ear system. Normal ears present relatively low acoustic impedances because a sizable amount of energy is absorbed and enters the middle ear. If the eardrum is prevented from vibrating freely or if the ossicles cannot move freely, the reactance (or resistance) increases, less energy is absorbed, and there is a loss of transmission to the cochlea. Compliance of the ear differs from the compliance of a similarly sized hard walled cavity because some of the energy is absorbed at the eardrum and by the middle ear. The more compliant the drum and middle ear system, the more energy will be absorbed or, to put it differently, acoustic impedance increases as compliance decreases and vice versa.[1,2] In the case of the ear, sizable changes in impedance are exhibited audiometrically. Specifically, increased stiffness in the middle ear results in an audiogram that displays a "stiffness tilt" (poorer than normal hearing in the low frequencies and normal or better than normal hearing in the higher frequencies) in the air-conduction thresholds.[3]

There are currently two acoustic bridges (Madsen and Zwislocki) commercially available for measuring impedance in the ear. Because of the time

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[1]Madsen Model ZO 70 Electro-Acoustic Impedance Bridge Manual, p. 2.

[2]K. Terkildsen and H. A. E. van Dishoeck, "Impedance Measuring and Tubal Function," (Buffalo: Madsen Electronics Corp.).

[3]P. Campbell, "The Importance of the Impedance Formula in the Interpretation of Audiograms," Transactions of the American Academy of Ophthalmology and Otolaryngology, 54 (1950), pp. 245-252.

constraints in this research[1] and because of the severe physical limitations of the testing environment, the Madsen Model ZO 70 Electro-Acoustic Impedance Bridge was selected. This particular bridge has been successfully used in a variety of research.

Lamb and Peterson, using the Madsen Bridge, demonstrated how pseudohypacusis was identified in two adult subjects. They comment: "Whenever reflex thresholds are better than auditory thresholds, there can be little doubt that some degree of pseudohypacusis is present."[2]

Robertson et al.[3] used this acoustic bridge and measured acoustic reflex thresholds to stimuli of 500 Hz, 1000 Hz, and 2000 Hz in a group of ten very young children (aged 12 to 36 months). They concluded that the use of an acoustic bridge to help diagnose auditory problems of young children has merit.

Norris and Lamb[4] used the Madsen Bridge with 15 normal children and 15 mentally retarded children ranging in age from 4-1/2 to 12 years. They found about 5 dB test-retest variability in the acoustic reflex threshold to a stimulus of 250 Hz.

The Schuster Bridge, prototype of the Madsen Bridge, and slight variations of it have been used in a large body of research.[5] Impedance bridges

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[1]Since it was not known how long the effect of the cold exposure on the ear would last it seemed desireable to be able to make all measurements following the exposure as quickly as possible.

[2]L. E. Lamb and J. L. Peterson, "Middle Ear Reflex Measurements in Pseudohypacusis," Journal of Speech and Hearing Disorders, 32 (1967), p. 50.

[3]E. O. Robertson, J. L. Peterson, and L. E. Lamb, "Relative Impedance Measurements in Young Children," Archives of Otolaryngology, 88 (1968), pp. 162-168.

[4]T. W. Norris and L. E. Lamb, "Relative Acoustic Impedance Measurements with Mentally Retarded Children," presented at the convention of the American Speech and Hearing Association, Denver 1969.

[5]See bibliography.

in general, and the Madsen Bridge in particular, have provided a simple and reliable method for determining the presence of middle ear muscle reflexes.

Tympanic Thermometer

In 1963 a method was reported by the National Naval Medical Center in Bethesda for taking body temperature at a site not previously used, the tympanic membrane. Experimental evidence was presented which described the method and supported its accuracy. A thermoelectric method was chosen (as opposed to thermistor methods) because suitable thermocouples could be easily and inexpensively produced which are disposable and because their response is linear. The probe was inserted into the external auditory meatus until it touched the tympanic membrane. This point is determined both tactually and by following instructions given in the manual. Benzinger and Taylor[1] described the development of the tympanic thermometer and compared tympanic temperature measurements with rectal temperature and cranial temperature measurements taken in the anterior ethmoidal region, the anterior wall of the sphenoid sinus, and Rosenmueller's fossa (all entered through the nasal cavity). The authors concluded that tympanic temperature measurements are highly sensitive and accurate as measures of body core temperature[2] and, in addition, are quick and simple to obtain.

The equipment for taking tympanic temperature is now being commercially manufactured and is available to the public.[3] It has been successfully used in the operating room for monitoring the patient's body temperature during

[1] T. H. Benzinger and G. W. Taylor, "Cranial Measurements of Internal Temperature in Man," pp. 111-120.

[2] The authors found that cold environments did affect tympanic temperatures, however.

[3] Tympanic Thermometer Probe #104382, Radiation Systems, Inc., McLean, Virginia.

surgery[1,2] and shows particular promise in cases where the patient's body temperature is lowered during surgery in order to reduce circulation, etc. Tympanic thermometry has been suggested[3] as a possible way to identify incipient drastic changes in body temperature which sometimes occur during anesthesia for an operation.[4]

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[1] W. T. Dickey, E. W. Ahlgren, and C. R. Stephen, "Body Temperature Monitoring Via the Tympanic Membrane," The Tympanic Thermometer in the Operating Room Environment (McLean: Radiation Systems Inc.), pp. 1-18.

[2] R. D. Wilson, et al., "Anesthetic Management of the Poor Risk Patient," The Tympanic Thermometer in the Operating Room Environment, pp. 19-40.

[3] George E. Shambaugh, Jr., "Tympanic Thermometry During Anesthesia," Archives of Otolaryngology, 90 (1969), p. 28.

[4] General anesthesia removes the body's ability to monitor its own temperature. Drastic changes in body temperature may occur which are sometimes fatal.

CHAPTER III

EXPERIMENTAL DESIGN

Subjects

Fifty college students with normal hearing and excellent general health were selected to serve as subjects for this study. They were chosen on the basis of age (between 17 and 26), sex (an effort was made to use an equal number of males and females), and body build (only subjects judged to be of approximately average height and weight were used). In addition, each subject used passed a hearing screening test at the following frequencies by air conduction: 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. The screening test was administered to both ears (separately) in the non-sound treated room in which the actual testing was to be done. A 20 dB screening level was used for 125 Hz, 250 Hz, and 500 Hz and the remaining frequencies were screened at 15 dB (ISO 1964). A subject was considered to have passed the screening test if he missed no more than one of the frequencies presented to either ear at the levels given, as long as it was possible to reach his threshold at the frequency failed within 10 dB above the screening level. In addition, each subject had his ears inspected by an otologist in order to determine that the tympanic membrane in both ears was intact and healthy and to rule out any subjects whose external auditory canals were not of normal size, configuration, and angle of inclination. Lastly, whenever necessary the ears were cleaned of wax and/or other material.

Of the 50 subjects thus selected four were discarded. In three cases the subjects did not follow major directions properly during the cold exposure (came out of the cold room too early, had their ears and/or mouths covered during the cold exposure, etc.). In the fourth case the subject repeatedly complained of discomfort and was dismissed before the testing had been completed. The remaining 46 subjects served as the subjects for this study. The subjects were paid for their participation in the study.[1]

Table IV gives the means, ranges, and standard deviations for the age, height, and weight of these 46 subjects as well as the number of males and females used.

From this sample of 46 subjects nine were selected for more extensive testing. These nine were chosen on the basis of having shown the greatest post-exposure air-conduction threshold shifts and their availability for continued testing.

Equipment

A commercially available portable audiometer (Beltone, Model 12C) with TDH 39 10Z earphones mounted in MX 41/AR cushions was used for all pure-tone air-conduction testing. This audiometer allows for thresholds to be made to the nearest decibel and is calibrated to ISO 1964 standards.

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[1]These 46 subjects were selected from an initial group of 100 college students who had volunteered to be included in this research. Of these remaining 54 students 4 were rejected as described above, 15 never showed up for their initial otological examination, and 35 were rejected on the following grounds: did not pass the hearing screening test - 9; were judged to be considerably heavier than average - 3; had some medical condition such as high blood pressure which contraindicated cold exposure - 5; failed to pass the otological screening for reasons such as retracted drums, steep angulating canals, scarring on drums, external otitis, etc. - 18.

Table IV.--Means, Standard Deviations, and Ranges of Age, Height and Weight for the 46 Subjects. The Number of Males and Females is also Given.

	Mean	Standard Deviation	Range Minimum Value	Range Maximum Value
Age (years)	19.80	1.78	17	26
Height (inches)	66.78	3.65	59	73
Weight (pounds)	136.59	20.62	100	180

Number of Males: 20 Number of Females: 26

It was found to be satisfactorily linear for use in 2 dB steps. A 20 dB attenuation pad was inserted in one air-conduction line and in the bone-conduction circuit. American Optical Company ear muffs were used in measuring occluded bone-conduction thresholds. The bone-conduction oscillator used was a Radioear B 70 A white dot provided with the audiometer.

The pure-tone air-conduction system was calibrated weekly during the course of the investigation using an artificial ear assembly (Bruel and Kjaer type 4152) employing a condenser microphone (Bruel and Kjaer type 4132) with the associated sound level meter (Bruel and Kjaer type 2203) and octave band filter network (Bruel and Kjaer type 1613). The bone-conduction system was calibrated at the beginning of the research and again at its conclusion in the standard manner using an artificial mastoid (Beltone Model M5A) and was found to be satisfactory.[1]

For making the impedance measurements necessary to this study an impedance bridge (Madsen Acoustic Bridge, Model ZO 70) was used. A schematic diagram of this bridge is presented in Figure 1. This bridge is composed of a pure-tone generator which produces a probe tone of 220 Hz, a pressure system made up of a pump and an electro-manometer, and a section for acoustic impedance measurements. The pure-tone generator is connected to a receiver and a tube from the receiver conveys the 220 Hz tone to the probe unit (which is part of the headset) and then into the external auditory meatus. The meatus has been sealed forming an air-tight cavity. Some of the acoustic energy is absorbed; the remainder is reflected by the eardrum and conveyed back to a microphone in the probe unit through a second tube. A third tube

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[1]W. Olsen, "Artificial Mastoid Calibration of Bone Vibrators," Archives of Otolaryngology, 85 (1967), pp. 314-318.

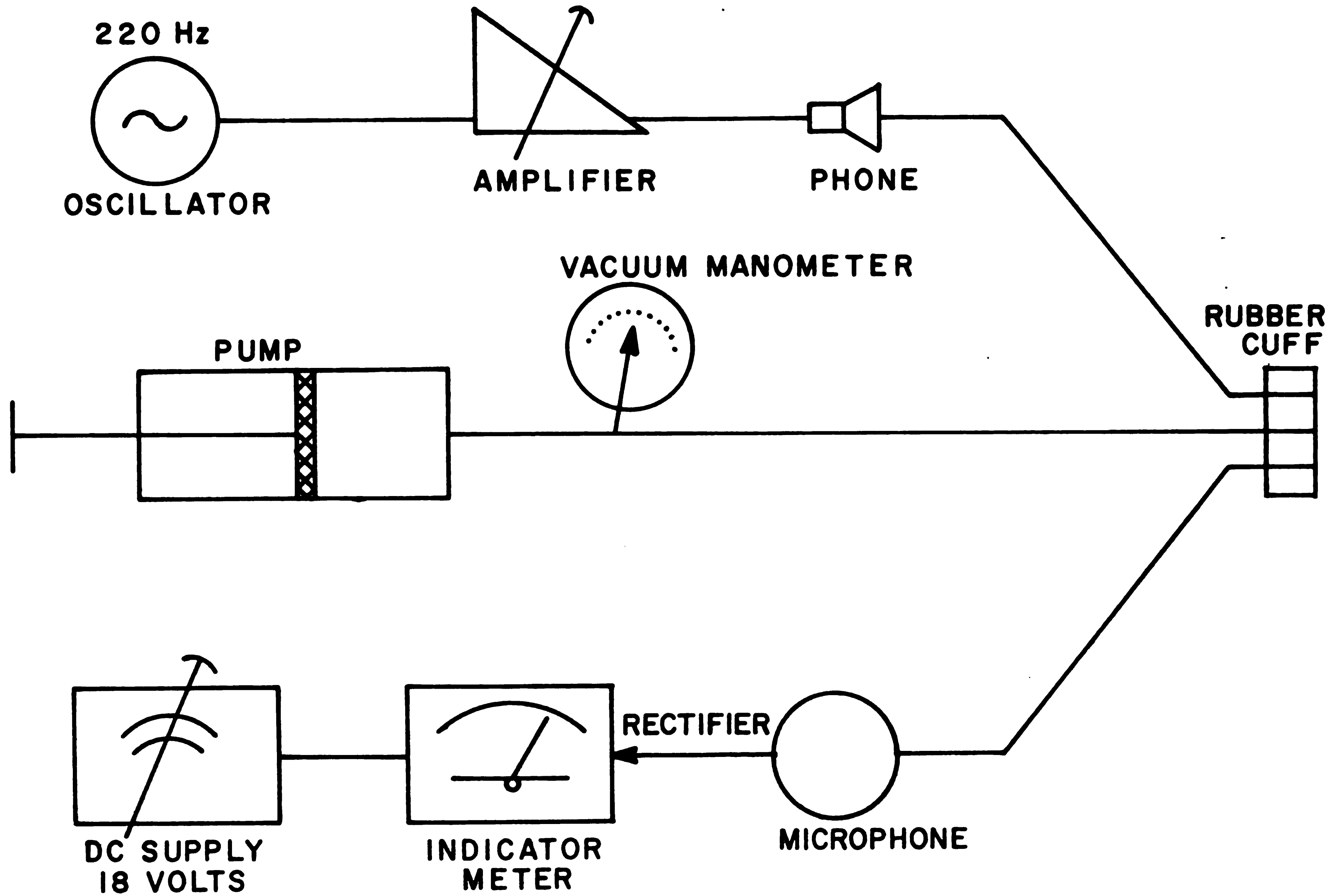

Figure 1.--A schematic diagram of the Madsen Acoustic Bridge (Model ZO 70)

is connected to the probe unit from the pressure system which allows positive or negative air pressures to be applied to the external auditory canal. The sound pressure level in the canal may be varied.

When the compliance control is adjusted to give a zero reading on the balance meter the sound pressure level in the canal is precisely 95 dB. (When the microphone voltage equals 18 volts the voltage at the balance meter is zero since it has been perfectly balanced with the DC 18 volt supply provided by the bridge on the other side of the meter.) With this equipment the reactance or compliance of the ear may be read on a scale in acoustic ohms or in cc and the impedance calculated in acoustic ohms. In addition, it is possible to determine the presence or absence of the middle ear muscle reflexes, measure the compliance of the ear under a variety of air pressures and perform other impedance measurements.

A tympanic thermometer (Radiations Systems, Inc. Model #104382) was used for making temperature measurements at the tympanic membrane. The tympanic thermometer itself is battery operated and is a small (13" x 9" x 7") portable (14-1/2 lbs.) cabinet from which a six foot lead connects to interchangeable, disposable probes or thermocouples which consist of constantan and copper wire embedded in thin polyethylene tubing. The end of the wire is looped and the soldered junction is embedded in the tubing, also. Thermocouple wires surrounded with polyethylene tubing facing the interior of the auditory canal with their free ends help to hold the probe in place against the tympanic membrane while the temperature measurement is being made.

The use of a thermoelectric method (as opposed to thermistor measurements) requires amplification. This is provided so that readings may be made to 1/100° C. Using this equipment tympanic temperature may be obtained within

15 seconds at an accuracy of up to 0.2° C. Readings on the tympanic thermometer may be made in either degrees Fahrenheit or Centigrade.

Test Environment

All of the pre and post-exposure pure-tone air and bone-conduction thresholds, acoustic impedance readings, and tympanic temperature measurements were made in an empty and quiet, but not sound-treated room. This room is ordinarily used as a conference room and is located on the main floor of the Michigan State University Food Stores building. The ambient noise level in this room is described in Table V. These measurements represent the average of measurements on several different occasions. They were obtained with a sound level meter (Bruel and Kjaer type 2203) and associated octave band filter network (Bruel and Kjaer type 1613) employing a one-inch sound field condenser microphone (Bruel and Kjaer type 4131). The noise levels obtained were felt to be sufficiently low so as not to seriously interfere with pure-tone air-conduction threshold measurement.[1] However, it was felt that it was necessary to use ear muffs in order to obtain bone-conduction threshold measurements.

For the cold exposure the subjects were placed in a very large (120 feet by 120 feet) commercial type freezer located on the main floor of the Michigan State University Food Stores building, across a hallway from the testing room. The temperature in the freezer ranged from -3° F. to -10° F. during the course of the investigation and averaged -7.07° F. The freezer is located about 50 feet from the area which was used for the testing. The doors to the freezer can be electrically or manually operated both from within and from without.

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[1] J. Cox, "How Quiet Must it be to Measure Normal Hearing?" Noise Control, 1 (1955), pp. 25-29.

Table V.--Mean Ambient Noise Measurements in the Conference Room of the Michigan State University Food Stores Building. N = 8.

Octave Band	Readings (in dB SPL re 0.0002 microbar)
125 Hz	54
250 Hz	47
500 Hz	41
1000 Hz	35
2000 Hz	25
4000 Hz	17
8000 Hz	14
A scale 43	
B scale 56	
C scale 65	

The freezer was in use during the period of the testing but the testing was carried out in the evenings, following the close of the ordinary working day.

Test Procedures

The subjects were instructed to eat nothing following lunch on the day on which they were to participate in the research. Immediately upon their arrival they were provided with a donut and a glass of milk and then waited 30 minutes to one hour before testing began. In this way an attempt was made to rule out differences in body metabolism as a complicating factor. Following the completion of the testing the subjects were provided with a light supper.

Each of the 46 subjects had their pure-tone air-conduction thresholds determined in both ears at octave intervals from 125 Hz through 8000 Hz. Because of the high ambient noise level in the test environment, conditions were not ideal for bone-conduction testing. It was desireable, nevertheless, to obtain the most sensitive and reliable bone-conduction thresholds possible under these conditions. Therefore, bone-conduction thresholds were obtained without masking at octave intervals from 250 Hz through 4000 Hz using a forehead oscillator placement and with the ears occluded. Occlusion of the ears results in enhanced bone conduction sensitivity, particularly in the low frequencies.[1] Masking was not used in order to avoid the central masking phenomenon which produces an adverse effect on sensitivity of about 5 dB.[2] It was, of course, assumed that the bone-conduction responses were consistently elicited from the better ear (since masking was not used) and that, since

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[1] R. F. Naunton, "Clinical Bone-Conduction Audiometry," Archives of Otolaryngology, 66 (1957), pp. 281-298.

[2] D. Dirks, "Bone Conduction Measurements," Archives of Otolaryngology, 79 (1964), pp. 594-599.

both ears were exposed to the cold, they would both be affected by it in the same way. Forehead oscillator placement was used because it has been demonstrated to yield more reliable thresholds than mastoid placement.[1] The bone-conduction oscillator was positioned at the midline of the forehead approximately one inch above an imaginary line drawn across the subject's eyebrows. As Jerger and Tillman[2] noted, exact placement of the oscillator is not critical in this region.

In order to make the research conditions as similar as possible to clinical routine all pure-tone testing was carried out employing the Hughson-Westlake ascending technique as described by Carhart and Jerger[3] with the exception that thresholds were measured in two decibel steps. The specific order in which the frequencies were presented to all subjects at all times was: 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz, 125 Hz, 250 Hz, 500 Hz with the single exception that at times 1000 Hz was rechecked between 8000 Hz and 125 Hz. (The bone-conduction testing order was 1000 Hz, 2000 Hz, 4000 Hz, 250 Hz, 500 Hz: at times 1000 Hz was rechecked between 4000 Hz and 250 Hz.)

Following the first air-conduction threshold testing, the better ear was selected and identified as the test ear. Air-conduction thresholds were obtained a second time in this ear. Following a twenty minute break, air-conduction thresholds were obtained a third time in the test ear.

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[1]D. Dirks, "Factors Related to Bone Conduction Reliability," Archives of Otolaryngology, 79 (1964), pp. 551-558.

[2]J. Jerger and T. Tillman, "A New Method for the Clinical Determination of Sensorineural Acuity Level (SAL)," Archives of Otolaryngology, 71 (1960), p. 949.

[3]R. Carhart and J. Jerger, "Preferred Method for Clinical Determination of Pure-Tone Thresholds," Journal of Speech and Hearing Disorders, 24 (1959), pp. 330-345.

The bone-conduction threshold testing was also done at this time. This provided pre-exposure thresholds and eliminated the complication of having thresholds improve with practice and thereby contaminate the results obtained following the cold exposure.

For 37 of these subjects tympanic temperature was also determined prior to the cold exposure. The thermocouple wires were inserted into the external canal until they reached the tympanic membrane. This point was determined in three ways. Tactually, when the probe reached the drum there was the distinct feeling of a sudden resistance to further insertion. Secondly, the subject usually reported a slight "twinge" when the probe touched the drum. Thirdly, the highest temperature reading possible in the canal is on the drum. Therefore, a final check to correct placement was to slightly withdraw the probe. If the probe was correctly placed originally the tympanic temperature dropped somewhat when the probe was withdrawn slightly (and then, of course, replaced).[1]

In some of the subjects a variety of impedance measurements were made using the acoustic bridge. Measurement of acoustic impedance in the

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[1]It is of interest to note that of the 39 subjects who originally participated in this aspect of the study only two (leaving 37 included) found having their tympanic temperature taken to be so unpleasant that the attempt was ended before the temperature had been properly registered (the procedure takes about 15 seconds). Most of the subjects felt that the sensation of having the probe touch the tympanic membrane was unpleasant but not overly so. In a few cases the subject's head jerked slightly when the probe touched the drum but once the sensation had been experienced there were no further head movements.

plane of the eardrum was made in 45 subjects. The procedure followed was to first check that the sensitivity and pump controls on the bridge were set to zero. The headset was then fitted with a TDH 39 earphone and the three apertures in the probe checked to see that they were clear. An eartip of suitable size was selected and fitted onto the probe. The probe was then inserted into the meatus and then checked to ascertain that an airtight seal had been achieved (by increasing the canal pressure to +200 mm water pressure and waiting a few seconds to observe on the pump control that the pressure had held steady).[1] The sensitivity control was then set to position 1 (which provides a balance meter sensitivity of ± 1 cc). The compliance control was then adjusted as necessary in order to obtain a zero reading on the balance meter and the reading noted in acoustic ohms from the main scale. This reading represents Z_1 in the formula below. It is the point at which the ear is least compliant and approximately represents the actual canal volume. (As stated earlier, these readings may be made in ohms or in cc.)

The pressure in the ear canal was then reduced until the point was reached when the balance meter needle had reached its maximum left swing and

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[1]If an airtight seal had not been achieved, either a different size eartip was tried or some vaseline was applied to the outer edges of the eartip.

the compliance control adjusted in order to obtain a zero reading on the balance meter. This reading from the main scale was again made in acoustic ohms and represents Z_2 in the formula below. It is the point of maximum compliance of the middle ear system. Acoustic impedance in the plane of the eardrum was then calculated using the following formula:

$$Z_x = \frac{Z_1 \times Z_2}{Z_1 - Z_2}$$

A measurement of middle ear pressure was noted for 11 subjects. The headset was not removed. Sensitivity and pump controls were reset at zero, the canal pressure raised to +200 mm and the sensitivity control returned to position 1. The compliance control was adjusted until the balance meter registered 10. The pump control was then rotated to reduce the canal pressure until the balance meter reading was at the lowest point that could be achieved. The pump control was rotated back and forth in order to be sure of the minimum reading. At this point the eardrum is in the midline position and the air pressure on both sides of it are equal. The equivalent middle ear pressure (presumably 0 mm water pressure in a normal ear) was then read off of the manometer.

Compliance readings at a variety of pressure settings were taken for 15 subjects, in order to determine the compliance of the eardrum under varying canal pressure conditions. Again, the headset was not removed and sensitivity and pump controls were returned to zero. The pressure in the canal was then raised to +200 mm and the sensitivity control set to position 1. The compliance control was adjusted so that the balance meter reading was 10. The canal pressure was then reduced in 40 mm steps and the balance meter readings noted at each of the pressure settings tested: +160 mm, +120 mm, +80 mm, +40 mm, 0 mm, -40 mm, -80 mm, -120 mm, -160 mm, and -200 mm.

In five cases the intra-aural stapedius muscle reflex threshold to a 250 Hz[1] stimulus was measured. Again, the headset was not removed. Sensitivity and pump controls were returned to zero and the pump control adjusted to the middle ear pressure found previously. The sensitivity control was then set consecutively to positions 1, 2, 3, and 4. At each setting the compliance control was adjusted in order to obtain a zero reading on the balance meter. (The final sensitivity setting, position four, provided a balance meter sensitivity of ± 0.025 cc.) The audiometer frequency was set at 250 Hz and short bursts (1 to 2 seconds) were presented beginning at 70 dB in five dB steps until the balance meter needle was clearly deflected, indicating that the intra-aural muscle reflex threshold had been reached.

Each subject was allowed to dress as warmly as he desired (leaving the head and ears exposed) before entering the freezer. The subjects were instructed as follows:

1. When you enter the freezer do not close the door behind you. It is to remain open at all times.

2. Do not remain near the door, however. Move to the back or side of the freezer. You may walk around but do not run, jog, exercise or engage in any type of strenuous activity.

3. Do not touch anything in the freezer.

4. Do not cover your mouth or ears at any time. If you become too cold, your ears get numb, you start to "tingle," or become uncomfortable in any way come out of the freezer and directly back to the testing room.

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[1]This frequency was chosen because it was within the range of frequencies affected by the cold exposure.

The subjects were shown how to operate the freezer doors and again reminded to leave it open from two to three feet at all times. (This does not affect the temperature deeper within the freezer.) The subjects were asked to spend twenty minutes in the freezer. The examiner escorted the subjects into the freezer and took them back to the testing area following the twenty minute exposure period. Each subject was alone in the freezer for the twenty minutes, however.

The order of tests was as follows: air-conduction testing, bone-conduction testing, impedance testing (when done), temperature testing (when done). The same order of testing was followed during the post-exposure testing session. When hearing thresholds shifted, the subjects were not allowed to leave the building until the affected thresholds had returned to pre-exposure levels. Generally a threshold check was made one hour following the conclusion of the cold exposure. If thresholds had not yet returned to their pre-exposure levels, another check was made 15 or 20 minutes later. In all cases thresholds had returned to normal within 80 minutes following the conclusion of the cold exposure.

Nine subjects were selected for more intensive testing. Each returned for three additional testing sessions with at least 24 hours but not more than four days between each session. These sessions differed in the length of cold exposure -- one being of five minutes duration, one of ten minutes duration, and the third a repeat of the 20 minute duration. At each of these three testing sessions the following procedures were carried out in the test ear both before and after the cold exposure: tympanic temperature was ascertained, pure-tone air-conduction thresholds were obtained once for practice and once for pre-exposure thresholds as described above, and various impedance measurements were made in the following order -- acoustic impedance in the plane of the eardrum, middle ear pressure, compliance readings at various pressure settings and intra-aural muscle reflex threshold to a stimulus of 250 Hz. The order in which these procedures were carried out both in pre and post-exposure testing was as follows:

Subjects 1, 2, and 3:

Exposure 5 minutes -- tympanic temperature, acoustic bridge, pure-tone thresholds

Exposure 10 minutes -- acoustic bridge, pure-tone thresholds, tympanic temperature

Exposure 20 minutes -- pure-tone thresholds, tympanic temperature, acoustic bridge

Subjects 4, 5, and 6:

Exposure 5 minutes -- acoustic bridge, pure-tone thresholds, tympanic temperature

Exposure 10 minutes -- pure-tone thresholds, tympanic temperature, acoustic bridge

Exposure 20 minutes -- tympanic temperature, acoustic bridge, pure-tone thresholds

Subjects 7, 8, and 9:

Exposure 5 minutes -- pure-tone thresholds, tympanic temperature, acoustic bridge

Exposure 10 minutes -- tympanic temperature, acoustic bridge, pure-tone thresholds

Exposure 20 minutes -- acoustic bridge, pure-tone thresholds, tympanic temperature

In addition, in order to examine recovery patterns, pure-tone air-conduction thresholds were obtained in the test ear for each subject immediately following the cold exposure (as described above) and then every 20 minutes until the thresholds returned to normal and became stable.[1]

Finally, tympanic temperature and all impedance measurements were made once more for each subject.

[1]For the purposes of this study thresholds were considered stable when they had been measured no less than two times at 20 minute intervals with no changes observed ($\pm$ 2 dB).

CHAPTER IV

RESULTS

This chapter is divided into five sections. The first deals with the effect of a 20 minute cold exposure on pure-tone air and bone-conduction thresholds for the total group of 46 subjects. The second section is concerned with the effect of the cold exposure on tympanic temperature and the relationship between air and bone-conduction thresholds and tympanic temperature. The third section deals with the impedance measurements and their relationship to the first two variables. The next section concerns these three variables for nine subjects who were subjected to varying exposure durations. Finally, the fifth section examines the nature and pattern of the recovery from the shifts found.

Various statistical techniques were applied to the data, including such tests as tests of significance, simple correlation, and one-way analysis of variance. The .05 confidence level was selected as the point at which data were determined to be significant throughout the text, except where a specific statement is made to the contrary. The analyses were carried out on the Michigan State University CDC 3600 computer. All of the data on the significance levels of the means and correlation coefficients were derived from the Michigan State University Agricultural Experiment Station MDSTAT computer routine (Description #6), "Calculation of Basic Statistics when Missing Data Is Involved."[1] The data concerning the analysis of variance and

[1] Program published by Michigan State University Agricultural Experiment Station, the MDSTAT Routine, (STAT Series Description No. 6), Computer Laboratory, Michigan State University, East Lansing, Michigan.

the F statistics for significance levels were derived from the Michigan State University Agricultural Experiment Station UNEQ 1 computer routine (Description #13), "One-Way Analysis of Variance with Unequal Number of Replications Permitted."[1]

Pure-Tone Air and Bone-Conduction Thresholds

> This section will attempt to answer the first experimental question: What effect, if any, does exposure for 20 minutes to temperatures ranging from -3° F. to -10° F. have on an individual's pure-tone air and bone-conduction thresholds?

No effort was made to directly compare air-conduction and bone-conduction thresholds. The primary reason for this was that the high intensity level of the low frequency ambient noise in the test environment would have interfered with obtaining absolute bone-conduction thresholds. Further, it was felt that if a subject passed the screening test administered at the start of this study it was highly unlikely that any significant air-bone gap could be present. For these reasons no attempt was made to establish bone-conduction thresholds prior to the cold exposure that could be directly compared to the air-conduction thresholds found. Instead, great care was taken to insure that the bone-conduction thresholds obtained prior to the cold exposure would be perfectly comparable to those obtained following the exposure. For this reason a forehead oscillator placement was used and occluded bone-conduction thresholds were obtained. Therefore, pre-exposure and post-exposure bone-conduction thresholds per se are not presented. Instead the shifts in bone conduction following the exposure are given. In Table VI are found the ranges, standard deviations, and means for the shifts in

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[1]Program published by Michigan State University Agricultural Experiment Station, The UNEQ 1 Routine, (STAT Series Description No. 13), Computer Laboratory, Michigan State University, East Lansing, Michigan.

occluded bone-conduction thresholds and the significance levels of the mean shifts (from pre-exposure readings to post-exposure readings) found at the frequencies tested for the total group of 46 subjects following a 20 minute cold exposure.

Table VI.--Ranges, Means, Standard Deviations, and Significance Levels of the Shifts in Occluded Bone-Conduction Thresholds Found for the 46 Subjects Following a 20 Minute Cold Exposure.

	Range*				
	Minimum Value	Maximum Value	Mean*	Standard Deviation*	Significance Level of Mean
250 Hz	-20.00	14.00	-0.59	7.43	0.62
500 Hz	-16.00	18.00	-0.44	6.09	0.65
1000 Hz	-10.00	10.00	0.15	4.13	0.82
2000 Hz	-12.00	14.00	-0.29	5.72	0.75
4000 Hz	-8.00	8.00	-0.83	3.82	0.17

*In dB re pre-exposure level

The mean shifts found by occluded bone-conduction testing following the cold exposure were extremely small (the largest mean shift being less than 1 dB), and none of the shifts differed significantly from zero ($P \geq .17$). In addition, no one subject showed consistent bone-conduction threshold shifts following the cold exposure. It would appear, then, that 20 minutes of cold exposure under these conditions does not measurably affect bone-conduction thresholds.

The ranges, means, and standard deviations of the pre and post-exposure air-conduction thresholds and the significance levels of the mean shifts for the total group of 46 subjects, as well as the shifts in air-conduction thresholds, at the frequencies tested, are shown in Tables VII and VIII, and graphically in Figure 2.

The effect of the ambient noise level in the testing room can be seen on the low frequencies. Since the high frequency thresholds are close to

Table VII.--Ranges, Means, and Standard Deviations of the Pre and Post-Exposure Air-Conduction Thresholds Found for the 46 Subjects Following the 20 Minute Cold Exposure

	Range*			
	Minimum Value	Maximum Value	Mean*	Standard Deviation*
Pre-exposure A/C Thresholds				
125 Hz	1	20	10.80	5.28
250 Hz	7	24	15.13	4.50
500 Hz	6	24	17.59	3.49
1000 Hz	-7	13	5.91	3.99
2000 Hz	-14	16	-1.98	6.69
4000 Hz	-12	10	-2.33	5.31
8000 Hz	-14	23	2.67	8.71
Post-exposure A/C Thresholds				
125 Hz	4	23	13.97	4.65
250 Hz	10	28	17.65	4.28
500 Hz	8	27	19.42	4.38
1000 Hz	-5	19	6.82	4.40
2000 Hz	-16	16	-2.24	6.93
4000 Hz	-14	16	-2.41	6.50
8000 Hz	-16	21	2.06	9.16

*In dB re 0 Hearing Level (ISO 1964).

Table VIII.--Ranges, Means, Standard Deviations and Significance Levels (of the Means) of the Air-Conduction Threshold Shifts Found for the 46 Subjects Following the 20 Minute Cold Exposure.

	Range* Minimum Value	Maximum Value	Mean*	Standard Deviation*	Significance Level of Mean
125 Hz	-8	12	3.17	4.21	<0.0005
250 Hz	-4	10	2.52	3.30	<0.0005
500 Hz	-6	8	1.83	3.70	<0.002
1000 Hz	-4	6	0.91	2.37	0.01
2000 Hz	-10	6	-0.26	2.75	0.52
4000 Hz	-6	10	-0.09	3.40	0.86
8000 Hz	-8	10	-0.61	3.67	0.27

*In dB re pre-exposure threshold

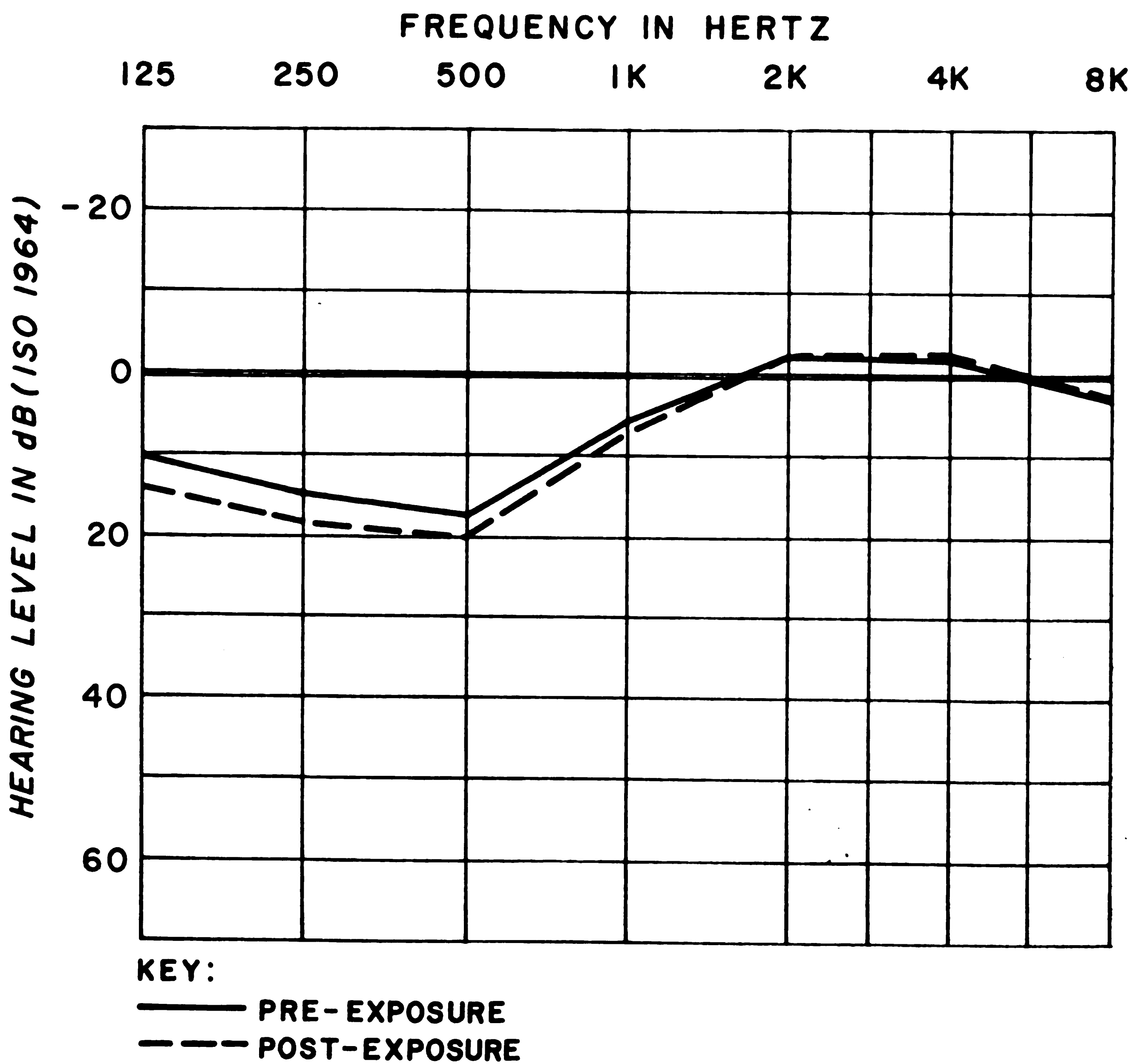

Figure 2.--Audiogram showing the mean pre and post-exposure air-conduction thresholds for the total group of subjects. N = 46

0 dB hearing level it seems reasonable that the low frequencies should also be near 0 dB hearing level. Thresholds appeared to be worsened by about 10 dB at 125Hz, 15 dB at 250 Hz, 18 dB at 500 Hz, and 6 dB at 1000 Hz.[1] This does not seem unreasonable given the ambient noise levels (see Table V). Even with this level of "masking" present, however, it can be seen that the cold exposure did adversely affect the air-conduction thresholds in the lower frequencies (from 125 Hz through 500 Hz) following the 20 minute cold exposure, and slightly improved (though not significantly so) the higher frequencies (from 2000 Hz through 8000 Hz).

The mean air-conduction shift found was significantly different from zero at 125 Hz, 250 Hz, and 500 Hz at a confidence level greater than 0.0005. The mean shift at 1000 Hz was also significant statistically. The shifts at the remaining frequencies, however, were not. The mean threshold shifts found from 125 Hz through 1000 Hz were all in the direction of poorer hearing whereas at the higher frequencies the shifts were all in the direction of slightly improved hearing. This type of audiometric curve, with depressed low frequency air-conduction thresholds and somewhat improved high frequency thresholds, when accompanied by normal bone-conduction thresholds, is usually considered to be representative of increased stiffness in the mechanical action of the ear.[2]

An operational definition was established for determining which of these subjects should be classified as "shifters" in air-conduction thresholds following the cold exposure. It was decided that a subject would be classified as a shifter if two of the three low frequency thresholds (125 Hz, 250 Hz

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[1] The possibility exists that the threshold shifts found would have been even larger had true pre-exposure air-conduction thresholds been obtained.

[2] Campbell, "The Importance of the Impedance Formula in the Interpretation of Audiograms," pp. 245-252.

and 500 Hz) shifted by +4 dB or more and the third shifted by at least +2 dB. In this way 20 subjects (10 males and 10 females) were found to have had air-conduction thresholds that were shifted downward by the cold exposure. Tables IX and X show the ranges, means, and standard deviations of the pre and post-exposure air-conduction thresholds for this group of subjects, the shifters, as well as the shifts in air-conduction thresholds found, at the frequencies tested. Figure 3 presents this same data graphically. Tables XI and XII and Figure 4 present the same data for the remaining 26 subjects classified as "non-shifters." One-way analysis of variance was used to determine statistical significance of the differences between the shifters and non-shifters. The F statistic and the significance level of the F statistic for the two groups is shown in Table XIII.

The threshold shifts found in the shifters' group were greatest in the low frequencies (in the direction of poorer hearing), dissappeared in the mid frequencies and became very slightly improved in the high frequencies. This is the same "stiffness tilt" as seen in Figure 2. The non-shifters, on the other hand, showed virtually no threshold shifts at any frequency and the variation around zero appeared to have no pattern. It can be seen in Table XIII that the differences in the air-conduction shifts between the two groups are highly significant at 125 Hz, 250 Hz, and 500 Hz (at a level of >0.0005). Moreover, when Tables IX and XI are compared it can be seen that the subjects classified as shifters had slightly better pre-exposure air-conduction thresholds than the non-shifters at all frequencies; however, none of the pre-exposure thresholds are significantly different from those found for the total group (Table XIII). The post-exposure thresholds found for the shifters are poorer from 125 Hz through 500 Hz (as would be expected by definition),

Table IX.--Ranges, Means, and Standard Deviations of the Pre and Post-Exposure Air-Conduction Thresholds Found for the 20 Subjects Classified as Shifters.

	Range*			
	Minimum Value	Maximum Value	Mean*	Standard Deviation*
Pre-exposure A/C Thresholds				
125 Hz	2	19	9.70	4.34
250 Hz	7	24	13.85	4.22
500 Hz	6	22	16.60	3.28
1000 Hz	-5	11	5.70	3.74
2000 Hz	-10	7	-3.30	5.36
4000 Hz	-12	10	-3.40	5.92
8000 Hz	-14	18	1.40	8.27
Post-exposure A/C Thresholds				
125 Hz	8	23	15.80	4.32
250 Hz	13	28	19.25	4.30
500 Hz	12	27	21.80	3.66
1000 Hz	-5	13	6.90	4.08
2000 Hz	-10	8	-3.00	5.35
4000 Hz	-14	16	-3.90	7.52
8000 Hz	-16	12	1.30	8.63

*In dB re 0 Hearing Level (ISO 1964)

Table X.--Ranges, Means, and Standard Deviations of the Shifts in Air-Conduction Thresholds Found for the 20 Subjects Classified as Shifters.

	Range* Minimum Value	Maximum Value	Mean*	Standard Deviation*
125 Hz	2	12	6.10	2.94
250 Hz	2	10	5.40	1.96
500 Hz	2	8	5.20	1.77
1000 Hz	-4	6	1.20	2.38
2000 Hz	-4	6	0.30	2.45
4000 Hz	-6	6	-0.50	3.17
8000 Hz	-6	8	-0.10	3.70

*In dB re pre-exposure threshold.

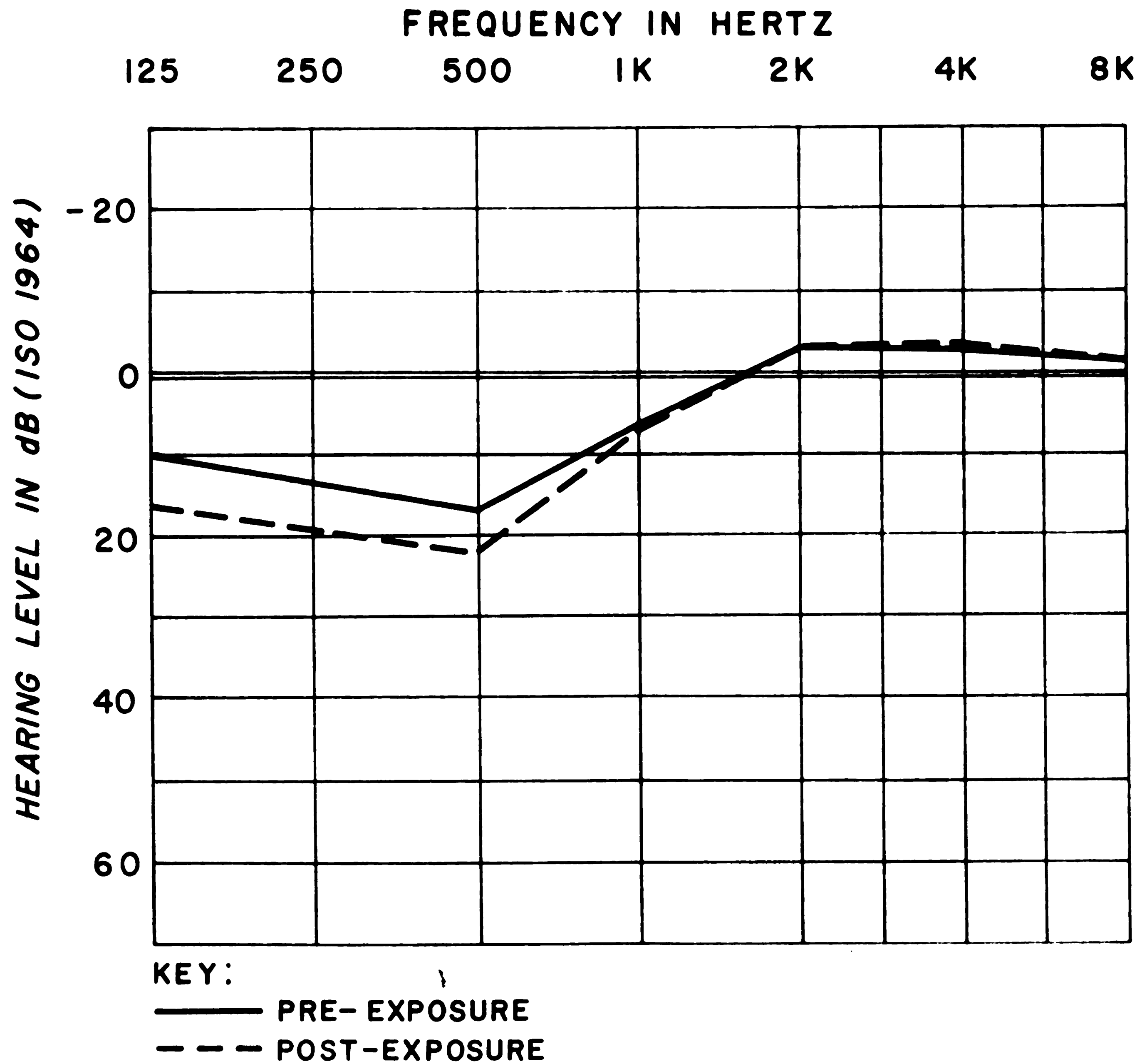

Figure 3.--Audiogram showing the mean pre and post-exposure air-conduction thresholds for the "shifters." N = 20

Table XI.--Ranges, Means, and Standard Deviations of the Pre and Post-Exposure Air-Conduction Thresholds Found for the 26 Subjects Classified as Non-Shifters.

	Range*			
	Minimum Value	Maximum Value	Mean*	Standard Deviation*
Pre-exposure A/C Thresholds				
125 Hz	1	20	11.65	5.84
250 Hz	8	24	16.12	4.54
500 Hz	8	24	18.35	3.52
1000 Hz	-7	13	6.08	4.24
2000 Hz	-14	16	-0.96	7.50
4000 Hz	-9	6	-1.50	4.75
8000 Hz	-14	23	3.65	9.07
Post-exposure A/C Thresholds				
125 Hz	4	20	12.57	4.48
250 Hz	10	26	16.43	3.91
500 Hz	8	24	17.58	4.04
1000 Hz	-5	19	6.77	4.71
2000 Hz	-16	16	-1.65	7.99
4000 Hz	-11	8	-1.27	5.46
8000 Hz	-16	21	2.65	9.68

*In dB re 0 Hearing Level (ISO 1964).

Table XII.--Ranges, Means, and Standard Deviations of the Shifts in Air-Conduction Thresholds Found for the 26 Subjects Classified as Non-Shifters.

	Range*			
	Minimum Value	Maximum Value	Mean*	Standard Deviation*
125 Hz	-8	8	0.92	3.63
250 Hz	-4	4	0.31	2.24
500 Hz	-6	6	-0.77	2.47
1000 Hz	-4	6	0.69	2.40
2000 Hz	-10	4	-0.69	2.94
4000 Hz	-6	10	0.23	3.59
8000 Hz	-8	10	-1.00	3.68

*In dB re pre-exposure threshold.

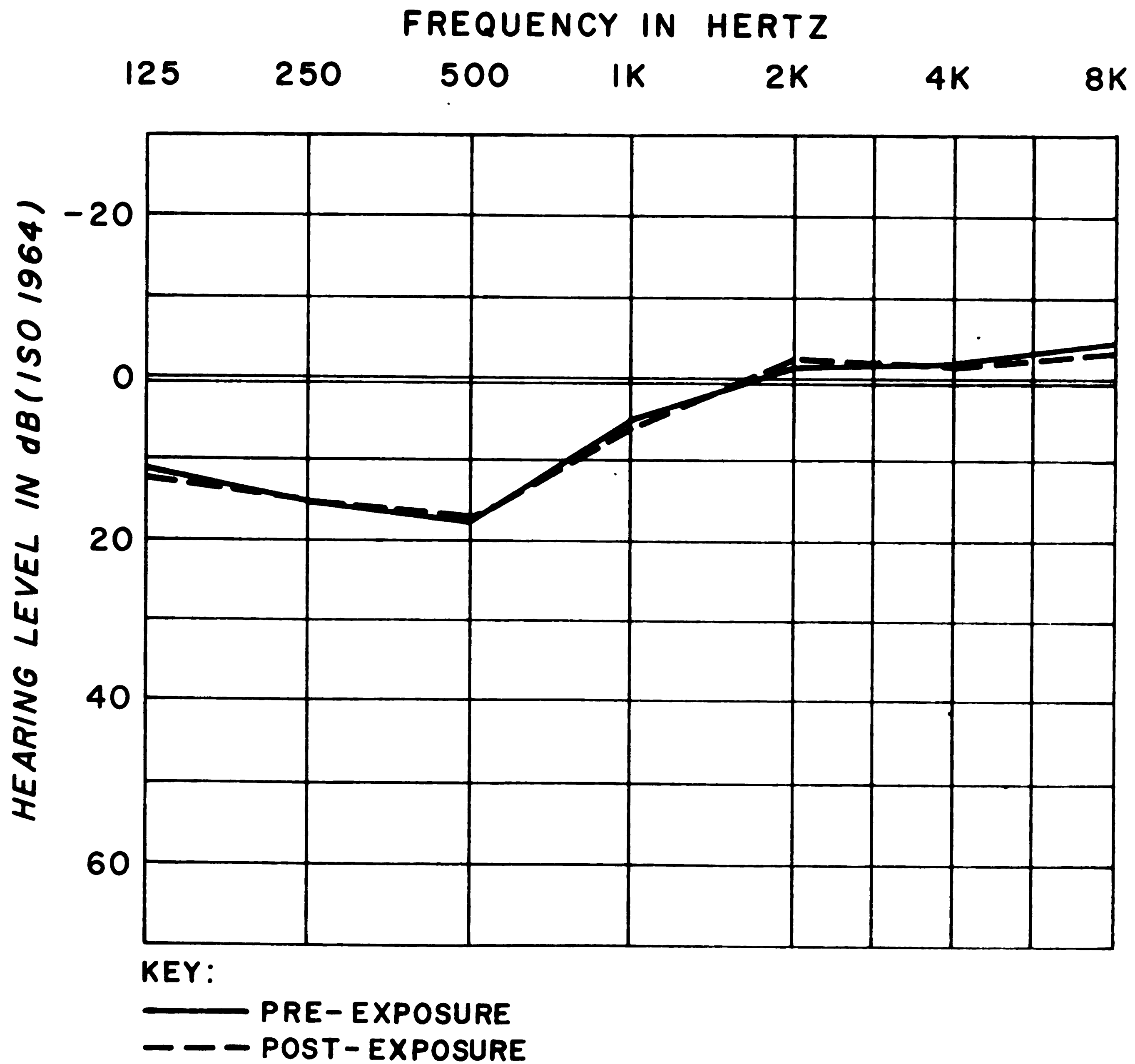

Figure 4.--Audiogram showing the mean pre and post-exposure air-conduction thresholds for the "non-shifters." N = 26

Table XIII.--The F Statistic and the Significance Level of the F Statistic for the Shifters Versus the Non-Shifters: By Frequency.

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Pre-exposure A/C Thresholds							
F Statistic	1.57	2.99	2.95	0.10	1.39	1.46	0.75
Significance Level	0.22	0.09	0.09	0.76	0.24	0.23	0.39
Post-exposure A/C Thresholds							
F Statistic	6.03	5.41	13.37	0.01	0.42	1.89	0.24
Significance Level	0.02	0.03	0.001	0.92	0.52	0.18	0.63
A/C Threshold Shifts							
F Statistic	27.00	65.03	83.67	0.51	1.49	0.52	0.67
Significance Level	< 0.0005	< 0.0005	< 0.0005	0.48	0.23	0.48	0.42

approximately the same at 1000 Hz and slightly better at 2000 Hz through 8000 Hz than the non-shifters.

Table XIV presents the correlations by frequency between pre and post-exposure air-conduction thresholds for the total group of 46 subjects and between pre-exposure threshold levels and the size of the threshold shift for the total group and for the shifters and non-shifters. The significance levels for the various correlations are also given. As would be expected the correlations are highly significant at all frequencies between pre and post-exposure thresholds which indicates that those persons who originally had relatively poorer hearing continued to have it post-exposure. The correlation was highest at the higher frequencies since there was little change in threshold following exposure at these frequencies.

A comparison of Tables IX and XI shows that the mean thresholds of the shifters at all frequencies were better than those of the non-shifters although this does not appear to be significant in Table XIII because of variability in thresholds. When the threshold shifts were correlated with pre-exposure thresholds at 125 Hz and 250 Hz, they were very significantly related and there was a marginal correlation at 500 Hz. In all three cases the relationship was negative indicating that the better the original threshold at these frequencies, the greater the size of the threshold shift.

Tympanic Temperature

This section will attempt to answer the second set of experimental questions:

> Will pre-exposure tympanic temperature readings be within the normal range and how will they be affected by the cold exposure?
>
> What will be the relationship between tympanic temperature and air and bone-conduction threshold shifts?

Table XIV.--Correlations and Their Significance Levels for the Pre and Post-Exposure Air-Conduction Thresholds for the Total Group of 46 Subjects and for the Shifters and Non-Shifters: By Frequency

	Pre-Exposure Threshold						
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Total Group Post-Exposure Threshold							
Correlation	0.65	0.72	0.58	0.84	0.92	0.85	0.92
Significance Level	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Total Group Threshold Shift							
Correlation	-0.54	-0.43	-0.25	-0.12	-0.12	0.07	-0.09
Significance Level	< 0.0005	0.003	0.09	0.44	0.44	0.66	0.57
Shifters Threshold Shift							
Correlation	-0.34	-0.19	-0.04	-0.17	-0.23	0.31	-0.13
Significance Level	0.14	0.42	0.87	0.47	0.32	0.19	0.60
Non-Shifters Threshold Shift							
Correlation	0.78	0.87	0.80	0.86	0.93	0.76	0.93
Significance Level	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005

The ranges, means, and standard deviations of the pre and post-exposure tympanic temperature readings and shifts in tympanic temperature as well as the significance level of the mean shift is given in Table XV. It can be seen that the mean pre-exposure temperature was 98.00° F. which agrees very well with the figure cited earlier by Ganong (98.10° F.) for healthy young adults. The mean post-exposure temperature reading was 97.28° F. showing a mean shift in tympanic temperature for the total group of 37 subjects following the cold exposure of -0.72° F. In no case did tympanic temperature rise following the cold exposure although in a few cases it was unchanged by the cold exposure. There was a slight difference in the pre-exposure temperatures of the shifters and non-shifters. The mean pre-exposure temperature for the shifters was 97.83° F., for the non-shifters 98.15° F.[1] The mean temperature shift was virtually the same for both groups, being -0.68° F. for the shifters and -0.75° F. for the non-shifters.

Table XV.--Ranges, Means, and Standard Deviations of the Pre and Post-Exposure Tympanic Temperature Readings and Shifts in Tympanic Temperature for the Total Group of 37 Subjects.

	Range* Minimum Value	Range* Maximum Value	Mean*	Standard Deviation*
Pre-exposure	96.70	99.50	98.00	0.55
Post-exposure	95.40	98.40	97.28	0.68
Temperature Shift	-2.40	0.00	-0.72**	0.55

*In degrees Fahrenheit.
**Significant at less than the 0.0005 level.

[1] The F statistic for this difference is significant at the 0.07 level.

In Table XVI are found the correlation coefficients and significance level of the correlation between the size of the temperature shift and the size of the air-conduction threshold shift at each of the frequencies tested. It can be seen that none of these figures are statistically significant: temperature shift and threshold shift are apparently unrelated.

Table XVI.--Correlation Coefficients and Significance Level of the Correlation between the Size of the Temperature Shift and Size of the Air-Conduction Threshold Shift at Each of the Frequencies Tested for the Total Group of 37 Subjects.

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Correlation Coefficient	0.07	0.03	0.18	-0.04	-0.17	-0.02	0.15
Significance Level	0.70	0.85	0.30	0.81	0.31	0.90	0.39

It is of interest to note that for a period of several days the outdoor temperature dropped to below the temperature in the freezer and it was found that subjects had to wait in a warm (72° F.) room for approximately one hour before tympanic temperatures reached normal. In one case tympanic temperature readings were made at 20 minute intervals beginning with the subject's arrival at the testing building. The particular evening involved was not an especially cold one, 22° F., but there was considerable wind bringing the chill factor down to +7° F. This subject walked from his home to the Food Stores Building which took him almost half an hour. His head was exposed -- his usual winter clothing consisted of a warm coat, mittens, and boots but no head or ear protection. His tympanic temperature upon his arrival at the testing building was 93.7° F. At 20 minute intervals the tympanic temperature readings were 96.3° F., 96.8° F., 97.3° F. (normal for this subject). It took somewhere between 40 and 60 minutes for this subject's tympanic temperature to return to its normal state following a 25 minute exposure of 22° F. with a chill factor of +7° F.

Impedance Measurements

This section will attempt to answer the third set of experimental questions:

> Will pre-exposure impedance measurements be within the normal range and how will they be affected by the cold exposure?
>
> What will be the relationships between various impedance measurements and tympanic temperature and air and bone-conduction threshold shifts?

A variety of impedance measurements were made and these will be considered separately. They are: acoustic impedance in the plane of the eardrum, middle ear pressure, compliance readings at various pressure settings, and intra-aural muscle reflex threshold. As explained earlier not all of these measurements were made on all 46 of the subjects, therefore the N used will be given in each case.

Acoustic impedance in the plane of the eardrum is a measure of the overall impedance of the middle ear system. On the average high impedance reflects a stiffer middle ear system (as in a pathology such as otosclerosis) and low acoustic impedance implies increased compliance (such as in the case of a disarticulation in the middle ear ossicles). There are, however, quite wide statistical variations within the range of normal impedance. Hood reported a mean acoustic impedance of 1565 with a standard deviation of 593 and a range of 657 to 2964 ohms using a sample of 42 normal ears.[1] Some of this variation is undoubtedly due to the depth of insertion of the eartip. In order to test this theory, two post-exposure impedance readings were made for five of the subjects, once using an insertion done in the normal manner and once with the eartip inserted to the point at which the pre-exposure volume had been matched. The former shall be referred to as free impedance and the latter as controlled impedance. The results for each of the five subjects is given in Table XVII.

Table XVII.--Pre-Exposure Acoustic Impedance Readings in the Plane of the Eardrum and Controlled and Free Post-Exposure Acoustic Impedance Readings in the Plane of the Eardrum for Each of Five Subjects Thus Tested.*

	Pre-Exposure	Post-Exposure Controlled	Post-Exposure Free
Subject 1 (shifter)	1621	1659	1562
Subject 2 (shifter)	2245	2053	1989
Subject 3 (shifter)	2148	2254	2142
Subject 4 (shifter)	1908	2576	2475
Subject 5 (non-shifter)	2475	2547	2382

*In acoustic ohms.

The controlled post-exposure acoustic impedance measurement was always larger (stiffer) than the free measurement. The differences, however, were very small and well within normal test-retest variability. Hood reported a mean test-retest variation of 130 ohms with a range of 4 to 347 ohms.[2] Measurements of acoustic impedance in the plane of the eardrum were made on

[1] R. B. Hood, Convention Presentation, American Speech and Hearing Association, Chicago, 1969.

[2] Ibid.

44 out of the 46 subjects: free impedance measurements on 32 and controlled impedance measurements on 17.[1] The ranges, means and standard deviations of the acoustic impedances found during pre and post-exposure testing and the shifts found and the significance of the mean shifts are presented for the total group of subjects and for the shifters and non-shifters separately in Table XVIII. The post-exposure impedance measurements are presented separately for the controlled and free impedance measurements. The mean pre-exposure impedance levels agree quite well with Hood's although the readings found in this study are slightly higher. It would appear that the non-shifters had slightly stiffer ears to start with (1764 ohms as compared to 1688 ohms), however the difference between them is not statistically significant. All of the shifts in impedance were in a positive (stiffer) direction following the cold exposure regardless of whether the post-exposure measurements were controlled or free. The total amount of the shift found following the exposure was not significant for either the controlled or the free impedance, however ($P = .23$ and $P = .12$, respectively). It is of interest to note, however, that the non-shifters shifted slightly more than the shifters, however again the difference between the two groups is not statistically significant. Finally, the differences found in the size of the shift depending on whether the post-exposure measurements were controlled or free is very small.

It would appear then that the 20 minute exposure had no significant effect on overall acoustic impedance and that the differences between shifters and non-shifters are small and not significant with regard to overall acoustic

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[1] The total is more than 44 because both measurements were made on the five subjects.

Table XVIII.--Ranges, Means, and Standard Deviations of the Acoustic Impedance in the Plane of the Eardrum for the Pre and Post-Exposure Conditions and the Shift Found for the Total Group of Subjects, Shifters and Non-Shifters: Controlled and Free Impedance Readings

	Range*			
	Minimum Value	Maximum Value	Mean*	Standard Deviation*
Total Group (N=44)				
Pre-exposure	687	3258	1733	590
Post-exposure				
Controlled Impedance	1097	2576	1699	450
Free Impedance	783	3467	1884	643
Shift				
Controlled Impedance	-192	668	58	194
Free Impedance	-453	761	62	221
Shifters (N=18)				
Pre-exposure	1041	3134	1688	529
Post-exposure				
Controlled Impedance	1097	2576	1623	510
Free Impedance	1154	2725	1867	513
Shift				
Controlled Impedance	-192	668	54	252
Free Impedance	-409	567	34	233
Non-Shifters (N=26)				
Pre-exposure	687	3258	1764	638
Post-exposure				
Controlled Impedance	1415	2547	1787	352
Free Impedance	783	3467	1899	732
Shift				
Controlled Impedance	-39	326	64	116
Free Impedance	-453	761	81	217

*In acoustic ohms.

impedance. This is probably because this measure is too gross for our purposes. When we examine middle ear pressure pre and post-exposure for the total group and between the two groups, shifters and non-shifters, some differences do appear. The measurement taken here is the amount of air pressure that must be added to the external auditory canal in order to reach the point at which the ear canal and middle ear pressures are equal and the eardrum is in the midline position. Or, in other words, it is the reading of the equivalent middle ear pressure. The ranges, means, and standard deviations of the pre and post-exposure middle ear pressure readings and the shift in middle ear pressure following exposure and the significance of this shift is given in Table XIX for the total group and for the shifters and non-shifters.

Looking at the total group it can be seen that there was a real difference in middle ear pressure from pre-exposure to post-exposure in that the cold exposure apparently caused the middle ear pressure to increase by more than 10 mm. This shift in middle ear pressure is significant at the 0.001 level of confidence. However, both the shifters and non-shifters showed this increase in middle ear pressure following exposure. Although the shifters showed a slightly larger increase it was not statistically significantly different from the shift shown by the non-shifters. Prior to the exposure, however, the shifters' middle ear pressure was significantly lower than that of the nonshifters'. The pre exposure level in the shifters (1.67 mm) was very close to what would be considered the mean normal reading (0 mm) and well within the range reported by Hood, -5 mm to +5 mm.[1] The non-shifters, on the other hand, appeared to have somewhat

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[1]R. B. Hood, Convention Presentation, American Speech and Hearing Association, Chicago, 1969.

Table XIX.--Ranges, Means, and Standard Deviations of the Pre and Post-Exposure Middle Ear Pressure Readings and the Shift in Middle Ear Pressure and Significance Level of the Shift for the Total Group, Shifters, and Non-Shifters.

	Range* Minimum Value	Maximum Value	Mean*	Standard Deviation*
Total Group (N=11)				
Pre-Exposure	0	30	8.64	10.02
Post-Exposure	10	40	19.55	11.28
Shift	0	25	10.91	7.35
Shifters (N=6)				
Pre-Exposure	0	10	1.67	4.08
Post-Exposure	10	35	15.00	10.00
Shift	10	25	13.33**	6.06
Non-Shifters (N=5)				
Pre-Exposure	10	30	17.00	8.37
Post-Exposure	10	40	25.00	11.18
Shift	0	20	8.00**	8.37

*In mm water pressure.

**Difference between shifters and non-shifters is not statistically significant (P = 0.25).

greater middle ear pressure prior to the exposure, 17.00 mm. The implication is that the non-shifters' ears were stiffer prior to the exposure but then moved in the same direction as the shifters' ears moved.

In addition, it is helpful to know the compliance readings at various pressure settings, so that the relationship between pressure and compliance can be determined. In the present study the pressure was varied in 40 mm steps from +200 mm water pressure to -200 mm water pressure. The balance meter on the acoustic bridge was set at +10 for the condition of +200 mm water pressure and its readings then noted for each of the other conditions. The lower the balance meter readings, the more compliant the system would be. One would therefore expect, if one were to draw a curve using these points from +200 mm water pressure to -200 mm water pressure, to have the curve peak at 0 mm water pressure since this should be the point of greatest compliance in the normal ear.[1]

Table XX displays the mean compliance readings at each of the pressures tested for the total group (15 subjects) and for the shifters (7 subjects) and non-shifters (8 subjects) in the pre and post-exposure conditions. The mean shifts are also given for each group at each pressure level. This same data is presented graphically in Figures 5, 6, 7, and 8. Figure 5 displays this data for the total group, Figure 6 for the shifters, Figure 7 for the non-shifters, and Figure 8 combines the data from the previous three figures for comparison purposes.

Again, differences in pre-exposure readings are found between the shifters and non-shifters. If the pre-exposure curves in Figure 8 are examined, it can be seen that, at most pressure levels, the non-shifters'

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[1]L. Lamb, University of New Mexico, Alburerque, Personal Communication, November, 1969.

Table XX.--Mean Compliance Readings at the Pressures Tested for the Total Group, Shifters, and Non-Shifters Pre-Exposure, Post-Exposure, and Shifts*

	mm Water Pressure										
	+200	+160	+120	+80	+40	0	-40	-80	-120	-160	-200
Total Group (N=15)											
Pre-exposure	10.00	9.51	8.83	7.75	6.01	4.28	5.87	7.55	8.53	9.04	9.27
Post-exposure	10.00	9.48	8.75	7.50	5.51	4.45	6.40	8.04	8.86	9.30	9.48
Shifts	0.00	-0.03	-0.08	-0.25	-0.50	0.17	0.53	0.49	0.33	0.26	0.21
Shifters (N=7)											
Pre-exposure	10.00	9.56	8.90	7.96	6.34	3.56	5.06	7.06	8.34	8.86	9.06
Post-exposure	10.00	9.49	8.84	7.75	5.81	3.62	5.60	7.53	8.57	9.05	9.20
Shifts	0.00	-0.07	-0.06	-0.21	-0.53	0.06	0.54	0.47	0.23	0.19	0.14
Non-Shifters (N=8)											
Pre-exposure	10.00	9.46	8.78	7.58	5.71	4.91	6.58	8.00	8.70	9.20	9.46
Post-exposure	10.00	9.46	8.69	7.29	5.23	5.17	7.11	8.51	9.13	9.53	9.75
Shifts	0.00	0.00	-0.10	-0.29	-0.48	0.26	0.53	0.51	0.43	0.33	0.29

*From 0 (most compliant) to 10 (least compliant).

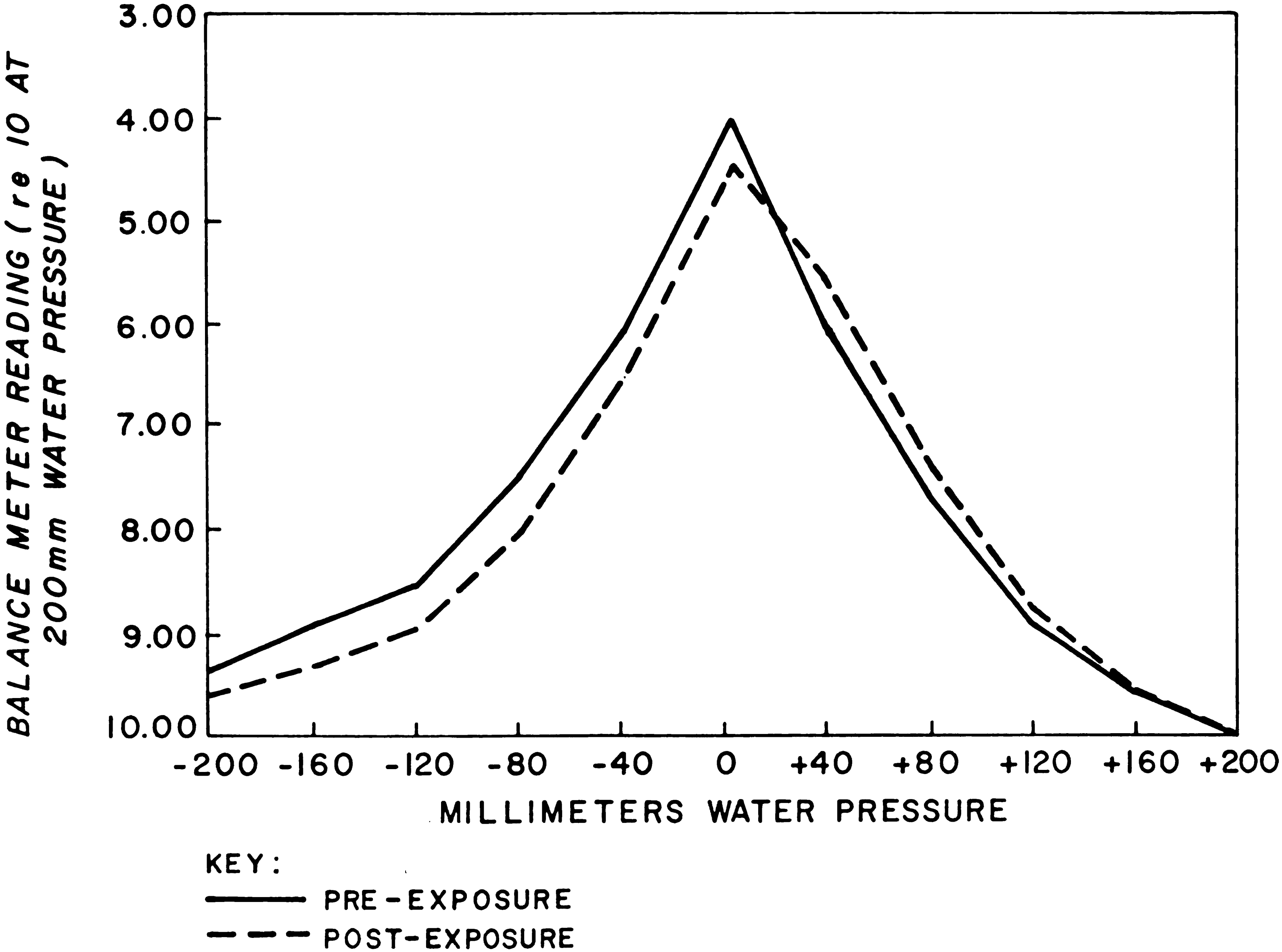

Figure 5.--Mean pre and post-exposure compliance readings at each of the pressures tested for the total group. N = 15

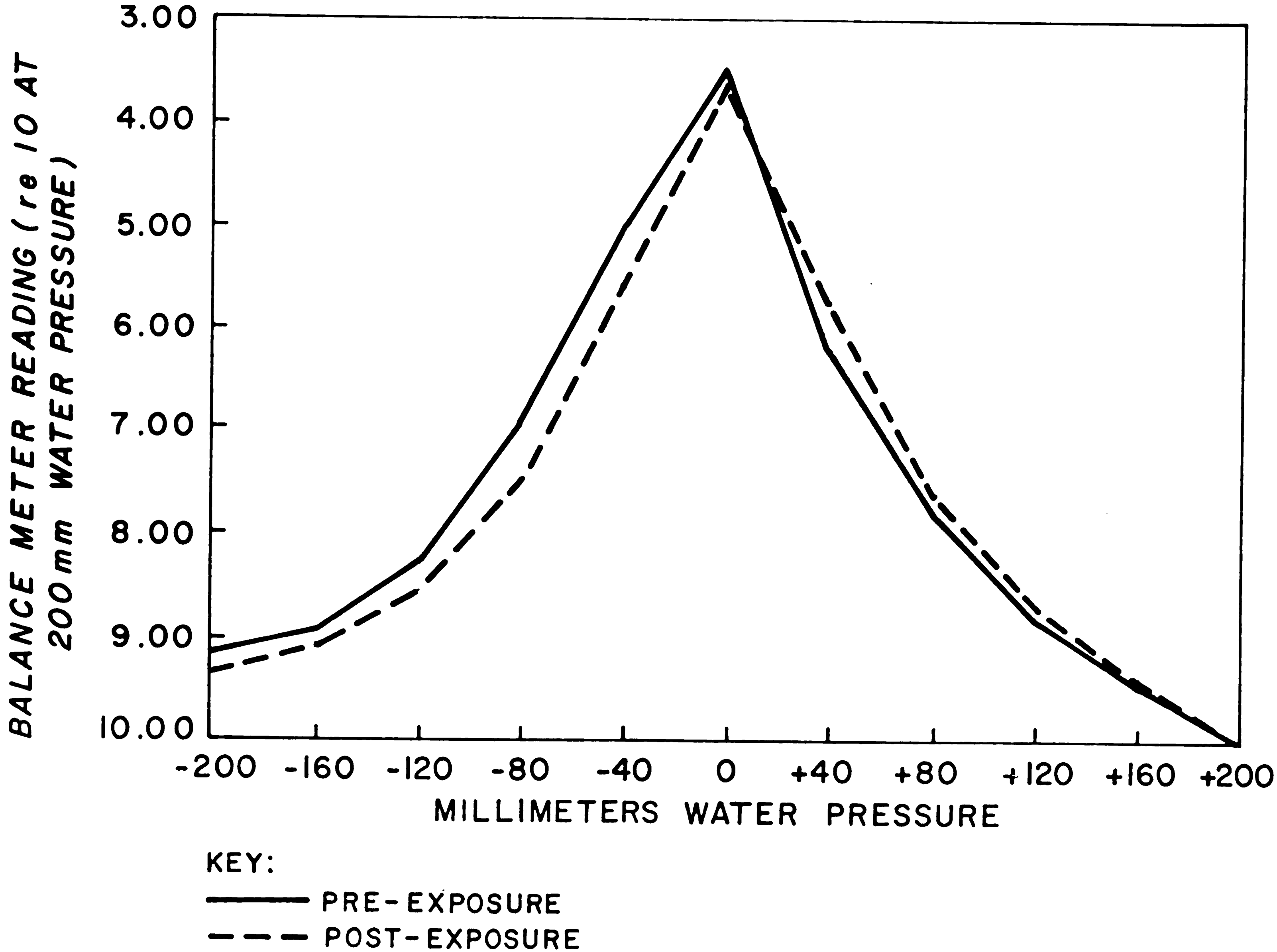

Figure 6.--Mean pre and post-exposure compliance readings at each of the pressures tested for the "shifters." N = 7

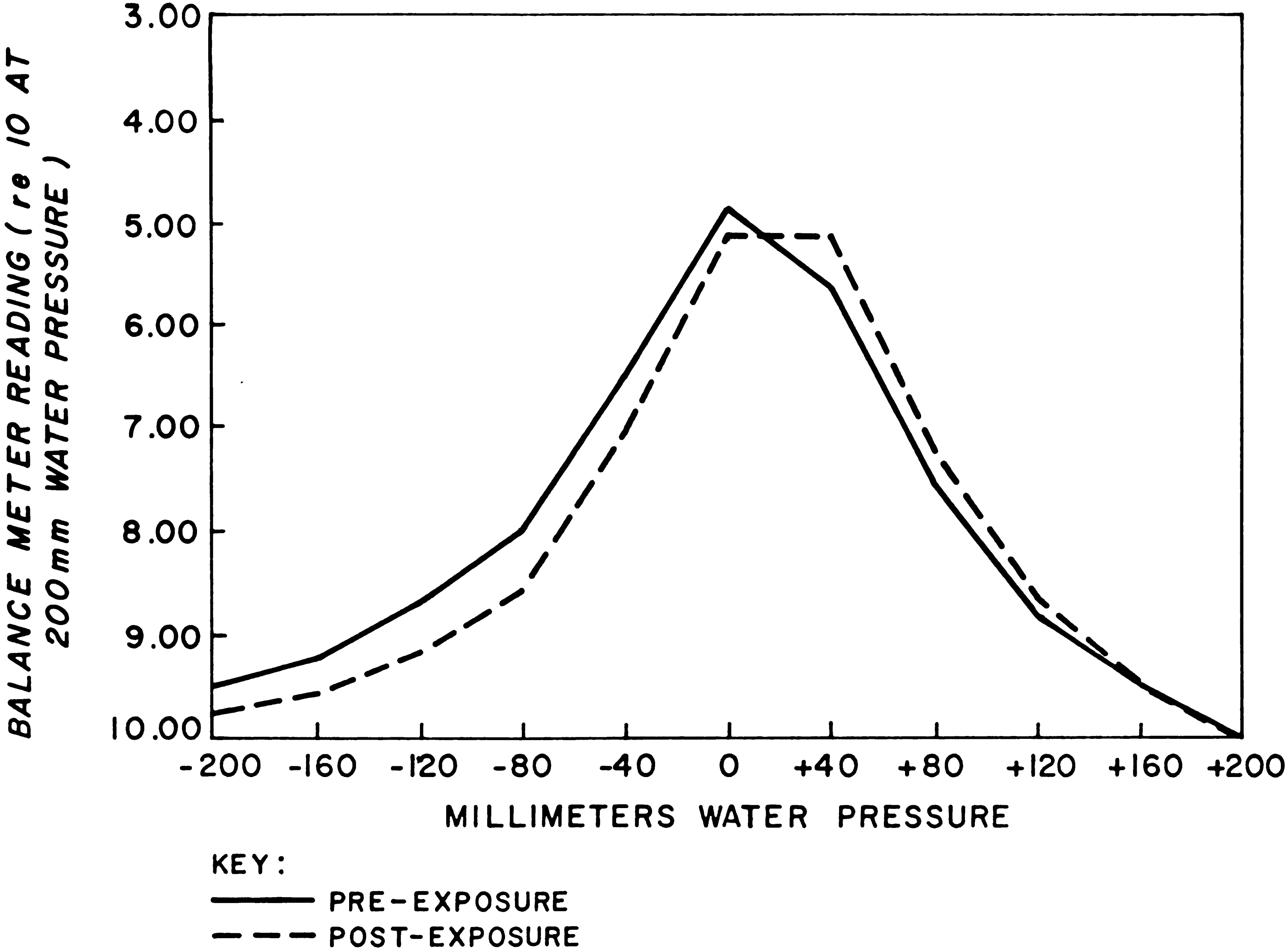

Figure 7.--Mean pre and post-exposure compliance readings at each of the pressures tested for the "non-shifters." N = 8

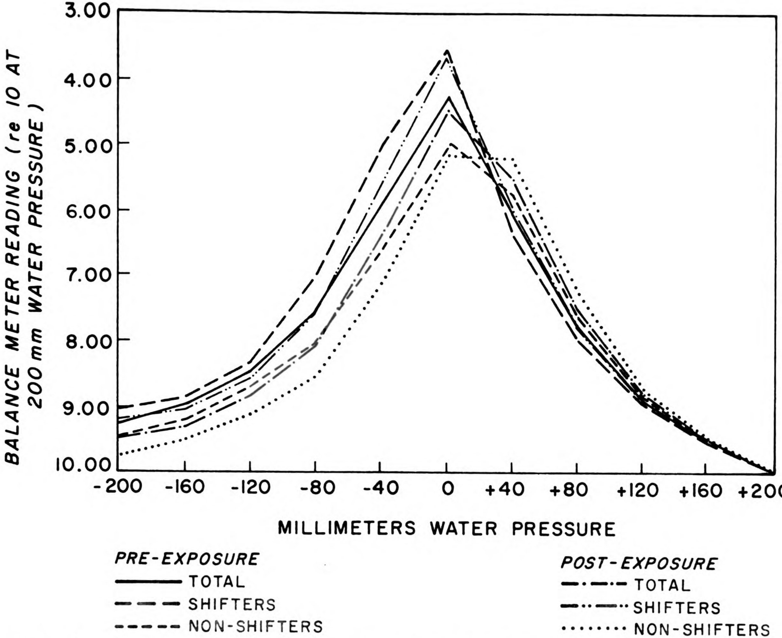

Figure 8.--Mean pre and post-exposure compliance readings at each of the pressures tested for the total group, "shifters," and "non-shifters" for purposes of comparison

ears are less compliant than the shifters' ears. This agrees with the findings cited earlier. A difference appears to exist between the shifters' and non-shifters' ears prior to the cold exposure. All of the various impedance measurements indicated that shifters had more compliant ears to start with. The implication is that the cold only affected hearing thresholds in ears with normal compliance. Threshold shifts did not occur in those ears that were already stiffer than normal (by about 15 mm water pressure) prior to the exposure. However, both of the groups' (shifters and non-shifters) compliance readings reacted similarly to the cold exposure. The compliance curve in both cases seems to have been shifted to the right with the result that compliance under negative canal pressure conditions appears to be reduced following the cold exposure and enhanced under positive canal pressure conditions. This goes along with the previous finding concerning the change in middle ear pressure following the cold exposure. The implications of this finding will be discussed in the next chapter. The post-exposure curves for the total group (Figure 5), shifters (Figure 6), and non-shifters (Figure 7) look as if they have been shifted to the right by approximately 10 mm water pressure, the change in middle ear pressure found following the cold exposure.

The three types of impedance measurements discussed so far all resulted in the same conclusions: 1) all of the subjects appear to be affected in much the same way and to the same extent following the cold exposure and 2) the subjects whose hearing thresholds did not shift following the exposure had stiffer ears prior to exposure.

The last type of impedance measurement made was concerned with the intra-aural stapedius muscle reflex threshold to a stimulus of 250 Hz. The ranges, means, and standard deviations for the pre and post-exposure levels and the shifts and the significance of the mean shift for the total group of subjects tested in this way are given in Table XXI.

Table XXI.--Ranges, Means, and Standard Deviations for the Pre and Post-Exposure Intra-Aural Muscle Reflex Threshold to a Stimulus of 250 Hz and the Shifts and Significance of the Shifts: Total Group, Shifters, and Non-Shifters

	Range*			
	Minimum Value	Maximum Value	Mean*	Standard Deviation*
Total Group (N=5)				
Pre-exposure	75	90	82.00	5.70
Post-exposure	70	95	81.00	2.00
Shifts	-5	+5	-1.00	4.18
Shifters (N=2)				
Pre-exposure	80	85	82.50	3.54
Post-exposure	80	80	80.00	0.00
Shifts	-5	0	-2.50**	3.54
Non-Shifters (N=3)				
Pre-exposure	75	90	81.67	7.64
Post-exposure	80	85	81.67	2.38
Shifts	-5	+5	0.00**	5.00

*In dB re 0 Hearing Level (ISO 1964).
**Difference between shifters and non-shifters is not statistically significant (P = 0.591).

The mean intra-aural muscle reflex threshold at 250 Hz is approximately the same for all of the groups both before and after the cold exposure, and the level found agrees well with previous research. Jepsen reported mean thresholds of hearing and stapedius reflexes by frequency according to the age of the subjects. He found the reflex threshold for a stimulus of 250 Hz for age 20 subjects to be approximately 85 dB above threshold (and normal threshold at 250 Hz to be 0 dB).[1] If one assumes that the threshold for the groups of subjects tested here would have been approximately 0 dB if they had been tested under ordinary audiometric testing conditions, i.e., in a sound-proof room, which seems to be a reasonable assmption, one would conclude that the muscle reflex thresholds found here agree very closely with those found by Jepsen (82 dB as compared with 85 dB). The results imply that all of the subjects had normal hearing at 250 Hz, and that differences in middle ear pressure and degree of stiffness of the system have no effect on the intra-aural muscle reflex threshold when a 250 Hz stimulus is used.

Varying Exposure Durations

Nine of the 20 subjects who had been classifed as shifters were asked to return for three additional testing sessions. The same tests were administered as for the 46 subjects (except for bone-conduction testing which was dropped from the test battery at this time) and in the same manner but the lengths of the cold exposure were varied. Each of these subjects was exposed for five minutes, ten minutes, and twenty minutes on three separate days. The purpose of this second set of exposures was threefold: 1) to check the reliability of the 20 minute exposure, 2) to find out what the critical length of exposure was before hearing thresholds were affected, and 3) to allow for recovery tracking which had not been done previously. This section, then, will attempt to answer the fourth set of experimental questions:

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[1]Otto Jepsen, "Middle Ear Muscle Reflexes in Man," Modern Developments in Audiology edited by James Jerger (Houston: Academic Press, 1963), p. 208.

What is the replicability of the twenty minute exposure experience? When the length of the exposure time is less than 20 minutes (5 or 10 minutes) will the same effects be found with regard to air-conduction threshold shifts, tympanic temperature, and impedance measurements? What is the relationship between varying the length of the exposure and all of the variables discussed?

Replicability

One would expect the pre-exposure air-conduction thresholds to be the same prior to each of the four testing sessions (once as part of the total group of 46 subjects and three return visits at the varying exposure durations). The ranges, means, and standard deviations of the pre-exposure thresholds for the nine subjects prior to the first testing session (Exposure 1) and prior to each of the second series of three exposure sessions (Exposures 2, 3, and 4) are presented in Table XXII. Note first that these nine subjects, with regard to their pre-exposure thresholds, are quite representative of the total group of 20 shifters from which they were drawn (see Table IX, page 46). The mean pre-exposure thresholds tend to improve from the first testing session to each of the three remaining testing sessions. This is most likely due to the effect of continued practice since the subjects obviously became more sophisticated as the research proceeded. The differences are not large, however, and, of course, the subjects were given some practice prior to the first actual testing session. It is felt that although the differences found tend to show progressively improved thresholds, they are generally within the accepted limits of test-retest reliability.

Table XXII.--Means and Standard Deviations of the Pre-Exposure Air-Conduction Thresholds for the Nine Subjects Both as Part of the Original Group of 46 Subjects and for Each of the Three Re-exposures.

	1 (20 minutes)	2 (20 minutes)	3 (10 minutes)	4 (5 minutes)
125 Hz				
Mean*	7.11	2.67	6.11	5.33
Standard Deviation	3.44	4.82	6.03	3.74
250 Hz				
Mean*	12.66	7.33	9.56	10.22
Standard Deviation	3.04	6.16	5.27	5.04
500 Hz				
Mean*	15.44	8.89	11.11	9.55
Standard Deviation	4.28	6.49	8.31	8.35
1000 Hz				
Mean*	5.89	-0.78	3.22	3.22
Standard Deviation	2.47	5.33	4.52	4.74
2000 Hz				
Mean*	-2.89	-6.44	-5.33	-5.33
Standard Deviation	3.92	7.38	5.83	3.32
4000 Hz				
Mean*	-3.00	-9.22	-7.67	-5.89
Standard Deviation	6.98	9.46	9.64	10.82
8000 Hz				
Mean*	3.22	-9.89	-8.22	-7.44
Standard Deviation	10.56	7.17	8.67	7.92

*In dB re 0 Hearing Level (ISO 1964).

The ranges, means and standard deviations of the post-exposure thresholds for the nine subjects for their first (Exposure 1) and second (Exposure 2) twenty minute exposures is given in Table XXIII and the shifts found are presented in Table XXIV. The statistical significance of the differences between the Exposure 1 and Exposure 2 threshold shifts is displayed in Table XXV.

Table XXIII shows that the post-exposure thresholds following the second 20 minute exposure are slightly better than those obtained following the first 20 minute exposure. They are improved by about the same amount as the pre-exposure$_2$ thresholds were when compared with the pre-exposure$_1$ thresholds (and for presumably the same reason, that of increased sophistication), implying that the shifts found following both 20 minute exposure sessions should be approximately the same. It can be seen by looking at Table XXIV that this is indeed the case. The mean threshold shifts following Exposure 1 are very similar to the mean threshold shifts following Exposure 2 for these nine subjects. In fact, there were no significant differences in mean threshold shift at any frequency between the two exposures as can be seen in Table XXV.

In general, then, the 20 minute exposure was replicable. Pre and post-exposure thresholds were both somewhat improved following the second 20 minute exposure session and it is presumed that this effect was due to increased test sophistication on the part of the subjects. The size of the shifts found, however, was essentially the same following both exposure sessions.

Table XXIII.--Ranges, Means, and Standard Deviations of the Post-Exposure Air-Conduction Thresholds for the Nine Subjects for Exposure 1 and Exposure 2.

	Range*			
	Minimum Value	Maximum Value	Mean*	Standard Deviation*
Exposure 1				
125 Hz	8	23	15.33	4.72
250 Hz	13	24	17.78	3.19
500 Hz	12	26	20.78	4.52
1000 Hz	1	11	7.00	3.61
2000 Hz	-9	2	-2.00	4.39
4000 Hz	-14	16	-2.78	9.52
8000 Hz	-16	12	2.33	10.02
Exposure 2				
125 Hz	2	23	8.67	6.34
250 Hz	6	24	12.44	5.73
500 Hz	4	22	13.56	7.06
1000 Hz	-9	11	1.44	6.23
2000 Hz	-20	0	-7.33	6.34
4000 Hz	-21	7	-9.66	8.83
8000 Hz	-21	0	-10.56	7.65

*In dB re 0 Hearing Level (ISO 1964).

Table XXIV.--Ranges, Means, and Standard Deviations of the Post-Exposure Air-Conduction Threshold Shifts for the Nine Subjects for Exposure 1 and Exposure 2.

	Range*			Standard
	Minimum Value	Maximum Value	Mean*	Deviation*
Exposure 1				
125 Hz	6	12	8.22	2.54
250 Hz	4	8	5.11	1.45
500 Hz	2	8	5.33	2.00
1000 Hz	-4	4	1.11	2.26
2000 Hz	-4	6	0.89	3.02
4000 Hz	-6	6	0.22	3.53
8000 Hz	-6	6	-0.89	3.48
Exposure 2				
125 Hz	2	12	6.00	2.83
250 Hz	2	8	5.11	2.03
500 Hz	0	10	4.67	3.16
1000 Hz	-2	6	2.22	2.54
2000 Hz	-4	2	-0.89	2.03
4000 Hz	-2	2	-0.44	1.33
8000 Hz	-4	2	-0.67	1.73

*In dB re pre-exposure thresholds.

Table XXV.--The F Statistic and Its Significance Level for the Differences in Air-Conduction Threshold Shifts between Exposure 1 and Exposure 2 for the Nine Subjects: By Frequency.

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
F Statistic	3.08	0.00	0.29	0.96	2.15	0.28	0.03
Significance Level	0.10	1.00	0.60	0.34	0.16	0.60	0.87

Pure-Tone Air-Conduction Thresholds and Exposure Duration

The pre-exposure thresholds for each of the latter three exposures, twenty minutes, ten minutes, and five minutes, are displayed by frequency and by length of exposure in Table XXVI. Analysis of variance showed that these thresholds did not differ significantly ($P \geq .15$) from one exposure to another at any frequency; however, there is some variation as would be expected. Table XXVII presents the post-exposure thresholds for each of the three exposure durations by frequency.

Table XXVI.--Means and Standard Deviations of the Pre-Exposure Air-Conduction Thresholds for the Three Exposure Durations for the Nine Subjects: By Frequency.

	Means*			Standard Deviation*		
	20 min.	10 min.	5 min.	20 min.	10 min.	5 min.
125 Hz	2.67	6.11	5.33	4.82	6.03	3.74
250 Hz	7.33	9.56	10.22	6.16	5.27	5.04
500 Hz	8.89	11.11	9.56	6.49	8.31	8.35
1000 Hz	-0.78	3.22	3.22	5.33	4.52	4.74
2000 Hz	-6.44	-5.33	-5.33	7.38	5.83	3.32
4000 Hz	-9.22	-7.67	-5.89	9.46	9.64	10.82
8000 Hz	-9.89	-8.22	-7.44	7.12	8.67	7.92

*dB re 0 Hearing Level (ISO 1964).

Table XXVII.--Means and Standard Deviations of the Post-Exposure Air-Conduction Thresholds for the Three Exposure Durations for the Nine Subjects: By Frequency.

	Mean*			Standard Deviation*		
	20 min.	10 min.	5 min.	20 min.	10 min.	5 min.
Frequency						
125 Hz	8.56	9.00	6.00	6.33	5.02	5.48
250 Hz	12.44	13.56	11.56	5.73	6.31	6.62
500 Hz	13.56	13.33	10.67	7.06	7.48	10.68
1000 Hz	1.44	3.22	3.22	6.23	5.52	4.52
2000 Hz	-7.33	-6.00	-6.44	6.34	5.66	4.03
4000 Hz	-9.67	-8.78	-7.89	8.83	10.65	10.99
8000 Hz	-10.56	-9.78	-7.22	7.65	8.93	8.97

*In dB re 0 Hearing Level (ISO 1964).

These mean pre and post-exposure figures have been plotted on audiograms. Figure 9 presents this data for the 20 minute exposure, Figure 10 for the 10 minute exposure, and Figure 11 for the 5 minute exposure. It can easily be seen that the three pre-exposure curves are quite similar and that the size of the shift is largest following a 20 minute exposure, smaller following a 10 minute exposure, and virtually disappears following a five minute exposure.

The means and standard deviations of the threshold shifts for each of the three exposure durations is presented in Table XXVIII. Also presented is the significance level of the F statistic which was derived from an analysis of variance in the shifts found by frequency at each exposure duration. The length of the exposure duration has a statistically significant effect on the size of the threshold shift at the 0.001 level of confidence at 125 Hz, 0.01 level at 250 Hz, and approaches significance at 500 Hz and 1000 Hz (0.08 level). By 2000 Hz the length of exposure no longer appears to have any significant effect on the size of the threshold shift.

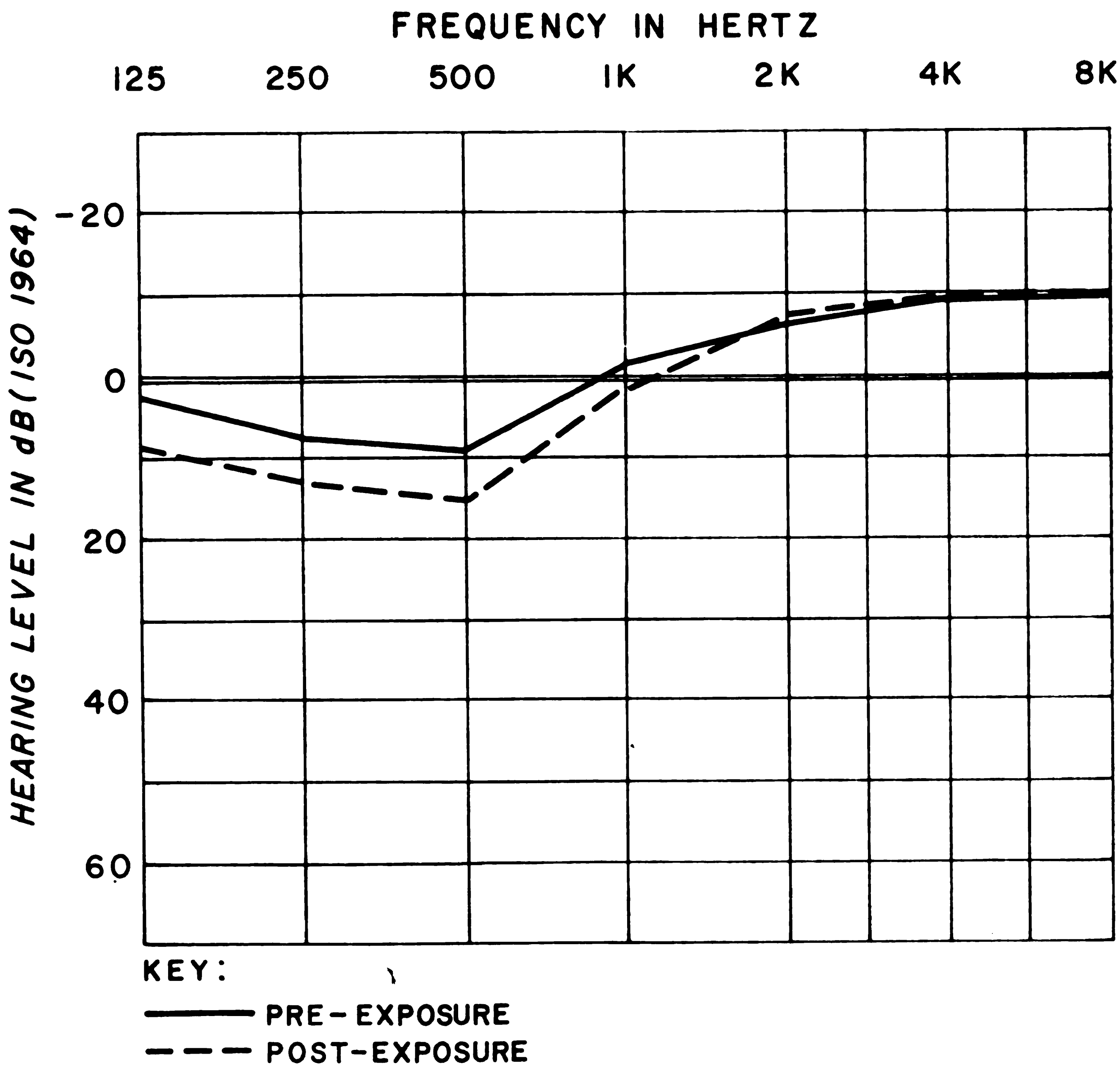

Figure 9.--Audiogram showing the mean pre and post-exposure air-conduction thresholds for the 20 minute exposure duration. N = 9

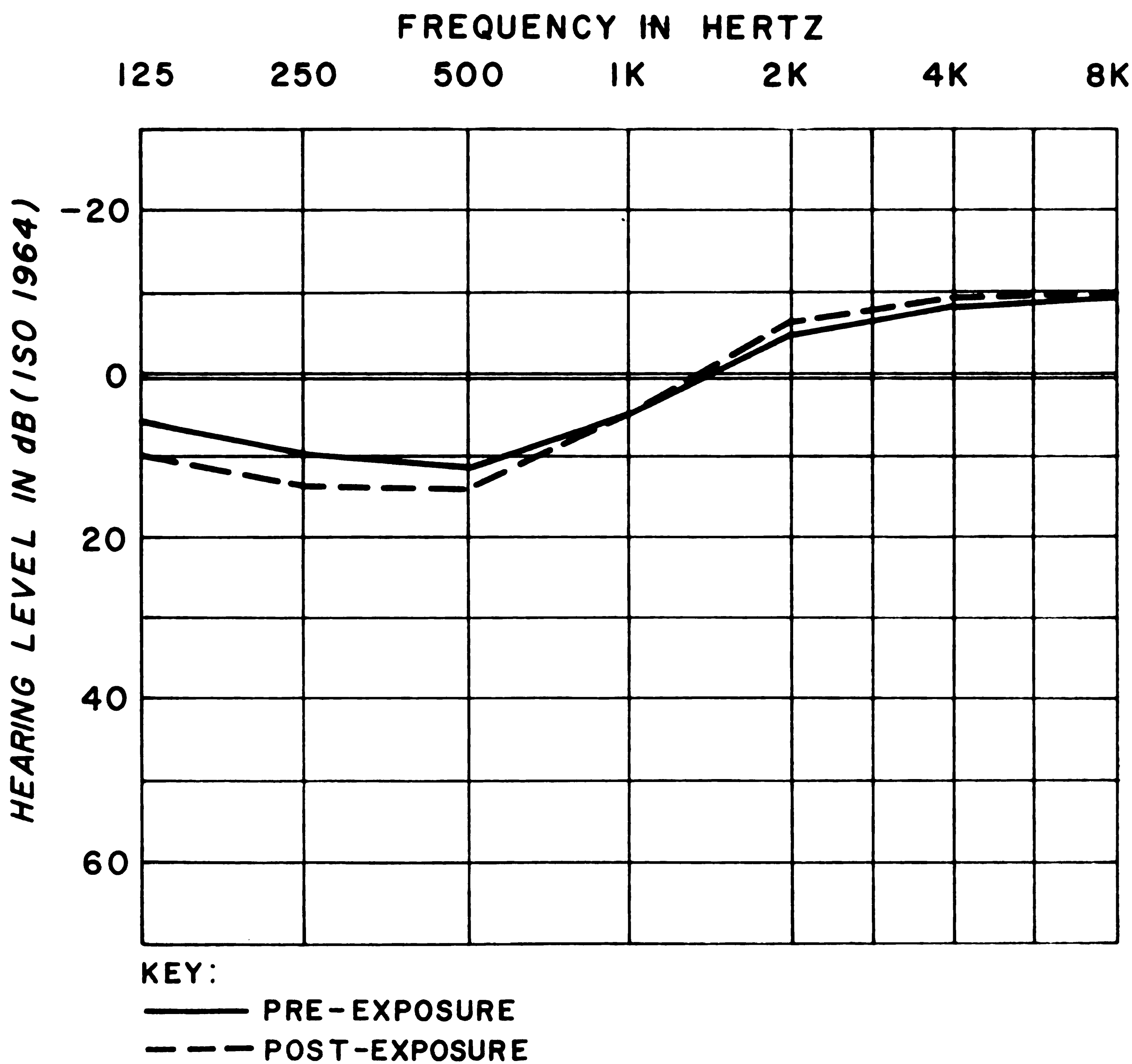

Figure 10.--Audiogram showing the mean pre and post-exposure air-conduction thresholds for the 10 minute exposure duration. N = 9

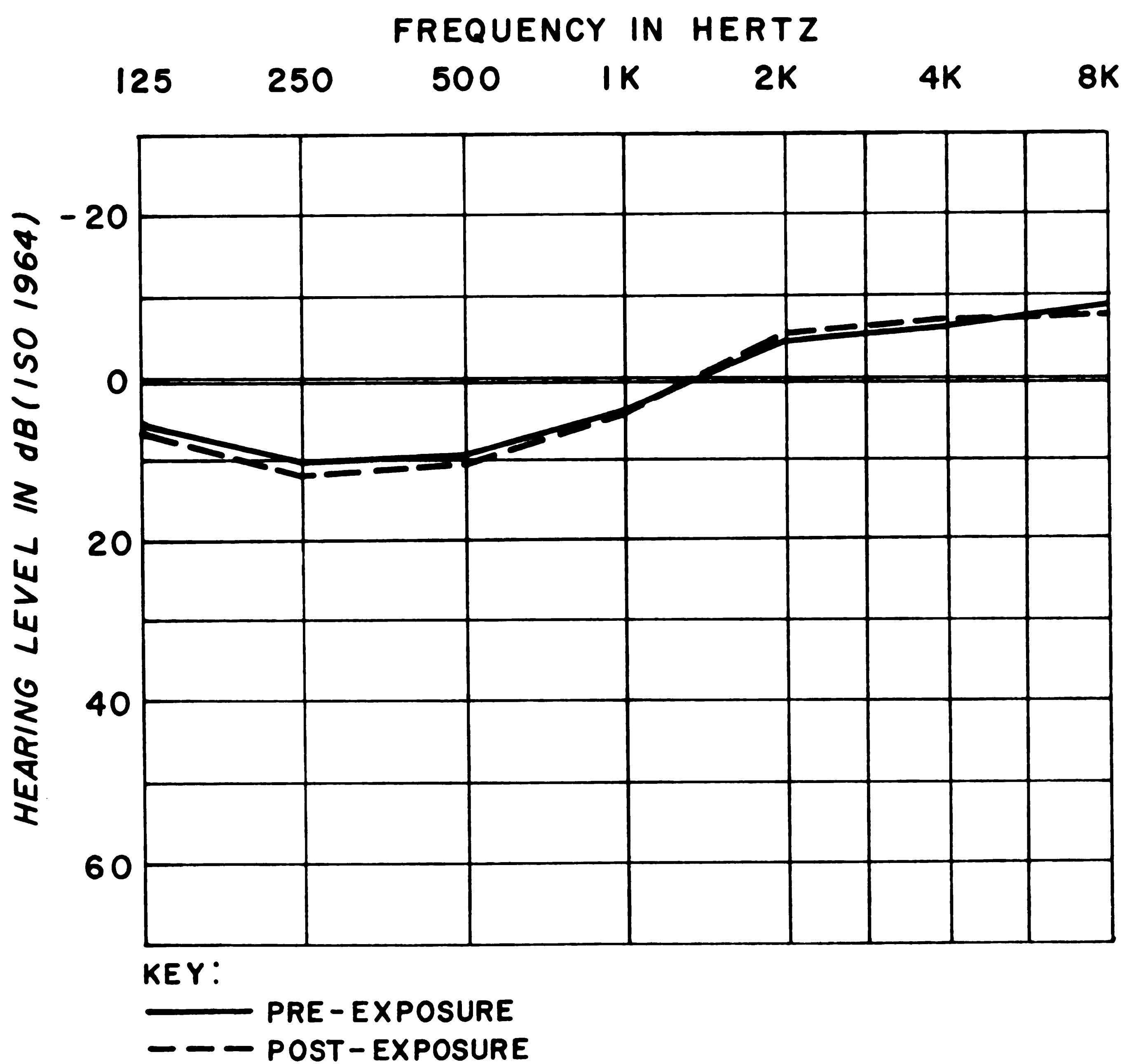

Figure 11.--Audiogram showing the mean pre and post-exposure air-conduction thresholds for the 5 minute exposure duration. N = 9

Table XXVIII.--Means, Standard Deviations, and Significance Levels of the Air-Conduction Threshold Shifts for the Nine Subjects at Each of the Three Exposure Durations.

	Means*			Standard Deviations*			Significance Level of AOV F Statistic
Frequency	20 Minutes	10 Minutes	5 Minutes	20 Minutes	10 Minutes	5 Minutes	
125 Hz	6.00	2.89	0.67	2.83	2.03	3.16	0.001
250 Hz	5.11	4.00	1.33	2.03	2.83	2.45	0.01
500 Hz	4.67	2.22	1.11	3.16	3.38	3.33	0.08
1000 Hz	2.22	0.00	0.00	2.54	2.24	2.00	0.08
2000 Hz	-0.89	-0.67	-1.11	2.03	2.00	2.47	0.91
4000 Hz	-0.44	-1.11	-2.00	1.33	2.03	2.24	0.24
8000 Hz	-0.67	-1.56	0.22	1.73	1.67	2.11	0.15

*In dB re pre-exposure thresholds.

It would appear then that there is a real difference in threshold shift, particularly in the lowest frequencies, depending on the length of the exposure: the longer the exposure the greater the air-conduction threshold shift in hearing.

Tympanic Temperature
And Exposure Duration

Table XXIX presents the means and standard deviations of the pre and post-exposure tympanic temperature readings and the shifts found for the nine subjects at each of the exposure durations. The mean pre-exposure temperature (97.44° F.) was slightly below that found for the total group of 46 subjects (98.0° F.) but agreed quite well with the mean pre-exposure threshold found for the shifters (97.83° F.), the group from which the nine were drawn. The pre-exposure differences from Exposure 1 to Exposure 2, 3, and 4 were not significantly different. However, the shift found following the second 20 minute exposure was somewhat larger (-1.46° F.) than that found for the shifters following the first 20 minute exposure (-0.68° F.). The shifts found following the 10 and 5 minute exposures were similar to each other and to the level found originally following the 20 minute exposure. Exposure of the ears, then, for even five minutes to a temperature of approximately -7° F. affects the temperature on the tympanic membrane. There appears to be no distinct relationship between the length of exposure and the size of the shift. The shifts following all of the exposure durations were approximately the same with the exception of the second twenty minute exposure duration.

It is difficult to explain why the temperature shift following the second twenty minute exposure is so much larger. On suggestion has been made that this may be due to the fact that the subjects were somewhat fearful during their first exposure which resulted in an increase in circulation rate and a reduction in the effect of the cold on the tympanic temperature. Another possibility is the relationship between the outdoor temperature, which had dropped considerably during most of this portion of the testing, and the temperature shift found. However, an effort was made to warm the subjects thoroughly (to each one's normal reading) prior to the initiation of the testing. In many cases the subjects sat in a warm (72° F.) room for an hour or longer before the actual testing was begun. The relationship between tympanic temperature and body temperature under varying types of cold exposures is certainly one that requires further research.

Table XXIX.--Means and Standard Deviations of the Pre and Post-Exposure Tympanic Temperature Radings and Shifts in Tympanic Temperature for the Nine Subjects at Each of the Three Exposure Durations.

	Mean*	Standard Deviation*
20 Minute Exposure (N=8)***		
Pre-exposure	97.63	0.32
Post-exposure	96.17	0.82
Shift	-1.46**	0.60
10 Minute Exposure (N=9)		
Pre-exposure	97.37	0.35
Post-exposure	96.75	0.56
Shift	-0.62**	0.51
5 Minute Exposure (N=7)		
Pre-exposure	97.33	0.35
Post-exposure	96.60	0.68
Shift	-0.73**	0.49

*In degrees Fahrenheit.

**The mean shifts are significantly different from zero at the P = .001, P = .01, and P = .01 levels for the 20, 10, and 5 minute exposures respectively. Analysis of variance indicated that the three groups differed significantly at 0.009 level.

***Due to equipment difficulties it was not possible to use the tympanic thermometer during one testing session, therefore the N does not always equal 9.

Impedance Measurements And Exposure Duration

Ideally, an acoustic bridge would have been used that allowed for absolute volume measurements to be made (such as the Zwislocki Bridge). However, this was not practical because of the time constraints of the experimental design, difficulty in hearing a null under the poor testing conditions available, and because of the severe physical limitations of the testing environment (it would have been very difficult to arrange for subjects to recline during testing, for example) and since no significant differences had been found between controlled and free impedance measurements with the original group of subjects (see Tables XVII and XVIII), it was decided to use the Madsen Bridge and only one method of eartip placement with the nine subjects in this portion of the study. For all of the post-exposure measurements the eartip was inserted to the point at which the canal volume equalled the pre-exposure volume (controlled impedance).

The means and standard deviations of the acoustic impedance in the plane of the eardrum found for the nine subjects before and after the three exposures, and the shifts found, are given in Table XXX. As in the case of the 46 subjects, none of the differences found in pre or post-exposure impedance are significant, nor are the shifts found significant. Either there is no change in absolute impedance following the cold exposure or this measure is too gross for the small effects being considered here.

When we look at middle ear pressures, however, differences do appear, as they did among the group of 46 subjects. The means and standard deviations for the nine subjects before and after the three exposures, and the shifts found, are given in Table XXXI. Except for the ten minute exposure, a real

Table XXX.--Means and Standard Deviations of the Acoustic Impedance in the Plane of the Eardrum for the Three Exposure Conditions and the Shift Found for the Nine Subjects

	Mean*	Standard Deviation*
20 Minute Exposure		
Pre-exposure	1442	414
Post-exposure	1482	418
Shift	40.67**	84.32
10 Minute Exposure		
Pre-exposure	1464	395
Post-exposure	1455	380
Shift	9.33**	21.46
5 Minute Exposure		
Pre-exposure	1528	345
Post-exposure	1479	392
Shift	-50.56**	107.22

*In acoustic ohms.

**The mean shifts are not significantly different from zero ($P \geq .19$).

Table XXXI.--Means and Standard Deviations of the Pre and Post-Exposure Middle Ear Pressure Readings and the Shift in Middle Ear Pressure for the Nine Subjects at Each Exposure Duration.

	Mean*	Standard Deviation*
20 Minute Exposure		
Pre-exposure	-6.11	10.24
Post-exposure	5.00	10.00
Shift	11.11**	4.17
10 Minute Exposure		
Pre-exposure	3.33	16.58
Post-exposure	0.00	9.01
Shift	-3.33**	13.87
5 Minute Exposure		
Pre-exposure	-7.78	13.94
Post-exposure	0.56	7.68
Shift	8.33**	13.69

*In mm water pressure.
**The mean shifts are significantly different from zero only for the 20 minute exposure (P = <.001).

difference in middle ear pressure of about +10 mm is found again following the cold exposures. The length of the exposure probably has no effect on the size of the shift. The peculiar shift found following the ten minute exposure is very difficult to explain. It is most likely due to a couple of subjects who reacted peculiarly to this particular exposure in this regard and represent extreme values. The ten minute post-exposure middle ear pressure readings are most likely a fluke and should probably be ignored.

The compliance data for the nine subjects at the three exposure durations is summarized in Table XXXII, and the F statistic and its significance are given in Table XXXIII for the shifts found. There are no significant differences between the pre-exposure compliance measurements found prior to any of the three exposure sessions. There are, however, significant differences found in the compliance shifts following each of the three exposure durations for the nine subjects. The shifts become significantly different according to the length of the exposure under positive canal pressures only (with the exception of -40 mm water pressure). The data from Table XXXII is plotted in Figure 12 for the twenty minute exposure, Figure 13 for the ten minute exposure, and Figure 14 for the five minute exposure. The pre and post-exposure curves for the twenty and five minute exposures (Figures 12 and 14) are very similar and very like the pre and post-compliance curves found for the total group of subjects (see Figure 5). The ten minute exposure compliance curves, however, as shown in Figure 13, are different from the others. The shift in direction is directly related to the shift in direction found in the middle ear pressure for this exposure duration. Whatever caused the pressure changes must have caused the compliance changes also and cannot be explained. These results are out of keeping with the air-conduction

Table XXXII.--Mean Compliance Readings at the Pressures Tested for the Nine Subjects at Each of the Exposure Durations: Pre-Exposure, Post-Exposure, and Shifts*

	mm Water Pressure										
	+200	+160	+120	+80	+40	0	-40	-80	-120	-160	-200
20 Minute Exposure											
Pre-exposure	10.00	9.56	8.93	8.04	6.56	4.09	4.76	7.00	8.16	8.59	8.82
Post-exposure	10.00	9.52	8.83	7.78	5.92	3.83	5.66	7.63	8.55	8.98	9.19
Shifts	0.00	-0.04	-0.10	-0.26	-0.64	-0.26	0.90	0.63	0.39	0.39	0.37
10 Minute Exposure											
Pre-exposure	10.00	9.47	8.66	7.60	5.91	4.26	5.30	7.21	8.23	8.72	8.94
Post-exposure	10.00	9.51	8.84	7.91	6.31	3.95	5.03	7.11	8.22	8.76	9.02
Shifts	0.00	0.04	0.18	0.31	0.40	-0.31	-0.27	-0.10	-0.01	0.04	0.08
5 Minute Exposure											
Pre-exposure	10.00	9.56	8.92	8.08	6.61	4.36	4.80	7.06	8.27	8.79	9.04
Post-exposure	10.00	9.52	8.81	7.74	5.94	3.79	5.47	7.52	8.39	8.83	9.04
Shifts	0.00	-0.04	-0.11	-0.34	-0.67	-0.57	0.67	0.46	0.12	0.04	0.00

*From 0 (most compliant) to 10 (least compliant).

Table XXXIII.--The F Statistic and Significance Probability of the F Statistic for the Nine Subjects for the Compliance Shifts Found Following Each of the Three Exposure Durations: At the Pressures Tested

	mm Water Pressure										
	+200	+160	+120	+80	+40	0	-40	-80	-120	-160	-200
F Value	0.0	3.41	5.44	13.05	8.87	0.28	6.31	2.60	1.52	1.72	1.79
Significance Level	1.0	0.05	0.01	<0.0005	0.001	0.76	0.006	0.10	0.24	0.20	0.19

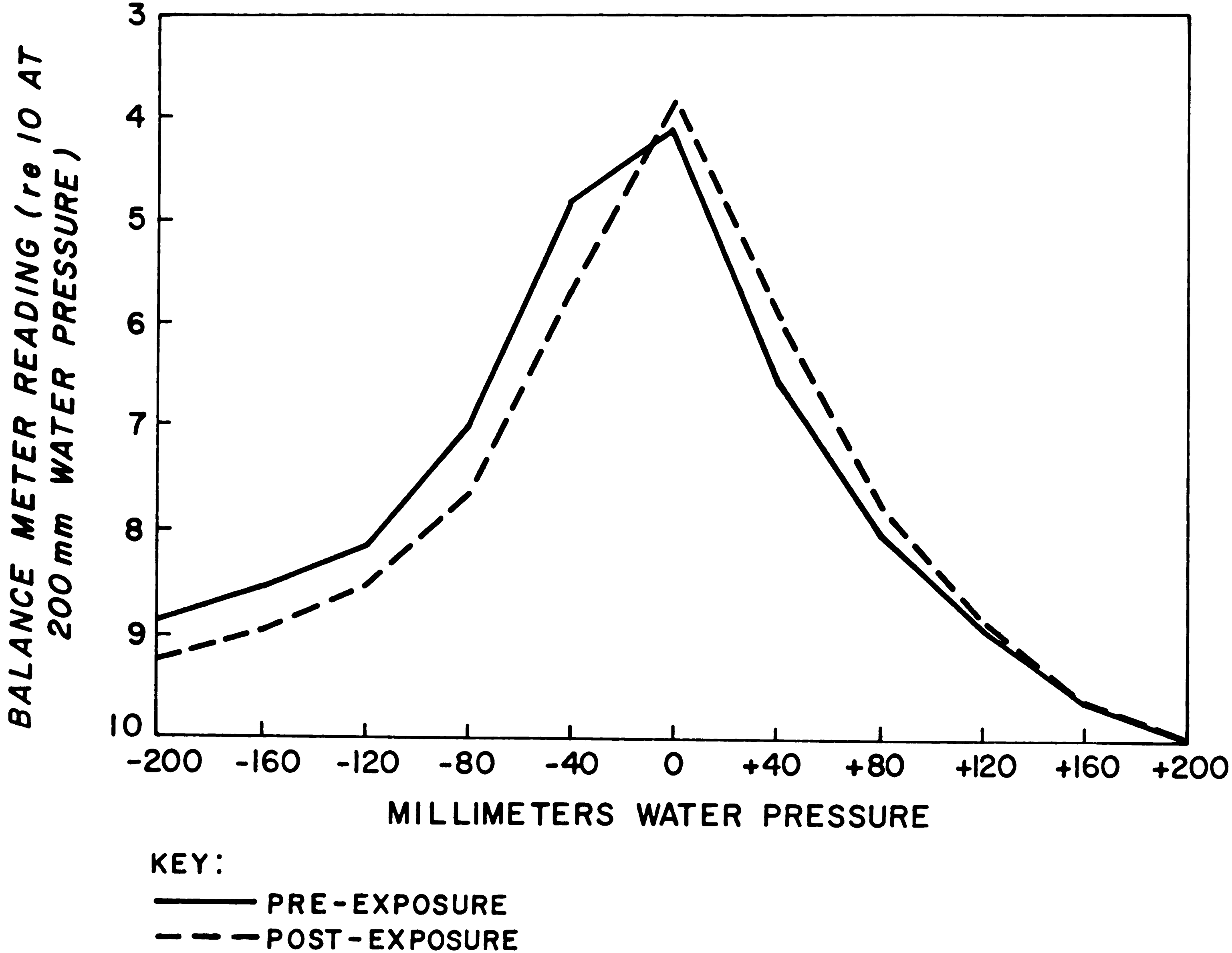

Figure 12.--Mean pre and post-exposure compliance readings at each of the pressures tested for the 20 minute exposure. N = 9

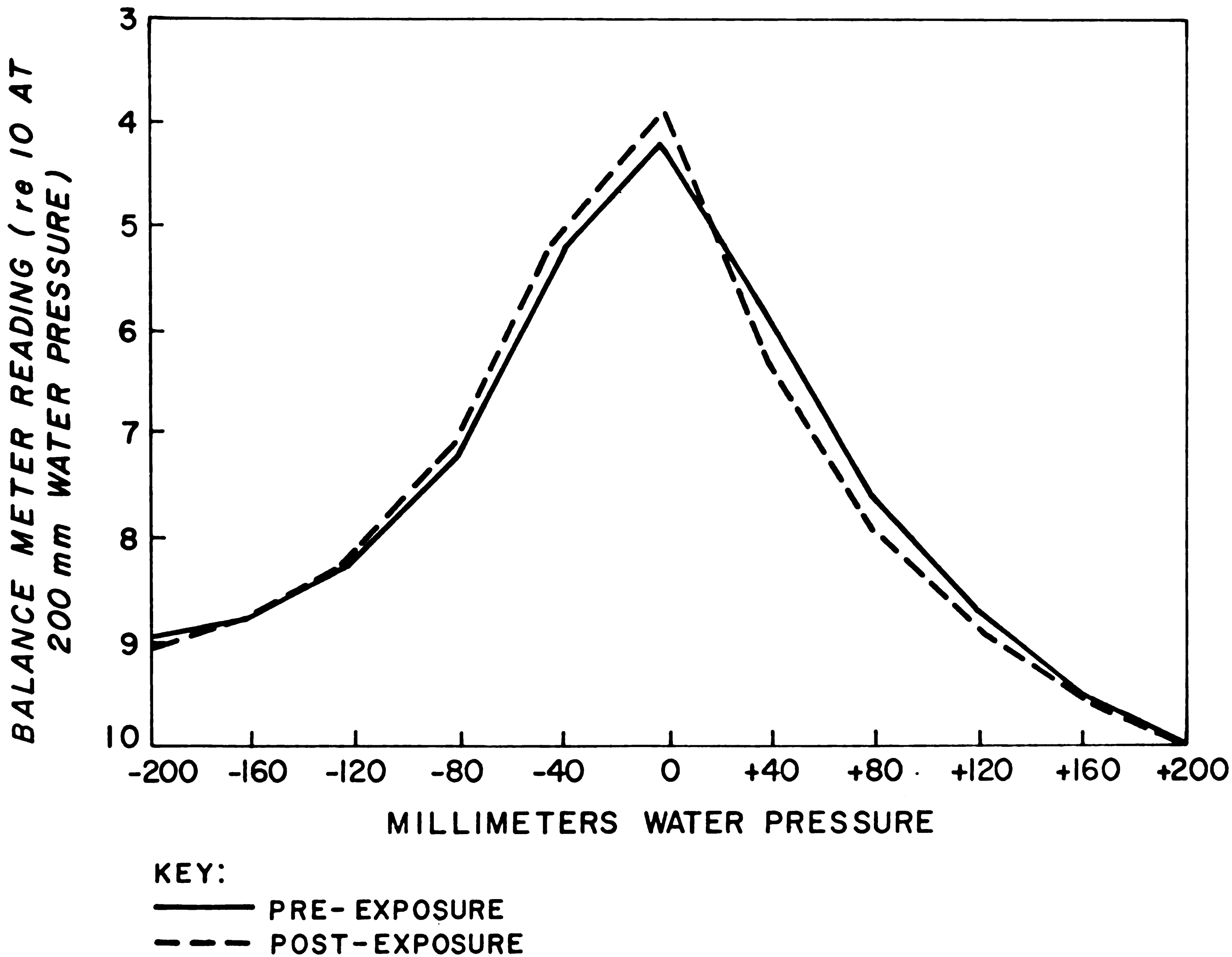

Figure 13.--Mean pre and post-exposure compliance readings at each of the pressures tested for the 10 minute exposure. N = 9

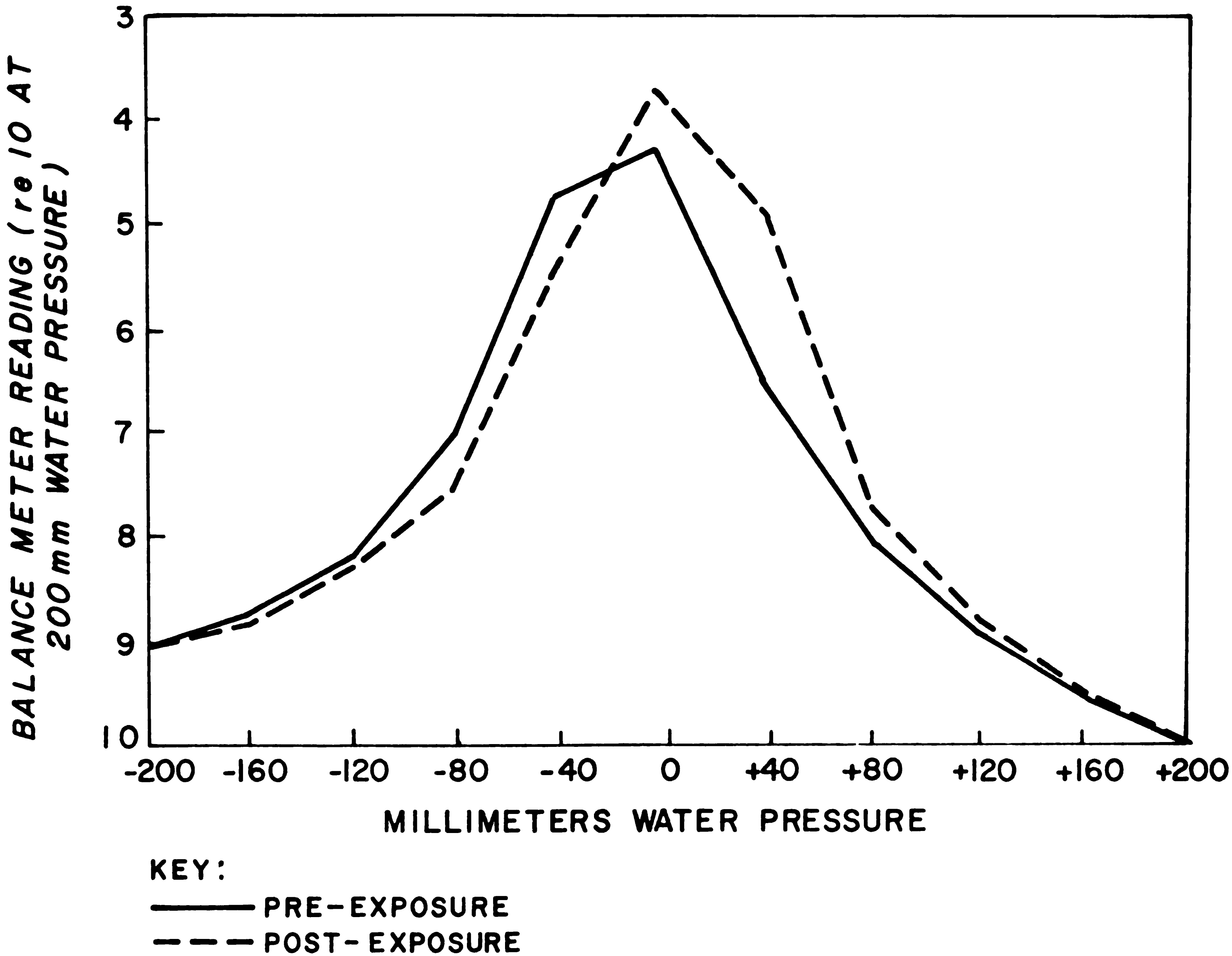

Figure 14.--Mean pre and post-exposure compliance readings at each of the pressures tested for the 5 minute exposure. N = 9

results obtained. (The air-conduction shifts found following the 10 minute exposure were intermediate between the 20 and 5 minute exposures.) It appears, as mentioned above, that this was probably due to the peculiar responses of two subjects following the ten minute exposure, however, it was felt that there was no justification for eliminating them from the sample.

If we compare the differences in pre and post-exposure compliance readings for the 20 minute and 5 minute exposure durations, as are shown in Figure 15, the effect of the length of the exposure on the compliance of the ear can be seen. The differences are small but all in the direction of greater stiffness following the 20 minute exposure at both negative and positive pressures. This is most pronounced under the positive pressure conditions as was the case following the first 20 minute exposure (see page 67) and an explanation for why this occurs is discussed in the following chapter. This is what would be expected and is reflected in the air-conduction threshold shifts following the 20 minute exposure that are not seen following the 5 minute exposure, since, of course, we have been attributing the threshold shifts found to increased impedance (whether due to increased middle ear pressure or to other factors). The compliance curve, then, as was the case in the 46 subjects, appears to be the most sensitive measure of the effect of the cold exposure on the ear other than the shift in hearing threshold, and the variation in length of the cold exposure seems to affect the extent of the shift in compliance in the direction of the longer the exposure duration, the greater the stiffness of the ear.

The last measure of acoustic impedance examined was the intra-aural muscle reflex threshold to a stimulus of 250 Hz. The means and standard deviations for the nine subjects before and after the three cold exposures and the shifts found are given in Table XXXIV. The pre-exposure stapedius muscle reflex

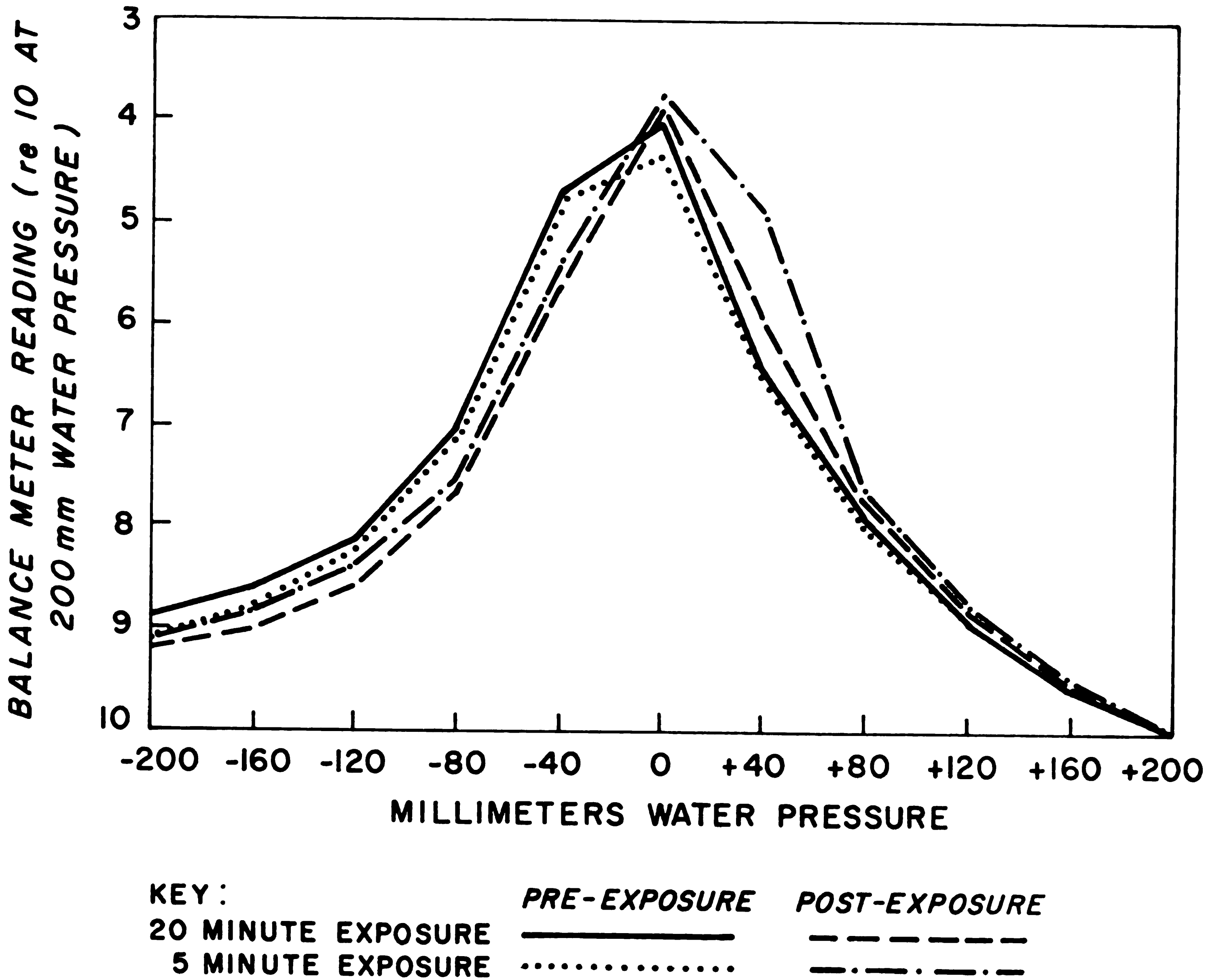

Figure 15.--Mean pre and post-exposure compliance readings at each of the pressures tested for the total group for the 20 minute exposure and the 5 minute exposure for purposes of comparison

Table XXXIV.--Means and Standard Deviations for the Pre and Post-Exposure Intra-Aural Muscle Reflex Threshold to a Stimulus of 250 Hz and the Shifts Found for the Nine Subjects at Each of the Three Exposure Durations.

	Mean*	Standard Deviation*
20 Minute Exposure (N=8)		
Pre-exposure	81.25	6.41
Post-exposure	80.63	5.63
Shift	-0.63**	3.20
10 Minute Exposure (N=8)		
Pre-exposure	76.88	6.61
Post-exposure	78.13	7.04
Shift	1.25**	4.43
5 Minute Exposure (N=7)		
Pre-exposure	77.14	4.88
Post-exposure	79.29	6.07
Shift	2.14**	5.67

*In dB re 0 Hearing Level (ISO 1964).

**The mean shifts are not significantly different from zero ($P > .35$). Analysis of variance indicated that the three groups did not differ significantly ($P = .48$).

levels were normal and very similar to those found for the total group of shifters (82.50). The differences in intra-aural stapedius muscle reflex thresholds following the three exposures were not significant. Again, the implication is that the intra-aural muscle reflex threshold to a stimulus of 250 Hz is not affected by the cold exposure and not related to shifts in compliance of the ear or to air-conduction threshold shifts.

Recovery

This section will attempt to answer the fifth experimental question: What is the nature and pattern of the recovery to the shifts found?

Pure-tone air-conduction thresholds were obtained for each of the nine subjects immediately following each of the three exposures and then at twenty minute intervals until the thresholds returned to normal. Table XXXV presents the mean air-conduction thresholds by frequency post-exposure and at 20 minute intervals following exposure for the 20 minute exposure duration.[1]

Table XXXV.--Mean Air-Conduction Thresholds* by Frequency Following the Exposure and Then at Twenty Minute Intervals: Nine Subjects, Twenty Minute Exposure.

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
T	8.67	12.44	13.56	1.44	-7.33	-9.66	-10.56
T_{20}	6.86	10.96	11.63	2.82	-7.49	-9.28	-8.99
T_{40}	5.09	8.29	10.52	2.60	-7.71	-9.95	-9.66
T_{60}	3.53	8.07	9.19	1.04	-7.27	-9.73	-10.32
T_{80}	3.31	8.07	8.52	1.26	-7.05	-9.73	-9.44
T_{100}	3.31	8.06	8.52	1.49	-7.05	-8.62	-9.44

*In dB re 0 Hearing Level (ISO 1964).

[1]The intervals are labeled T (threshold immediately following the exposure), T_{20} (the threshold after 20 minutes of recovery), T_{40}, etc.

This data is plotted in curves along with the pre-exposure thresholds prior to the 20 minute exposure for comparison purposes, in Figure 16. The recovery appears to proceed rather methodically from T to T_{60} and is then more or less complete within 60 minutes following the conclusion of the exposure. Of the nine subjects tested one took only 20 minutes for full recovery to take place, one took 40 minutes, six took 60 minutes, and one took 80 minutes.[1]

Individual recovery curves for the frequencies 125 Hz, 250 Hz, and 500 Hz are presented in Figure 17 for the nine subjects following the twenty minute exposure. As can be seen, the three recovery curves are quite similar (with the exception of 250 Hz at T_{40}) and the rate is fairly constant, approximately 0.1 dB per minute, until recovery is complete (unlike recovery from temporary threshold shifts due to noise which recover faster at first, slower later[2]). The point of complete recovery should ideally be the time at which the recovery curve reaches the 0 point. In actual practice, however, there is a certain amount of test-retest variability that affects the threshold readings, especially with a sample of only nine subjects. Full recovery probably takes place approximately 60 minutes following the cold exposure for the frequencies of 125 Hz and 250 Hz and approximately 80 minutes following the exposure at 500 Hz. However, the difference at 500 Hz from T_{60} to T_{80} is so slight that for all practical purposes one might conclude that the air-conduction threshold shift at 125 Hz, 250 Hz, and 500 Hz which follows a cold exposure of 20 minutes has fully recovered within one hour following the conclusion of the exposure.

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[1]Recovery is defined here as the point in time at which thresholds returned to normal (pre-exposure) levels (±2 dB) and does not include the final or stabilization check thresholds.

[2]W. Dixon Ward, "Auditory Fatigue and Masking," Modern Developments in Audiology, pp. 241-286.

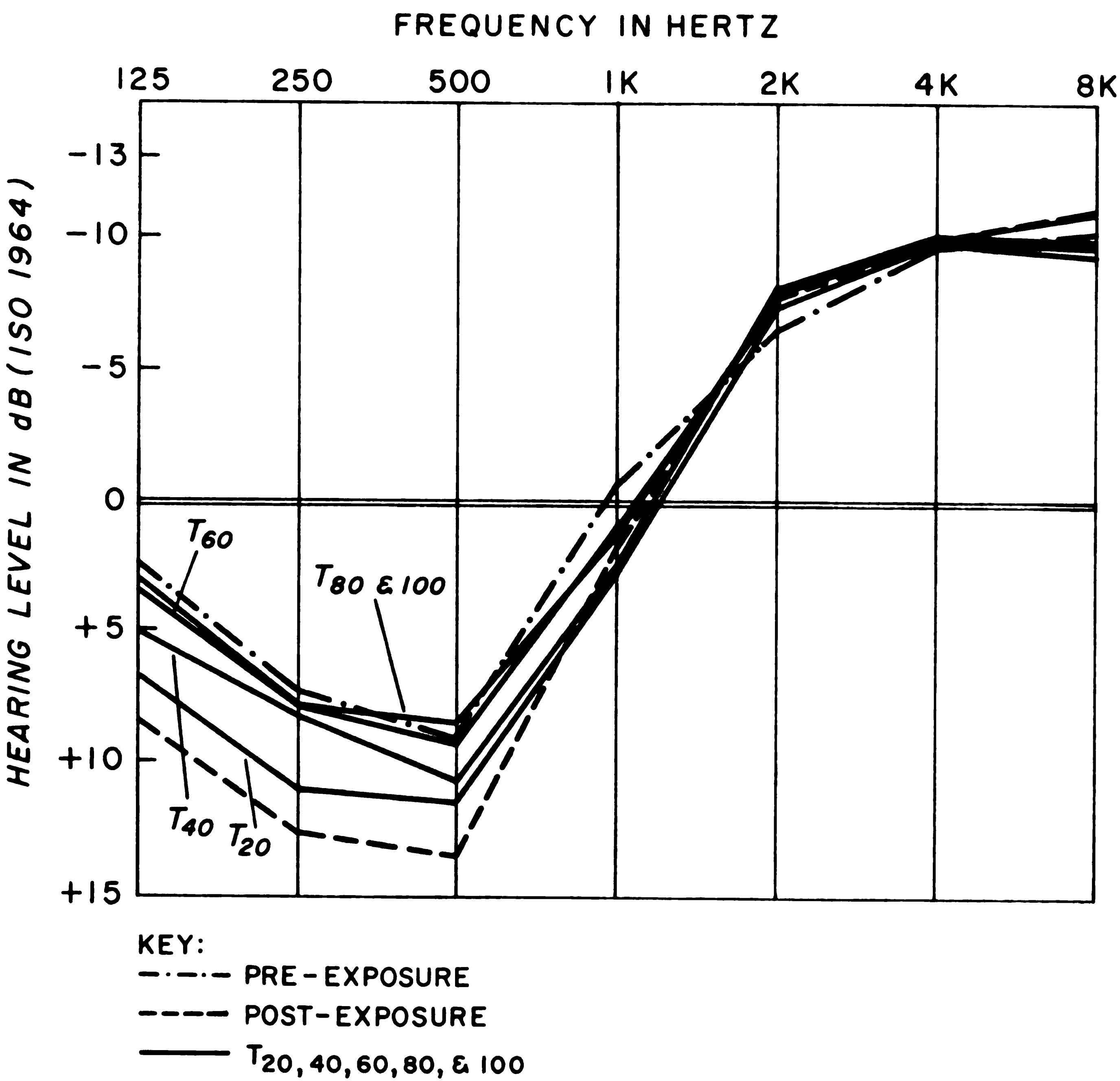

Figure 16.--Mean air-conduction thresholds by frequency post-exposure and at 20 minute intervals following the exposure: 20 minute exposure duration. N = 9

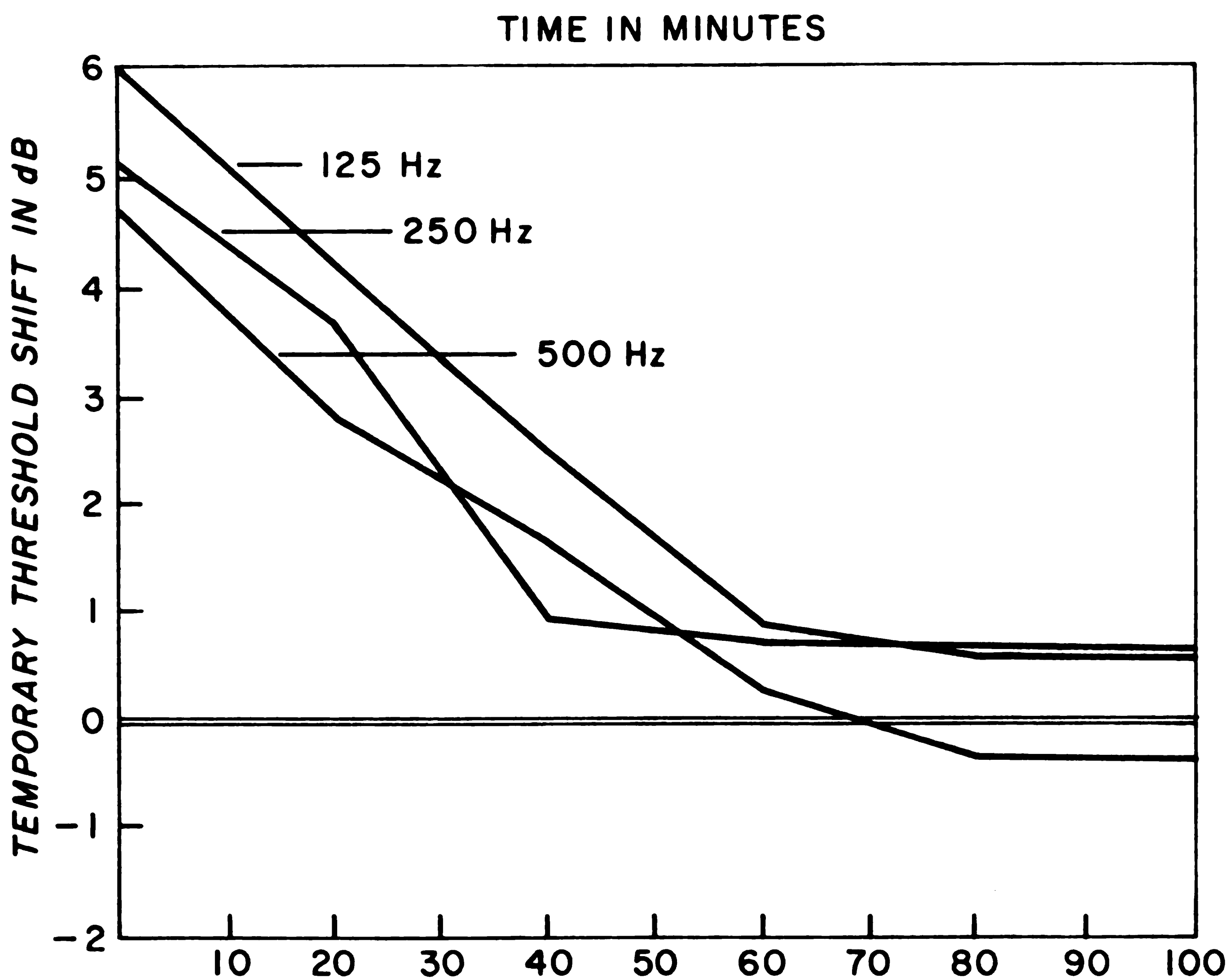

Figure 17.--Mean recovery curves for the frequencies 125 Hz, 250 Hz, and 500 Hz following the 20 minute exposure duration. N = 9

The mean air-conduction thresholds by frequency following the 10 minute exposure and then at 20 minute intervals are presented in Table XXXVI for the nine subjects. It is difficult to compare these figures directly to those in Table XXXV because the pre-exposure thresholds are slightly different; however, the recovery from the threshold shifts can be compared. Figure 18 presents individual recovery curves for the frequencies 125 Hz, 250 Hz, and 500 Hz for the nine subjects following the 10 minute exposure. Although the starting points are somewhat lower than in Figure 17 (the threshold shift following the 20 minute exposure), the recovery curves are again quite similar and the rate fairly constant again at about 0.1 dB per minute. Full recovery, however, takes place at approximately 40 minutes following the conclusion of the exposure for all three of the frequencies (as opposed to 60 minutes for the twenty minute exposure). Of the nine subjects, seven showed full recovery following 40 minutes, one following 60 minutes, and one subject did not show any threshold shift at all.[1]

Table XXXVI.--Mean Air-Conduction Thresholds* by Frequency Following the Ten Minute Exposure and Then at Twenty Minute Intervals for the Nine Subjects

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
T	9.00	13.56	13.33	3.22	-6.00	-9.67	-8.00
T_{20}	7.53	11.53	11.85	3.38	-6.56	-8.12	-8.75
T_{40}	5.98	9.98	10.96	3.38	-6.56	-8.12	-9.19
T_{60}	6.42	9.76	10.74	3.60	-5.67	-10.56	-9.86
T_{80}	6.42	9.98	10.96	3.60	-5.67	-10.34	-9.86

*In dB re 0 Hearing Level (ISO 1964).

[1]It is interesting to note that this subject's pre-exposure air-conduction thresholds were somewhat elevated (in comparison with her other three sets of pre-exposure thresholds) and her pre-exposure tympanic temperature was almost half a degree lower than is normal for her. It is possible that the "warm-up time" allowed this subject on this particular evening was not quite sufficient prior to the beginning of testing.

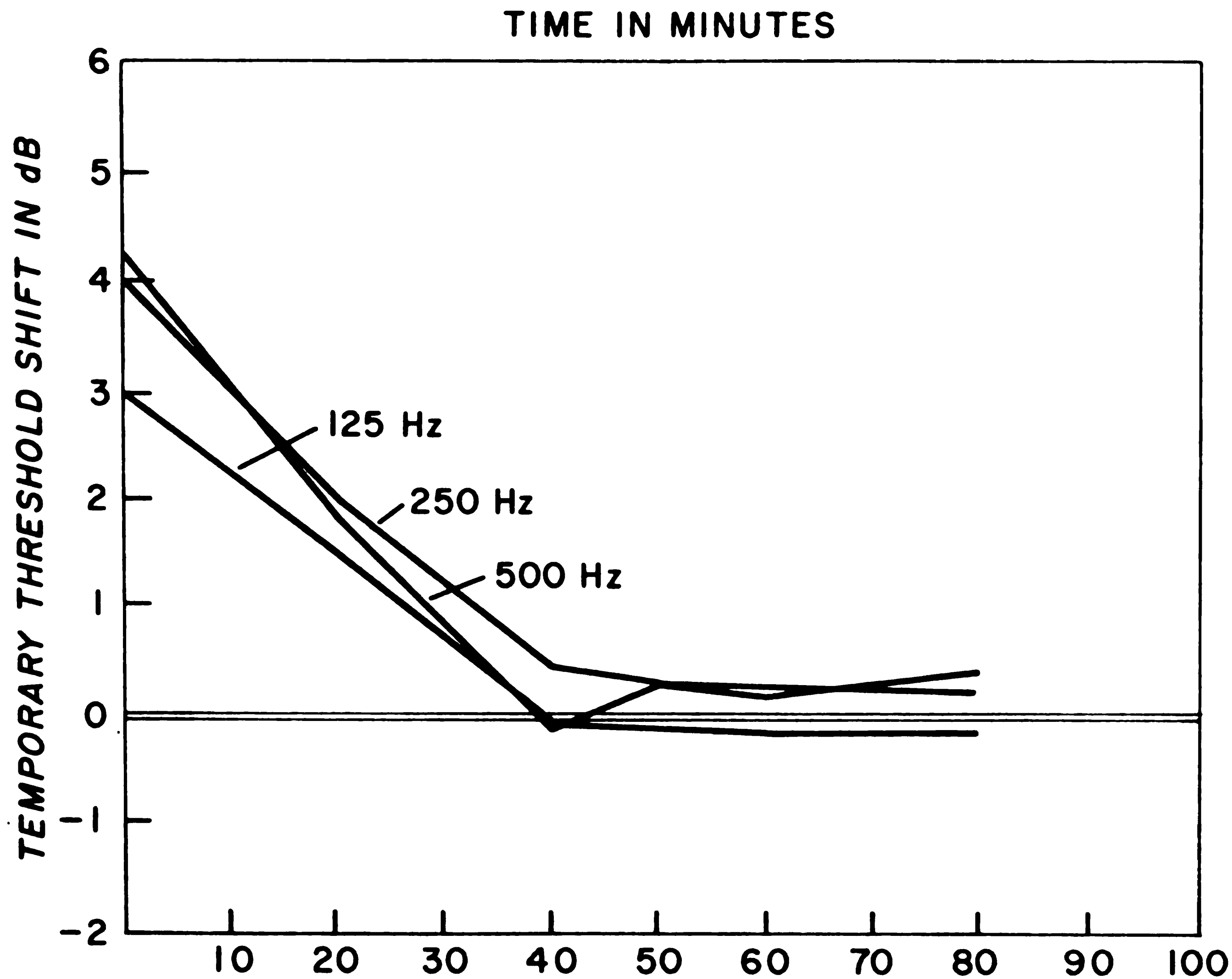

Figure 18.--Mean recovery curves for the frequencies 125 Hz, 250 Hz, and 500 Hz following the 10 minute exposure duration. N = 9

Recovery following a five minute exposure cannot be examined, of course, since there were no significant threshold shifts following this length exposure. It appears that the rate and pattern of recovery from temporary threshold shifts caused by cold exposure are similar for varying lengths of exposure but that the length of the exposure does determine how long it takes before recovery is complete. The mean length of time needed to fully recover from a 20 minute exposure to temperatures of approximately -7° F. is about 60 minutes. Somewhat less time, 40 minutes, is necessary before full recovery occurs following a 10 minute exposure at -7° F.

Although impedance and tympanic temperature readings were not tracked in the same manner as air-conduction threshold readings were, a final check was made on all of the impedance readings and on tympanic temperature following the final stabilization check threshold testing. The purpose of this final check was to see if impedance readings and tympanic temperature had also returned to normal (pre-exposure) levels when air-conduction thresholds had done so. Pre-exposure, post-exposure, and final tympanic temperature readings are compared in Table XXXVII.

Table XXXVII.--Means of Pre-Exposure, Post-Exposure, and Final Tympanic Temperature Readings for the Twenty and Ten Minute Exposures for the Nine Subjects.

	Pre-Exposure*	Post-Exposure*	Final Exposure*
20 Minute Exposure	97.63	96.17	97.34
10 Minute Exposure	97.37	96.75	97.30

*In degrees Fahrenheit.

The tympanic temperature readings following both exposures did return to pre-exposure levels within the same amount of time needed for the air-conduction thresholds to recover. Of course, it is not possible to say exactly how long it took for tympanic temperature to return to pre-exposure levels, only that it took no longer than one hour following a 20 minute exposure or 40 minutes following a 10 minute exposure.

The differences between the pre-exposure and final acoustic impedance measurements is also very small. The mean difference from pre-exposure to final reading was -2.78 ohms for the 20 minute exposure. Middle ear pressure, on the other hand, did not completely return to pre-exposure levels by the time of the final measurement. The mean middle ear pressure reading prior to the 20 minute exposure was -6.1 mm water pressure, immediately following the exposure it was +5.00 mm water pressure, and by the time of the final check it was +1.2 mm water pressure. The question does exist as to whether some of this difference is due to test-retest variability or whether perhaps the middle ear pressure had not fully recovered by the time the air-conduction thresholds had done so.

There were differences between the pre-exposure and final compliance readings also. Figure 19 displays the pre and post-exposure and final compliance readings for the nine subjects for the 20 minute exposure. The ears apparently were somewhat more compliant at all pressures at the time of the final check but it should be noted that the differences are approximately equal at all of the pressure levels. It is possible that the compliance curve "passed through" the pre-exposure readings at some earlier time and have "overshot" them and may yet bounce back to pre-exposure levels. The compliance curve appears to be one of the most sensitive impedance measures in terms of the effect of cold exposure on the ear and certainly needs to be investigated further. The type of shift in compliance readings found following both 20 minute exposures, however, is completely gone by the time

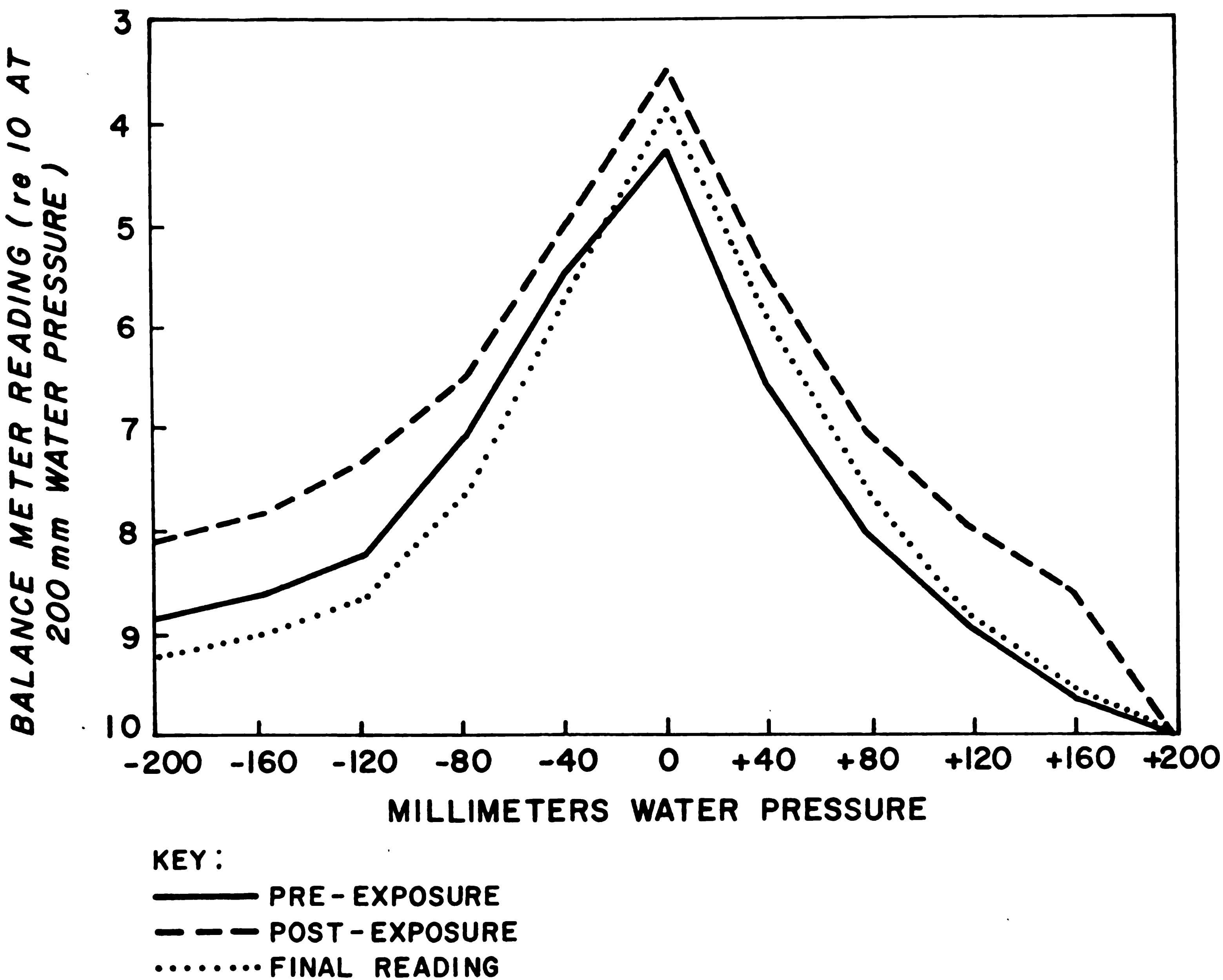

Figure 19.--Mean pre and post-exposure and final compliance readings at each of the pressures tested for the 20 minute exposure duration. N = 9

of the final compliance check. Lastly, the acoustic reflex was unaffected by the cold exposure and remained at the same levels at the time of the final testing.

It would appear, then, that the effect of cold exposure on impedance is also temporary and that the shifts found recover pretty much within the time necessary for the air-conduction thresholds to recover.

CHAPTER V

DISCUSSION

This chapter will attempt to answer the question: What physiological changes take place in the ear that cause reduced pure-tone air-conduction thresholds and middle ear impedance changes?

This chapter will present six possible explanations to account for the threshold shifts found. These are: 1) the shift in hearing threshold following the exposure is due to the psychological effect of the cold exposure on the subject and not to any direct physical changes in the ear; 2) the shift in threshold is due to the fact that the cold affects the entire body, not only the ear, resulting in generalized chilling, shivering, etc.; 3) there is a direct effect of the cold air on the action of the inner ear; 4) there is a direct effect of the cold air on the action of the middle ear muscles, tendons, and ligaments; 5) the threshold shifts are due to a disequilibrium in air pressure between the external canal and the middle ear following the cold exposure; and 6) there is a direct effect of the cold air on the action of the tympanic membrane. Although it is unlikely that any one of these possibilities will provide the total explanation for the effects found, each of them will be considered individually in this chapter.

1) The shift in hearing threshold following the exposure is due to the psychological effect of the cold exposure on the subject and not to any direct physical changes in the ear.

It might be suggested that due to the shock of the cold exposure the subjects were unable to concentrate as well on listening for pure-tone thresholds, and, therefore, pure-tone thresholds were depressed following the cold exposure. These depressed thresholds then were not due to any physical effect, but simply to the psychological effect of the cold air on the subject's ability to concentrate. It seems highly unlikely that this is adequate for explaining the effects found, because whatever effects one might attribute to the psychological aspects of the cold exposure should be expected to affect the air and bone-conduction thresholds similarly. Since the air-conduction thresholds were not uniformly affected and the bone-conduction thresholds were not affected in any measurable way by the cold exposure, one must assume that the effects on the air-conduction thresholds were probably due to factors other than psychological ones.

2) The shift in threshold is due to the fact that the cold affects the entire body, not only the ear, resulting in generalized chilling, shivering, and overall muscular contractions.

It was necessary to know what effect generalized body chilling would have on hearing thresholds. For this reason, three subjects who were lightly dressed were exposed for longer periods of time to somewhat higher temperatures, 35° to 40° F.[1] Each of these subjects remained in this environment for 30 to 40 minutes, or until they were thoroughly chilled as evidenced by shivering and horripilation. None of these three subjects showed any shift in hearing following this exposure. The subjects in the present study were,

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[1]See Chapter II, pp. 5-8.

of course, warmly dressed, but their heads were exposed and the possibility existed that even with only their heads exposed the shift in hearing thresholds might have been caused by generalized body cooling or by muscular contractions throughout the body rather than by specific cooling in the head only. The pilot study referred to above demonstrated that thoroughly chilling subjects does not have any effect on hearing thresholds.

The subjects in the thesis research did not show any of the typical signs of chilling (such as shivering) and it is assumed that their body temperature was not affected by the type of exposure to which they were subjected. Since no shivering occurred it is also assumed that muscular contractions throughout the body did not occur following the exposure, and that, therefore, the shift in threshold found in the present study was not due to generalized body chilling or to the muscular contractions throughout the body caused by shivering. This does not rule out the specific effect of cold on the ear itself. These results imply that the threshold shifts found are due to factors other than muscular contractions throughout the body as a reaction to chilling or to an overall drop in body temperature caused by the chilling.

3) There is a direct effect of the cold air on the action of the inner ear.

As discussed in the review of the literature in Chapter II, Kahana, Rosenblith and Galambos[1] and Gulick and Cutt[2] demonstrated that when body temperature was reduced the magnitude of the cochlear response was likewise

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[1]L. Kahana, W. A. Rosenblith, and R. Galambos, "Effect of Temperature Change on Round Window Responses in the Hampster," pp. 213-223.

[2]W. L. Gulick and R. A. Cutt, "The Effects of Abnormal Body Temperature Upon the Ear: Cooling," pp. 35-50.

reduced, and Gulick and Cutt also reported concomitant hearing losses. But it is also well established that the inner ear can be affected by cold air even when body temperature is unchanged, and this, of course, is what occurs in caloric testing, whether cold water or cold air is employed as the stimulus. The question, therefore, of whether the threshold shifts found following the cold exposure might be due to changes in the response of the inner ear is certainly a pertinent one.

One would expect, however, there were these threshold shifts due to changes in the inner ear, the bone-conduction thresholds would also have been affected. But since bone-conduction thresholds remained essentially the same following the cold exposure, one must conclude that the shifts in air-conduction thresholds following the cold exposure were probably due to factors other than changes in the response of the inner ear. However, this conclusion must be made cautiously. It is entirely possible that given longer exposure durations or lower temperatures in the cold room that an effect on the bone-conduction thresholds would have occurred.[1] This will be discussed in more detail later in conjunction with the section concerned with middle ear pressure.

4) There is a direct effect of the cold air on the action of the middle ear muscles, tendons, and ligaments.

As discussed earlier, extreme chilling of the human body results in overall muscular contractions and shivering. There are two muscles in the middle ear and the possibility needs to be explored that the middle ear became so cold following the exposure that these muscles contracted, thereby creating the air-conduction loss found. Since no threshold shift was found when the pilot study subjects were put into the cold room lightly dressed

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[1]One would expect the effect of the cold exposure on bone-conduction thresholds to be smaller than it would be on air-conduction thresholds. The possibility that a slight bone-conduction shift did occur--but was completely masked by the ambient noise level in the testing environment must be considered.

and were thoroughly chilled and shivering, it seems highly unlikely that middle ear muscle contractions can be credited with the threshold shifts found following the exposure under the present conditions. Also, even if muscular contractions had occurred, it seems highly unlikely that the duration of the contraction would have extended for up to an hour post-exposure, the length of time necessary for full recovery following a 20 minute exposure. It is possible, however, that there was some contraction of the tendons and ligaments in the middle ear, most particularly the tendons of the stapedius muscle, which might have contributed somewhat to the hearing threshold shifts found. It seems unreasonable to state that the increased muscle stiffness in the middle ear can be held responsible for the total effects found, but it does seem possible that if the ligaments and tendons in the middle ear were slightly cooled and slightly stiffened, that subtle effects on the muscles might have occurred which might contribute to the overall increased impedance of the middle ear system, resulting in the type of air-conduction thresholds found following the exposure session.

Smith[1] mechanically fixated the stapes in cats and measured changes in the cochlear responses for air and bone conduction which resulted. The degree of stapes fixation varied according to the amount of tension he placed on it, but he reported average hearing losses by air and bone conduction in decibels. The losses found were greatest in the low frequencies by air conduction, the mean losses ranging between 30 and 40 dB, whereas by bone conduction the losses were very small, i.e., ranging between

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[1]K. R. Smith, "Bone Conduction During Experimental Fixation of the Stapes," Journal of Experimental Psychology, 33 (1943), pp. 96-107.

0 and 10 dB. The implication of this research is that if there were some cooling of the tendons of the stapedius muscle, one might expect to get similar results to those Smith found, i.e., hearing loss in the low frequencies by air conduction and little or no hearing loss by bone conduction. It should be pointed out, however, that whereas Smith found small but measurable hearing losses by bone conduction, these were not found in the present investigation.

The air-conduction losses found here, however, were much smaller than those found by Smith, implying that if increased tension in the stapedial muscle was responsible for the threshold shifts found in the thesis research, the increase in tension must have been quite small. It seems reasonable to conclude that the hearing threshold shifts found following the cold exposure may be due in part to increased tension in the tendons of the stapedius muscle which could subtly affect the action of the entire middle ear system, but this does not seem to be a likely explanation for the total threshold shifts found.

5) The threshold shifts are due to a disequilibrium in air pressure between the external canal and the middle ear following the cold exposure.

The greatest effect of the cold air exposure would be expected in the outer ear canal. Pre and post-exposure otological examinations were made by an otolaryngologist on a sample of the subjects. He found that the walls of the canal were definitely cooled by the exposure, and the resultant stiffening of the canal walls to be very noticeable. It can be demonstrated by use of the tympanic thermometer that the tympanic membrane is also affected by the cold exposure. It does not seem unreasonable to further assume that the middle ear is somewhat cooler than normal also, but undoubtedly not as cool as the external canal. Air, of course, expands as temperature rises and should the temperature in the middle ear be warmer than that in the external auditory canal, a disequilibrium in air pressure between the external canal and the middle ear cavity would result. Under ordinary circumstances, one would expect that this difference in air pressure would be equalized through the action of the eustachian tube. For a variety of reasons the eustachian tube may not have been capable of correcting these pressure differentials under the experimental conditions used in this investigation. In the first place, a certain minimum amount of pressure difference is necessary to open the eustachian tube, probably between 0.5 and 4 mm Mercury.[1] The increase in air pressure in the middle ear found in this investigation, i.e., approximately + 10 mm of water pressure,[2] simply may not have been enough to "blow open" the eustachian tube. However, it may have been enough to cause a slight change in the mechanical action of the middle ear.

Secondly, it was noted that many of the subjects emerged from the cold room with "sniffles." The effect of chilling is to cause "reflex vasoconstriction of the nasal mucous membrane. The normal temperature of the mucous membrane of the nose has been shown to vary between 33° and 34° C. Chilling of the body surface may reduce the temperature of the nasal mucosa by as much as 6° C. . . ." The effect occurs "most commonly in the nasopharyngeal mucous membrane . . . the nose, or in the pharynx or larynx.

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[1] J. J. Ballenger, Diseases of the Nose, Throat, and Ear, (London: Henry Kimpton, 1969), p. 630.

[2] 10 mm water pressure approximately equals 0.7 mm Mercury.

. . . Typical symptoms are sneezing and watery nasal discharge. The mucous membrane is red and swollen."[1] Other authorities such as Boies[2] also comment on temporary congestion, inflamation, membrane swelling, and nasal discharge as a result of chilling. This could very well have reduced the patency of the eustachian tube as would happen in the case of a common cold. It is more difficult to equalize pressure between the middle ear and outer ear when there is mucosal congestion. In fact, the possibility exists that the patency of the eustachian tube may be the key factor that differentiated subjects who shifted from those who did not shift. Those subjects whose eustachian tubes remained most patent were perhaps more able to compensate for the disequilibrium in air pressure and therefore did not show the threshold shift, whereas those subjects who were not able to equalize the pressure between the middle and outer ear showed the threshold shift. This, of course, agrees with the findings of this investigation cited earlier in Chapter IV. In Table XVI of Chapter IV, it can be seen that following the cold exposure the middle ear pressure had increased more in the shifters than in the non-shifters. Presumably the non-shifters were able to equalize the air pressures in their external canals and middle ears, thereby maintaining normal impedance and normal air-conduction thresholds. The differences are small, however, as is the number of subjects involved. More important perhaps is the fact that most of the subjects showed some increase in middle ear pressure following the exposure. This shift in middle ear pressure following the cold exposure was significant at the 0.001 level of confidence.

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[1] W. G. Scott-Brown, et al., Diseases of the Ear, Nose and Throat, (London: Butterworth, 1965), pp. 174-179.

[2] L. R. Boies, Fundamentals of Otolaryngology: A Textbook of Ear, Nose and Throat Diseases, (Philadelphia: W. B. Saunders Co., 1957), pp. 178-183.

In Chapter IV reference was made twice (pp. 67 and 92) to the fact that post-exposure compliance curves showed reduced compliance under negative canal pressure conditions and enhanced compliance under positive canal pressure conditions. If the middle ear pressure has indeed been somewhat increased, and the tympanic membrane displaced outwards slightly, this is exactly what one would expect to occur. Adding pressure to the external canal would help to bring the air pressures back into equilibrium and allow the tympanic membrane to come closer to its normal (mid-line) position, thereby reducing the stiffness (and increasing the compliance) of the system. Withdrawing air from the external canal, creating a negative canal pressure, would simply make the disequilibrium even greater, resulting in an even stiffer (less compliant) system. It seems reasonable to assume that this is what did occur and that this accounts for the post-exposure compliance curves found.

An attempt was made to compare the present findings to the research reported by Wever and Lawrence. They discussed this problem of the relationship between middle ear pressure and hearing thresholds in general. "Impairments of hearing of a more or less temporary nature are often found as secondary effects of congestion in the nasal pharynx, as from a common cold. . . . In the clinical situation it is often difficult to determine to what extent the auditory symptoms are due to pressure changes and to what extent they are due to . . . the . . . congestion in the ear itself. This problem requires an understanding of the effects of pressure in the normal ear."[1] In the case of the present investigation, the differences in middle ear pressure were very small. However, the trend was the same as in all of

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[1]E. G. Wever and M. Lawrence, Physiological Acoustics, (New Jersey: Princeton University Press, 1954), pp. 197-198.

the experimental studies Wever and Lawrence presented. The basic premise is that the disequilibrium in air pressure between the external canal and middle ear results in depressed low frequency air-conduction thresholds. The effect of the pressure disequilibrium on the higher frequencies is not as clear but the consensus seems to be that there is little or no effect on hearing acuity in the high frequencies.

Using the Valsalva procedure, Loch[1] found that a moderate increase in middle ear pressure reduced hearing acuity in the lower frequencies by approximately 10 dB. Wever and Lawrence concluded, "Usually these effects have been attributed to the altered tensions of the drum membrane, and there is no doubt that this is the principal condition."[2] They further suggested, however, that should the pressure in the middle ear be sufficient, the effect might continue on into the inner ear. One would suspect that in the present investigation the pressure build-up in the middle ear was not sufficient to affect the inner ear since the bone-conduction thresholds were unchanged. Wever and Lawrence continued, "From the form of the changes in sensitivity for air-conducted tones as caused by both positive and negative pressures, we can conclude that these pressures increase both the stiffness and the damping of the drum membrane. The increased damping accounts for the general impairment of sensitivity whereas the increased stiffness causes this impairment to be more severe for the low tones."[3] In conclusion then,

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[1] W. E. Loch, "Effects of Experimentally Altering Air Pressure in the Middle Ear on Hearing Acuity in Man," <u>Annals of Otology, Rhinology, and Laryngology</u>, 51 (1942), pp. 995-1006.

[2] E. G. Wever and M. Lawrence, <u>Physiological Acoustics</u>, p. 209.

[3] <u>Ibid.</u>, p. 211.

it seems likely that the increased middle ear pressure following the cold exposure was due at least in part to the fact that the mucosal tissue had been irritated and perhaps swollen slightly, thereby preventing the eustachian tube from opening as easily as it would under ordinary conditions.

6) There is a direct effect of the cold air on the action of the tympanic membrane.

As disccused in Chapter II, the possibility certainly exists that the tympanic membrane was affected by the cold air reaching it through the external auditory canal. If the tympanic membrane were to be cooled, the result would be increased stiffness in its action, since there is no reason to believe that this body tissue would react any differently than any other human body tissue to cooling. The physiology involved in this is discussed in some detail in Chapter II. In order to demonstrate whether or not the tympanic membrane actually is cooled by the cold exposure, each individual's temperature was taken on the tympanic membrane both before and after each exposure session. The findings are given in detail in Chapter IV. Briefly, however, the temperature of the tympanic membrane was decreased by approximately 0.7° F. following the cold exposure as used in this investigation. It seems reasonable to assume that the action of the tympanic membrane is very likely affected. However, it is not possible at this time to say to what degree the membrane's action was affected or to predict what affect the change in tympanic activity would have on hearing thresholds. One would assume, however, that should the tympanic membrane be stiffened as a result of the cooling, which seems a reasonable assumption, the change in impedance would result in depressed low frequency air-conduction thresholds which is, of course, what was found.[1]

Ideally, the recovery of tympanic temperature would then have been tracked in order to see what the relationships between tympanic temperature recovery and air-conduction threshold recovery were. Unfortunately, the constraints of the research design did not permit this type of analysis. In summary, then, it appeared that the cold exposure did affect the temperature of the tympanic membrane. The mean shift in temperature following the 20 minute exposure was -0.7° F. It is not possible, however, to predict how much of an effect this drop in temperature would have on the action of the membrane or on air-conduction hearing thresholds. But when the pure-tone air-conduction thresholds had returned to normal so had tympanic temperature. This must certainly be considered as a possible explanation, or at least as part of the explanation for the threshold shifts observed.

At the beginning of this chapter, six possible explanations were presented in order to account for the air-conduction threshold shifts found. The first two, that the effects seen were due to psychological factors or generalized body chilling and/or overall muscular contractions, seem highly unlikely. The third, that the effects were due to changes in the action of the inner ear seems unlikely, also. However, it is felt that this could be a factor were the exposure longer or the cold more extreme. The most likely explanation for the threshold shifts found appears to be some combination of explanations four, five, and six. The contribution of the fourth

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[1]The same result would occur, of course, if there were a pressure build-up in the middle ear causing the tympanic membrane to bulge outward slightly. Again, one would expect that its vibratory capacity would be somewhat reduced.

possibility, concerning middle ear muscle activity, is probably minimal. The air-conduction "stiffness tilt" found following the cold exposure is probably best explained in terms of the last two explanations, the disequilibrium in air pressure between the external canal and the middle ear and the direct effect of the cold air on the vibratory capacity of the tympanic membrane.[1]

Undoubtedly, there are other possibilities, but at this time, it seems most likely that the threshold shifts found in this investigation were due to one or more of the following factors: 1) subtle changes in the action of the middle ear muscles, 2) increased air pressure in the middle ear and/or 3) a reduction in the vibratory capacity of the tympanic membrane. The combination of one or more of these factors would result in an increase in the stiffness of the middle-ear system. This change in impedance of the system would be reflected in the post-exposure depressed low frequency pure-tone air-conduction threshold shifts found.

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[1]These conclusions were arrived at, in part, through personal communication with Merle Lawrence, University of Michigan, Ann Arbor, March 1970.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The major purpose of this research was to determine the effect of cold air temperatures on the human peripheral auditory system. An attempt was made to explain the effects found.

Summary

Forty-six college students with normal hearing served as the subjects for this study. Each of the subjects had their pure-tone air-conduction thresholds determined bilaterally and occluded bone-conduction thresholds were obtained using a forehead oscillator placement. Each subject was given considerable practice in pure-tone testing using 2 dB steps. For 37 of the subjects, tympanic temperature was also determined at this time. Measurements of acoustic impedance in the plane of the eardrum were made in 44 subjects. Measurements of middle ear pressure were noted for 11 subjects and in five cases, the intra-aural muscle reflex threshold to a 250 Hz stimulus was also obtained. Compliance readings at a variety of pressure settings were made on 15 subjects.

Following these measurements, each subject was allowed to dress as warmly as he wished leaving the head and ears exposed and then entered a cold room where the temperature varied from -3° F. to -10° F., with a mean of -7.07° F. Following 20 minutes of this exposure all of the pre-exposure tests were repeated. All pure-tone testing was done employing the Hughson-Westlake ascending technique. The air-conduction frequencies tested were

125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz, and 1000 Hz was repeated. Bone-conduction was tested at the same frequencies with the exception, of course, of 125 Hz and 8000 Hz.

There were no significant shifts by bone-conduction for these subjects following the cold exposure. The air-conduction thresholds, however, were affected. The mean shift at 125 Hz was +3.17 dB; at 250 Hz, +2.52 dB; at 500 Hz, +1.83 dB; and at 1000 Hz, +0.91 dB. All of these shifts were statistically significant. The shifts found at frequencies above 1000 Hz were too small to be statistically significant, but were all in a negative direction, i.e., in the direction of improved hearing following the exposure.

Further analysis of the data demonstrated that the subjects could easily be divided into two groups, shifters and non-shifters. It was decided that a subject would be classified as a shifter if two of his three low frequency thresholds (125 Hz, 250 Hz, and 500 Hz) were shifted downward by at least 4 dB and the third frequency shifted downward by at least 2 dB. Twenty subjects were thus classified as shifters. They showed mean air-conduction threshold shifts at 125 Hz of +6.10 dB; at 250 Hz, +5.40 dB; at 500 Hz, +5.20 dB; at 1000 Hz, +1.20 dB; at 2000 Hz, +0.30 dB; at 4000 Hz, -0.50 dB; and at 8000 Hz, -0.10 dB. The group composed of the remaining 26 subjects showed no significant threshold shifts following the exposure. Specifically, the group classified as non-shifters showed mean shifts of 1 dB or less at all frequencies.

The mean pre-exposure tympanic temperature of all of the subjects was 98.0° F., and the mean shift following the cold exposure was -0.72° F. There was no significant difference in the size of the temperature shifts between the shifters and non-shifters, nor was there any significant relationship between the size of the temperature shift and the size of the threshold shift.

The pre-exposure acoustic impedance measurements in the plane of the eardrum were within the normal range for the subjects tested. However, the non-shifters appeared to have slightly stiffer (less compliant) ears to begin with. The shifts found in overall acoustic impedance following this exposure were minimal for all of the subjects and no distinctions could be made between shifters and non-shifters on the basis of the size of the acoustic impedance shifts following the exposure.

The mean pre-exposure middle ear pressure readings for the group of shifters was +1.67 mm water pressure, for the non-shifters, +17 mm water pressure. Both the shifters and non-shifters showed an increase of approximately +10 mm in middle ear pressure following the cold exposure. Compliance readings were made in 40 mm steps from +200 mm to -200 mm water pressure. The non-shifters' ears were found to be less compliant at the time of the pre-exposure testing but the effect of the cold exposure on compliance measurements was the same for all of the subjects. Following the cold exposure, compliance appears to have been reduced under negative canal pressure conditions and enhanced under positive canal pressure conditions. The intra-aural stapedius muscle reflex threshold level to a stimulus of 250 Hz was normal for all of the subjects both before and after the cold exposure.

In the second phase of the study, nine of the 20 shifters returned for three additional testing sessions where the same tests were administered but the length of the cold exposure was varied. Each of these subjects was exposed on three different days, once for five minutes, once for ten minutes, and once for 20 minutes. In addition, the order of presentation of the tests (i.e., air-conduction testing, impedance testing, and tympanic thermometry) was now varied. It was found that there were no significant differences in mean threshold shift at any frequency between the first 20 minute exposure and the second 20 minute exposure. The threshold shifts found following the latter three exposures are presented in Table XXXVIII.

Table XXXVIII.--Mean Air-Conduction Threshold Shifts* for the Nine Subjects Following Each of the Three Exposure Durations.

Frequency	20 Minutes	10 Minutes	5 Minutes
125 Hz	6.00	2.89	0.67
250 Hz	5.11	4.00	1.33
500 Hz	4.67	2.22	1.11
1000 Hz	2.22	0.00	0.00
2000 Hz	-0.89**	-0.67	-1.11
4000 Hz	-0.44	-1.11	-2.00
8000 Hz	-0.67	-1.56	0.22

*In dB re pre-exposure threshold.
**The negative sign indicates that the post-exposure threshold was better than the pre-exposure threshold.

Although the size of the tympanic temperature shift was somewhat larger following the second 20 minute exposure (-1.46° F.), the shifts found following the ten minute exposure (-0.62° F.) and following the five minute exposure (-0.73° F.) were very close to that found following the first 20 minute exposure.

There were no significant differences in overall acoustic impedance in the plane of the eardrum for these nine subjects following any of the three exposures. Again, however, an increase of approximately 10 mm water pressure was found in the middle ear following all three of the cold exposures. There were no significant differences in pre-exposure compliance measurements prior to any of the three exposure sessions. When the post-exposure compliance curve for the 20 minute exposure duration and the five minute exposure duration were compared, however, a distinctly greater increase in stiffness in the ear following the 20 minute exposure under both negative and positive pressure conditions was found. The length of the cold exposure seemed to affect the extent of the compliance shift in the direction of the longer the exposure duration, the greater the stiffness of the ear. Again, the pre-exposure muscle reflex thresholds to a stimulus of 250 Hz were normal and no significant differences were found following any of the exposure durations.

Recovery of the air-conduction shifts found were tracked following all three exposure sessions at all frequencies. Recovery took 60 minutes following the 20 minute exposure at -0.7° F. and approximately 40 minutes following the 10 minute exposure. The recovery rate appeared to be similar for all of the frequencies affected.

Once air-conduction thresholds had reached pre-exposure levels and had stabilized (± 2 dB), final impedance and tympanic temperature readings were also made. In all cases tympanic temperature had returned to the pre-exposure levels by this time. Overall acoustic impedance measurements in ohms were not changed by the exposure and the readings made at the final testing time were the same as the pre and post-exposure readings. Middle ear pressure levels did not completely return to pre-exposure levels by the time of the final measurement. The type of shift in compliance found following both the 20 minute exposures was completely gone by the time of this final compliance check,however overall compliance was greater at this time than at any other testing time. Lastly, the acoustic reflex threshold remained the same as it had been before and after all of the exposure durations.

Conclusions

Within the limitations of this study, the following conclusions appear to be warranted:

1. Exposure to temperatures of approximately -7° F. for 20 minutes resulted in a conductive-type of hearing loss in approximately half of the subjects tested.

2. The post-exposure air-conduction audiometric curve for the subjects affected was depressed in the low frequencies (125 Hz, 250 Hz, 500 Hz) by approximately 5 dB to 6 dB, unaffected at 1000 Hz and slightly enhanced in the high frequencies (2000 Hz, 4000 Hz and 8000 Hz). The main factor determining which subjects' hearing was affected by the cold exposure and which subjects' hearing was not affected appeared to be the pre-exposure compliance of the ear. The stiffer the middle ear system was prior to the cold exposure, the less likely a threshold shift would occur.

3. When the length of the exposure duration was reduced, the size of the air-conduction threshold shift was likewise reduced. The ten minute exposure duration resulted in low frequency shifts of approximately 3 dB,

and the five minute exposure duration did not affect thresholds significantly.

4. Bone-conduction thresholds were not affected by the cold exposure.

5. The mean pre-exposure tympanic temperature was 98.0° F. and the mean shift in tympanic temperature was approximately the same following all of the exposure durations. The overall range was 0° F. shift to -2.40° F. shift, with an overall mean shift of -0.80° F.

6. Overall acoustic impedance (in ohms) was normal pre-exposure and was not significantly affected by the cold.

7. Middle ear pressure was normal for the group of shifters (+1.67 mm water pressure) prior to the exposure and somewhat increased for the group of non-shifters (+17.00 mm water pressure) at this time. The mean post-exposure shift in middle ear pressure was 10.91 mm for all subjects, however.

8. At most pressure levels, the shifters' ears were more compliant than the non-shifters' ears prior to the exposure. Following the exposure, however, both groups showed reduced compliance under negative canal pressure conditions and enhanced compliance under positive pressure conditions which implies increased middle ear pressure resulting from the cold exposure.

9. The mean intra-aural stapedius muscle reflex threshold to a stimulus of 250 Hz was normal before and after all of the exposure durations.

10. Recovery from the air-conduction threshold shifts was regular and constant for all of the exposures. Recovery from the 20 minute exposure to -7.0° F. was complete within 60 minutes and recovery from the 10 minute exposure was complete within 40 minutes.

11. The shift in tympanic temperature recovered within the time needed for the air-conduction thresholds to recover.

12. Middle ear pressure shifts had not fully recovered by the time the threshold shifts had done so. The mean compliance readings at this final testing time revealed more compliant ears than either immediately pre or post-exposure.

13. It appeared that cold air apparently increased middle ear pressure and affected the tympanic membrane's vibratory capacity in some of the subjects, resulting in a slight conductive-type hearing loss (displayed audiometrically as an air-conduction "stiffness tilt").

14. Given the fact that the type of audiogram obtained following the cold exposure is similar to that found in patients with adhesive otitis media and pre-clinical otosclerosis, great care should be taken to determine how long the patient being tested was outdoors in cold air temperatures immediately preceding an audiometric evaluation. Sufficient time should be allowed for threshold shifts caused by the cold air outdoors to fully recover before the actual pure-tone testing is begun to help insure valid pure-tone test results and to aid in avoiding mis-diagnoses of middle ear pathology.

Recommendations for Further Research

The present study should be replicated using an adequate testing environment (a sound treated booth) and Bekesy audiometry, and the effects of longer exposures and lower temperatures should be examined.

Research that resulted in a table that could be used clinically to determine how long a subject needed to wait following a particular cold exposure before beginning audiometric testing would be desirable.

Investigations should be made of the relationship between the recovery patterns of the various impedance measurements and tympanic temperature measurements and the air-conduction threshold recovery patterns found.

The possibility of animal research concerning the effect of cold air on the action of the tympanic membrane and middle ear muscles, tendons, and ligaments should be explored.

The effect of long term cold exposure on the auditory system (such as on men who work in commerical freezers) should be investigated.

BIBLIOGRAPHY

BIBLIOGRAPHY

Books

Ballenger, J. J., Diseases of the Nose, Throat, and Ear. London: Henry Timpton, 1969.

Bard, T., Medical Physiology. St. Louis: C. V. Mosby Co., 1956.

Benzinger, T. H., "The Thermal Homeostasis of Man" from Les Concepts de Claude Bernard sur le Milieu Interieur, edited by Claude Bernard. Paris: Masson and Co., 1967.

Benzinger, T. H., and Kitzinger, C., "The Human Thermostat" from Temperature - Its Measurement and Control in Science and Industry. New York: Reinhold Publishing Corp., 1963.

Benzinger, T. H., and Taylor, G. W., "Cranial Measurements of Internal Temperature in Man" from Temperature - Its Measurement and Control in Science and Industry. New York: Reinhold Publishing Corp., 1963.

Boies, L. R., Fundamentals of Otolaryngology: A Textbook of Ear, Nose and Throat Diseases. Philadelphia: W. B. Saunders Co., 1957.

Ganong, W. F., Review of Medical Physiology. Los Altos: Lange Medical Publications, 1967.

Jepsen, Otto, "Middle Ear Muscle Reflexes in Man," from Modern Developments in Audiology, edited by James Jerger. Houston: Academic Press, 1963.

Scott-Brown, W. G., et al., Diseases of the Ear, Nose and Throat. London: Butterworth, 1965.

Ward, W. D., "Auditory Fatigue and Masking" from Modern Developments in Audiology, edited by James Jerger. Houston: Academic Press, 1963.

Wever, E. G., and Lawrence, M., Physiological Acoustics. New Jersey: Princeton University Press, 1954.

Periodicals

Brody, J. A., et al., "Draining Ears and Deafness Among Alaskan Eskimos," Archives of Otolaryngology, 81 (1965), 29-33.

Campbell, P., "The Importance of the Impedance Formula in the Interpretation of Audiograms," Transactions of the American Academy of Ophthalmology and Otolaryngology, 54 (1950), 245-252.

Carhart, R., and Jerger, J., "Preferred Method for Clinical Determination of Pure-Tone Thresholds," Journal of Speech and Hearing Disorders, 24 (1959), 330-345.

Chambers, A. H., and Lucchina, G. D., "Reversible Frequency Selective Reduction by Cold of Round-Window Potentials," Federation Proceedings, 15 (1956).

Cox, J., "How Quiet Must It Be to Measure Normal Hearing?" Noise Control, 1 (1955), 25-29.

Dirks, D., "Bone Conduction Measurements," Archives of Otolaryngology, 79 (1964), 594-599.

Dirks, D., "Factors Related to Bone Conduction Reliability," Archives of Otolaryngology, 79 (1964), 551-558.

Gulick, W. L., and Cutt, R. A., "The Effects of Abnormal Body Temperature Upon the Ear: Cooling," Annals of Otology, Rhinology, and Laryngology, 69 (1960), 35-50.

Hughson, W., and Crowe, S., "Experimental Investigation of Physiology of the Ear," Acta Oto-Laryngologica, 18 (1933), 291.

Jerger, J., and Tillman, T., "A New Method for the Clinical Determination of Sensorineural Acuity Level (SAL)," Archives of Otolaryngology, 71 (1959), 948-955.

Kahana, L., et al., "Effect of Temperature Change on Round-Window Response in the Hampster," American Journal of Physiology, 1963 (1950), 213-223.

Lamb, L., and Peterson, J., "Middle Ear Reflex Measurements in Pseudohypacusis," Journal of Speech and Hearing Disorders, 32 (1967), 1-6.

Loch, W. E., "Effects of Experimentally Altering Air Pressure in the Middle Ear on Hearing Acuity in Man," Annals of Otology, Rhinology, and Laryngology, 51 (1942), 995-1006.

Naunton, R. F., "Clinical Bone-Conduction Audiometrics," Archives of Otolaryngology, 66 (1957), 281-298.

Olsen, W., "Artificial Mastodi Calibration of Bone Vibrators," Archives of Otolaryngology, 85 (1967), 314-318.

Patterson, W. C., et al., "The Relationship of Temperature to the Cochlear Response in Poikilotherm," The Journal of Auditory Research, 8 (1968), 439-448.

Robertson, E. O., et al., "Relative Impedance Measurements in Young Children," Archives of Otolaryngology, 88 (1968), 70-76.

Shambaugh, G. E., "Tympanic Thermometry During Anesthesia," Archives of Otolaryngology, 90 (1969), 28.

Smith, K. R., "Bone Conduction During Experimental Fixation of the Stapes," Journal of Experimental Psychology, 33 (1943), 96-107.

Wever, E. G., and Bray, C. W., "The Nature of Cochlear Activity after Death," Annals of Otology, Rhinology, and Laryngology, 50 (1941), 317-329.

Unpublished Material

Hood, R. B., and Lamb, L. E., "Tympanometry: Reliability and Applicability," Unpublished Paper Presented at the Annual Convention of the American Speech and Hearing Association, Chicago, Illinois, November. 1969.

Norris, T. W., and Lamb, L. E., "Relative Acoustic Impedance Measurements with Mentally Retarded Children," Unpublished Paper Presented at the Annual Convention of the American Speech and Hearing Association, Denver, Colorado, November 1968.

Other Sources

_________ "Hearing Levels of Adults by Race, Region and Area of Residence: United States, 1960-1962," United States Department of Health, Education, and Welfare, Public Health Service Publication No. 1000, Series 11, No. 26.

_________ "Madsen Model ZO 70 Electro-Acoustic Impedance Bridge: Applications and Instructions for Use," Manual Published by Madsen Electronics Corp. Buffalo, New York.

_________ "Calculation of Basic Statistics When Missing Data Is Involved (the MDSTAT Routine)", Program Published by Michigan State University Agricultural Experiment Station (STAT Series Description No. 6), Computer Laboratory, Michigan State University, East Lansing, Michigan.

_________ "One Way Analysis of Variance with Unequal Number of Replications Permitted (UNEQ 1 Routine)", Program Published by Michigan State University Agricultural Experiment Station (STAT Series Description No. 13), Computer Laboratory, Michigan State University, East Lansing, Michigan.

Benzinger, T. H., (Naval Medical Research Institute, Bethesda, Maryland), Personal Communication, April 1968.

Dickey, W. T., et al., "Body Temperature Monitoring Via the Tympanic Membrane," Booklet Published by Radiation Systems, Inc., McLean, Virginia.

Lamb, L. E., (Department of Speech, The University of New Mexico, Albuquerque, New Mexico), Personal Communication, November 1969.

Lawrence, M., (Kresge Hearing Research Center, University of Michigan, Ann Arbor, Michigan), Personal Communication, March 1970.

Terkildsen, K., and van Dishoeck, H. A. E., "Impedance Measuring and Tubal Function," Published by Madsen Electronics Corp., Buffalo, New York.

Wilson, R. D., et al., "Anesthetic Management of the Poor Risk Patient," Booklet Published by Radiation Systems, Inc., McLean, Virginia.

General References

Periodicals

Benzinger, T. H., "Human Calorimetry by Means of the Gradient Principle," Journal of Applied Physiology, 12 (1958), S1-24.

Benzinger, T. H., "The Human Thermostat," Scientific American (January 1961), 1-9.

Benzinger, T. H., "Peripheral Cold- and Central Warm-Reception, Main Origins of Human Discomfort," Proceedings of the National Academy of Sciences, 49 (1963), 832-839.

Benzinger, T. H., "The Thermal Homeostasis of Man," Symposia of the Society for Experimental Biology, 18 (1964), 49-80.

Benzinger, T. H., "The Sensory Receptor Organs and Quantitative Mechanism of Human Temperature Control in Warm Environment," Federation Proceedings, 19 (1960), 32-43.

Benzinger, T. H., "The Thermostatic Control of Human Metabolic Heat Production," Proceedings of the National Academy of Sciences of the United States of America, 47 (1961), 730-739.

Bicknell, M. R., and Morgan, N. V., "A Clinical Evaluation of the Zwislocki Acoustic Bridge," Journal of Laryngology, 82 (1968), 673-691.

Brooks, D. N., "An Objective Method of Detecting Fluid in the Middle Ear," International Audiology, 7 (1968), 280.

Djupesland, G., "Intra-Aural Muscular Reflexes Elicited by Air Current Stimulation of the External Ear," Acta Oto-Laryngologica, 54 (1962), 143-153.

Djupesland, G., "Middle Ear Muscle Reflexes Elicited by Acoustic and Non-Acoustic Stimulation," Acta Oto-Laryngologica, Supplement 188 (1964), 287-292.

Djupesland, G., et al., "Size and Duration of Acoustically Elicited Impedance Changes in Man," Acta Oto-Laryngologica, Supplement 224 (1967), 220-228.

Feldman, A. S., "Acoustic Impedance Measurement as a Clinical Procedure," International Audiology, 3 (1954), 1-11.

Feldman, A. S., "Acoustic Impedance Studies of the Normal Ear," Journal of Speech and Hearing Research, 10 (1967), 165-176.

Feldman, A. S., "Impedance Measurements at the Eardrum as an Aid to Diagnosis," Journal of Speech and Hearing Research, 6 (1963), 315-327.

Feldman, A. S., and Zwislocki, J., "Effect of the Acoustic Reflex on the Impedance at the Eardrum," Journal of Speech and Hearing Research, 8 (1965), 213-222.

Fowler, E. P., "Drum Tension and Middle Ear Air Pressures; Their Determination, Significance, and Effect Upon the Hearing," Annals of Otology, Rhinology, and Laryngology, 29 (1920), 688-693.

Glickman, N., et al., "Shivering and Heat Production in Intense Cold," Journal of Applied Physiology, 22 (1967), 1-8.

Jepsen, O., "Intra-Tympanic Muscle Reflexes in Psychogenic Deafness (Impedance Measurements)," Acta Oto-Laryngologica, Supplement 109 (1953), 61-69.

Jepsen, O., "The Threshold of the Reflexes of the Intra-Tympanic Muscles in a Normal Material Examined by Means of the Impedance Method," Acta Oto-Laryngologica, 39 (1951), 406-408.

Lamb, L., "Application of Stapedius Muscle Reflex Measures to Diagnosis of Auditory Problems," International Audiology, 7 (1968), 188-199.

Metz, O., "Studies on the Contraction of the Tympanic Muscles as Indicated by Changes in the Impedance of the Ear," Acta Oto-Laryngologica, 39 (1951), 397-405.

Metz, O., "The Acoustic Impedance Measured on Normal and Pathological Ears," Acta Oto-Laryngologica, Supplement 63 (1946).

Morgan, L., "Effect of Temperature and Humidity on Hearing Acuity," The Volta Review, 62 (1960), 364-368.

Nilges, T. C., et al., "The Zwislocki Acoustic Bridge: Clinical Correlation," Archives of Otolaryngology, 89 (1969), 69-86.

Rawson, R. O., and Hammel, H. T., "Hypothalamic and Tympanic Membrane Temperatures in Rhesus Monkey," Federation Proceedings, 22 (1963), 283.

Simmonds, F. B., "Middle Ear Muscle Activity at Moderate Sound Levels," Annals of Otology, Rhinology, and Laryngology, 68 (1959), 1126-1143.

Terkildsen, K., "Acoustic Reflexes of the Human Musculus Tensor Tympani," Acta Oto-Laryngologica, Supplement 158 (1960), 230-236.

Terkildsen, K., "Movements of the Eardrum following Intra-Aural Muscle Reflexes," Archives of Otolaryngology, 66 (1957), 484-488.

Terkildsen, K., and Nielsen, S., "An Electroacoustic Impedance Measuring Bridge for Clinical Use," Archives of Otolaryngology, 72 (1960), 339-346.

Terkildsen, K., and Thompsen, K. A., "The Influence of Pressure Variations on the Impedance of the Human Eardrum," Journal of Laryngology, 73 (1959), 409-418.

Thompsen, K. A., "Case of Psychogenic Deafness Demonstrated by Measuring of Impedance," Acta Oto-Laryngologica, 45 (1955), 82-85.

Thompsen, K. A., "Employment of Impedance Measurement in Oto-logic and Oto-neurologic Diagnostics," Acta Oto-Laryngologica, 45 (1955), 159-167.

Wyndham, C. H., et al., "Reactions to Cold," Journal of Applied Physiology, 24 (1968), 282-287.

Zwislocki, J., "An Acoustic Method for Clinical Examination of the Ear," Journal of Speech and Hearing Research, 6 (1963), 303-314.

Zwislocki, J., "Analysis of the Middle-Ear Function. Part I: Input Impedance," The Journal of the Acoustical Society of America, 34 (1962), 1514-1523.

Zwislocki, J., "Some Impedance Measurements on Normal and Pathological Ears," The Journal of the Acoustical Society of America, 29 (1957), 1312-1317.

Zwislocki, J., "Some Measurements of the Impedance at the Eardrum," The Journal of the Acoustical Society of America, 29 (1957), 349-356.

Unpublished Material

Harford, E. R., "Panel on Impedance Bridges," Unpublished Paper Presented at the Annual Convention of the American Speech and Hearing Association, Denver, Colorado, November 1968.

Lamb, L. E., et al., "Pressure-Compliance Measurements as an Aid in Audiologic-Otologic Diagnosis," Unpublished Paper Presented at the Annual Convention of the American Speech and Hearing Association, Chicago, Illinois, November 1969.

Other Sources

__________ "A Collection of Papers on the Cranial Measurement of Temperature in Man," Radiation Systems, Inc., McLean, Virginia.

Brooks, D. N., "The Use of the Electro-Acoustic Impedance Bridge in the Assessment of Middle Ear Function," published by Madsen Electronics Corp., Buffalo, New York.