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STUDIES OF HUMAN TENSOR TYMPANI MUSCLE FUNCTION

by

ABRAHAM GREENBERG

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1976

This manuscript has been read and accepted for the Graduate Faculty in Speech and Hearing Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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ACKNOWLEDGEMENTS

In an era of high specialization, the success of any dissertation research depends on the sympathetic cooperation rendered by many individuals. The author is very grateful to Professor Irving Hochberg, Executive Officer, Program in Speech and Hearing Sciences, for serving as Advisory Committee Chairman. Without his valuable guidance, consultation, and sincere commitment, this project could not have been accomplished.

Grateful acknowledgement is also due to the other members of the advisory committee: Professor Harry Levitt, for his academic leadership and scholarly advice; and to Professor Harvey Halpern, who first exposed the author to the field of speech and hearing science, for his unfaltering faith and support.

Many thanks to Professor Thomas H. Fay, Columbia Presbyterian Medical Center, for help with the pilot study; also to Professors Joel Stark and Marvin Mazor, Queens College, for use of clinical facilities.

Finally, the author wishes to express his appreciation to his wife, Lillian, for her patience and forbearance; and to all those dear colleagues who unhesitatingly accepted a sexagenarian as their classmate and friend.

Abraham Greenberg, D.D.S.

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CHAPTER I

INTRODUCTION

General Aspects

Although many empirical investigations of the human tensor tympani muscle have been reported in the literature within the last half-century, a comprehensive theory of the organ's physiology has yet to emerge. That middle ear muscles respond to acoustic stimulation and to various non-acoustic stimuli, i.e., head movements, chewing, blinking, swallowing, vocalization, and REM sleep, has been well established (cf. Review of the Literature). Nevertheless, the role of the tensor tympani in many of these events has remained enigmatic, as attested by such characterizations in the literature of the muscle's function as "kaleidoscopic" (Simmons, 1963), "unknown" (Borg, 1972), and "puzzling" (Lidén *et al.*, 1972). The major stumbling block toward a solution of this problem has been the inability of investigators to observe and differentiate *musculus Tensor Tympani* (TT) reactions from those of *musculus Stapedius* (St) or from their combined effects during normal physiological behavior.

A number of specialized techniques have been employed to investigate middle ear muscle function in experimental animals and humans which may be classified into five groups: 1) direct visual examination, 2) electromyography, 3) cochlear microphonics, 4) manometry, and 5) impedance audiometry.

Direct visual examination of TT in vivo through eardrum perforations is generally hampered by the topographical complexity of the tympanum. The tensor tympani tendon and the entire area of insertion on the manubrium mallei lie above the field of vision through the external auditory meatus; the stapedius tendon can be more easily seen.

Intratympanic electromyography, a method of recording active potential flow in TT or St by means of electrode implantations, has been performed in conjunction with surgical operations on patients with otological disabilities. Inferences drawn from these data regarding normal middle ear muscle function may be subject to question. At its best, electromyography samples a few muscle fibers in a complex of multiform neuromuscular units comprising the muscle.

The cochlear microphonic (CM), defined as the aggregate electrical response of cochlear hair cells, is readily detected by placing one electrode on the round window and another elsewhere on the cochlea (Davis and Silverman, 1970, p.68). In the cat, CM is virtually proportional to cochlear fluid vibration velocity and provides an index of sound transmission (Møller, 1963). Since data are not readily obtainable in humans, the use of CM has thus far been limited to investigations of sound transmission properties in experimental animals.

Extratympanic manometry provides a technique of investigating middle ear muscle function in connection with eardrum movements, since the tensor muscle draws the tympanic membrane medially and the stapedius produces movement in either direction, usually laterally (Lidén et al., 1972). When the external canal is sealed, eardrum movements cause canal volume variations that are measurable using a special-purpose manometer. The different types of manometric systems used by various investigators will be reviewed below.

Impedance audiometry of the middle ear is, by far, the most frequently used procedure for investigating intratympanic muscle function in humans. "The study of impedance involves the analysis of the 'opposition' offered by a system to the 'flow' of energy." (Lilly, 1972, p.439). Specifically, for the system under study, acoustic impedance is the complex ratio between the effective sound pressure averaged over the surface of the system to the effective volume velocity through it (Tonndorf, 1973, p.252). When middle ear muscles are activated, the mobility of the ossicular chain is altered and impedance changes occur which affect the transmission properties of the middle ear. These impedance changes can be measured with an impedance bridge. Metz (1946) is credited as the originator of the instrument and the first to use it experimentally. Zwislocki (1957) refined the Metz bridge by eliminating an ear canal volume factor from its measurements. Terkildsen and Neilsen (1960) improved the bridge further by adding tympanography, thereby permitting its extensive utilization as a diagnostic tool in middle ear disorders. Routine impedance audiometry can supply intelligence about tympanic absolute impedance, eardrum compliance under systematically varied air pressures, and impedance changes caused by intratympanic muscle reflex activity in response to acoustic or tactile stimulation.

The acoustic reflex (AR), a much discussed psychoacoustic and audiologic phenomenon in which one or both intrinsic ear muscles are excited through acoustic stimulation, has a relatively stable threshold, a poststimulus onset time considerably shorter than other skeletal muscles, and typically develops an initial high tension within 100 msec followed by a 50% decrease of maximum within 10-20sec. Fatigue is apparently dependent upon auditory frequencies rather than intramuscular constraints (Blevins, 1963).

There is general agreement that TT and St perform combined reflectory contractions in experimental animals such as the guinea pig, cat , dog, and rabbit following acoustic stimulation of the cochlea (Kamoto *et al.*, 1954; Wersäll, 1958; Simmons, 1962; and Borg, 1972); that this does not hold unequivically for humans is most intriguing.* The muscular components of the acoustic reflex in humans is still an open question.

---

*It should be mentioned, in this connection, that 1-2% of the normal human population do not respond to acoustic reflex stimulation (Lilly, 1972).

Conventional Theories of Middle Ear Muscle Function

Jepson (1963) has discussed the conventional theories of middle ear muscle function: 1) protection theory, 2) accommodation theory, 3) fixation theory, 4) labyrinthine and pressure theory, and 5) overtone participation theory.

The protection theory was first introduced in 1837 by Müller when he suggested that the tensor tympani muscle acts reflexively in response to loud sounds so as to induce a "deadening or muffling of the ears." The theory, in its present form, assumes optimum sound transmission function at normal muscle tonus; but upon reflexive contractions of both muscles, the ossicular oscillations are restricted and thereby protect the inner ear from injury.

Littler (1965 p.33) has presented several arguments militating against the protection theory:

> . . . In man, it is doubtful if the protection can amount to as much as 10 dB for loud sounds, and it has been found that the time taken for the action to occur, about 10 msec, is much too long for protection to be obtained against loud sounds of sudden onset or even very loud transient sounds. Also, the deafness that is apparent as a result of exposure to some industrial noises during a working life is evidence that the ear has not really been an adequate protective device. On purely physical grounds, there would be no reason to expect protection merely by an increase of tension or a variation of elasticity. Such a change might decrease sensitivity over some frequencies while increasing it over others, so that whatever protection does occur appears to arise from the fact that the reflex action in response to a loud sound causes the tensor tympani to pull the drum inwards, and the stapedius muscle to pull the stapese out of the cochlea; . . . .

The accommodation theory, diametrically opposed to the protection theory, was first advocated by Köhler (1910). By analogy with visual accommodation, this theory regards the intratympanic muscles as mechanisms designed to adjust the sound conducting apparatus to its best possible efficiency. In its ultimate form, the accommodation theory asserts that the muscles are able to augment faint sounds and attenuate the intensity of excessively strong sounds. The presence of proprioceptive innervation (neuromuscular spindles) in the tensor tympani muscle (Candiollo, 1967) is a significant anatomical correlate that implies a capability for finely graded muscle movements.

The fixation theory hypothesizes that the middle ear musculature provides rigidity to the ossicular chain and prevents disarticulations between the ossicles during high frequency accelerations. According to this theory, the intratympanic muscles should have no major differential action on acoustic conduction.

Békésy (1936) expressed the view that the most important function of the middle ear muscles is to prevent the generation of clicking sounds in articular regions from occurring as a consequence of considerable accelerative forces which arise at high frequencies. By severing the tendons of the tensor tympani and the stapedius, he demonstrated that the ossicular chain had become loose. Jepson (1963) does not agree with Békésy's view because the threshold of AR becomes raised at higher frequencies.

The labyrinthine-pressure theory claims that contractions of the middle ear muscles affect acoustic reception by creating pressure changes in the labyrinthine fluid at the oval window. Experimental investigations by Lempert et al. (1949) did not disclose evidence supporting the labyrinthine-pressure theory.

The overtone participation theory emphasizes the role of intratympanic muscle activity in the formation of overtones. Stevens and Newman (1936) showed with cat CM recordings that harmonics could arise by pure tone stimulation of varying frequencies and intensities. When the investigators severed the tensor tympani tendon, changes in the second harmonic occurred but not the third. Wever and Bray (1942) found that mechanical pressure applied to the stapedius tendon in cats, led to a change in the overtones.

In recent years, organismic and environmental concepts of middle ear muscle function (Simmons, 1959, 1962, 1963, 1964a, 1964b) have attracted considerable notice. Dallos (1973, pp.474-5) discusses this subject:

> Simmons (1964) brought some order and considerable light to the jungle of conflicting middle ear muscle reflex theories. . . . Simmons' first question was aimed at the most popular protection theory. He asked where in nature sounds are loud enough to have necessitated the evolution of a protective mechanism to guard against them. . . .
>
> Simmons noted that there are three modes of muscle activity. The first is a simple change in muscle tonus, that is, spontaneous activity, which is clearly observable in awake and alert animals. . . . A second proposed function of fluctuating middle ear transmission brought about by changing muscle tonus is to pro-

> vide a variable auditory background which, in analogy of the operation of the visual system, would enhance the maintenance of auditory attention. . . .
>
> Simmons demonstrated that the muscle reflex can become active at sound levels considerably lower than those called for by the protection theory. . . . In this context the reflex could serve to attenuate inborn sounds of the organism and could thus help it to zero in on the external stimulus. . . . Simmons proposed that this function of the middle ear muscles, namely, the anticipatory contraction during noise-producing skeletal muscle activity, might be their most important contribution.

Review of the Literature

Early workers in the field of auditory physiology relied heavily on visual and optical means for investigating tympanic membrane movements attributed to middle ear muscle activity. Köhler (1910), for example, had a tiny mirror glued to his own eardrum by an obliging otologist in order that eardrum movements following acoustic stimulation could be studied with the aid of a light beam. With strong acoustic stimulation, changes in the direction of the reflected light could be detected. Later, Kobrak (1938) refined and repeated Köhler's mirror technique. Through reflecting a narrow beam of light from the mirror to a screen 4 m away, he was able to demonstrate small displacements of the eardrum concomitant with AR.

In a classic experiment, Wada (1924) used minute pieces of gold foil attached to the surface of the tympanic membrane to measure fluctuations in that organ.

Waar (1923) observed the effect on the eardrum of voluntary TT contractions by a subject. Using an otic microscope, he saw an upward and inward movement of the manubrium mallei approximately 40 micra in amplitude. The pars tensa of the tympanic membrane only accompanied the excursion of the manubrium for about 20 micra, according to Waar's observations. Kawata (1958) also claimed to have observed manubrial displacement by optical methods following acoustic reflex stimulation.

Later investigators utilized many different methods, either singly or in combination, to research human TT functions.

Manometric research.--Terkildsen's investigations (1957, 1960) made use of a capillary tube micromanometer connected to the auditory canal with an airtight fitting, and subsequently proved the presence of small eardrum movements during AR activity. The eardrum movements were in most instances lateral, "corresponding to a contraction of the stapedius muscle," but in several instances the movements were very definitely mesial and could only have been caused by the tensor muscle.

Mendelson (1957, 1961) reported almost identical observations as Terkildsen. He obtained the airtight seal of the external canal with an inflatable sleeve urethral catheter which was connected to a very sensitive electrical capacitance type of manometer in which applied pressure differences would change the transconductance of an ionization tube.

Holst, Ingelstedt, and Örtegren (1964) also recorded tympanic membrane movements through extratympanic manometry. The authors accepted inward movements of the eardrum, manifested by a pressure decrease, as evidence of tensor contractions; outward movements of the eardrum, manifested by a pressure increase, were presumed indicative of stapedius activity; and biphasic movements were interpreted as contractions of both muscles simultaneously. Holst *et al.* used an intense acoustic stimulus, 127 dB SPL at 500 Hz, to produce AR; they noted that the threshold for eliciting tensor activation was about 15 to 20 dB higher if the stapedius had been sectioned. It should be mentioned that at this intensity, the stimulus may have caused a gross startle reaction. The authors denied this possibility.

To complete the record, one other manometric investigation by Weiss, Mundie, Cashin, and Shinabarger (1962) showed evidence to support the hypothesis that both, TT and St, respond to intensive sound stimulation in humans.

Tympanic electromyography.--Salomon and Starr (1963) implanted electrodes in the tensor tympani and the stapedius muscle respectively in each of two patients who were about to undergo surgery for longstanding pathology. The authors investigated the effects of nonacoustic stimuli upon active potentials of middle ear muscles and found that an air jet stream directed at the ipsilateral supraorbit was *followed* by increased activity in TT only, whereas vocalization, yawning, laughing, swallowing, and coughing were *preceded* by increased activation of both middle ear muscles.

Djupesland (1964) studied the acoustic reflex during 125 surgical procedures by means of impedance audiometry, electromyography, and direct microscopic inspection. Data were obtained on responses to nonacoustic as well as acoustic stimulation. He concluded that pure tone stimulation in the range of 65-115 dB above threshold usually produces only a stapedius reflex; any tensor tympani contraction is part of a startle related cochleo-palpebral reflex and can be expected at 115-140 dB SPL.

Impedance audiometry research.--Jepson (1955) failed to record any indication of an acoustic reflex through impedance audiometry in seven ears in which the stapedii were definitely paralytic; moreover, in two ears suspected of tensor paralysis, a normal reflex was recorded.

Klockhoff (1961) performed impedance reflexometry on 15 patients afflicted with unilateral facial palsy. All patients displayed an acoustic reflex on the contralateral side but none responded to a 1000 Hz pure tone at 120 dB SPL on the palsied side. He considered these results *prima facie* evidence that the human acoustic reflex is produced by the stapedius alone. Commenting on the role of TT in the acoustic reflex, he stated:

> . . . there appears to be no conclusive evidence that isolated tensor tympani muscle activity has ever been recorded in humans. . . . The enigmatic behavior of the tensor tympani is underscored by the fact that, in humans, that muscle is incomparably the larger of the middle ear muscles and, by virtue of its attachment to the manubrium, could scarcely avoid being recorded in the event of contraction. Since no histologic signs of tensor atrophy have been demonstrable, it must be assumed that the muscle has an active function.

Klockhoff, furthermore, carried out extensive experiments on the effects of nonacoustic stimulation on the impedance of the middle ear with the hope of activating the tensor tympani muscle. When subjects' faces were stimulated by an air jet from a Politzer balloon directed toward the occular region, he found there appeared a new type of impedance response differing from that previously attributed to the stapedius. In the words of the author:

> The latency and duration of the response were clearly shorter than those observed for the stapedius reflex. The amplitude was often of considerable magnitude, being in some cases greater than the maximal deflection obtainable with acoustic stimulation in the same ear. The same type of response was recorded without exception in 50 normal ears.

After more investigations with patients having anesthetized corneas, rhizotomies for trigeminal neuralgia, and one having a prosthetic eye, Klockhoff concluded that <u>the supraorbital air jet stimulus causes a pure TT startle related reflex accompanied by a symmetrical eye blink</u>. This conclusion was supported later by the electromyographic findings of Salomon and Starr (1963).

Feldman (1967) performed impedance reflexometry with the Zwislocki acoustic bridge on many patients whose stapedii were inoperative because of pathological or post-surgical conditions and on five patients with sectioned tensor tympani muscles. In the former, he was unable to elicit acoustic reflexes, while in the latter, an acoustic reflex was demonstrated in each case. He concluded that it is not possible to document with impedance monitoring an acoustic TT response in humans.

In an effort to resolve the open question of TT acoustic physiology, Lidén, Peterson, and Harford (1970) carried out investigations of the muscle's responses to acoustic and nonacoustic stimuli using impedance audiometry and manometry for instrumentation. Their subjects were patients with suprastapedial facial palsy, otosclerosis (unilateral or bilateral), and a control group of normals. In their judgement, the acoustic reflex is primarily due to stapedial response; but in 13%, the recording patterns suggest that both muscles contracted during acoustic stimulation. The stapedius appeared to have a lower threshold than the tensor tympani muscle.

Shearer and Simmons (1965) studied middle ear muscle behavior during speech and stuttering, and Pessah and Roffwarg (1972) found spontaneous middle ear muscle activity "concurrent with or preceding" rapid eye movements (REM) sleep. None of the investigations could separate out TT function from St function through impedance audiometry; coactivity of the muscles was presumed by the investigators.

Table 1, page 14, shows a summary of ten investigations on the human aural reflex by type of stimulation.

Aims of the Present Investigation

From the above account, it is clear that further research into the physiology of the human tensor tympani muscle is needed. One objective of the present project is

TABLE 1

SUMMARY OF FINDINGS OF TEN INVESTIGATIONS ON HUMAN AURAL REFLEX BY TYPE OF STIMULATION

	Acoustic		Pneumatic (S.O.Jet)		Tactile (Ear)		Electric (Ear)	
	TT	St	TT	St	TT	St	TT	St
Terkildsen[a]	+	+						
Mendelson[a]	+	+						
Weiss *et al.*[a]	+	+						
Holst *et al.*[a]	+	+	+	+				
Jepson[b]	−	+						
Klockhoff[b]	−	+	+[e]	−	−	+	−	+
Feldman[b]	−	+						
Lidén *et al.*[ab]	+[d]	+						
Djupesland[c]	−	+		+	−	+		
Salomon & Starr[c]	+[f]	+	+	−				

[a] Used manometry.

[b] Used impedance audiometry.

[c] Used electromyography.

[d] In 13% of subjects.

[e] When St activity was precluded.

[f] Above 110 dB SPL.

Blank areas indicate unreported data.

to investigate the feasibility of separating TT function from St function by anesthetizing the tensor tympani motor nerve by a procedure commonly practiced in dentistry, i.e., intraoral conduction anesthesia of the mandibular division, Vth cranial nerve. The project will also gather data related to pre- and post-anesthesia behavior of the middle ear musculature; these data might provide new evidence regarding certain currently moot questions in middle ear physiology.

Do the intratympanic muscles actually conform with the "accommodation" theory of middle ear physiology? If the theory applies, the inactivation of TT by a local anesthetic should curtail the accommodation process sufficiently to adversely influence hearing threshold in a normal ear.

Is there an appreciable resting tonus in TT? Those muscles constantly engaging in rapid and delicate movements, characteristically possess higher degrees of tonicity when at rest than other less active muscles (Guyton, 1961,p.750). The magnitude of TT resting tonus will be reflected in pre- and post-anesthesia data of static and relative compliance measurements at the eardrum.

Does TT participate in the human acoustic reflex? The proposed reflexometry in the present study might shed some light on this issue.

Is the supraorbital air jet test a reliable method of assessing TT activity? According to Klockhoff and Anderson (1960), the sudden compliance shift recorded with impedance audiometry when an air stream is directed toward the supraorbit is a manifestation of a TT reflexive contraction. Further determinations of the Klockhoff test in association with anesthesia will be made on a group of normal subjects.

Briefly stated, the project proposes to achieve anesthesia of the tensor tympani muscle in normal young adults by <u>intraoral</u> means and gather pre- and post-anesthesia data as to hearing threshold, middle ear static and relative compliances, acoustic reflex, and the Klockhoff supraorbital air jet reaction.

CHAPTER II

BIOLOGICAL CONSIDERATIONS

Gross Anatomy of TT

It is a generally acknowledged biologism that form and function are mutually dependent variants of all living systems. In view of the disputation between the manometrists and the clinical impedance audiologists concerning certain functional aspects of TT (Terkildsen, 1957, 1960; Mendelson, 1957, 1966; Holst et al., 1964 versus Jepson, 1963; Klockhoff, 1961; Feldman, 1967), a comprehensive morphological analysis of the muscle seems to be especially warranted.

The intratympanic muscles are the smallest striated muscles existent in humans (Zemlin, 1968). The human tensor tympani muscle, Figure 1., first described by Eustachius in 1564, arises multiply from 1) the upper and cartilagenous portion of the Eustachian tube, 2) an area adjacent to the spine of the sphenoid's greater wing, and 3) from the walls of the bony canal housing the muscle. Distally, the muscle forms a tendonous cablet which emerges from the cochleariform process, executes a 90 degree turn of direction, traverses the tympanum laterally for 2.5 mm, and finally inserts onto the manubrium of the malleus. Wever and Lawrence

(1954) reported mean measurements of 25 mm in length and 5.85 sq. mm in cross section.

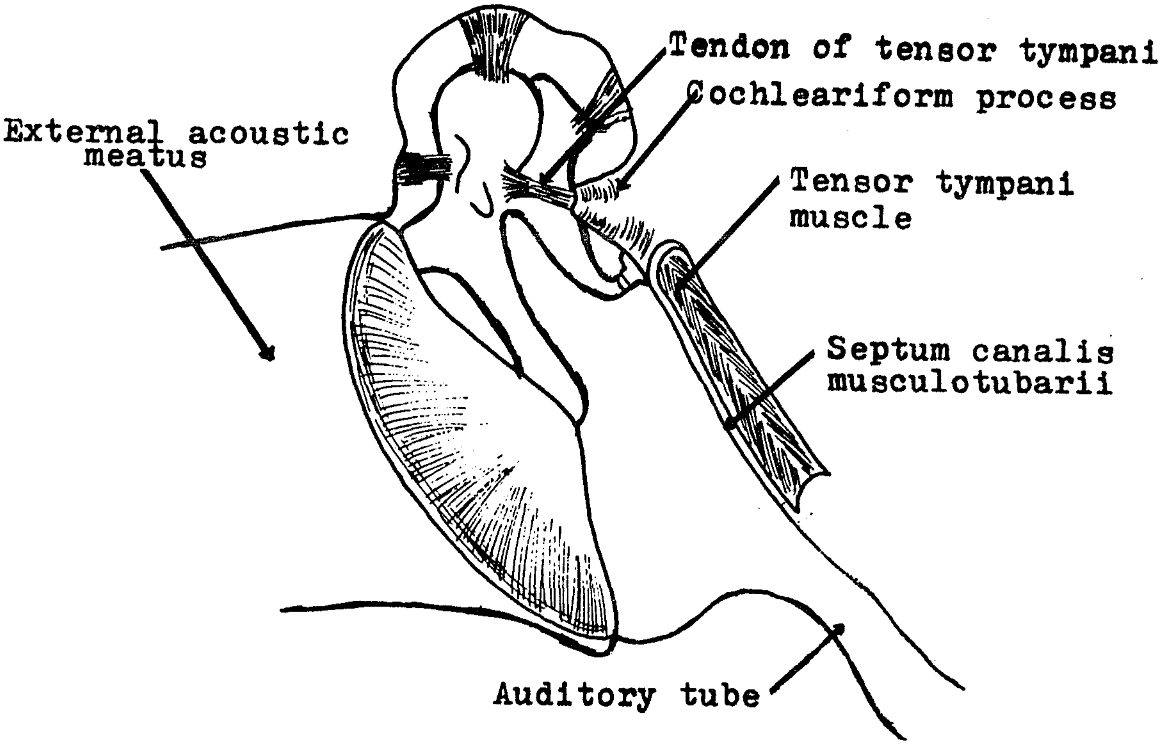

Fig. 1.--Schematic of musculus Tensor Tympani. (Adapted from W. R. Zemlin, Speech and Hearing Science, 1968, Prentice-Hall, Inc., Englewood Cliffs, New Jersey)

Architecturally, the tensor tympani muscle is penniform in design, that is, composed of fasciculi converging bilaterally on a central tendon, much like the structural organization of a feather. In penniform muscles, the combined power of all contracting muscle fibers becomes available upon activation, but the difference in overall muscle length only equals the differential executed by one fasciculus.

The tensor tympani's encasement by bone--as well as that of the stapedius--is unique in human anatomy; the converse, muscles covering bone, is prevalent. Békésy (1936) pointed out that bony encasements of the intratympanic muscles tend to improve hearing function by preventing lateral muscle vibrations during ossicular sound transmission.

Ontogenesis of the tensor tympani muscle commences in the first pharyngeal arch from the blastema of the internal pterygoid muscle; differentiation can be observed 42 days after fertilization in the 22 mm embryo (Schimert, 1934). The blood supply stems from the internal maxillary artery via branches of the middle meningeal and tympanic subdivisions.

Phylogenetically, the muscle can be identified with certainty only in mammals. Muscle fibers are present in amphibian and avian tympana but the mammalian analogue to these muscle fibers has not been clearly established.

The synergistic association, anatomically and physiologically, between the tensor tympani and tensor veli palatini muscles--the only tensor muscles in the human head --is well worth noting. Both muscles are innervated by the motor root, portio minor, of the mandibular division of the trigeminal nerve shown in Figure 2. Moreover, they have a common site of origin, an area adjacent to the spine of the sphenoid's greater wing. Lupin (1969) resected the two muscles in ten cadavers and concluded that they represent continuous parts of the same muscle group! This finding may explain the tinnitus experienced by patients with clonus of the posterior palate (Dieroff, 1965; Ogata, 1965) and why a

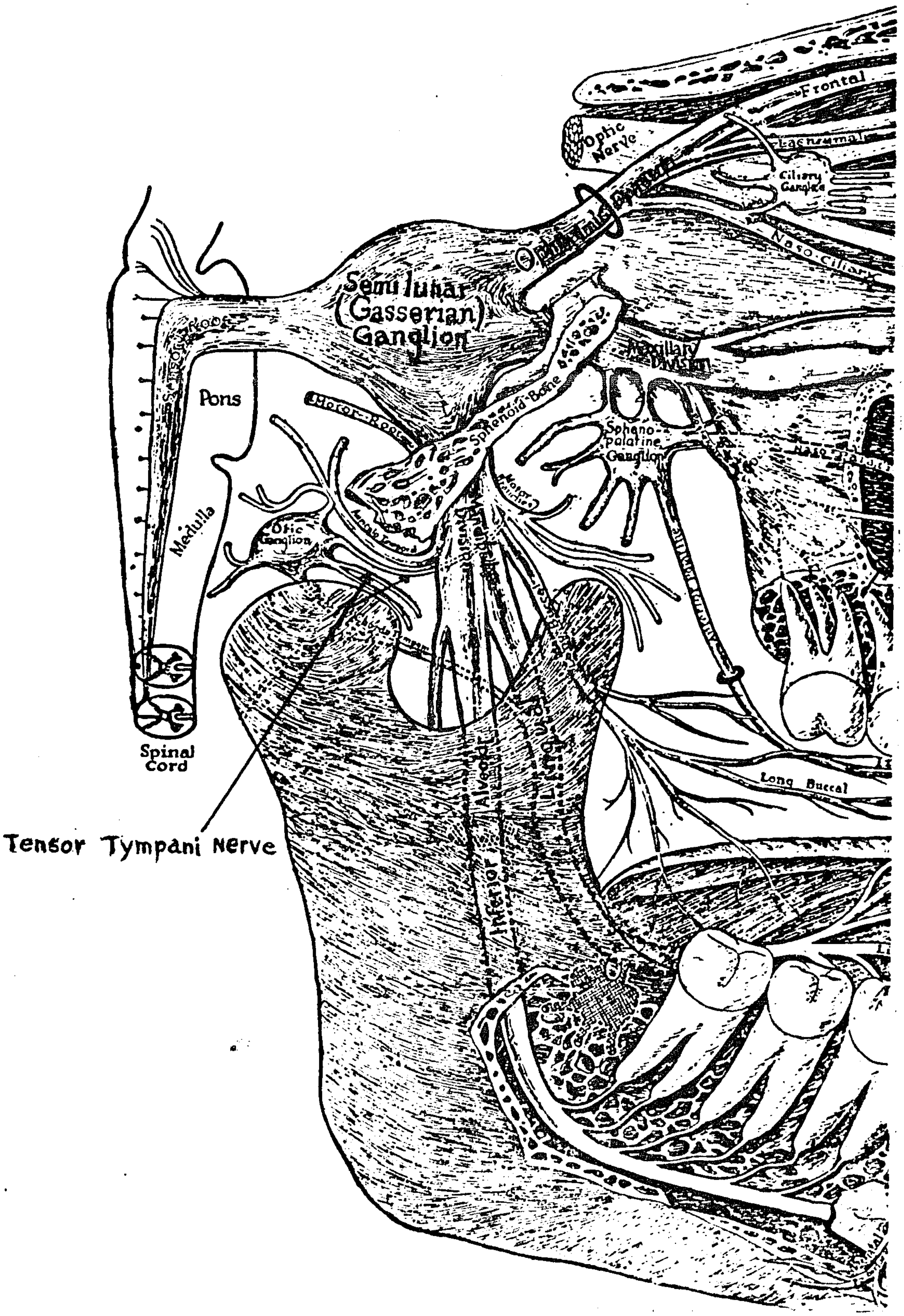

Fig. 2.--Schematic distribution of the trigeminal nerve. (Adapted from L. Winter, A Textbook of Exodontia, 1943, C. V. Mosby Co., St. Louis.)

spontaneous TT response occurs with swallowing (Salomon and Starr, 1963). With every swallow, the tensor veli palatini muscle opens the tubal lumen allowing, thereby, the middle ear to be aerated. Simultaneously, the tensor tympani muscle adjusts the tension of the tympanic membrane (Proctor, 1967).

Another example of functional correlation between the two tensor muscles of the head may be noted in the literature of phonology. Fritzell (1969) found that the palatal velum became preset on the order of 40-90 msec during articulatory transitions of English oral/nasal phonemes. Comparably, Salomon and Starr (1963) observed that TT activation occurs "usually 40 msec" before vocalization by a speaker.

The tensor tympani nerve branches from the motor root of the mandibular nerve, traverses the otic ganglion (Figure 2.), penetrates TT's epimysium at its proximal end, and after coursing briefly ramifies into numerous subdivisions. Winckler (1959) observed no less than 80 nerve fibers in a single cross section--a substantial number considering the small size of the muscle. Candiollo (1965) found a group of nerve cells similar in appearance to cerebral spinal ganglia at the site of the motor nerve's entry into the tensor tympani muscle.

Other nerves reportedly associated with TT are: branches from the tympanic plexus, branches from the lesser superficial petrosal nerve, and nerve fibers from the greater superficial petrosal nerve (Guerrier and Bolonyi, 1948; Lawrence, 1962); the significance of these neurologic findings is obscure at present.

Microscopic Anatomy of TT

Notwithstanding its striate histological appearance, TT functions are predominately involuntary; similar paradoxical characteristics may be seen in the diaphragm and cremaster muscles. Reger (1960) reported that only 2% of college students tested could voluntarily contract the auditory tensor muscle.

The structural unit of any skeletal muscle is its fiber, a large multinucleated cell whose length is measurable in centimeters and width is graded to almost naked eye visibility (about 100 microns). Within the cytoplasm (sarcoplasm) of a skeletal muscle fiber, can be seen many myofibrils, arranged in parallel columns. The transverse striations seen microscopically in a skeletal muscle fiber result from the synchronously disposed light and dark bands created by these myofibrils.

The fibers of mammalian tensor tympani muscles range in diameter from 5 to 60 microns, depending on species. In humans, peripheral muscle fibers are thinner than those more centrally situated (Candiollo, 1967). Atypical myofibrils, which appear to be annular or spiral and course obliquely within the fiber, have been described by Brzezinski (1962). Candiollo (1965) voiced the opinion that the atypical myofibrils may enable the muscle to make finer contractional adjustments.

Typical endomysial, perimysial, and epimysial connective tissue sheaths pervade the body of TT. Numerous connective tissue elastic fibers within the epimysium merge into the periosteum of the surrounding semicanal; more distal, the elastic fibers combine and constitute a third of the tensor tympani's tendon. Wersäll (1958) found relatively large amounts of adipose tissue in the endomysium and perimysium and postulated that its presence had no functional significance. Candiollo (1965) believed that the presence of fat in TT was not an indication of organic degeneration, for he demonstrated fatty tissue in the muscle of a cat 45 days of age.

Motor units in the human tensor tympani muscle were first investigated by Torre (1953) who found high innervation ratios of 1:7.5 and 1:7.7 in two specimens, i.e., 157 and 135 nerve fibers supplying 1184 and 1050 muscle fibers respectively. Inasmuch as the ability of a muscle to perform finely graded contractions is directly related to its innervation ratio, TT must be credited with this capability --a strong argument favoring the "accommodation theory" of TT function, cf. CHAPTER I.

The presence of neuromuscular spindles (proprioceptive organs) in the human tensor tympani muscle has been well established (Winckler, 1959; Brzezinski, 1962; and others). Typically, each spindle is enclosed by a connective tissue capsule containing capillary blood vessels, a variable number (2-10) of intrafusal muscle fibers, and nerve fibers. The spindle nerve fibers consist of specialized afferent nerve endings (spray or annulospiral) and efferent gamma nerve endings. The latter are made up of Gamma I motor fibers (3-8 μ-diameter) which terminate in discrete end plates, and Gamma II fibers (1-4 μ-diameter) which end in a diffuse network (Abbs, 1973). The efferent gamma system, Figure 3., regulates muscle length changes, while the afferent system serves to keep the central nervous system informed of differential length conditions. This peripheral information is then integrated with central influences, and the resultant relayed to anterior horn cells (Abbs, 1972). From the over-simplified viewpoint of a cybernetic circuit, the spindle appears to act as a genuine servomechanism that is controlled by a feedback mechanism.

Candiollo (1965) found neuromuscular spindles of the human tensor tympani muscle clearly distinguishable in the 6th month of fetal life; they were located within the entire length of the muscle and averaged 6 in number per specimen.

<u>Reflex Neuroanatomy of TT</u>

Sound signals received by the external ear are relayed through the middle ear to the cochlea. Here they excite the receptor cells of the organ of Corti and thus evoke nerve impulses within first-order neurons. These impulses travel toward the ventral and dorsal cochlear nuclei and from here along the polysynaptic central auditory pathways

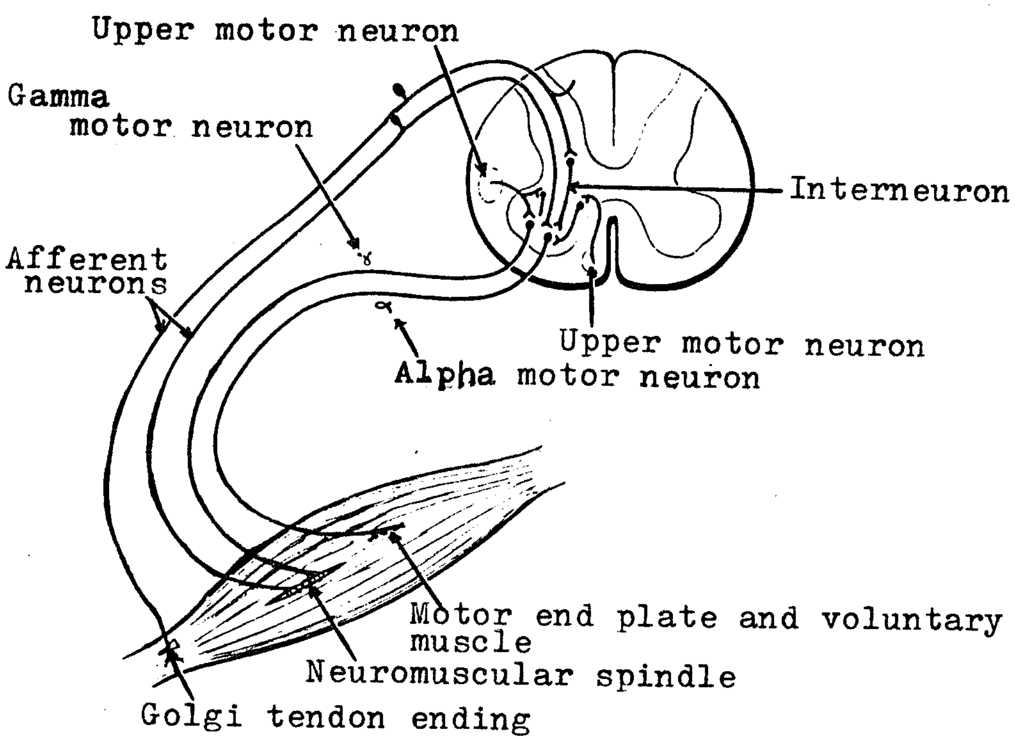

Fig. 3.--Neuromuscular spindle reflex loop. (Adapted from C. R. Noback, The Human Nervous System, 1967, McGraw-Hill Co., New York.)

and interposed nuclei toward the auditory areas in the temporal lobe of the cerebral cortex (Filogamo, 1967).

Simultaneously, the central nervous system is being continuously bombarded by a countless number of sensory impulses from peripheral receptor organs which evoke segmental as well as intersegmental reflex actions at the level of the lower centers and integrating actions in the higher nervous centers. Whenever an effector having to do with function of accessory structures of a sense organ is excited, such as the tensor tympani muscle in the middle ear, a reflex arc is activated and its action becomes an intrinsic part of the stimulus.

In its simplest form, a reflex circuit consists of an afferent neuron (ascending), a synapse (reflex center), and an efferent neuron (descending). Figure 4. shows schematically the middle ear acoustic reflex, in which the cochlear nerve constitutes the afferent portion of the reflex arc. The trophic center for the first neuron in the auditory pathway lies in the bipolar cell of the spiral ganglion in the spiral canal of the modiolus.

The central axons from the spiral ganglion enter the brain stem lateral to the facial nerve in the groove below the brachium of the pons and continue to the primary auditory centers, the ventral and dorsal nuclei of the cochlear nerve, which constitute the trophic center for the second neuron. Fibers from the contralateral ventral cochlear nucleus decussate to the opposite side, and together with the homolateral ventral cochlear fibers form the trapezoid body. In the lateral portion of the trapezoid body and in the anterior reticular formation lies the superior olivary nucleus where synapses occur with the nuclei of the trigeminal and facial nerves through the medial longitudinal fasciculus and the superior olivary peduncle (Jepson, 1963). The tensor tympani and the stapedius muscles are activated by the motor (descending) subdivisions of the trigeminal and facial nerves respectively. There is evidence that the motor nuclei of the middle ear muscles are also exposed to reflex activity from the brainstem reticular formation and from certain sensory areas of the skin of the face.

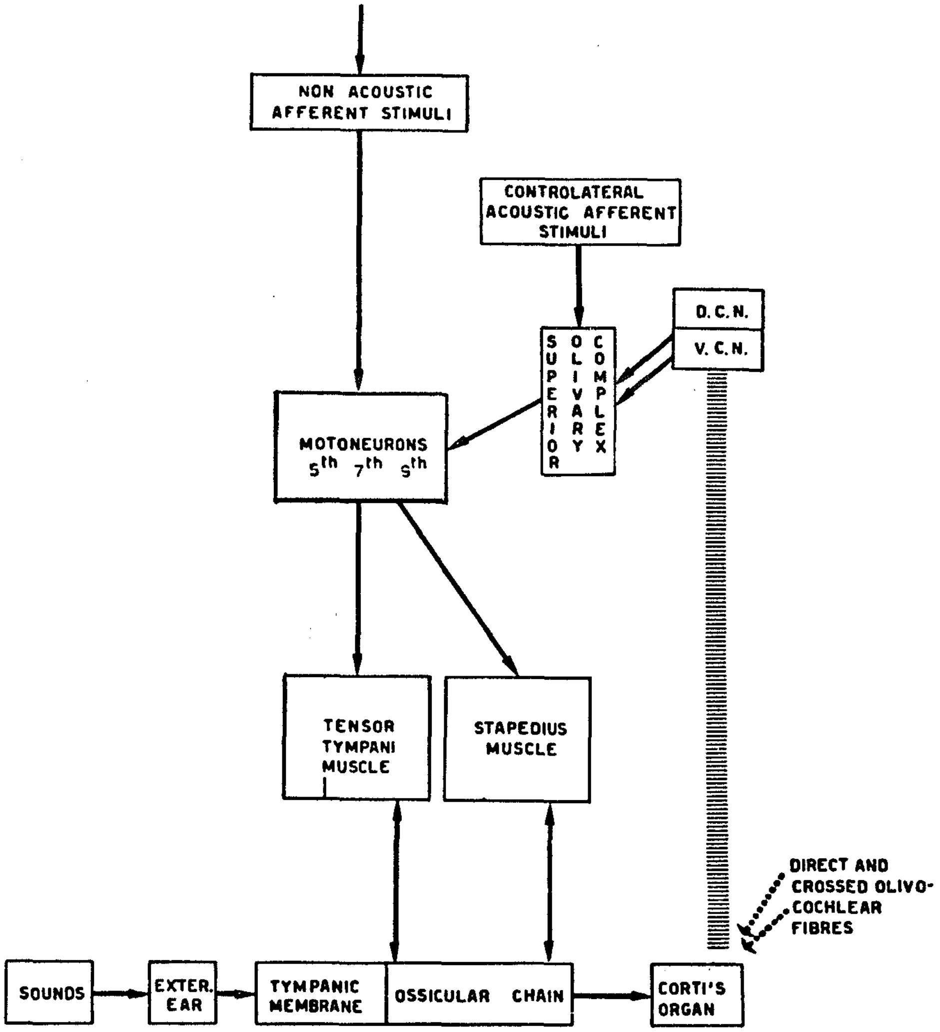

Fig. 4.--Block diagram showing acoustic and nonacoustic middle ear reflex pathways.

With respect to the connections between the reticular substance and the central cochlear pathways, the reticular substance gives rise to fibers which connect to all the motor and sensory nuclei of the cranial nerves in the brainstem; any individual reticular fiber may simultaneously send collaterals to the motor and sensory nuclei of these nerves (Rossi, 1967).

It was mentioned previously that tensor tympani activation has been reported in connection with vocalization, swallowing, chewing, and REM sleep (Salomon and Starr, 1963; Shearer and Simmons, 1965; Pessah and Roffwarg, 1972). By definition, these phenomena cannot be considered genuine reflexes but as synergistic and spontaneous motor acts, occurring concomitant with or preceding the initiating event; they are, presumably, integrated by higher cortical centers.

The supraorbital air jet reaction ad modum Klockhoff, however, does qualify as a true reflexive response in conjunction with the blink reflex.

Kugelberg (1952) demonstrated, by electromyography of the orbicularis oculi, that the supraorbital blink reflex in responding to a facial tap had two components, an initial proprioceptive (myotatic) reflex and a later nocioceptive (tactile) reflex. Moreover, the former produced an ipsilateral wink, while the latter caused a bilateral blink. When the supraorbital reflex was induced by "a light prick with a sharp needle or a faint puff of air applied to the skin . . .", only the second reflex occurred which had a latency between 25-40 msec, was asynchronous in character, and subject to habituation.

Rushworth (1962) obtained results similar to those of Kugelberg (1952). When the cornea was touched lightly with a minute wire loop, only the second component of the blink reflex could be observed electromyographically. Concerning the two components of the blink reflex, the author stated:

> . . . Both depend on the integrity of the supraorbital nerve and the first division of the trigeminal, but in some patients the first component seems to depend on the integrity also of the seventh nerve. . . .

The findings of Klockhoff (1961), Kugelberg (1952), and Rushworth (1962) suggest that the tensor tympani muscle and the orbicularis oculi participate in both components of the supraorbital blink reflex, whereas the stapedius only becomes an effector when the stimulation is sufficiently intense to trigger the first component.

Pharmacology of Lidocaine Hydrochloride

Nerve fibers are enclosed by semipermeable membranes and surrounded by tissue fluid. In the normal resting state, Na ions are concentrated outside and K ions within the nerve fiber. There are, also, positive charges external and negative charges internal to the membrane; an approximate electrochemical gradient of -70 to -90 mv exists across the membrane. Such a condition of normal resting potential is known as polarization (de Jong, 1970, p.45).

During impulse propagation, the difference in permeability of the membrane to Na^+ and K^+ is reversed by the action of acetylcholine. Consequently, Na^+ becomes concentrated on the internal surface of the membrane and K^+ now predominates in the extracellular fluid; a reversal of potential also occurs. Such a generally reversed condition is known as depolarization. The impulse passes along the nerve fiber as a wave preceded by a depolarization episode, and in its wake the original resting potential is restored after 3-4 msec in preparation for the following impulse.

A local anesthetic by an unknown action on the minute openings in the fiber membrane, prevents the passage of Na^+ into the nerve cell and the passage of K^+ through the membrane out of the fiber. Thus, the polarized nerve fiber is unable to depolarize to conduct an impulse. The prevention of depolarization must take place over an area of 2 or 3 nodes of Ranvier in a myelinated fiber, because the local anesthetic reaches the membrane of a myelinated nerve fiber only at these sites (de Jong, 1970, p.127).

The anesthetic must reach the nerve membrane in sufficient concentration; a minimal concentration (C_m) factor exists for each case. Once the anesthetic solution is deposited in the tissues, the extracellular fluid that surrounds the cells immediately begin to dilute it. The molecules of the solution diffuse in all directions with the concentration diminishing in geometric ratio as it leaves the original area of deposition. Thus C_m depends on the agent used, the technique of deposition, the absence of anatomical anomalies, and the type of nerve to be blocked. Loss of nerve function under local anesthesia takes place in the following rank order of selection: pain, temperature, touch, proprioception, and skeletal muscle tone (Monheim, 1968, p.106).

All synthetic local anesthetic agents available at the present time fall into two major groups: 1) those which contain an ester linkage in their chemical composition (e.g., procaine) and 2) those which contain an amide linkage (e.g., lidocaine). Esters are compounds derived from the interaction of an acid and an alcohol with the elimination of water; amides are substances derived from ammonia (NH_3) by replacing one or more hydrogen atoms by an equal number of monovalent acid radicals (Monheim, 1968).

Lidocaine (diethylaminoacet-2.6-xylidide), a local anesthetic known commercially as Xylocaine, has the structural formula depicted in Figure 5. It was first synthesized in 1943 but not fully tested or described until 1948 (Löfgren, 1948). The drug is a white crystalline powder dispensed as a hydrochloride, chemically very stable, and has a melting point of 69° C. Unlike the ester-type anesthetics, lidocaine can endure the lengthy heating often required in sterilizing procedures.

Tests have shown that the efficiency of lidocaine is highly superior to that of novocaine; comparatively,

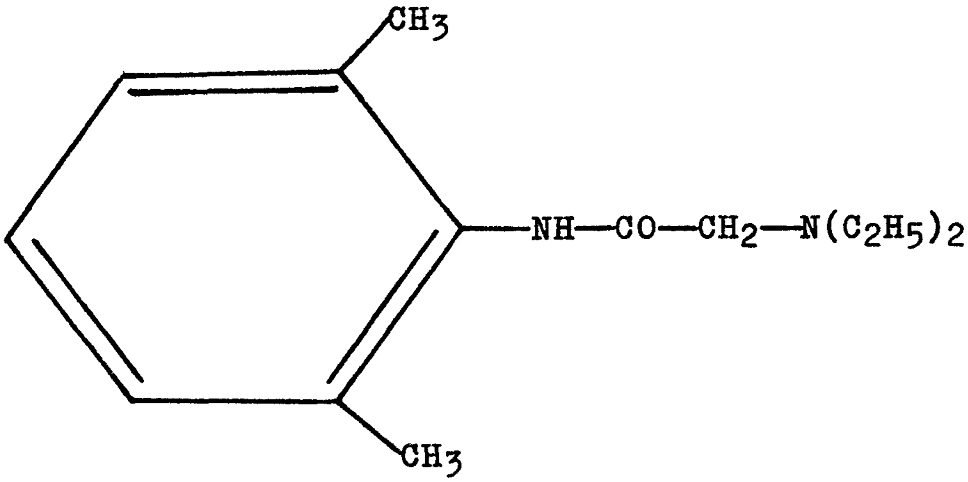

Fig. 5.--Structural formula of lidocaine

lidocaine hydrochloride has a shorter latency time, longer duration, higher frequency, and greater extent than novocaine (Löfgren, 1948, p.67). The eficiency of any anesthetic can be enhanced by addition of small quantities of a vasoconstrictor drug such as epinephrine (adrenaline); toxic effects are reduced by slower absorption of the constituents, and the depth and duration of anesthesia are increased by greater localization of the anesthetic agent. For general dental practice, 2% lidocaine hydrochloride with epinephrine 1:80,000 or 1:100,000 is best. In resistant cases, and for longer operations, 2% lidocaine hydrochloride with epinephrine 1:50,000 should be employed. An onset time from 2 to 4 minutes and a duration time from 180 to 195 minutes are obtained with the above solutions; the dosage (1 to 5 ml) varies individually.

A remarkable feature of lidocaine local anesthesia is the absence of untoward reactions. Löfgren (1948, p.66) wrote:

> . . . in 7,000 injections performed, side effects have been rare. Moreover, Siberg reports 8,000 injections of xylocaine (2 per cent solution with epinephrine 1:80,000) in dental practice without **any side effects**. It is interesting to note that Bremer et al. had access to 87 patients with poor novocaine-epinephrine tolerance. It was possible to anesthetize these patients with zylocaine-epinephrine without any side effects being observed. This fact indicates that not the epinephrine but the novocaine must be blamed for the symptoms in question. . . .

The present investigation used 1.8 ml of lidocaine hydrochloride with 1:100,000 epinephrine for intraoral mandibular nerve blockade.

CHAPTER III

METHODS

Subjects*

Ten volunteer subjects, between 21 and 35 years of age, were recruited from the student population at Queens College, New York City, by means of advertisement on classroom bulletin boards worded: SUBJECTS WANTED FOR HEARING TESTS BEFORE AND AFTER A ROUTINE LOCAL DENTAL ANESTHETIC OF ONE SIDE OF THE LOWER JAW. THOSE BETWEEN 21 AND 35 YEARS OF AGE WITH NO HISTORY OF EAR PATHOLOGY AND WITH PREVIOUS EXPERIENCE WITH DENTAL ANESTHESIA ARE ACCEPTABLE. STIPEND $25.00. CONTACT DR. A. GREENBERG AFTER 6:P.M. PHONE...... .

Six male and four female volunteers with a mean age of 22.25 years were accepted in order of application. Each subject received a project orientation in easily understood language (cf. Appendix B) to ensure his/her complete understanding of forthcoming procedures and was requested to sign a standard consent form (cf. Appendix C), a copy of which was retained by the subject. After participating in the project, each volunteer was given twenty-five dollars.

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*The Committee on Protection of Human Subjects, City University of New York, has granted certified approval of this research (cf. Appendix A).

Equipment

Grason-Stadler Békésy-type audiometer, model E800 with TDH-39 earphones.

American Electromedics impedance audiometer, model 83 equipt with tympanograph X/Y recorder, model 612.

Rubber-bulb ear syringe, 2 oz.

Anechoic chamber.

Dental operating chair.

Cook-Waite aspirating dental syringe, 1.8 ml.

Syringe needles, disposable, 25 gauge x 1.5 inches.

The Békésy audiometer.--The Békésy-type audiometer (Figure 6.) provides a pure tone test signal generated by a continuously variable beat-frequency oscillator with a range from 100 to 1000 Hz. Any one of three different modes of frequency presentation can be selected: through the full two decade range (100 to 10000 Hz), a limited area of two octaves, and a single frequency. The variable frequency modes can be presented in an ascending fashion from 100 Hz or descending from 10000 Hz; the test signal may be presented continuously or periodically interrupted at the rate of 2.5 interruptions each second (Hughes, 1972).

The attenuator is driven by an instantly reversible electric motor whose direction of rotation is determined by a push button hand-switch operated by the patient; his task is to keep the button depressed while he hears the tone, otherwise to release it. When the push button is held down, the signal is attenuated and when released, the signal is

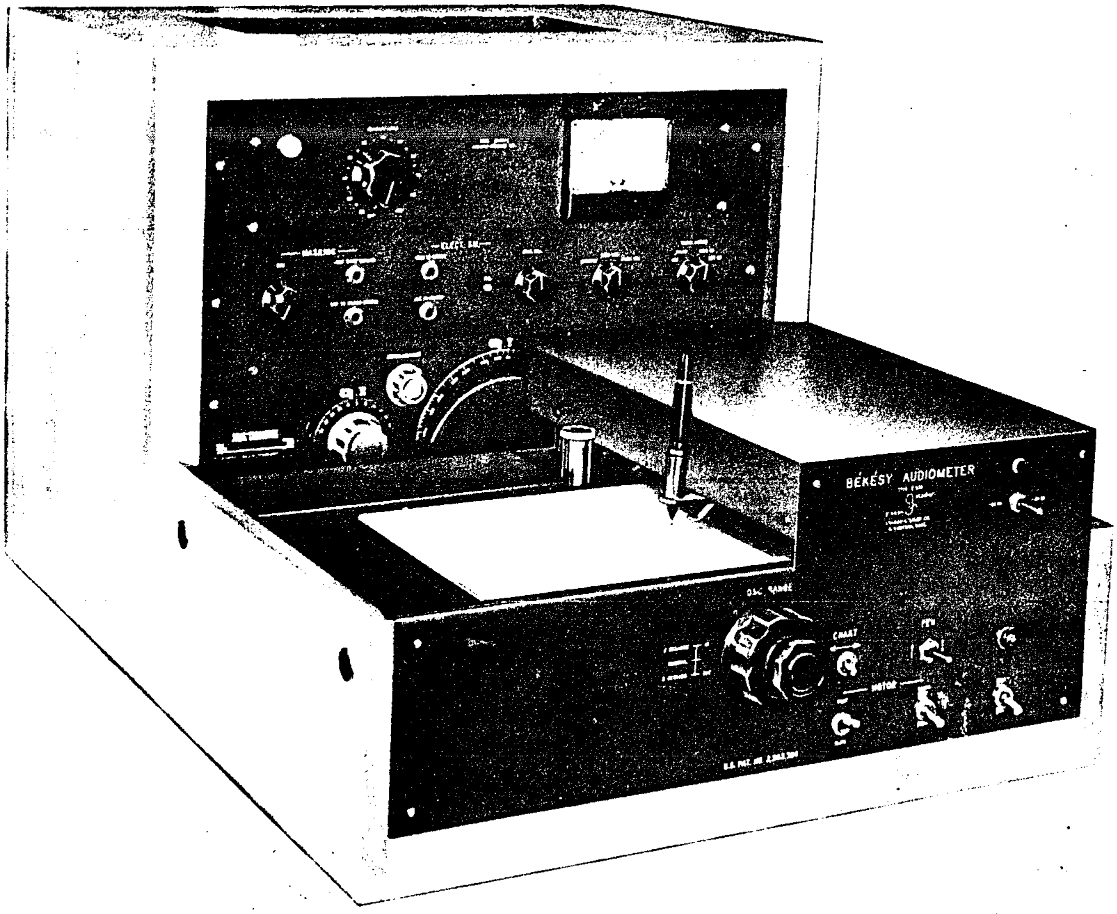


Fig. 6.--Békésy Audiometer, Model E800

automatically intensified. The signal can be attenuated or intensified optionally at the rate of 2.5 dB/sec or 5.0 dB/sec. A pen coupled to the attenuator traces a continuous recording of the subject's responses on a moving audiogram table that travels under the pen horizontally and vertically in synchronic relation to the frequency and hearing level controls.

An audiogram traced by the Békésy method represents the absolute threshold values at all frequencies in the range tested. In addition, it shows the difference in decibels between levels at which the patient just hears a signal of increasing intensity and those at which he just ceases to hear the signal when intensity is decreasing.

The American Electromedics Impedance Audiometer.--This instrument (Figure 7.) is an electroacoustic impedance measuring device or "impedance bridge" consisting essentially of three functional subsystems as diagramed in Figure 8.

1) Probe-tone generation.--A low-frequency probe-tone (220 Hz), 85 dB SPL, is emitted by a microtelephone inside a housing unit mounted unilaterally on the headset assembly.

2) Air pressure generation and measurement.--This subsystem contains a simple air pump and electromanometer to accurately measure induced outer canal pressure. It allows additional air to be pumped into, or withdrawn from, the outer canal, thereby producing medial or lateral static stress on the tympanic membrane.

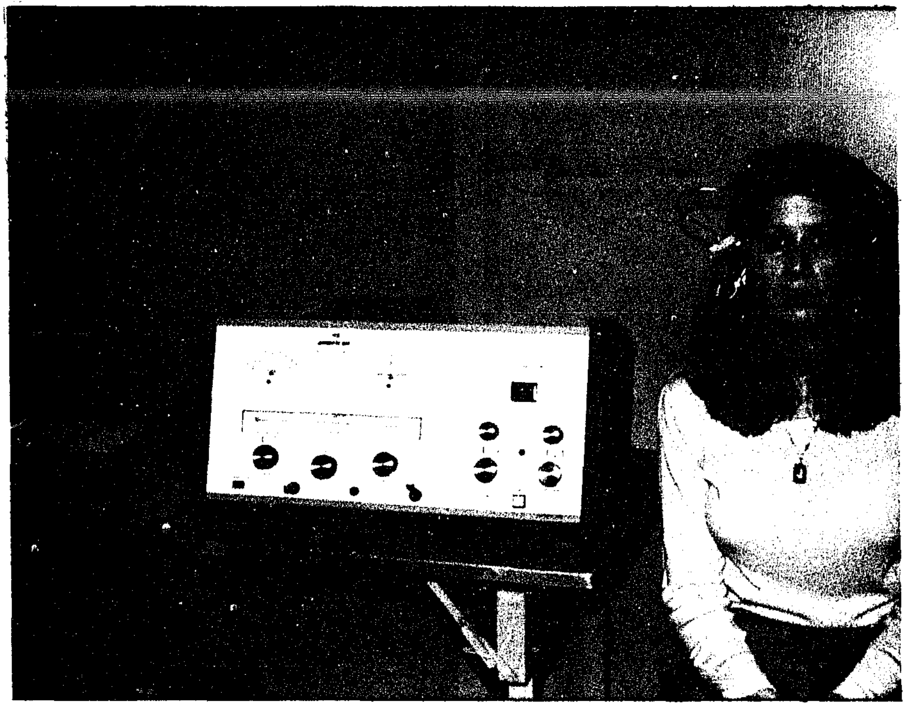


Fig. 7.--Patient, Impedance Audiometer A. E. 83, and X/Y Recorder, Model 612.

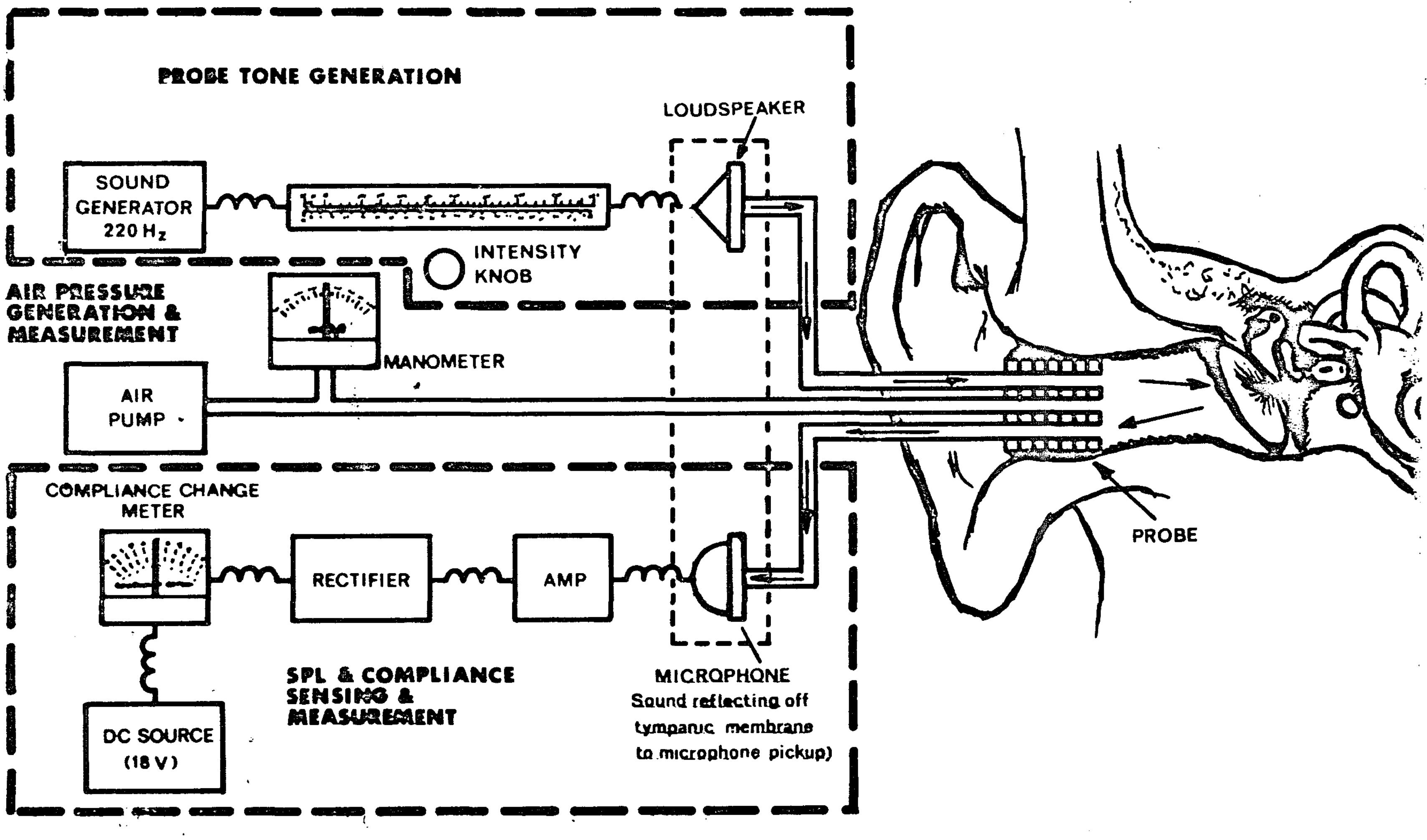


Fig. 8.--Functional representation of electroacoustic bridge, A. E. Model 83. (From Operation Manual, American Electromedics Corp., Dobbs Ferry, N.Y.)

3) Sound pressure level and compliance sensing measurement.--This component of the impedance audiometer monitors the sound pressure level of the residual probe-tone in the outer canal. "Residual" refers to the probe-tone energy which does not flow through the tympanic membrane. Inasmuch as middle ear acoustic impedance is the reciprocal of middle ear acoustic transmission (Tonndorf, 1964, p.35), the residual probe-tone energy is an index of the acoustic impedance magnitude.

A headband assembly carries an impedance measurement probe tip on one side and an earphone for contralateral presentation of acoustic stimuli on the other side. The probe tip contains three metal tubules connected to the probe-tone generation unit by three fine rubber hoses.

When the probe tip is sealed in the external meatus with the aid of a circumferential rubber cuff, a closed cavity is formed bounded by the inner surface of the probe tip, the walls of the external meatus, and the tympanic membrane. The three subsystems of the impedance audiometer can then operate individually through the fine rubber hoses and metal tubules. With such instrumentation, the basic clinical test procedures of impedance audiometry, viz., tympanometry, acoustic impedance, and acoustic reflex can be carried out.

Tympanometry measures eardrum compliance changes as air pressure in the external canal is systematically manipulated. Compliance is a coefficient expressing the responsiveness of a mechanical system to a periodic force and, according to Lilly (1972), the reciprocal of stiffness. Eardrum compliance is influenced by the condition of all middle ear components, e.g., tympanic membrane elasticity, <u>muscular tonicity</u>, ossicular mobility, and fluid content (Møller, 1972); consequently, tympanometry has become a valuable tool in clinical diagnosis. The basic datum of tympanometry, the tympanogram, is the pressure-compliance function usually taken between -200 and +200 mm (H_2O) air pressure in the ear canal and usually expressed in arbitrary units (1 to 10) of relative compliance change. The tympanograph X/Y recorder, model 612, coupled to the impedance audiometer is designed to automatically trace the tympanogram.

An <u>acoustic impedance</u> value can be obtained with the impedance audiometer by determining the static compliance of the middle ear in cubic centimeters of an equivalent volume of air. When the probe tip of the impedance audiometer is sealed in the ear canal of the subject, the tympanic membrane is the only structure to any degree susceptible to changes in ear canal pressure (Geffcken, 1934). By increasing ear canal pressure 200 mm (H_2O) or more over ambient pressure, the eardrum and middle ear system become effectively rigid and the compliance thus recorded (C_1) is minumum. Compliance measurement (C_1) is essentially that of the volume of air enclosed in the meatus. A second compliance measurement (C_2), taken when pressures on both sides of the eardrum are equal, is the compliance of the middle ear and the meatal air. Pinto and Dallos (1968) have shown that the compliances in C_2 are compounded additively when probe-tones are below 500 Hz. With these frequencies, wavelength distance far exceeds ear canal distance and no undesirable wave convolutions can appear in the canal. Inasmuch as the present project will employ a 220 Hz probe-tone, the difference between C_2 and C_1 will yield a compliance value attributable to the middle ear in terms of an equivalent volume (cc) of air. A curser scale on the impedance audiometer converts compliance values into acoustic ohms of impedance at standard conditions of atmospheric pressure (776.0 mm Hg), temperature (22° C), and relative humidity (50%).

Theoretically, <u>reactance</u> (X) and <u>resistance</u> (R) control <u>impedance</u> (Z), a complex vector quantity:

$$Z = \sqrt{X^2 + R^2}$$

The components of X, i.e., mass reactance and compliant reactance are frequency specific, are in direct opposition, and can cancel each other when carrier frequency is at resonant level. Above resonant frequency level, the transmission system is said to be "mass controlled"; below resonance, the system is"compliance controlled". In normals, a 220 Hz carrier frequency will produce a compliance controlled system (Lilly, 1972). In such a system, impedance can be inferred from compliance because the resistive component is either constant or negligible (Jerger <u>et al.</u>,1972).

The <u>acoustic reflex</u> refers to the consensual contraction of middle ear musculature following the introduction of loud sounds into either ear. The modification of middle ear impedance thus induced can be observed on the compliance change meter of the impedance audiometer. Model 83 is designed to provide any contralateral pure tone stimulus of .5K, 1K, 2K, or 4K Hz up to 125 dB HTL (ISO-1964) as well as broad-band, low pass, and high pass noise up to 125 dB SPL; stimulus duration may be set at 1.5 sec or 10.0 sec.

Procedures

Subjects were processed individually by appointment. A designated test ear from each of ten volunteers was given a screening otoscopic examination for the presence of gross eardrum defects or seruminal ear canal stenosis.

Condition I test procedures.--Condition I is defined as the subject's physiologic state of normal auditory function.

1) Pure tone hearing threshold.--Controls of the Békésy audiometer were set for continuous-tone, full-frequency sweep; the machine was turned on for ten minutes and then calibrated. After the subject was seated inside the anechoic chamber (IAC booth), a TDH-39 earphone was positioned over the test ear and a push button switch handed to the subject, who was thereupon instructed to keep the button depressed as long as a signal was heard and to release it when the signal was not heard. A one-minute practice run was allowed. Finally, an audiogram blank was secured to the recording platform, a blue-inked pen inserted into its holder, and the audiometer permitted to trace the hearing

threshold levels of the test ear. Pure tone threshold levels between .5K and 4K of the opposite ear were checked for normality in the same manner.

2) Tympanometry.--The impedance audiometer was allowed to warm up for ten minutes. The subject was instructed to remain as inactive as possible throughout all test procedures, and the headset was positioned on the head with an earphone covering the nontest ear and the tone-generator housing placed over the temporal region anterior to the test ear. A rubber cuff of appropriate size was forced over the probe tip and the entire unit wedged inside the ear canal to obtain an airtight seal. Audiometer sensitivity level was set at "tympanometry", +200 mm (H_2O) air pressure introduced in the ear canal, the compliance change meter indicator set at zero (extreme right unit marking), function switch set for "recorder", and the tympanograph lever pushed to "on". When air pressure was gradually reduced to -200 mm (H_2O), an automatic tracing in blue ink of the compliance-pressure function (tympanogram) was obtained.

3) Absolute impedance.--With air pressure in the canal at +200 mm (H_2O), the compliance change meter was set in the vertical position (5 units) and the C_1 value in cubic centimeters read off the curser scale on the impedance audiometer. Air pressure in the canal was then set at the level of maximum compliance shown on the tympanogram, the compliance change meter reset to the vertical position, and the C_2 value read off the curser scale.

$$C_2 - C_1 = C \text{ (static compliance in cc)}$$

4) <u>Acoustic reflex threshold</u>.--The acoustic reflex threshold was defined as the lowest HTL (ISO-1964) at which a full unit of compliance change is induced by a pure tone signal presented to the contralateral ear, or, as the lowest SPL of wide-band noise in the contralateral ear that can induce a full unit of compliance change.

The impedance audiometer was set for "sensitive reflex" (SR), at maximum compliance air pressure, with compliance change meter in vertical position, and a stimulus duration time of 1.5 sec. Acoustic reflex thresholds were then obtained for .5K, 1K, 2K, and 4K Hz with 5 dB bracketing. The procedure was repeated with wide-band noise stimulation.

5) <u>Supraorbital air jet test</u>.--A positive supraorbital air jet reaction was defined as a compliance change of at least two units superimposed on a steady state acoustic reflex following an air jet blown toward the eye on the test ear side.

An acoustic reflex was induced with a 1K Hz tone stimulus at 95 dB HTL (ISO-1964) for 10.0 sec. While the reflex was in effect, the compliance change meter was quickly set in the vertical position and a blast of air from a rubber-bulb ear syringe directed toward the subject's supraorbital region homolateral to the test ear. The magnitude of any consequent impedance change was noted visually. A similar procedure was used by Klockhoff (1961), Lidén <u>et al.</u> (1970), and Macrae (1971) to produce a pure tensor tympani muscle reflex.

Mandibular nerve anesthesia.--Immediately following audiometric testing, each subject was conducted to a dental operating facility near Queens College where he/she was administered 1.8 ml lidocaine HCl (Zylocaine), 2%, containing 1:100,000 parts epinephrine by intraoral mandibular nerve blockade (standard dental type) in order to anesthetize the tensor tympani branch (cf. Figure 2.).

Technique of injection.--The patient was seated in a dental chair with its headrest so adjusted that the mandibular occlusal plane appeared horizontal when the mouth was opened; the area about to be injected was cleansed and painted with an antiseptic solution. The dentist stood in front of the patient whenever administering the right injection, and behind the chair for the left injection.

By visual inspection, the distal angle or apex of the buccal pad of fat and the ridge of mucous membrane covering the ptergomandibular raphe was identified. The point of injection will usually coincide with the apex of the buccal pad, but since the position of this structure is variable, it is necessary to confirm the visual landmarks by palpation. The tip of the forefinger was passed along the buccal surfaces of the lower molar teeth until the external oblique ridge was felt; the tip was then rolled inward to lie in the retromolar fossa (Figure 9.A).

With the barrel of the syringe held parallel to the mandibular occlusal plane and over the premolar teeth of the opposite mandibular dentition, the tip of the needle was inserted about 0.5 cm, the syringe aspirated and checked for blood, and a few drops of the anesthetic solution injected to anesthetize the lingual nerve (Figure 9.B). The needle was then advanced 1.5 to 2.0 cm further until its tip lightly contacted the bone above the mandibular foramen. The needle was withdrawn slightly, the syringe aspirated and checked for blood, and about 1.5 ml of solution deposited. Keeping the needle straight, the syringe was carefully withdrawn from the mouth (Howe and Whitehead, 1972, p.58).

Criteria for tensor tympani anesthesia.--The tensor tympani muscle was considered anesthetized when the patient manifested the following symptoms:

a) Numbness of the homolateral tongue apex.

b) Numbness of the homolateral lip commissure.

c) A "wooden" or "swollen" feeling at the upper jaw below the zygomatic arch.

d) Difficulty in opening and closing the jaw.

e) A negative supraorbital air jet reflex.

Condition II test procedures.--Condition II refers to the patient's state of auditory function after receiving the mandibular blockade injection described above.

A 30 min anesthesia onset time was used in order to maximize infiltration of the anesthetic. After the injection, the patient returned to Queens College Hearing Clinic where all procedures mentioned under Condition I were repeated except that no contralateral hearing thresholds were obtained and red ink used in all tracings.

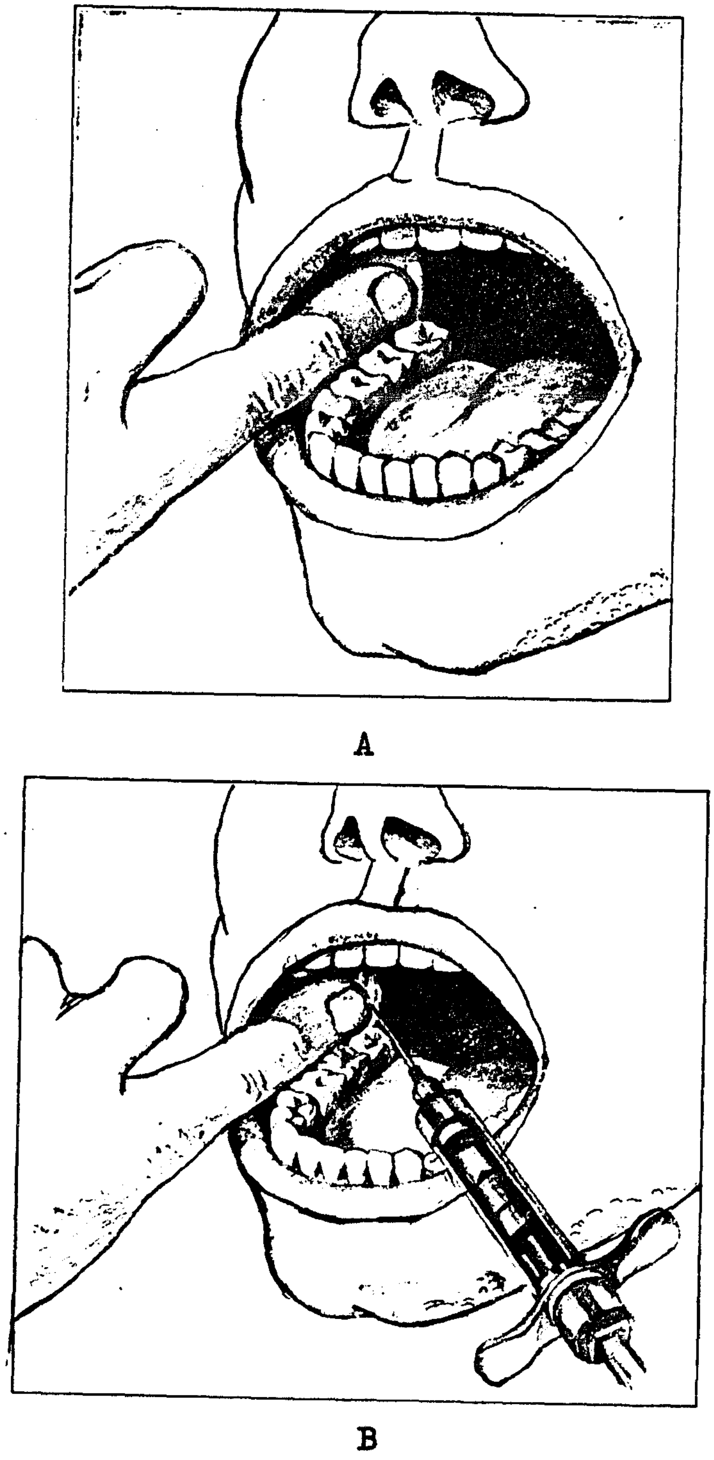


Fig. 9.--Mandibular nerve blockade. (A) Tip of the finger resting in the retromolar fossa. (B) Point of penetration of the needle into the mucous membrane.

CHAPTER IV

FINDINGS

Anesthesia

Anesthesia of the tensor tympani muscle was found to be variable in the group under investigation. Six of ten subjects (3,5,6,7,9,10) met all prescribed criteria for positive TT anesthesia. The other four subjects (1,2,4,8) manifested positive supraorbital air jet reactions in test ears and were, therefore, considered to have unanesthetized tensor tympani muscles.

Pure Tone Hearing Threshold

Individual audiograms with Békésy tracings of pure tone hearing functions under Conditions I and II are shown in Appendix D-1 through D-10. The method of Burns and Hinchcliffe (1957) was used to record pure tone threshold data shown in Tables 2 and 3. This method connects midpoints of ascending and descending arms of the Békésy tracing to produce a cursive line, and then notes points of intersection between the cursive line and the .5K, 1K, 2K, 4K, and 6K Hz lines on the audiogram.

Most interestingly, five of six subjects (3,5,6,7,9) with TT anesthesia developed hearing threshold shifts (reduced acuity), in varying degrees, between .25K and 2.5K Hz under Condition II. Of these five, the audiogram of Subject 3 showed the most pronounced threshold changes between conditions. Here, the between-conditions threshold differential gradually increased starting from .25K Hz, maximized at .9K Hz, and then gradually disappeared at 2.5K Hz. The maximum hearing loss was approximately 14 dB.

The sixth member of the anesthetized TT group (i.e., Subject 10) was atypical in that his audiogram showed lowered thresholds (increased acuity) in the 1.5K to 2.5K Hz range of approximately 5 dB; moreover, Subject 10's normal hearing was borderline throughout the audiogram.

The four members of the unanesthetized TT group manifested no threshold shifts between conditions.

Statistical analysis of data (Tables 2 and 3) indicated significant between-conditions threshold changes at .5K Hz ($p < .025$), 1K Hz ($p < .1$), and 2K Hz ($p < .025$) in the anesthetized TT group. Graphs of mean data for both groups are shown in Figures 10 and 11.

Tympanometry

In general, tympanograms displayed single Type A peaks located between ±25 mm (H_2O) air pressure. Individual tympanograms varied considerably in peak height measured in arbitrary units (1 to 10) of relative compliance. Between-conditions statistical analysis (Tables 4 and 5) indicated a significant ($p < .005$) change in relative compliance with anesthesia of the tensor tympani muscle. Cf. Appendix E.

TABLE 2

INDIVIDUAL CURSIVE HEARING THRESHOLD LEVELS IN DECIBELS (ISO-1964) IN THE ANESTHETIZED TENSOR TYMPANI GROUP

Subject	.5K Condition I	.5K Condition II	1K Condition I	1K Condition II	2K Condition I	2K Condition II	4K Condition I	4K Condition II	6K Condition I	6K Condition II
3	10.0	17.5	1.5	12.5	0.0	5.0	4.0	7.0	15.0	20.0
5	7.5	14.0	4.0	2.5	-10.0	- 3.0	- 8.5	- 8.5	-10.0	-14.0
6	7.0	18.0	1.5	5.0	- 5.0	- 2.0	17.0	18.0	10.0	14.0
7	10.0	16.0	- 2.5	13.0	- 5.0	- 2.5	2.0	6.0	0.0	- 1.0
9	12.5	15.0	7.5	7.5	6.5	14.0	10.0	17.5	14.0	15.0
10	18.0	18.0	18.0	17.0	12.0	10.0	19.0	18.0	15.0	11.5
Mean	10.8/16.4*		5.0 / 9.6**		- .3 / 3.6*		7.3 / 9.7		7.3 / 7.6	
SD ±	3.7/1.5		8.9/ 4.9		7.5/6.6		7.3/9.6		9.3/11.6	

*Significant at 0.025 level, one-tailed *t* test, difference between two dependent means.

**Significant at 0.1 level.

TABLE 3

INDIVIDUAL CURSIVE HEARING THRESHOLD LEVELS IN DECIBELS (ISO-1964) IN THE UNANESTHETIZED TENSOR TYMPANI GROUP

Subject	.5K Condition I	.5K Condition II	1K Condition I	1K Condition II	2K Condition I	2K Condition II	4K Condition I	4K Condition II	6K Condition I	6K Condition II
1	- 2.0	- 2.0	- 8.0	-11.5	-12.0	-13.0	-11.5	-14.0	8.0	7.0
2	8.0	3.0	4.5	1.0	- 5.0	- 6.0	- 9.0	- 5.0	3.0	- 1.5
4	- 8.0	- 5.0	-10.0	- 7.5	-15.0	-15.0	-18.0	-13.0	-16.0	-10.0
8	7.5	7.5	2.5	5.0	- 9.0	- 7.5	3.0	9.0	0.0	0.0
Mean	1.4/ .9		- 2.8/-3.3		-10.3/-10.4		- 8.8/-5.8		- 1.3/-1.1	
SD ±	6.7/4.8		6.3/6.4		3.7/3.7		7.6/9.2		9.0/6.0	

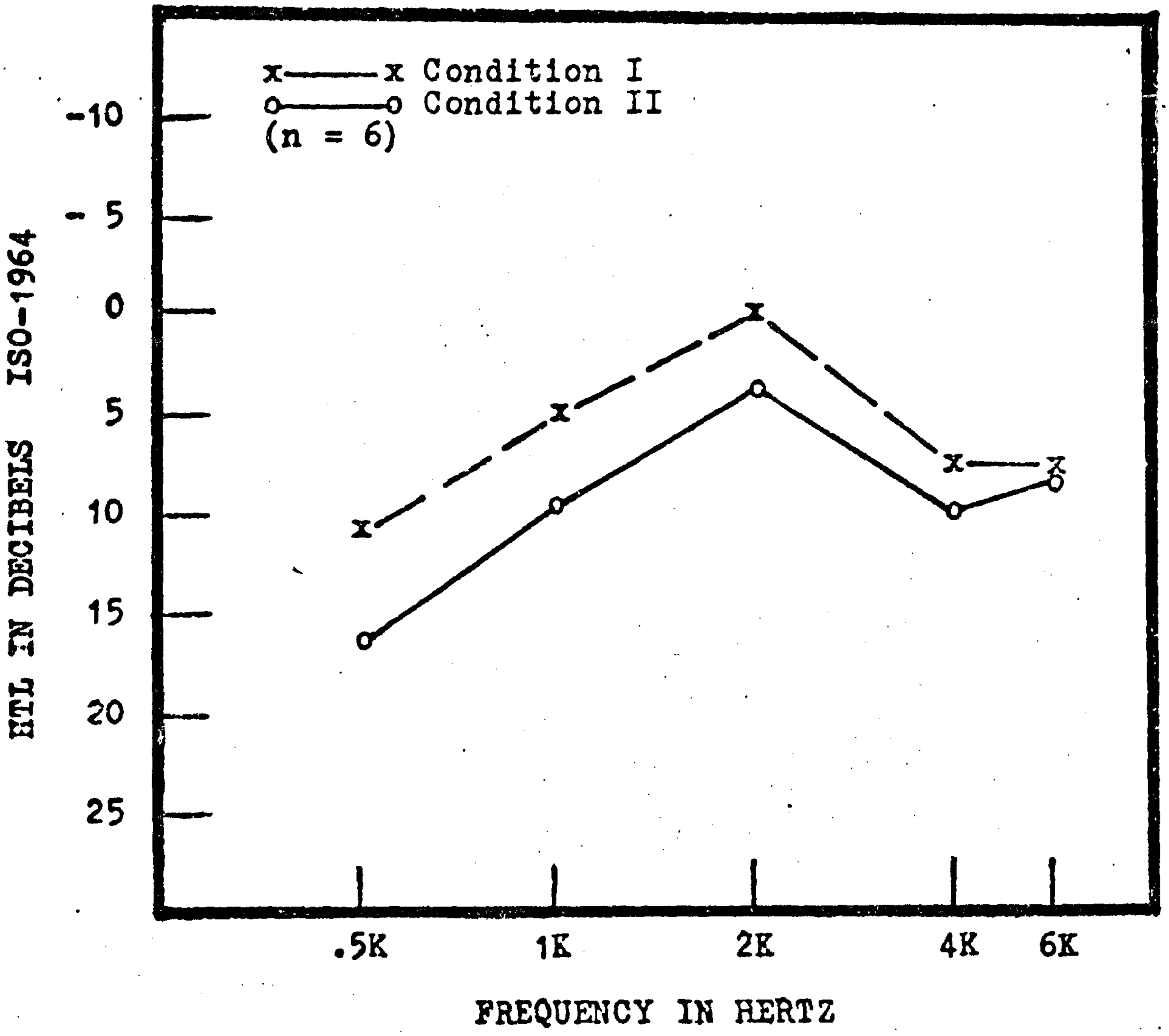


Fig. 10.--Mean hearing threshold levels in the anesthetized tensor tympani group.

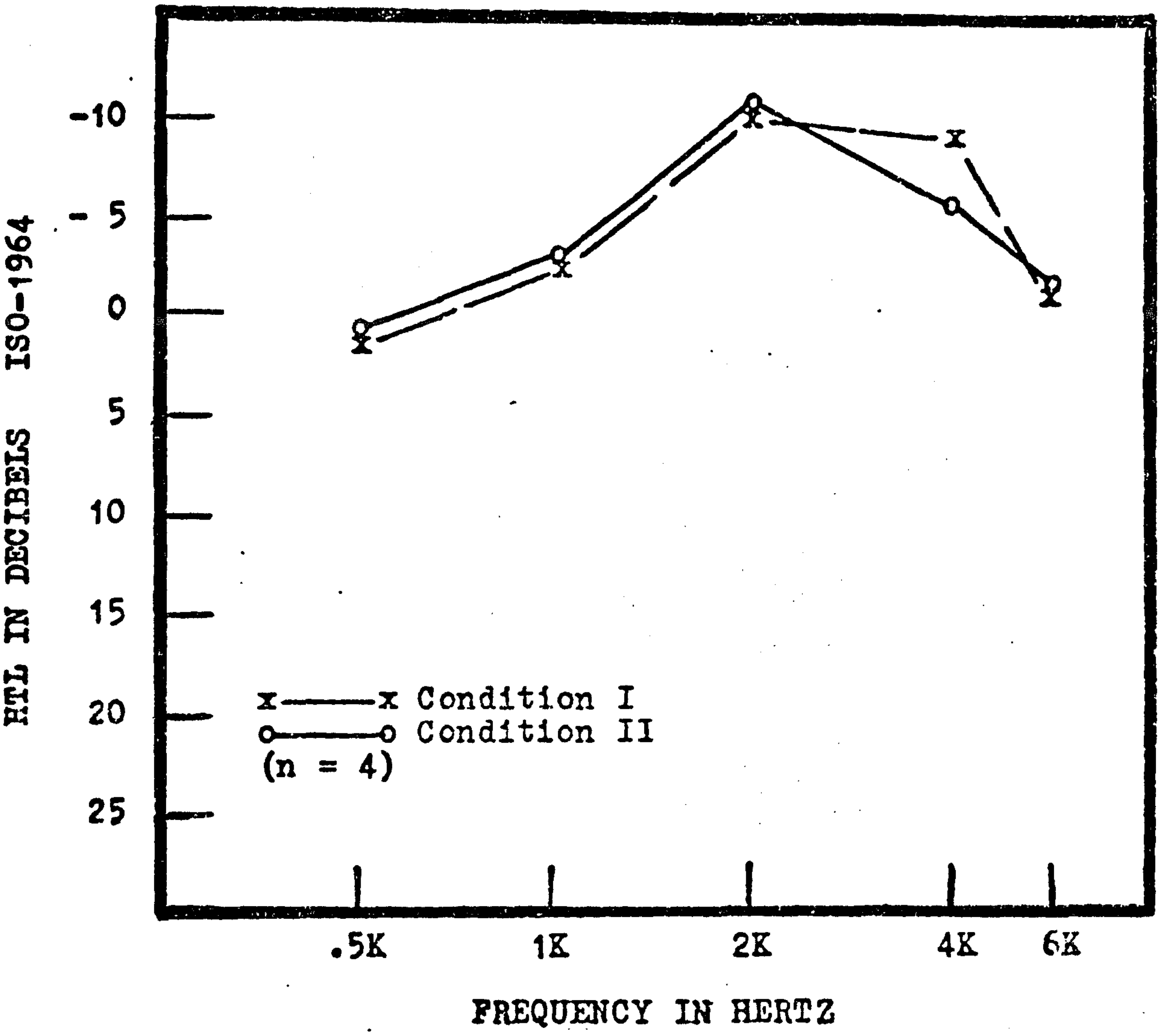


Fig. 11.--Mean hearing threshold levels in the unanesthetized tensor tympani group.

TABLE 4

INDIVIDUAL TYMPANOGRAM PEAK DATA IN ARBITRARY UNITS OF COMPLIANCE IN THE ANESTHETIZED TENSOR TYMPANI GROUP

Condition	Subject Number 3	5	6	7	9	10	Mean	SD±
I	4.3	6.0	3.1	6.0	6.3	7.1	5.49	1.8
II	5.5	7.4	3.6	7.1	6.8	7.4	6.30*	1.4

*Significant at 0.005 level, one-tailed t test , difference between two dependent means.

TABLE 5

INDIVIDUAL TYMPANOGRAM PEAK DATA IN ARBITRARY UNITS OF COMPLIANCE IN THE UNANESTHETIZED TENSOR TYMPANI GROUP

Condition	Subject Number 1	2	4	8	Mean	SD±
I	6.3	3.3	5.4	4.7	4.92	1.1
II	6.0	3.7	5.4	4.5	4.93	1.2

Absolute Impedance

Individual data of absolute impedance, expressed in cubic centimeters of static compliance of an equivalent volume of air, are reported in Appendix E, 1 through 10, and graphed in Figures 12 and 13. All results were well within normal limits (Jerger et al., 1972) ranging from .28 cc (Subject 6) to .60 cc (Subjects 1,7) in Condition I and .26 cc (Subject 6) to .66 cc (Subject 7) in Condition II.

In the anesthetized TT group, the findings of Subject 6 were atypical in that the static compliance was the smallest in the group and showed a reduction in Condition II. The other five members of this group manifested increased static compliances in Condition II. Statistical analysis of group findings indicated a significant ($p < .05$) increase of static compliance in Condition II (Wilcoxon Matched-Pairs Sign-Rank Test, $T < 2$).

In the unanesthetized TT group, Subjects 1 and 4 had decreased, Subject 8 increased, and Subject 2 equivalent static compliances in Condition II relative to Condition I.

Acoustic Reflex

Individual acoustic reflex threshold data are shown in Appendix E, means and standard deviations in Tables 6 and 7. Between-conditions mean variations were minimal in the anesthetized and unanesthetized TT groups; the greatest variation (5.8 dB) occurred in the former group at the 4K level, the least reliable frequency for acoustic reflex testing ac-

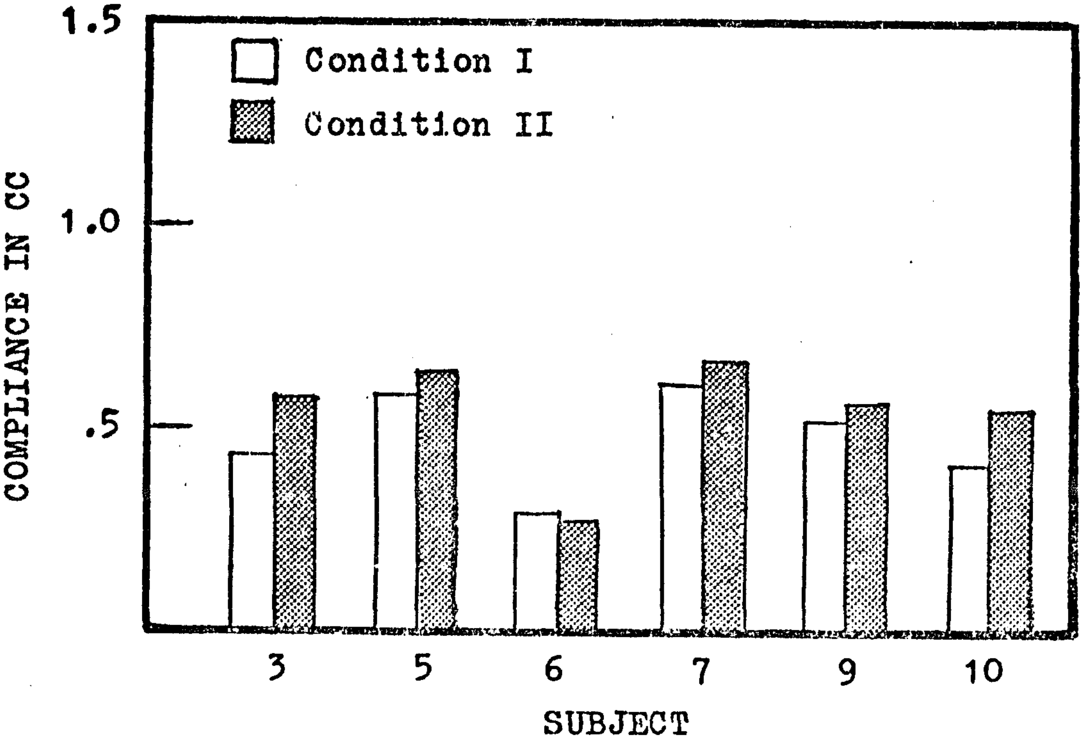


Fig. 12.--Individual static compliances in the anesthetized tensor tympani group.

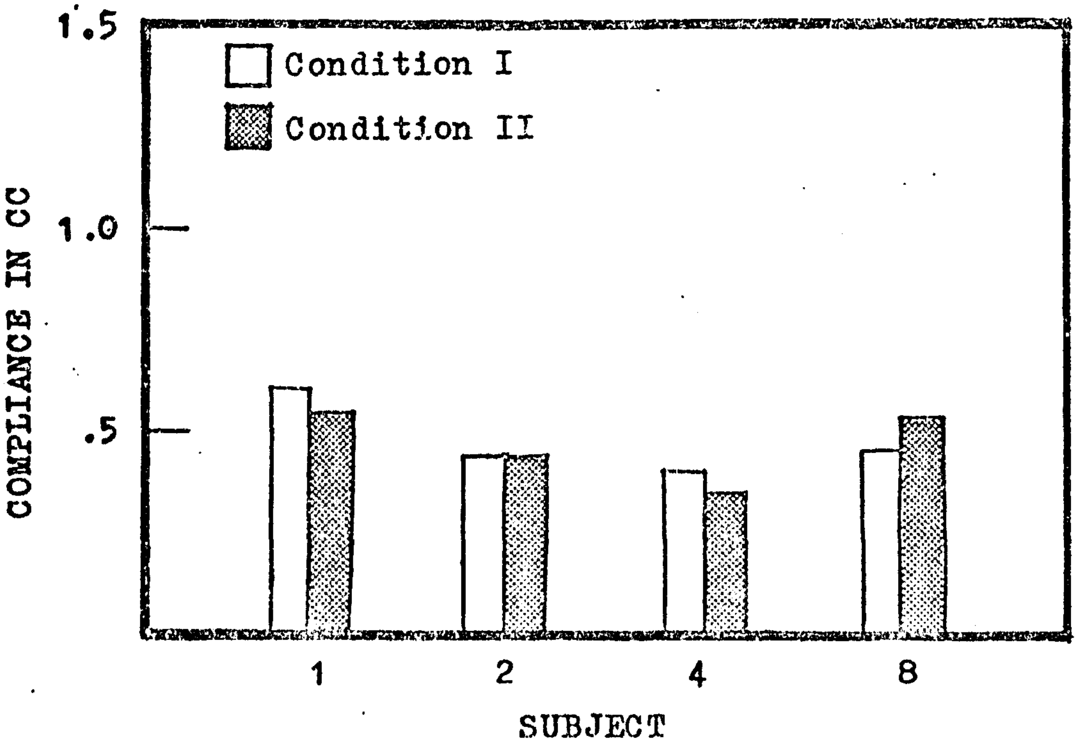


Fig. 13.--Individual static compliances in the unanesthetized tensor tympani group.

TABLE 6

MEANS AND STANDARD DEVIATIONS IN DECIBELS FOR ACOUSTIC REFLEX THRESHOLDS IN THE ANESTHETIZED TENSOR TYMPANI GROUP (WBN = WIDEBAND NOISE)

	Activating Stimulus*				
Measure	.5K	1K	2K	4K	WBN
Mean, Condition I	90.8	92.5	90.0	90.8	82.5
SD± (n = 6)	4.5	2.5	2.9	7.3	9.5
Mean, Condition II	90.8	92.5	89.2	85.0	82.5
SD± (n = 6)	3.5	2.5	1.9	0.0	8.5

*Pure tone stimuli in HTL (ISO-1964) and wideband noise in SPL re: 0.0002 μbar.

TABLE 7

MEANS AND STANDARD DEVIATION IN DECIBELS FOR ACOUSTIC REFLEX THRESHOLDS IN THE UNANESTHETIZED TENSOR TYMPANI GROUP (WBN = WIDEBAND NOISE)

	Activating Stimulus*				
Measure	.5K	1K	2K	4K	WBN
Mean, Condition I	85.0	83.8	86.3	91.3	85.0
SD± (n = 4)	7.1	8.2	7.4	14.7	15.4
Mean, Condition II	86.3	86.3	85.0	95.0	87.5
SD (n = 4)	10.8	10.2	9.4	14.6	13.5

*Pure tone stimuli in HTL (ISO-1964) and wideband noise in SPL re: 0.0002 μbar.

cording to Jerger et al. (1972).

Standard deviations were conspicuously higher in the unanesthetized group than those in the anesthetized TT group. The greatest standard deviation in either group occurred when wideband noise was used as the activating stimulus for the acoustic reflex.

CHAPTER V

DISCUSSION

The Anesthesia

In view of the complex anatomy of the target area and the inherent variability of all conduction anesthesia techniques, a 40% negative finding in tensor tympani anesthesia of subjects should not be entirely unexpected.

The target of the nerve blockade procedure in this study was the otic ganglion, lying medial and adjacent to the proximal portion of the mandibular nerve (Hollinshead, 1968, p.403). It will be recalled (cf. Figure 2.) that the tensor tympani nerve traverses the otic ganglion before entering the tensor tympani muscle. The site of lidocaine deposition was actually below the otic ganglion in the region where the mandibular nerve bifurcates into inferior alveolar and lingual segments. This means that the lidocaine solution must diffuse through the interstitial tissue above the site of injection in order to be effective in the study. In this regard, Monheim (1968, p.107) stated: "The molecules of the solution diffuse in all directions, with concentration diminishing in geometric ratio as it leaves the original site of deposition. Therefore, the greater the distance of the original injection from the target area, the fewer molecules that reach the desired site, and the lower the intensity of the resulting block." It is very likely that the presence or absence of fat in the target area influences the rate of diffusion through the area, for Sung and Truant (1954) have shown that lidocaine is markedly lipophilic when injected into loose connective tissue of the rat.

The constraints of the project did not permit trial experiments to determine optimum conditions of concentration and dosage of the anesthetic solution for inducing TT anesthesia. With more research, the technique might attain a higher incidence of successful anesthesia and improve its potential in middle ear muscle research. Even with the present 60% success rate, the procedure could be used to investigate human TT functions--more accurately, loss of TT functions--in such nonacoustic phenomena as chewing, swallowing, and middle ear pressure regulation.

<u>Is the supraorbital air jet compliance-change test a reliable method of assessing TT activity</u>? Klockhoff's exposition in 1961 on the elicitation of reflex activity in the tensor tympani muscle was lucid and convincing in that he systematically eliminated other possible causes of the compliance-change reaction. After making electrographic recordings, Lidén <u>et al.</u> (1970) reported: "Reflex response patterns in seven normal subjects during the combined acoustic and air-jet stimulation were very consistent. The activity of the tensor muscle is superimposed on the reflex elicited by acoustic stimulation and is evident in

all three channels." Holst et al. (1963) noted with manometry inward movements of the eardrum after air was blown against the eye. Moreover, Macrae (1972) adopted the supraorbital air jet procedure to test tensor tympani activity in his research on the effects of body position on audition.

From an empirical viewpoint, the present finding of significant differences between two experimental groups having contrasting supraorbital air jet test results tends to support the validity of the test.

Pure Tone Thresholds

The finding of a statistically significant decrement in auditory threshold acuity for tones below 2K Hz following TT anesthesia raises the issue of the tensor's role in supraliminal sound conduction. The data suggest that the tensor tympani muscle can selectively facilitate sound conduction at low or moderately low intensities.

Corroborative reports of related studies in humans are scarce in the literature. Smith (1943) presented audiometric threshold measurements of a subject before and after voluntary middle ear muscle contraction. The subject declared that the 2K Hz tone became louder after ear muscles were contracted. Reger (1960) mentioned that two of four subjects indicated increased loudness at 2K Hz while their middle ear muscles were voluntarily contracted.

Facilitation of sound conduction of certain frequencies through the middle ear during intratympanic muscle contraction (spontaneous or reflex) has been previously observed in animals (Wiggers, 1937; Wever and Vernon, 1956; Kevanishvili and Gvacharia, 1972). Wiggers (1937) noted enhancement of sound transmission in guinea pig ears in the 1.1K to 1.8K Hz range following middle ear muscle contraction. Wever and Vernon (1956) found that TT acting alone could produce a gain in transmission of pure tones in the cat at the .6K to 1K Hz range. Kevanishvili and Gvacharia (1972) reported an increase of cochlear microphonic amplitude in the cat at 1.8K to 2K Hz with TT stimulation. The present findings in humans agree well with the above. All authors expressed the opinion that the inequality of effects observed with intratympanic muscle contraction could be produced by changes in the resonance characteristics of the middle ear. Wever and Vernon (1956), in addition, mentioned "the elimination of looseness in the coupling of the ossicles. . ." as a reason for the effects. Apropos of the latter statement, Littler (1965, p.33) comments that an increase of tension or variation in ossicular elasticity might "decrease sensitivity over some frequency range while increasing it over another".

Does the tensor tympani muscle function in accordance with the accommodation theory of middle ear physiology? Wever and Bray (1937) regarded the accommodation theory of middle ear muscle function (cf. Chapter I, p.6) as a frequency-selection process, viz.

> According to the frequency-selection theory, the action of the tensor tympani muscle may cause

> certain tones to be favored over others in transmission. This theory has usually been called the accommodation theory. . . .

Paparella and Shumrick (1973, p.272) likewise described the accommodation concept of middle ear muscle function as a frequency-selection process. An analysis of individual differences in the Békésy audiograms of the present findings (Appendix D, Table 2) does, indeed, reveal individual frequency selectivity in the .25K to 2.5K Hz range with improvement (Subjects 3,5,6,7,9) or reduction (Subject 10) of hearing acuity when TT is functional. The mean threshold differential for the range under discussion was 4.7 dB. It may, therefore, be concluded that <u>at supraliminal sound intensities, the human tensor tympani muscle functions in accordance with the accommodation principle of middle ear muscle physiology</u>.

Before leaving the discussion of pure tone thresholds, two points should be mentioned regarding Békésy audiometry. The task of listening for the initiation and cessation of tones while pushing or releasing a push-button hand switch requires considerable subject alertness. Such combined states of alertness and motor activity are conducive to spontaneous middle ear muscle function (Simmons, 1964a, 1964b; Salomon and Starr, 1963). It is very likely that the brainstem reticular system is a mediating factor in these situations (cf. pp.26-27). Another point to be made is that sweep-frequency stimulation tends to promote spontaneous middle ear muscle activity by precluding adaptation (Simmons, 1964b; Salomon, 1966). The remarks of Simmons (1964b) are appropriate:

> It is, however, common experience that an interrupted tone, or one that continually changes pitch or intensity is more easily identified. It is of further interest to note that in the auditory cortex, AC electrical activity can be sustained only when a tone is constantly varied in amplitude or frequency.

Thus, type of stimulus presentation as well as behavioral context are important determinants of spontaneous reflex activity in middle ear musculature. The effects on the tensor tympani muscle resulting from these environmental factors would, of course, be negated with TT anesthesia.

Compliances

In designing the study, assumptions were made that: 1) the tensor tympani, similar to any striated muscle, maintains a resting tonus and 2) with TT anesthesia, a loss of tonicity would occur measurable with impedance audiometry. Assumption 1) has been convincingly demonstrated in cats by Simmons (1964a, 1964b) with electromyography and CM and by Salomon (1966) with electromyography. Assumption 2) is based on the biological consideration (cf. Chapter II, pp. 23-24) that gamma motor nerve endings are primarily responsible for muscle tonus (Guyton, 1961, p.252). According to Abbs (1973), gamma motor nerves accompany the alpha motor nerves in the portio minor of the mandibular division of the Vth cranial nerve and are subject to anesthesia by mandibular nerve blockade.

The findings justified the aforementioned assumptions, for each subject in the anesthetized TT group showed increased tympanogram peak compliance (measured in arbitrary units, 1 to 10) under Condition II. This was not the case for subjects in the unanesthetized group (cf. Table 5, p.53).

The question was posed earlier: "Is there an appreciable resting tonus in TT?". The answer must be in the affirmative inasmuch as statistical analysis indicated a significant ($p < .005$) change in tympanogram peak relative compliance following TT anesthesia. This information is considered important because it suggests a very active gamma motor system and, therefore, a capability for rapid and delicate muscle movements can be inferred (Guyton, 1961, p.750), not necessarily in response to acoustic stimuli exclusively. Further evidence of TT dynamism can be found in the relative size of the tensor over the stapedius and the strategic position held by TT in the tympanum.

According to Lilly (1972): "Static acoustic impedance measurements are made with ambient (atmospheric) air pressure in the external auditory meatus and with muscles in a state of 'normal' tonus." Any deviation from normal rigidity of the middle ear mechanism must, by definition, affect its acoustic impedance (measured in cc of compliance). A rather extreme example of this principle can be observed in clinical otology; a characteristically high static compliance (> 1.5) is considered pathognomonic of ossicular discontinuity (Jerger et al., 1974). For this reason, some increase in static compliance was to be expected with TT anesthesia, and, as anticipated, five of six subjects in the anesthetized TT group manifested increased static compliances in Condition II. Statistical analysis yielded a significant ($p < .05$) group increment over Condition I; another indication of an appreciable resting tonus in the tensor tympani muscle.

Acoustic Reflex

One of the expressed aims of the study was to seek evidence of TT participation in the acoustic reflex phenomenon. The acoustic reflex threshold data obtained showed no outstanding differences between conditions or between groups for either pure tones or wideband noise. Pure tone thresholds conformed with Jerger *et al.* (1972) normative data of 95% distribution between 70 dB and 100 dB, ISO-1964.

There are two possible explanations of the findings. The first is that TT simply does not participate in the human acoustic reflex below 110 dB, ISO-1964. The functions obtained could be those of the stapedius alone (Jepson, 1963; Klockhoff, 1961; Feldman, 1967).

The second possibility is that the tensor and stapedius participate in the reflex concomitantly but when the tensor muscle responds, after a longer latency than the stapedius, the impedance of the ear has already been increased by the contribution of the stapedius. Tensor latency has been estimated at 90-300 msec and stapedius latency at 10-60 msec by Møller (1972) and Jepson (1963) respectively. Unfortunately, present instrumentation did not permit quantitative assessments of acoustic reflex reactivity before and after TT anesthesia. Supplemental research using the present method in combination with manometry, *ad modum* Lidén *et al.* (1970), is needed before the question of TT's participation in the human acoustic reflex could be clarified.

In conclusion, a technique has been presented which, with some refinement, could be very valuable for future human tensor tympani studies. Through morphological analysis and experimental investigation, the dynamic character of this little understood organ in the acoustic and non-acoustic domains was definitely established.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Indirect observations were made of musculus Tensor Tympani (TT) functions in ten normal ears of ten paid volunteers aged 21 to 35 years recruited from Queens College, City University of New York. Five measures were carried out under each of two conditions: 1) normal functional state; 2) after attempted TT anesthesia by intraoral mandibular nerve blockade (standard dental type) with 1.8 ml lidocaine HCl (Zylocaine), 2%, containing 1:100,000 parts epinephrine. The five measures included pure tone hearing thresholds, impedance tympanometry, eardrum absolute impedance (measured as static compliance of an equivalent volume of air), acoustic reflex thresholds, and the supraorbital air jet test through impedance audiometry.

Major items of equipment were a Békésy audiometer, model E800, and an American Electromedics impedance audiometer, model 83. Local anesthesia was administered by a licensed dentist in a facility located near the audiology testing site. Criteria for TT anesthesia were prescribed as the usual subjective symptoms associated with Vth nerve peripheral anesthesia, difficulty of ipsilateral lower jaw movements associated with paresis of masticatory muscles, and a negative supraorbital air jet reflex when superimposed on a steady state acoustic reflex and monitored by impedance audiometry.

Results of the study included six successful tensor tympani anesthesias and significant mean threshold shifts during anesthesia at .5K, 1K, and 2K Hz accompanied by significant increments of relative and absolute compliances in six middle ears of six subjects. These findings suggest the following conclusions.

1) Anesthesia of the human tensor tympani muscle can be obtained in a limited number of cases through intraoral mandibular nerve blockade (standard dental type) with lidocaine HCl (Xylocaine). Further research as to dosage and concentration of the anesthetic solution is needed to improve the incidence rate of successful tensor tympani anesthesias obtained by this technique.

2) The consistency of measures within the anesthetized and within the unanesthetized tensor groups lends support to Klockhoff's supraorbital air jet procedure as a test for tensor tympani function.

3) At supraliminal intensities, a functional tensor tympani muscle may influence threshold hearing acuity at frequencies below 2.5K Hz consistent with the accommodation concept of tympanic muscle function described by Wever and Bray (1937) and Littler (1965, p.33).

4) An appreciable muscle tonus evidently exists in the resting tensor tympani indicative of a capability for rapid and delicate functional movements.

APPENDIXES

Appendix A

The Graduate School and University Center
of the City University of New York

Office of Sponsored Research and Program Funding
Graduate Center: 33 West 42 Street, New York, N.Y. 10036
212/790-4683

INSTITUTIONAL CERTIFICATION FOR INVESTIGATION INVOLVING HUMAN SUBJECTS

Principal Investigator(s): Abraham Greenberg, DDS.

Project Title: "Studies of Human Tensor Tympani Muscle Function"

Agency:

Assigned Number (if known):

As Chairman of the Graduate School and University Center Committee on Protection of Human Subjects, I hereby certify the above referenced application has been carefully reviewed by the Committee and has been found to meet appropriate standards regarding (1) the rights and welfare of the subjects involved; (2) the appropriateness of methods used to obtain informed consent of subjects; and (3) the risks and potential benefits of the investigation.

This review is in accordance with the Institutional Assurance submitted to the Department of Health, Education and Welfare under date of June 29, 1972 and approved by DHEW. These procedures are subject to continuing review as agreed upon in that Assurance.

Certification forms signed by the Chairman and other members of the Committee are on file in the Sponsored Research and Program Funding office, Graduate School and University Center, The City University of New York.

The members of the Committee are:

- Dr. Phyllis A. Katz, Ph.D. Program in Education
- Dr. Leonard S. Kogan, Ph.D. Program in Psychology
- Dr. Harry Levitt, Ph.D. Program in Speech
- Dr. Rolf Meyersohn, Ph.D. Program in Sociology
- Dr. Charles P. Smith, Ph.D. Program in Social-Personality Psychology
- Virginia P. White, Director, Sponsored Research and Program Funding
- Ms. Sheree West, Student, Ph.D. Program in Environmental Psychology

Phyllis A. Katz

Dr. Phyllis A. Katz, Chairman
The City University of New York, Graduate
School and University Center Committee on
Protection of Human Subjects

Date May 25, 1975

PAK:dr

Appendix B

PROJECT ORIENTATION FOR SUBJECTS

Before participating in the investigation, each subject was told the following.

> We want to do some hearing tests before and after and after a dental anesthetic. Have you ever had any hearing tests? Our first series of hearing tests will last about twenty minutes during which time we shall put sounds in earphones placed over your ears and take readings with our instruments. Part of the time you will wear a small plug in one ear, like a hearing aid. We shall then go to a neighborhood dental office where you will receive an oral injection to numb one side of your face and tongue. Have you ever had such an injection for dental work? This will be the same thing. Thirty minutes after the injection, we shall repeat the first series of tests to see if there is any change.
>
> Your jaw will be numb for two or three hours; it's best not to eat during that time as you might bite your lip or tongue.
>
> You may ask questions at any time, or even withdraw if you like. When we finish the experiment, you will receive $25.00 immediately. Do you have any questions now? If not, please sign a consent form.

Appendix C

SUBJECT'S CONSENT STATEMENT

City University of New York
The Graduate School and University Center

I hereby acknowledge that on ________________, 1975, I was informed by Abraham Greenberg, D.D.S. of the Graduate School and University Center of a research project having to do with Studies of Human Tensor Tympani Muscle Function.

I was told of the possible risks involved; the procedures involved; possible alternative procedures and the expected benefits from the program.

I am fully aware of the nature and extent of my participation in said project and possible risks involved or arising therefrom. I hereby agree, with full knowledge and awareness of all the foregoing, to participate in said project. I further acknowledge that I have received a complete copy of this consent statement. I also understand that I may withdraw my participation in said project at any time and that I may inspect a copy of the Institutional Assurance filed by the Research Foundation, CUNY, with the U.S. Department of Health, Education, and Welfare.

Dated: New York________________, 1975.

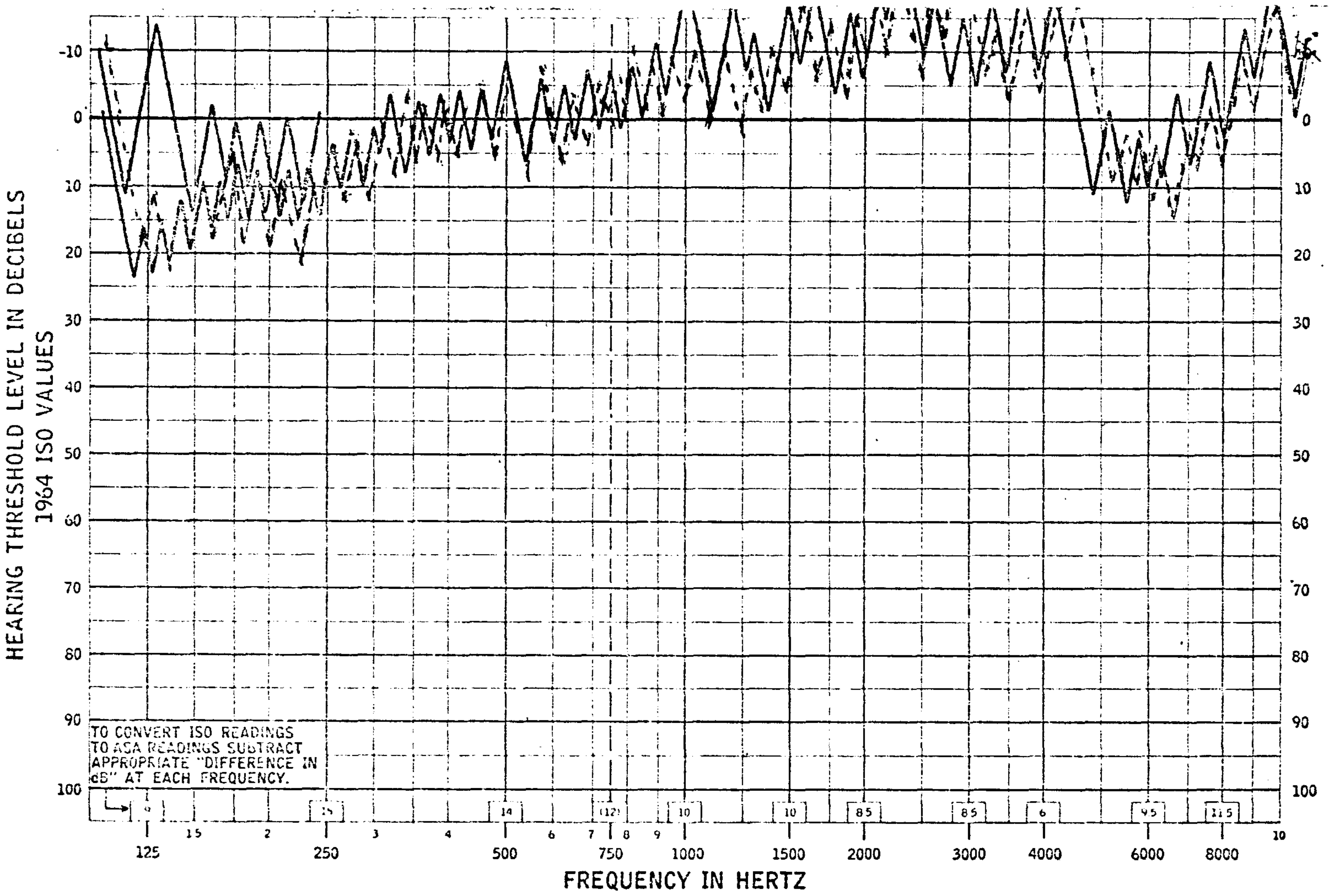
____
(Signature of Subject or Agent)

____
(Printed Name of Subject or Agent)

____
(Residence of Subject or Agent)

Appendix D-1

Békésy Audiograms, Subject #1

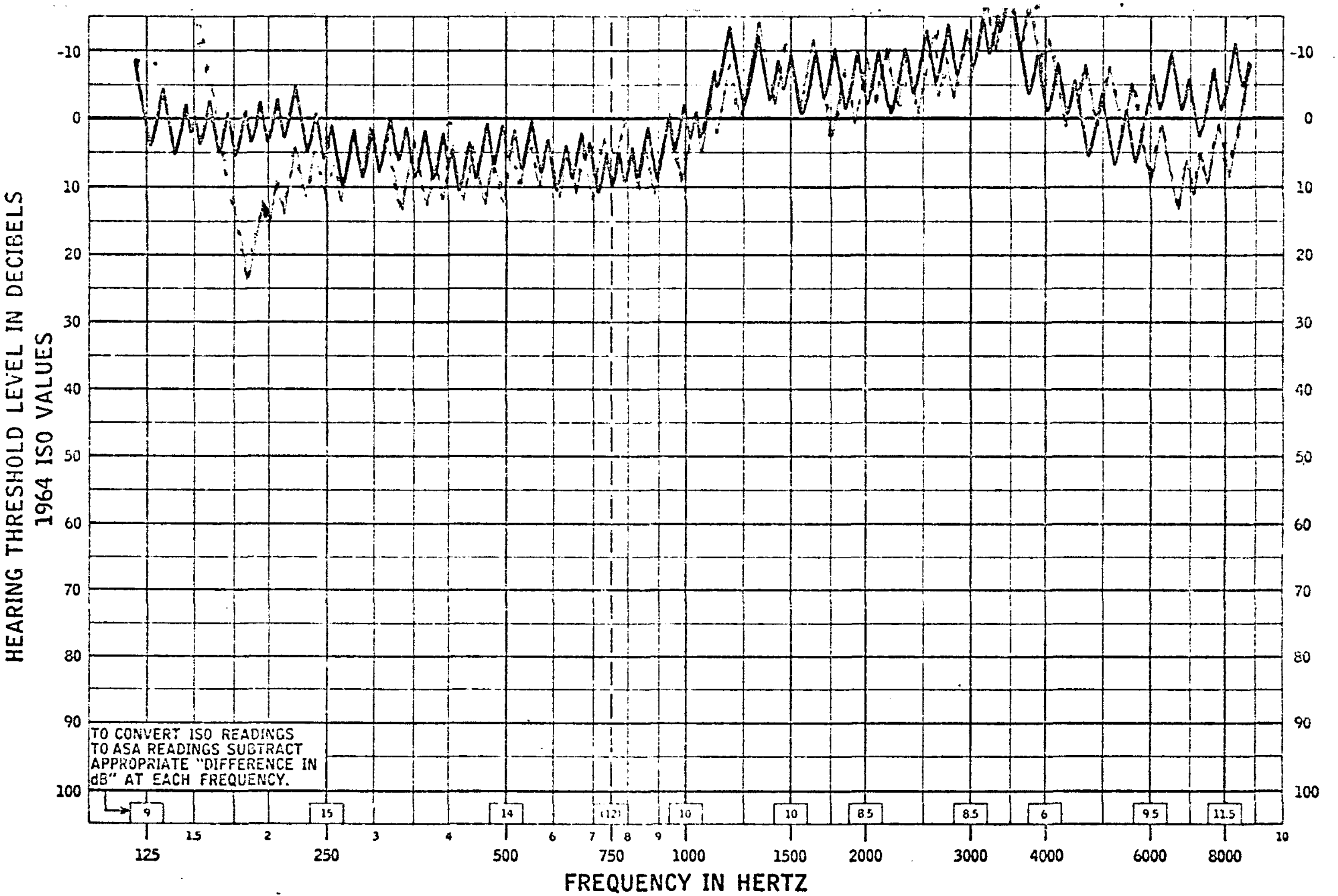


Beaded line = Condition I

Solid line = Condition II

Appendix D-2

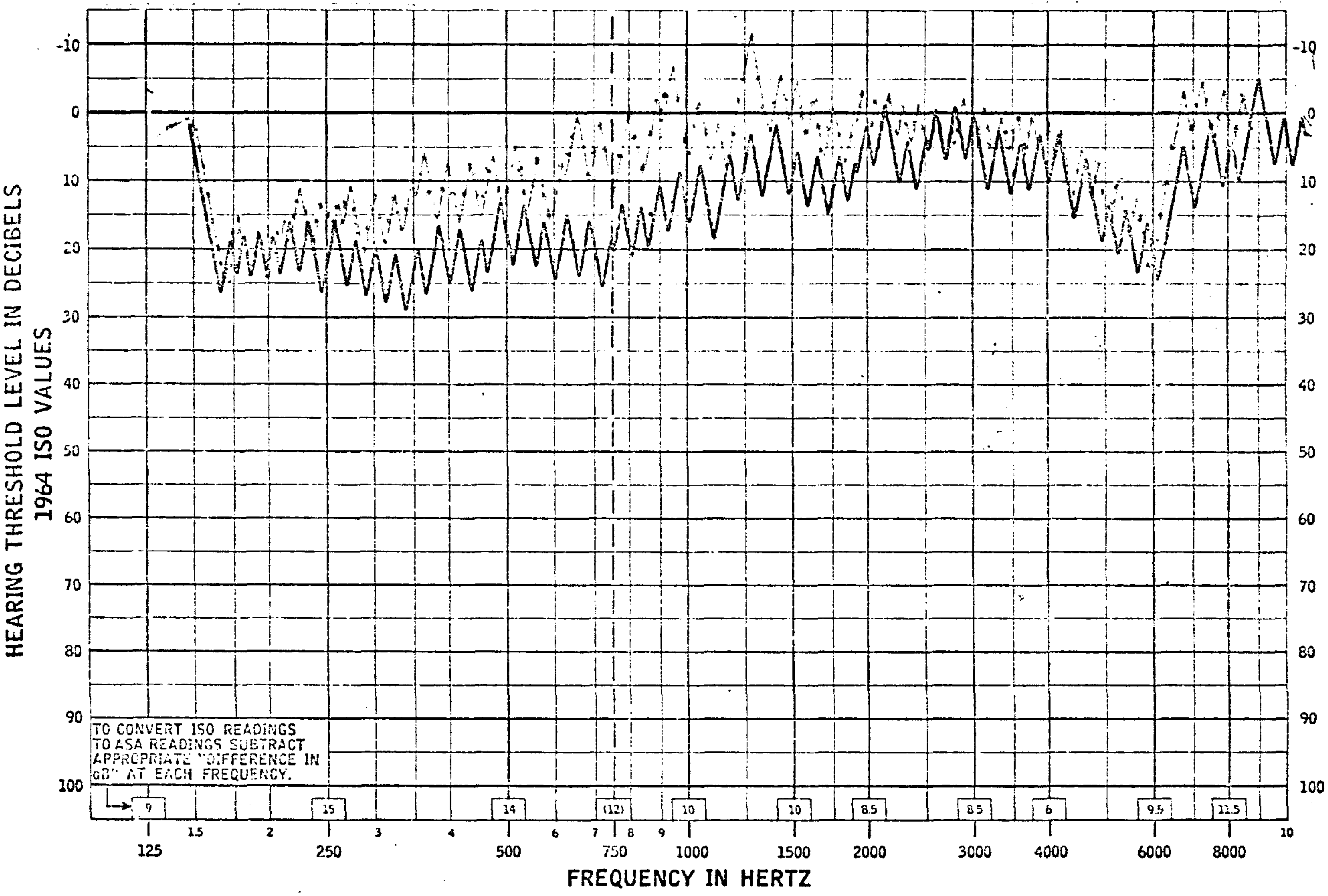
Békésy Audiograms, Subject #2



Beaded line = Condition I **Solid line = Condition II**

Appendix D-3

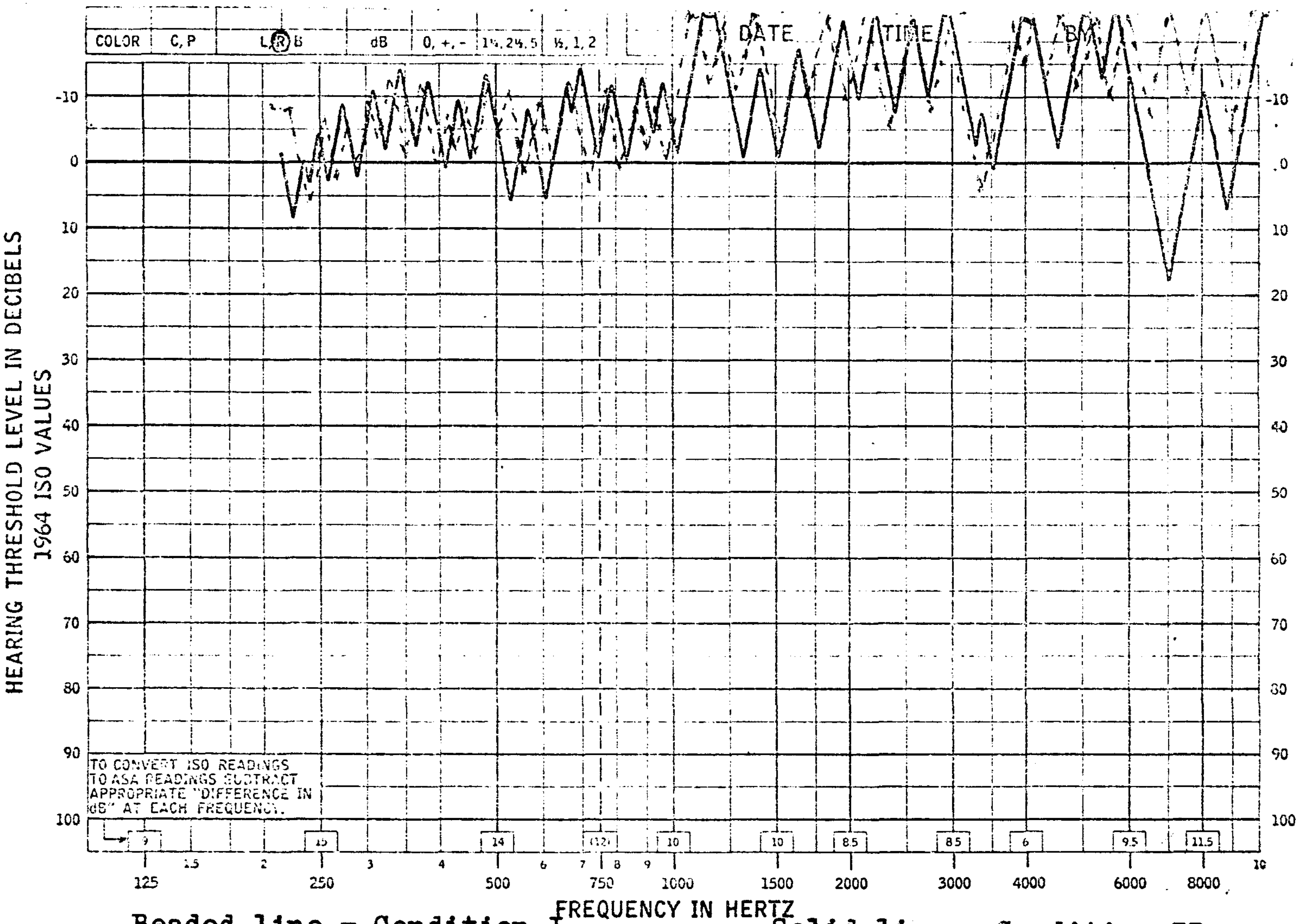
Békésy Audiograms, Subject #3



Beaded line = Condition I **Solid line = Condition II**

Appendix D-4

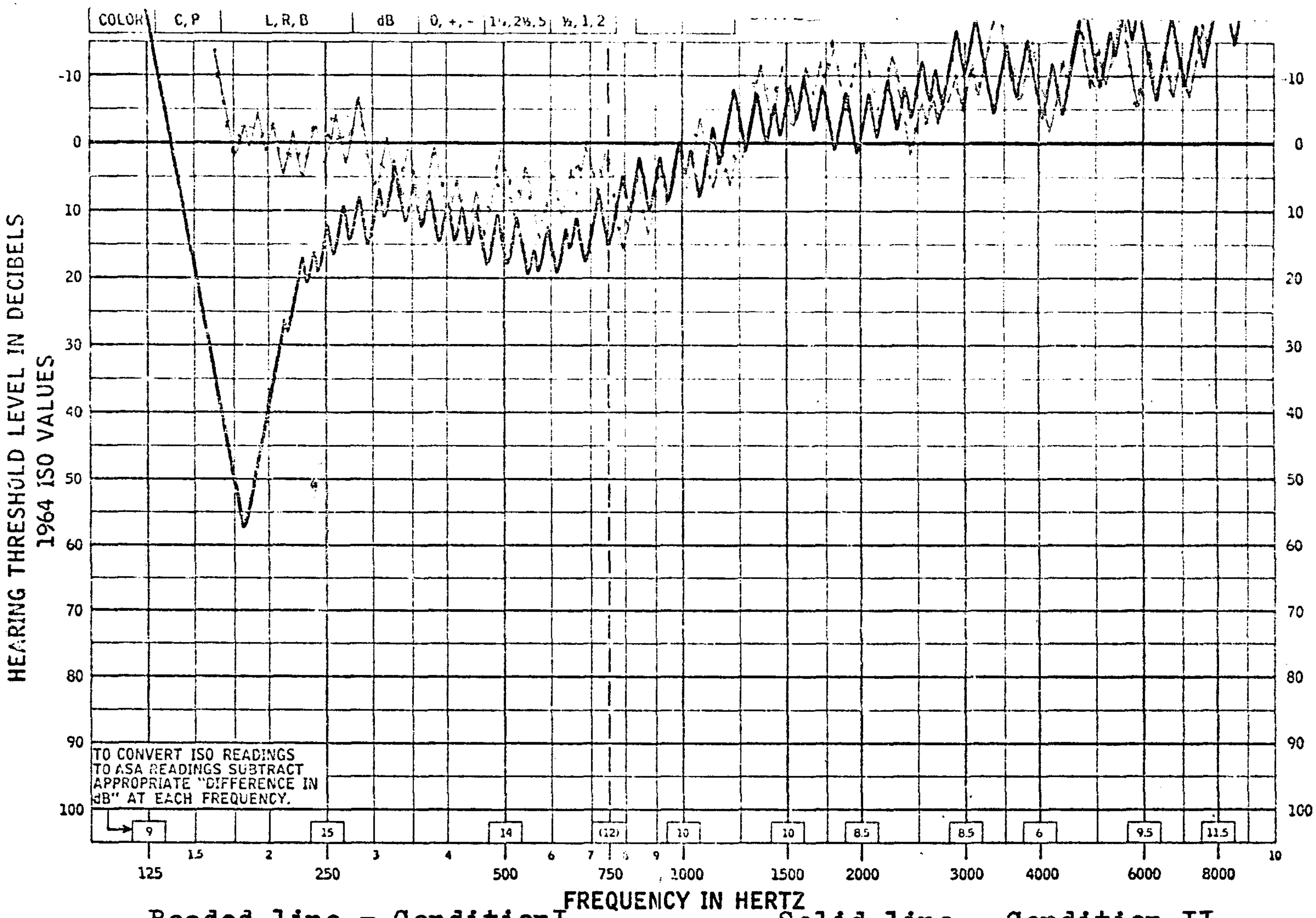
Békésy Audiograms, Subject #4



Beaded line = Condition I **Solid line = Condition II**

Appendix D-5

Békésy Audiograms, Subject #5

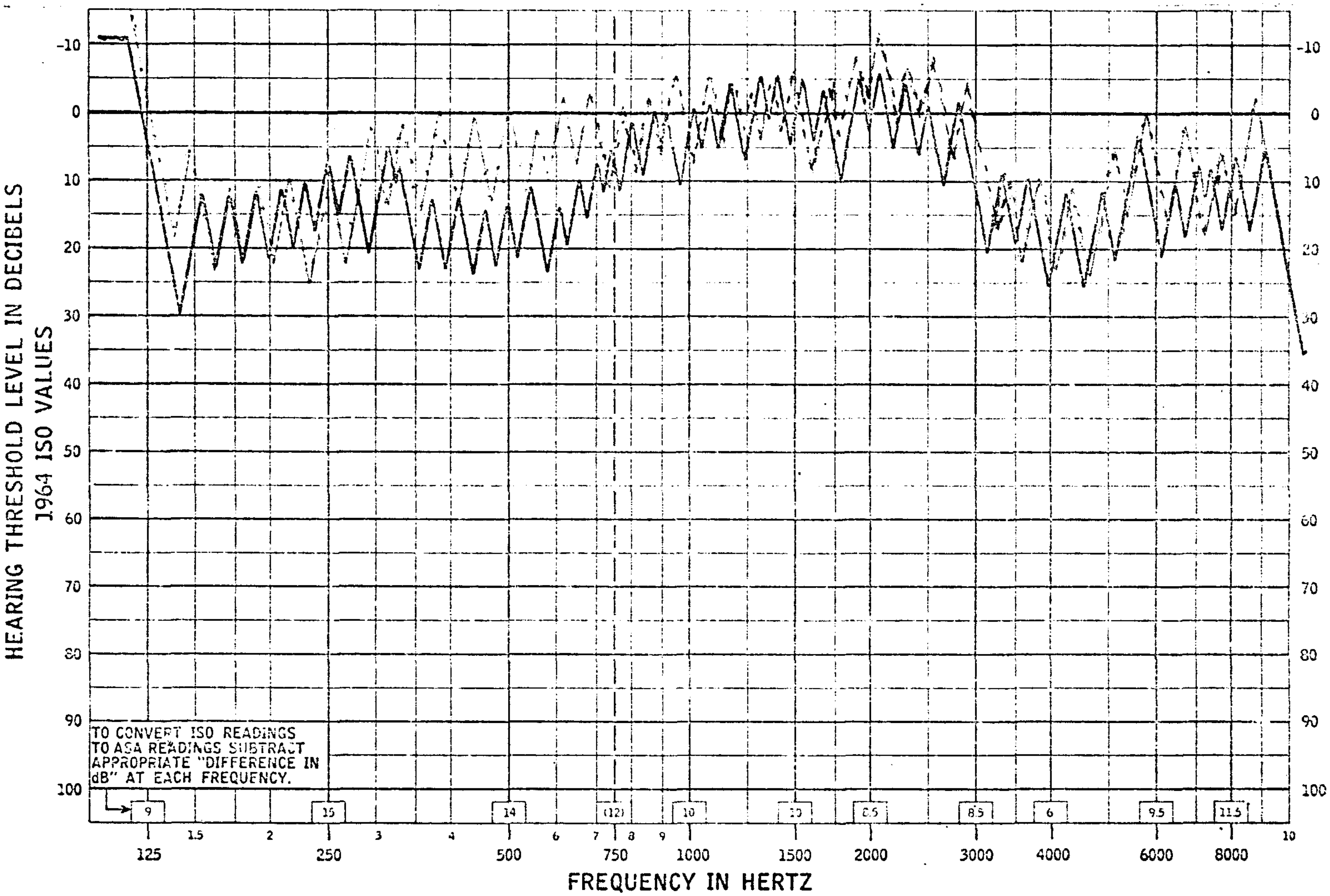


Beaded line = ConditionI

Solid line = Condition II

Appendix D-6

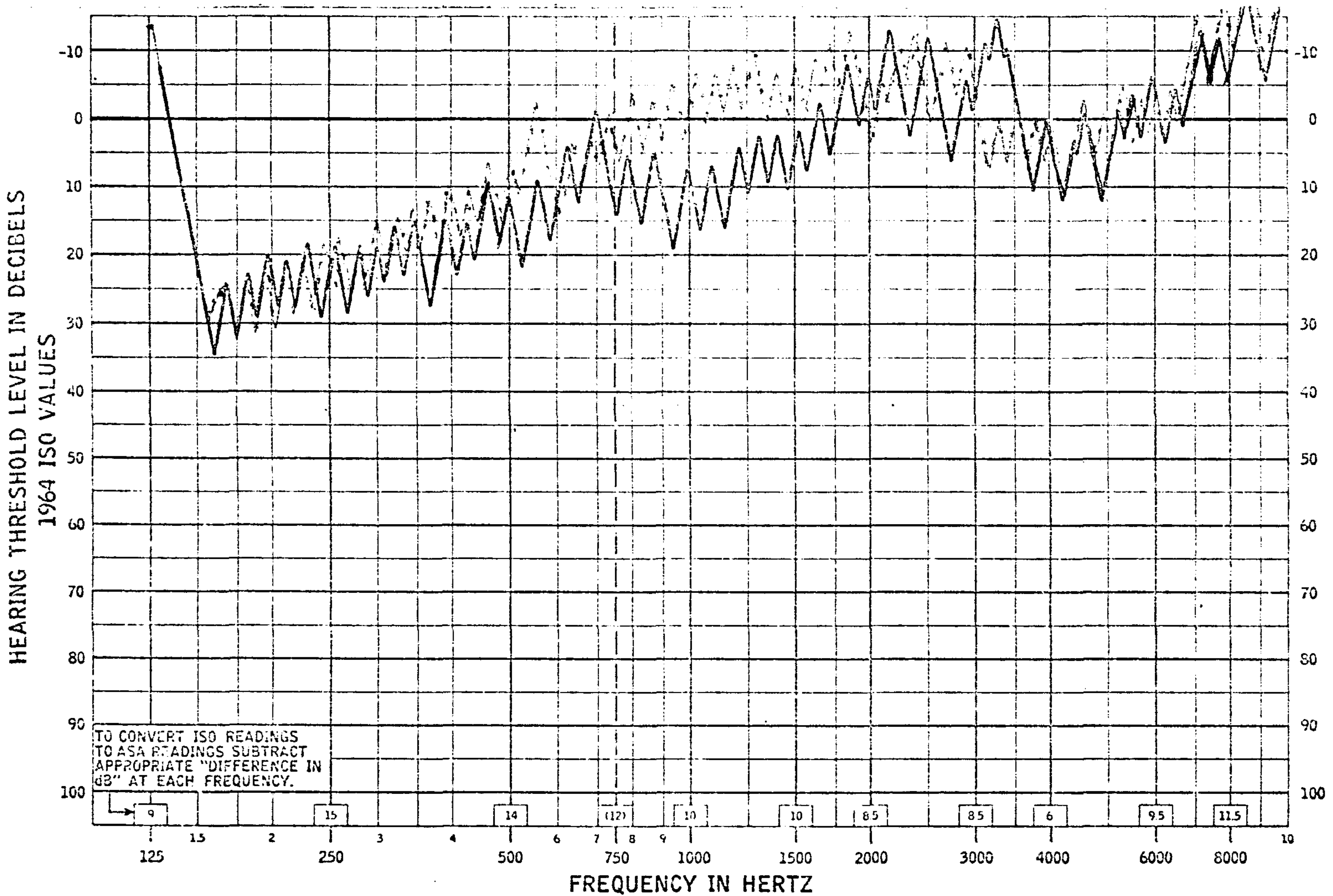
Békésy Audiograms, Subject #6



Beaded line = Condition I **Solid line = Condition II**

Appendix D-7

Bekésy Audiograms, Subject #7

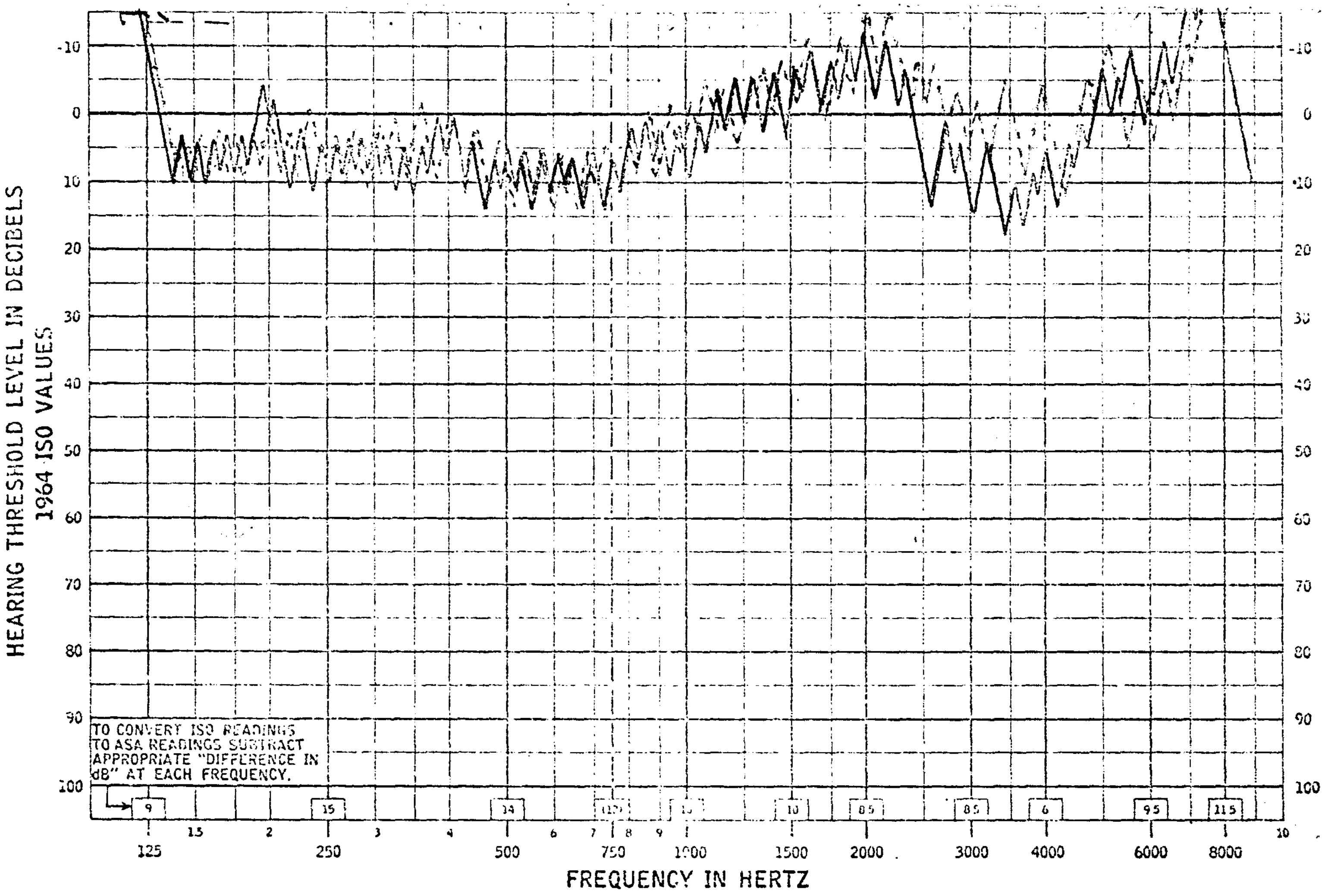


Beaded line = Condition I

Solid line = Condition II

Appendix D-8

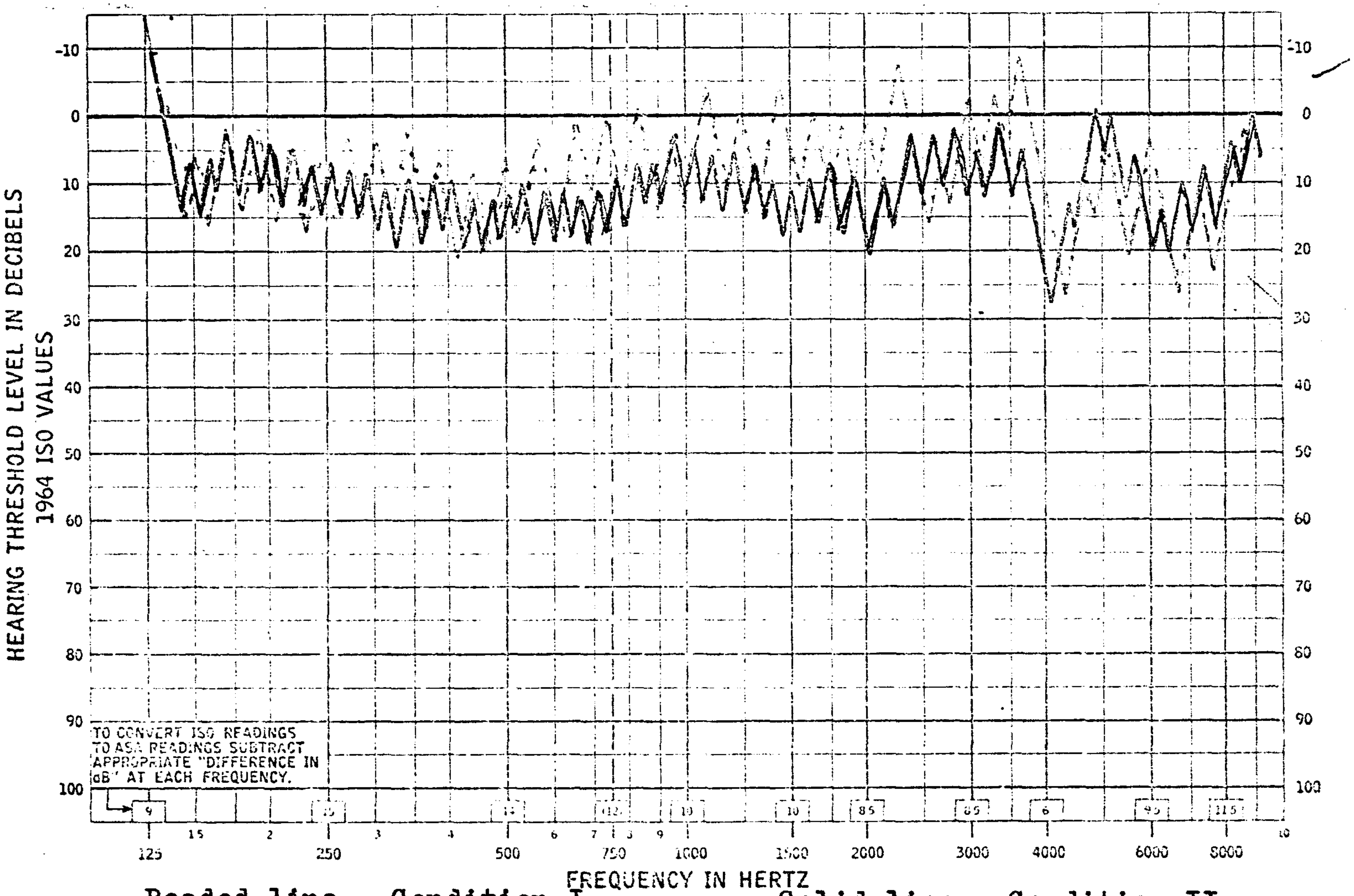
Békésy Audiograms, Subject #8



Beaded line = Condition I **Solid line = Condition II**

Appendix D-9

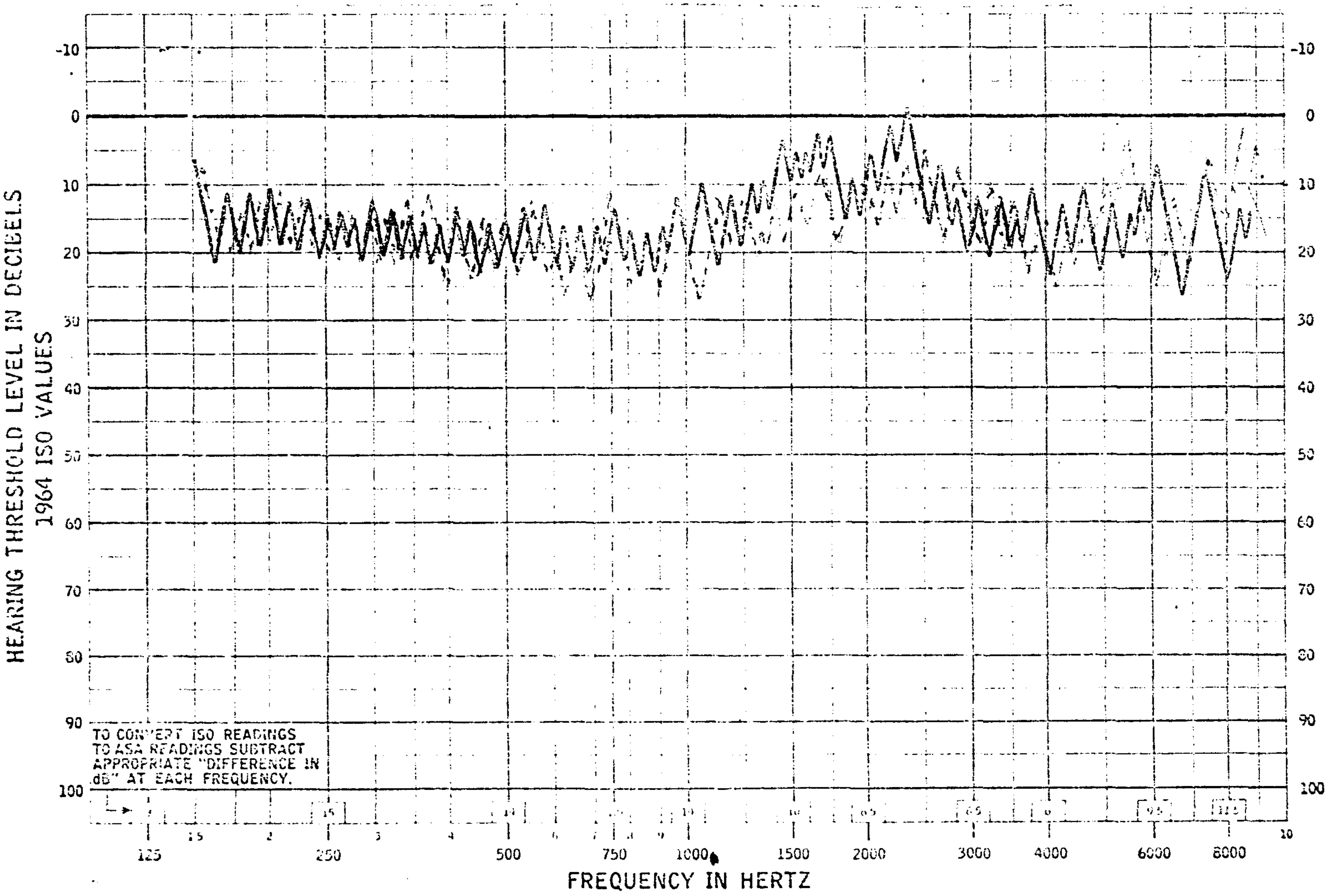
Békésy Audiograms, Subject #9



Beaded line = Condition I **Solid line = Condition II**

Appendix D-10

Békésy Audiograms, Subject #10



Beaded line = Condition I **Solid line = Condition II**

Appendix E-1
Impedance Audiometry Data, Subject #1

CASE 1		DATE 6/24
SEX M	AGE 21 Yrs 3 Mos	TIME 1975
EXAMINER		

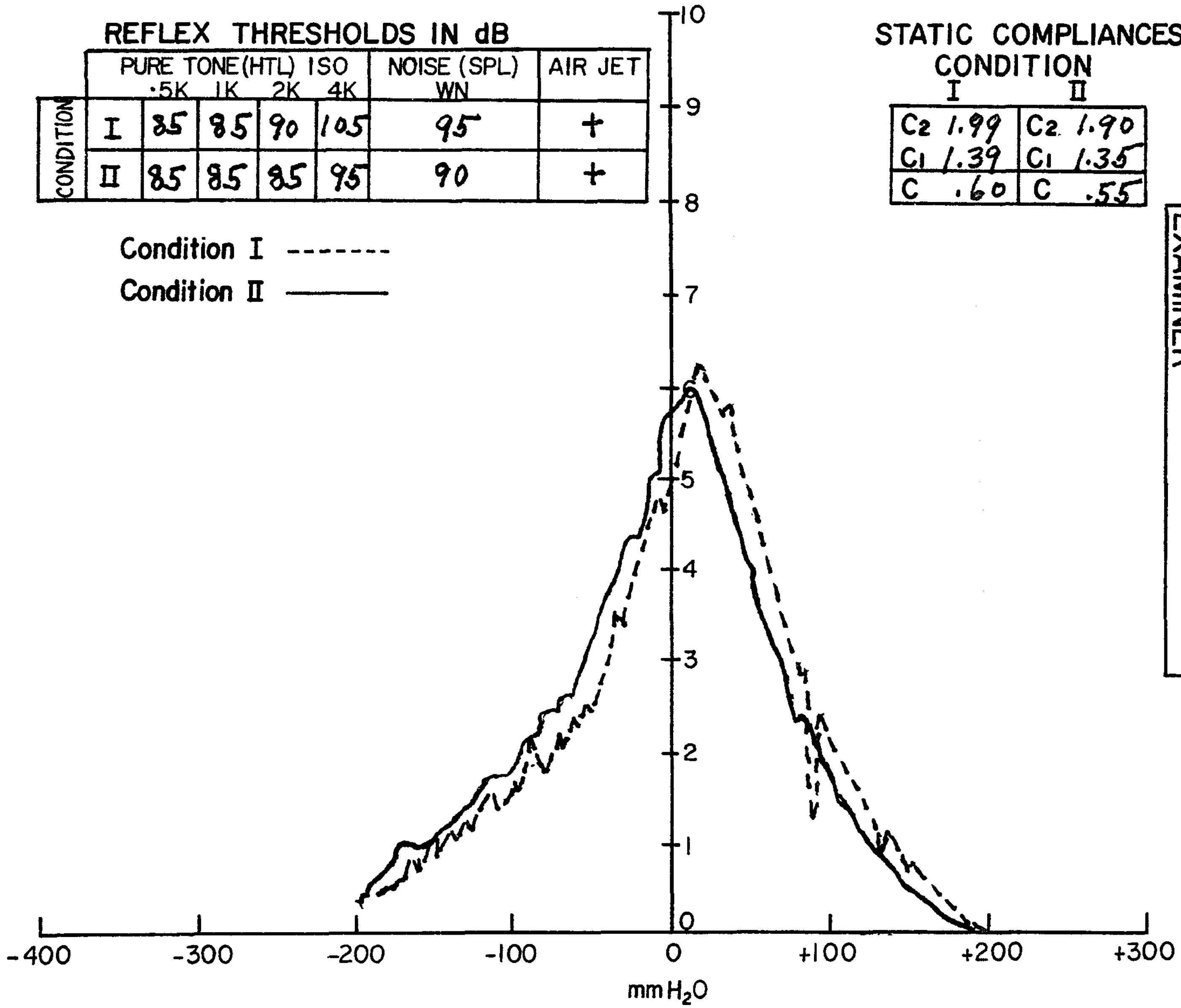
STATIC COMPLIANCES
CONDITION

I	II
C2 1.99	C2 1.90
C1 1.39	C1 1.35
C .60	C .55

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	85	85	90	105	95	+
II	85	85	85	95	90	+

Condition I - - - - - - -
Condition II ———



Appendix E-2

Impedance Audiometry Data, Subject #2

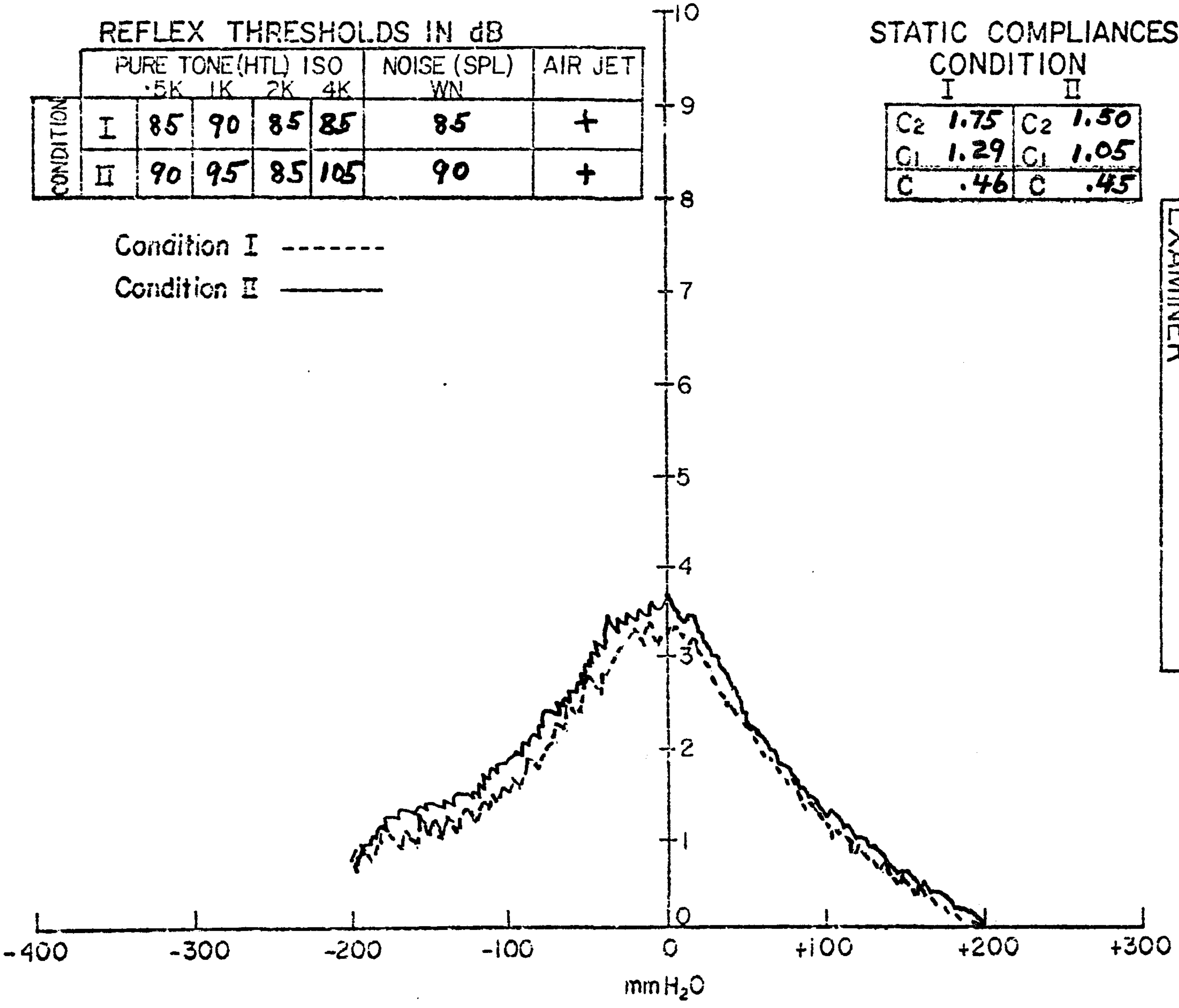
CASE 2		DATE 7/1
SEX F	AGE 21 Yrs. 10 Mos	TIME 1975
EXAMINER		

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	85	90	85	85	85	+
II	90	95	85	105	90	+

STATIC COMPLIANCES

CONDITION I		CONDITION II	
C2	1.75	C2	1.50
C1	1.29	C1	1.05
C	.46	C	.45



Appendix E-3

Impedance Audiometry Data, Subject #3

CASE 3		DATE 7/3
SEX M	AGE 21 Yrs. 2 Mos	TIME 1975
EXAMINER		

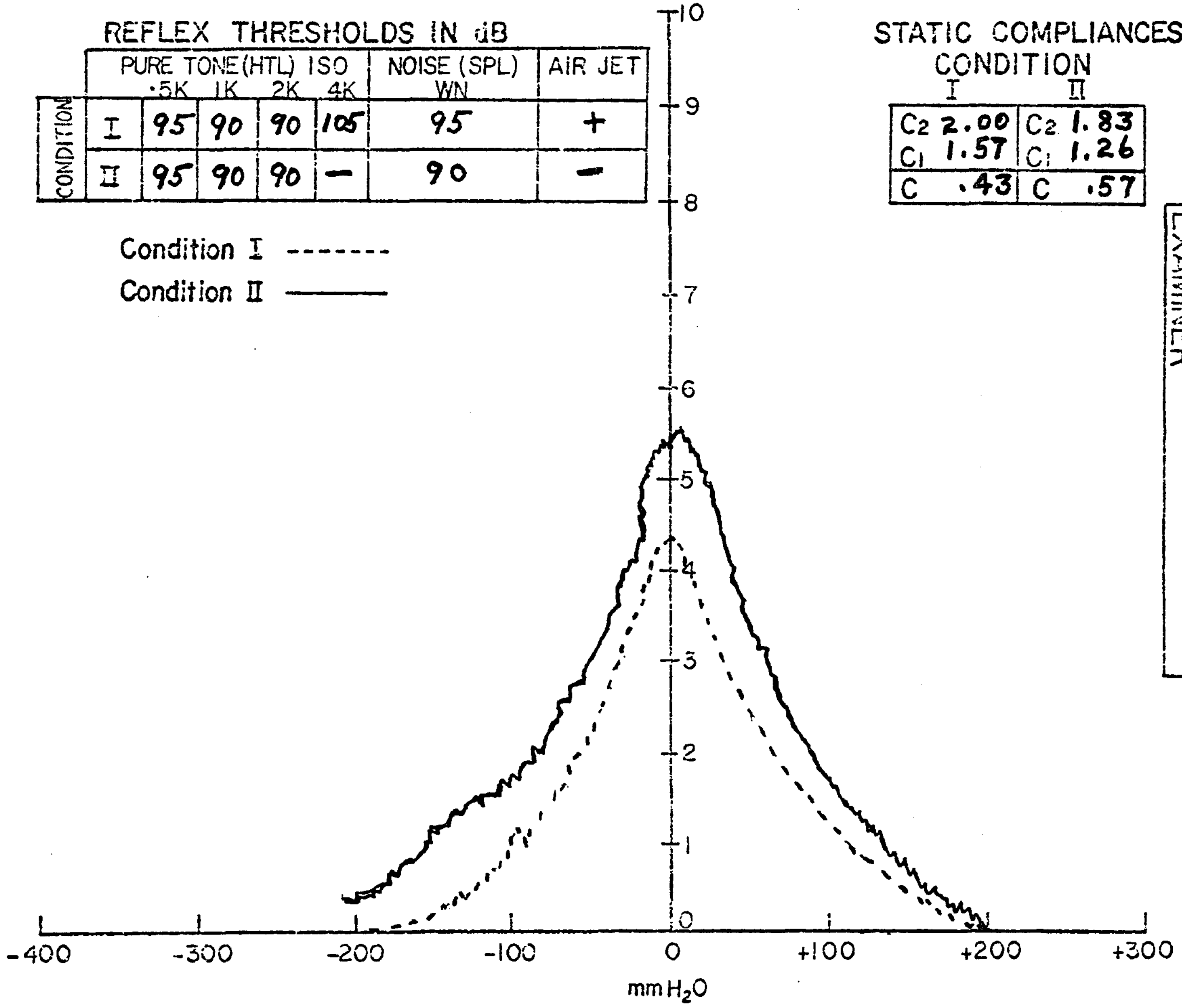
REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	95	90	90	105	95	+
II	95	90	90	—	90	—

STATIC COMPLIANCES

CONDITION

I		II	
C2	2.00	C2	1.83
C1	1.57	C1	1.26
C	.43	C	.57



Appendix E-4
Impedance Audiometry Data, Subject #4

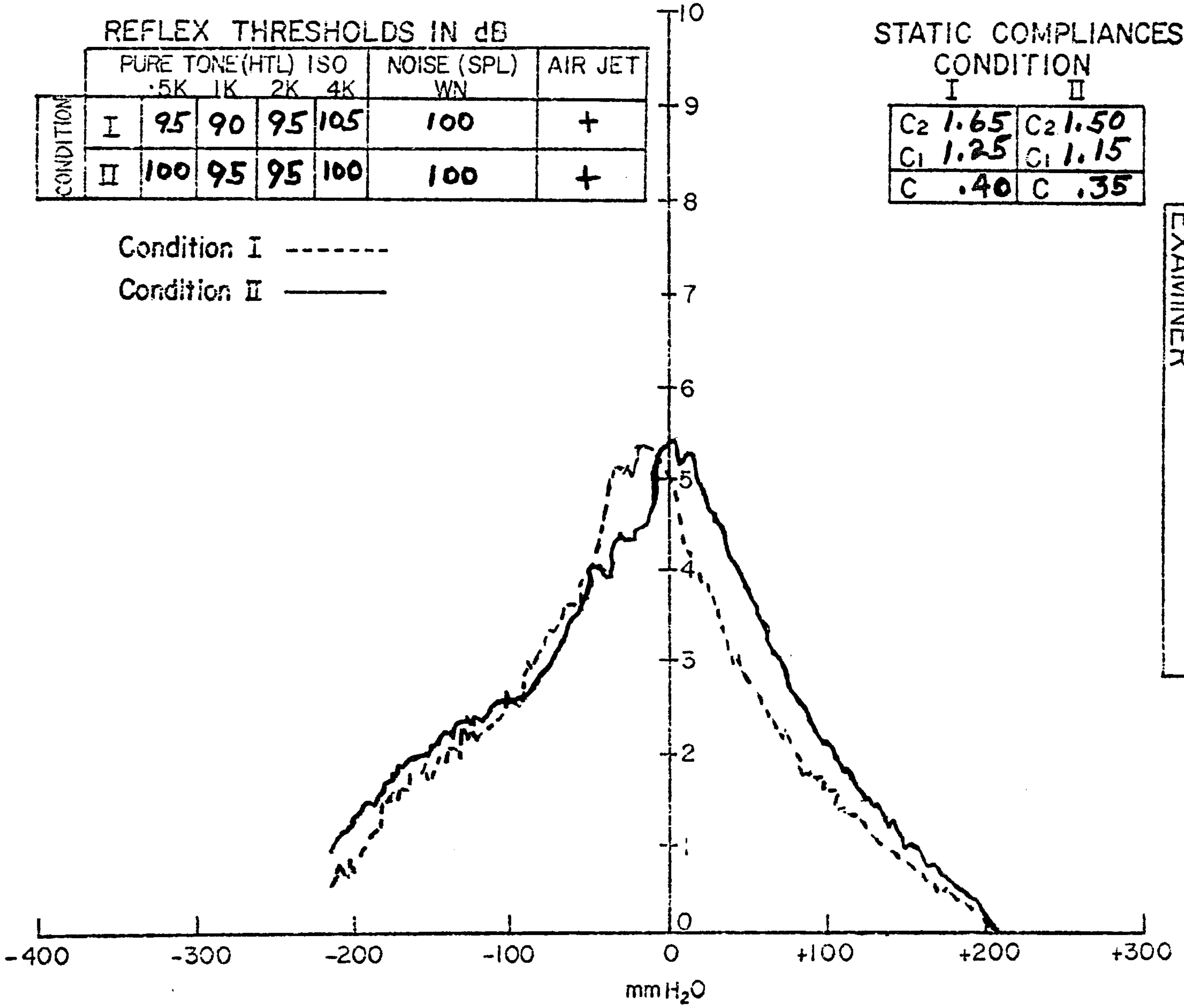
CASE 4		DATE 7/10
SEX M	AGE 21 Yrs. 5 Mos.	TIME 1975
EXAMINER		

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	95	90	95	105	100	+
II	100	95	95	100	100	+

STATIC COMPLIANCES

CONDITION I	CONDITION II
C2 1.65	C2 1.50
C1 1.25	C1 1.15
C .40	C .35



Appendix E-5
Impedance Audiometry Data, Subject #5

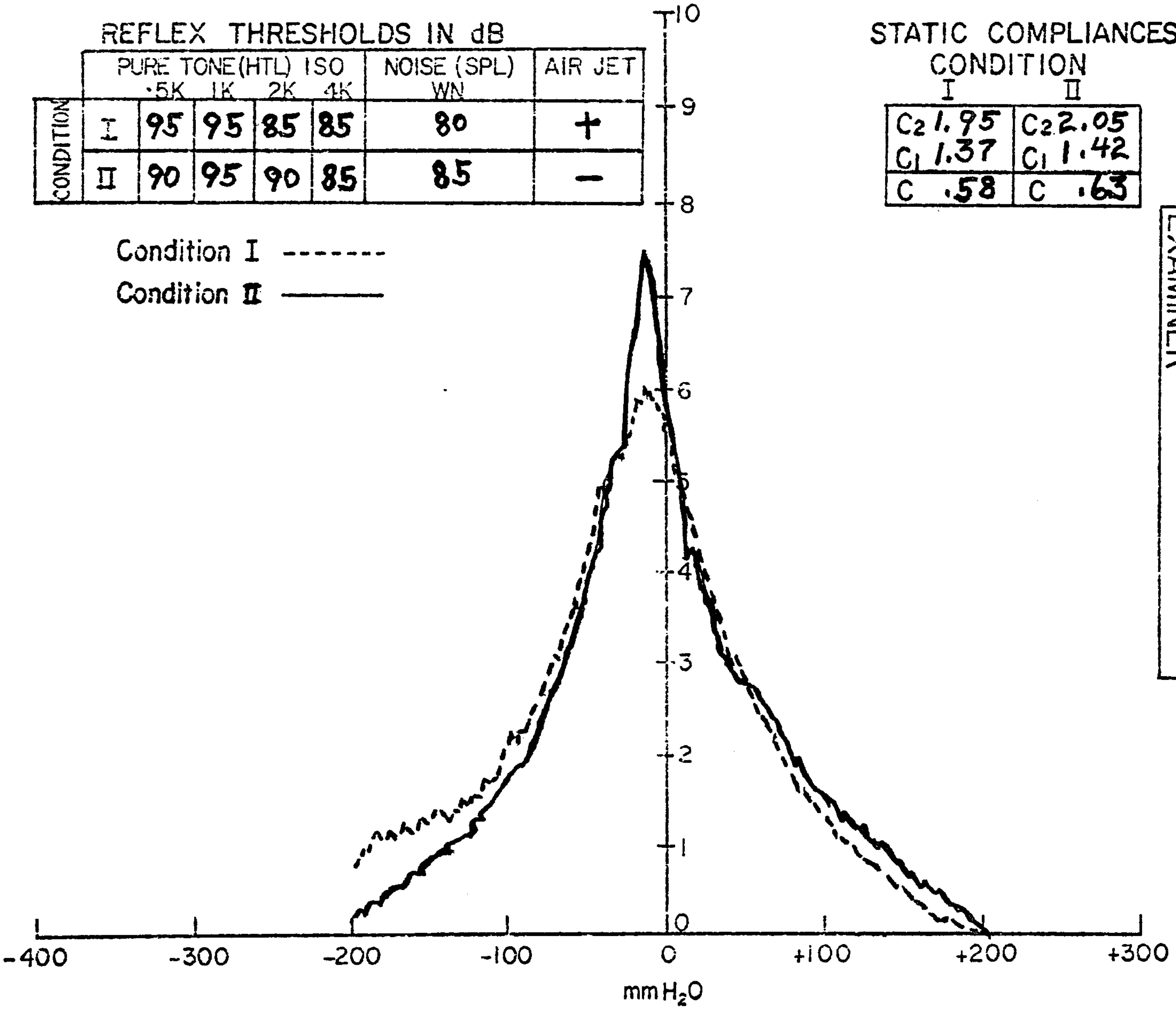
CASE 5		DATE 7/15
SEX F	AGE 21 Yrs. 6 Mos.	TIME 1975
EXAMINER		

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	95	95	85	85	80	+
II	90	95	90	85	85	−

STATIC COMPLIANCES

CONDITION I	CONDITION II
C2 1.95	C2 2.05
C1 1.37	C1 1.42
C .58	C .63



Appendix E-6
Impedance Audiometry Data, Subject #6

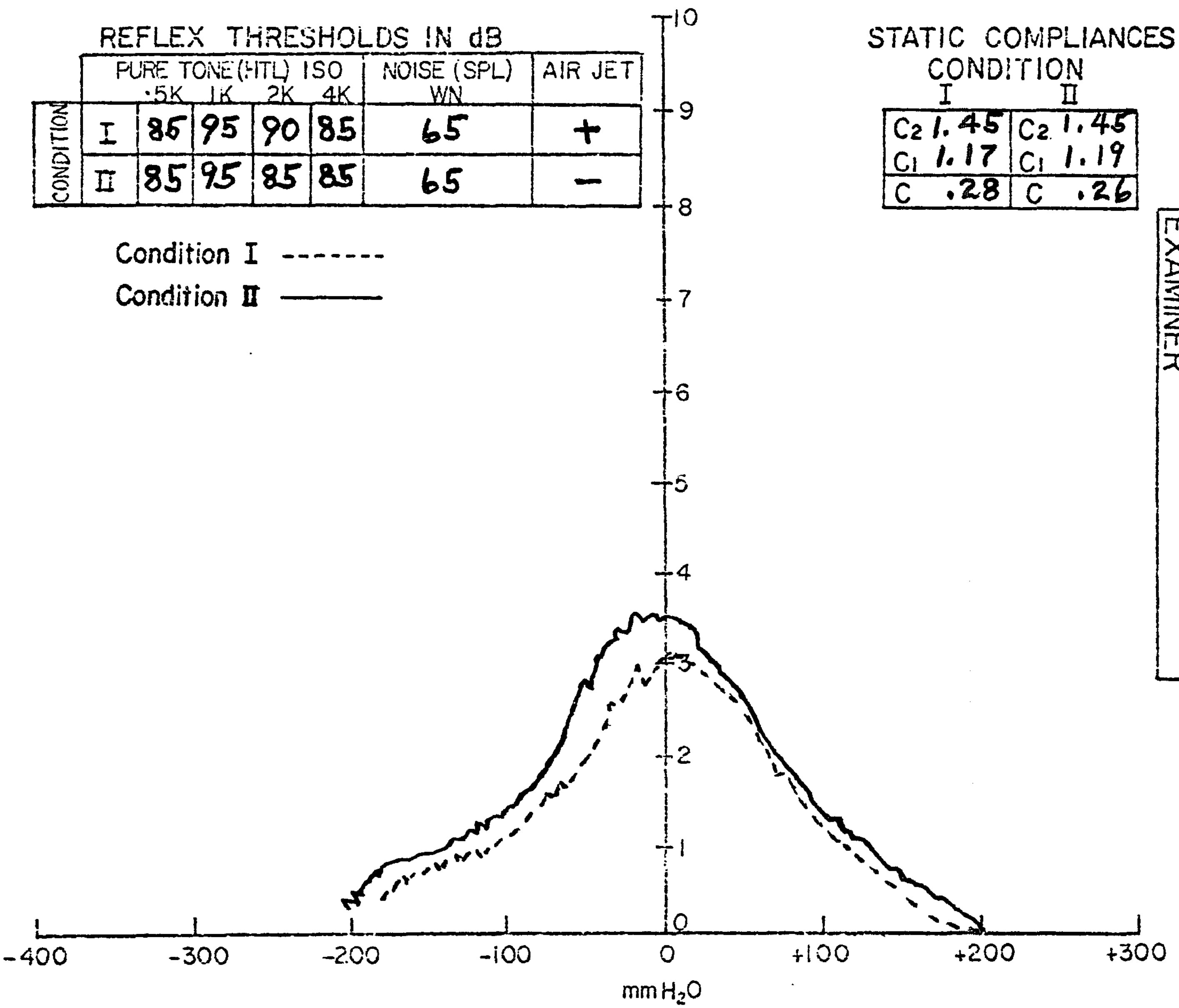
CASE 6		DATE 7/17
SEX M	AGE 21 Yrs. 1 Mo.	TIME 1975
EXAMINER		

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	85	95	90	85	65	+
II	85	95	85	85	65	−

STATIC COMPLIANCES
CONDITION

I	II
C2 1.45 C1 1.17	C2 1.45 C1 1.19
C .28	C .26



Appendix E-7

Impedance Audiometry Data, Subject #7

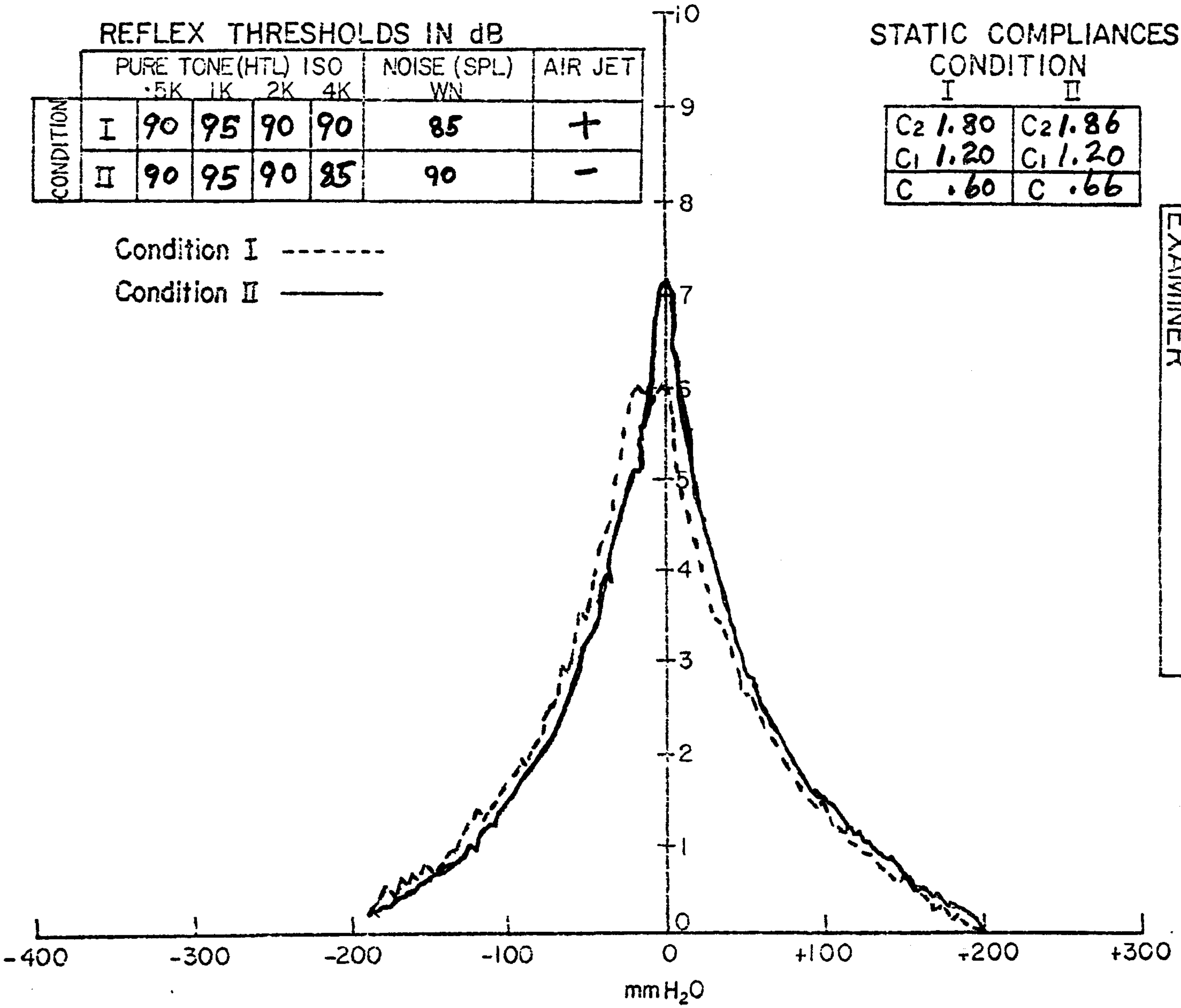
CASE 7		DATE 7/24
SEX M	AGE 21 Yrs. 5 Mos.	TIME 1975
EXAMINER		

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	90	95	90	90	85	+
II	90	95	90	85	90	−

STATIC COMPLIANCES

CONDITION I	CONDITION II
C2 1.80	C2 1.86
C1 1.20	C1 1.20
C .60	C .66



Condition I -------
Condition II ———

Appendix E-8
Impedance Audiometry Data, Subject #8

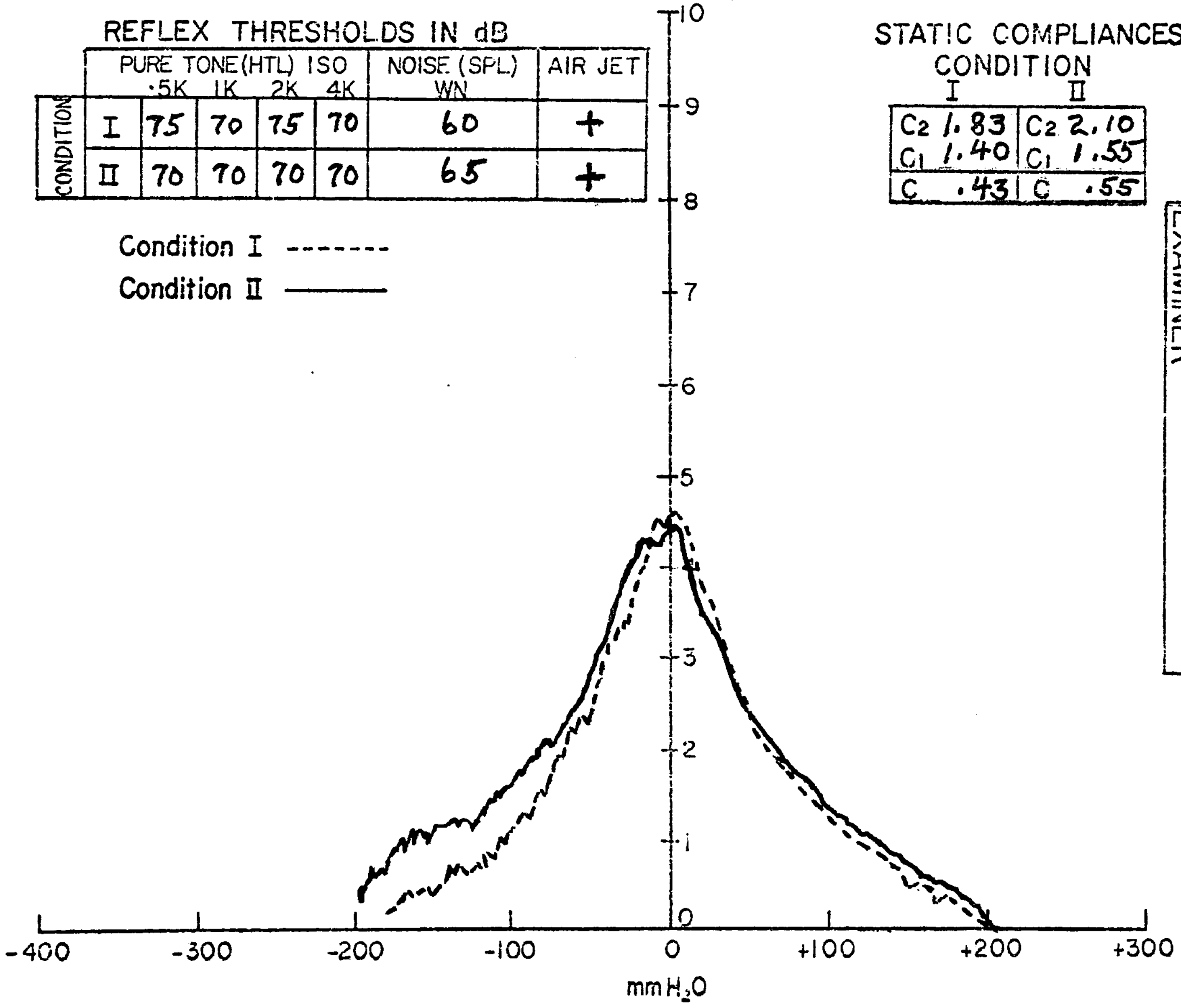
CASE 8		DATE 7/29
SEX M	AGE 30 Yrs	TIME 1975
EXAMINER		

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	75	70	75	70	60	+
II	70	70	70	70	65	+

STATIC COMPLIANCES
CONDITION

I	II
C2 1.83 C1 1.40	C2 2.10 C1 1.55
C .43	C .55



Appendix E-9
Impedance Audiometry Data, Subject #9

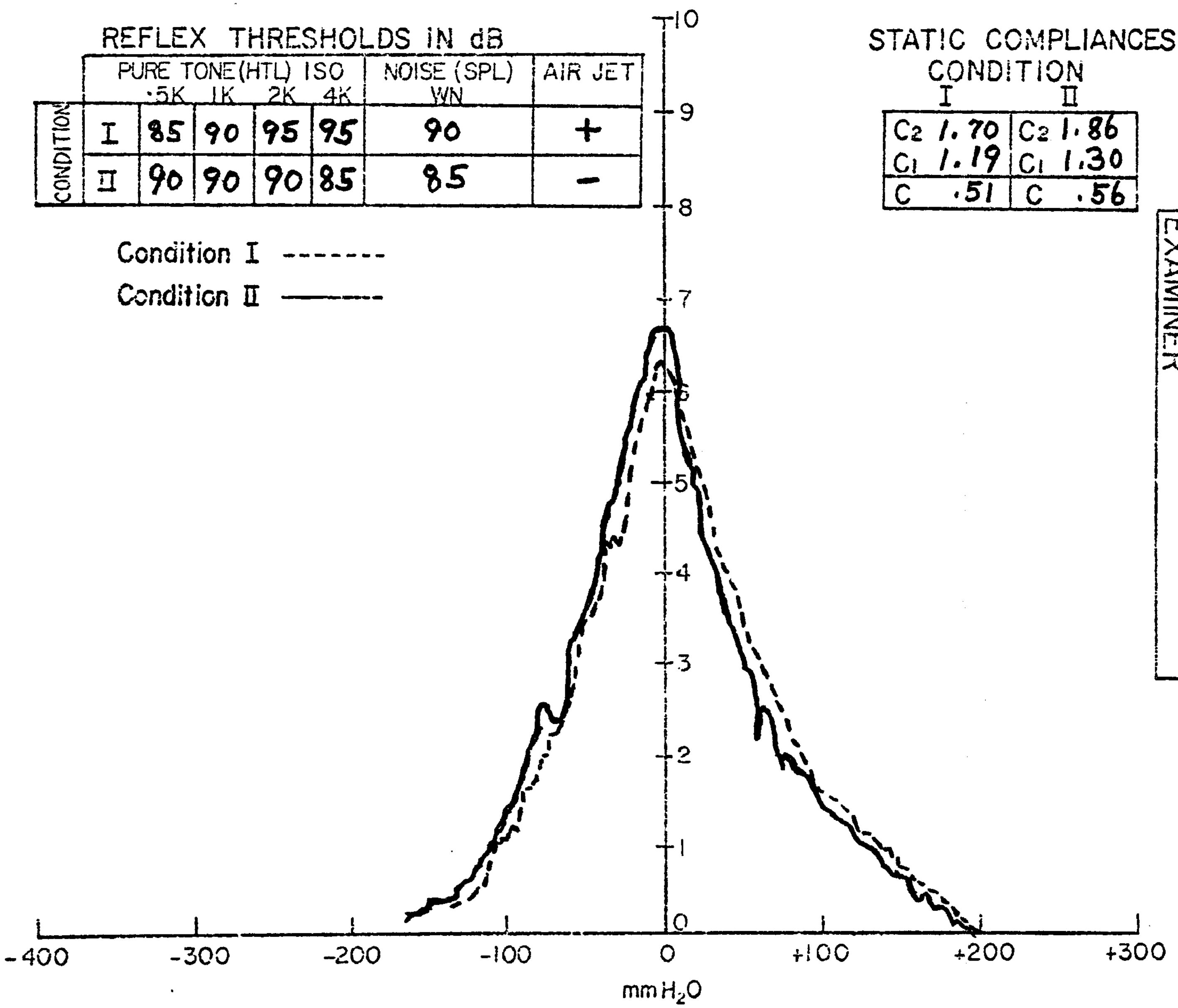
CASE 9		DATE 10/5
SEX F	AGE 21 Yrs. 6 Mos	TIME 1975
EXAMINER		

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	85	90	95	95	90	+
II	90	90	90	85	85	−

STATIC COMPLIANCES

CONDITION I	CONDITION II
C_2 1.70	C_2 1.86
C_1 1.19	C_1 1.30
C .51	C .56



Appendix E-10
Impedance Audiometry Data, Subject #10

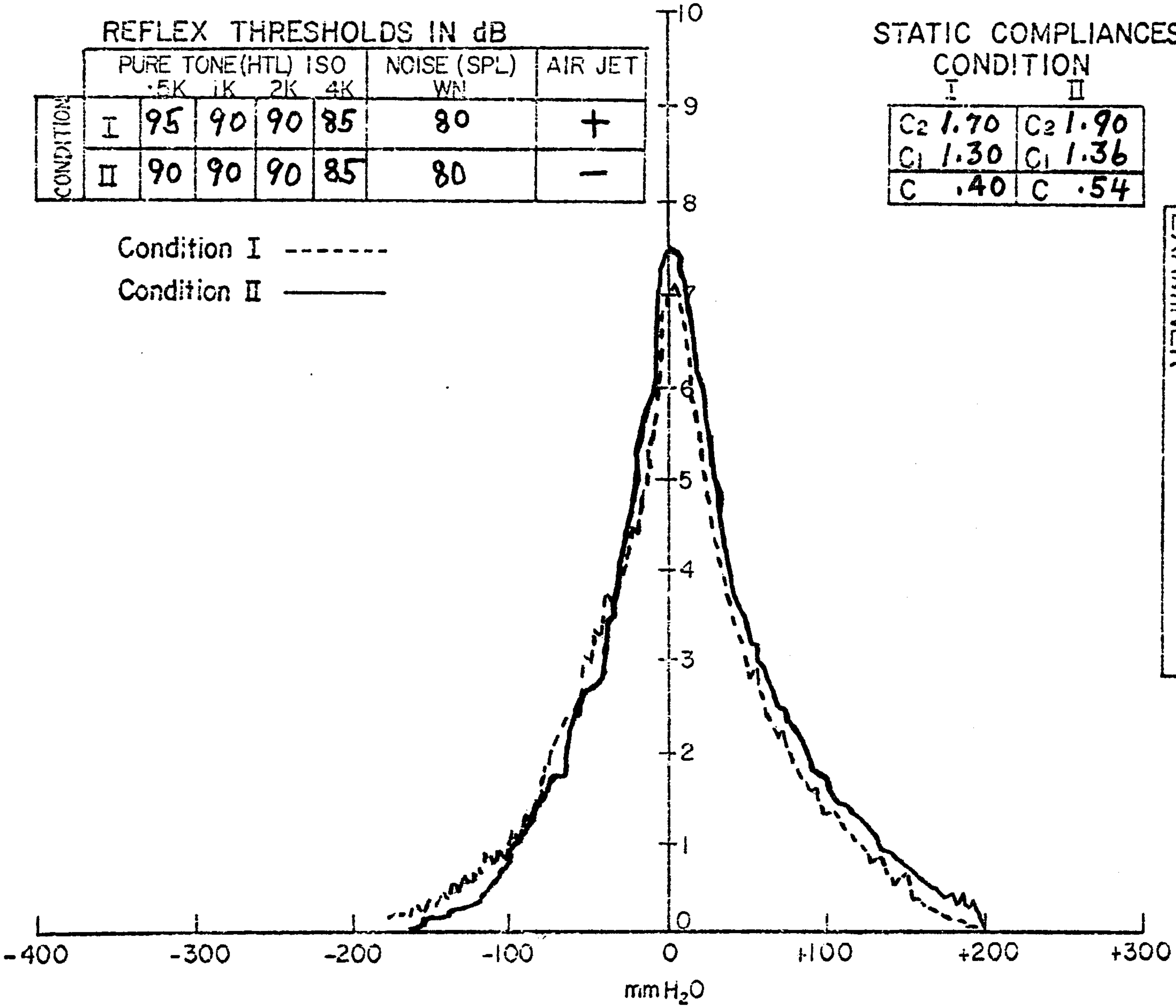
CASE 10	DATE 10/5
SEX M	AGE 21 Yrs. 3 Mos.
TIME 1975	
EXAMINER	

REFLEX THRESHOLDS IN dB

CONDITION	PURE TONE (HTL) ISO .5K	1K	2K	4K	NOISE (SPL) WN	AIR JET
I	95	90	90	85	80	+
II	90	90	90	85	80	−

STATIC COMPLIANCES
CONDITION

	I	II
C2	1.70	1.90
C1	1.30	1.36
C	.40	.54



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