Instrumental Auditory Examinations

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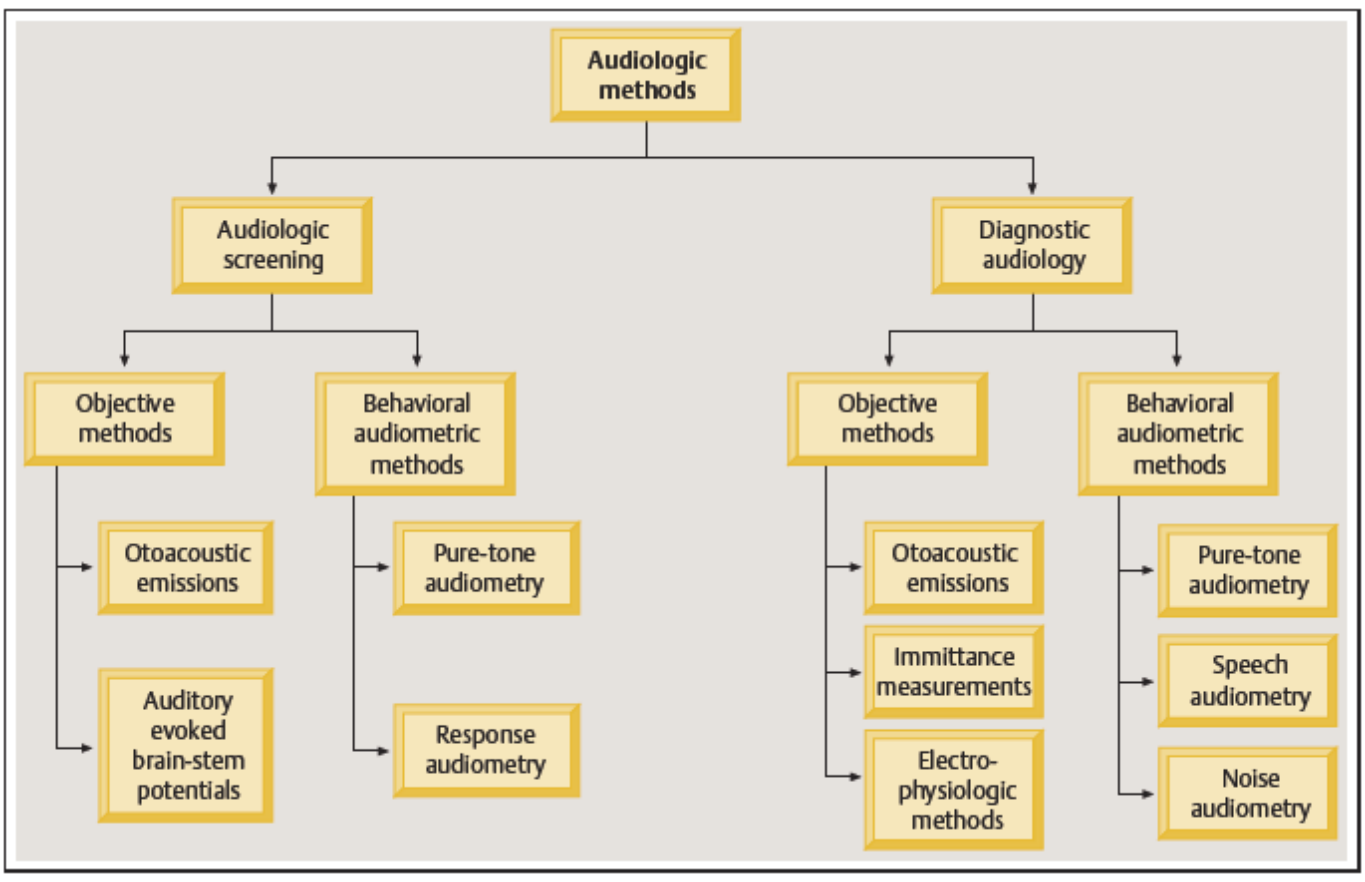
"Office" tests (auditory & vestibular) → see p. D1ear >>

Minimum comprehensive audiologic assessment:

1) pure-tone air and bone conduction thresholds
2) speech reception threshold
3) speech discrimination
4) tympanometry
5) acoustic reflex testing, including reflex decay testing.



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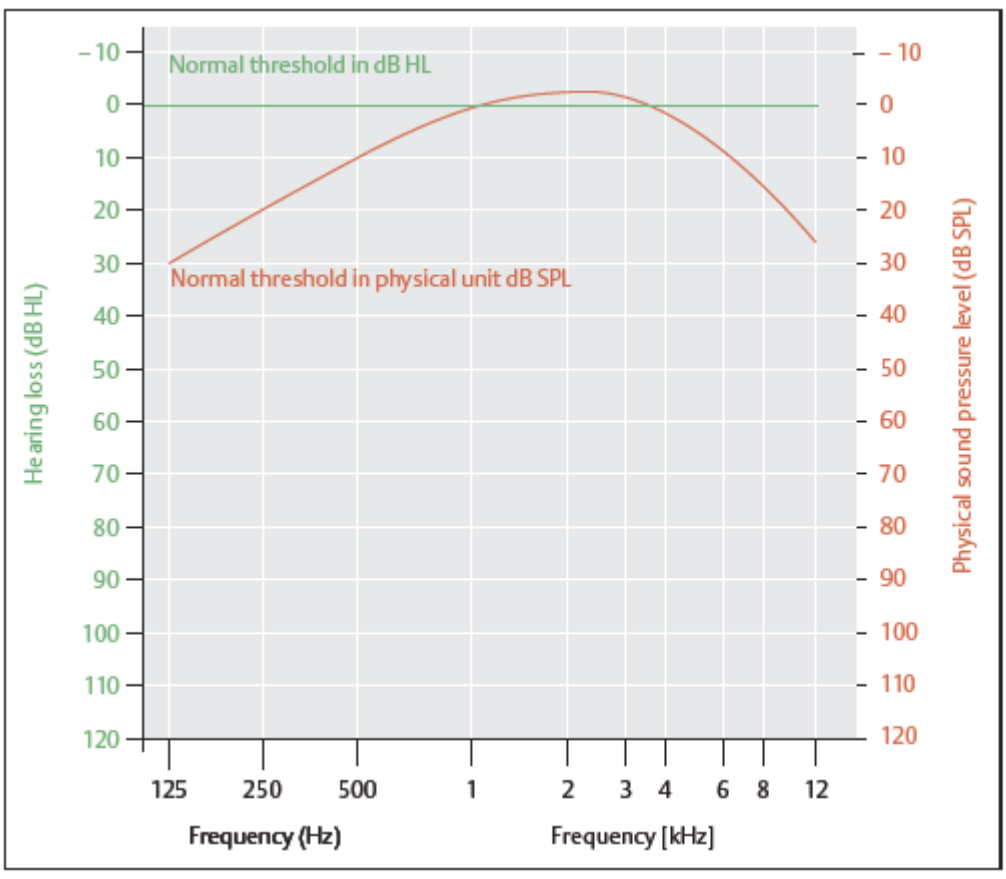
PURE-TONE AUDIOMETRY

- *objective measurement of auditory acuity*.

- single most useful test in hearing disorder / vertigo:
  - in hearing disorders, audiogram is crucial in defining degree and type of loss.
  - in vertigo, abnormalities in audiogram narrow differential diagnosis down to otological vertigo.
- **audiometer** presents specific frequencies (pure tones, range 125-8000 Hz) at specific intensities through:
  a) earphones (air conduction)
  b) oscillator in contact with mastoid process or forehead (bone conduction).
- at each frequency, **threshold intensity in dB** is determined and plotted on graph (**audiogram**) as percentage of normal hearing.
- in general:

  sensorineural deafness causes greater loss of ***high-pitched sounds***
  conductive deafness causes more loss of ***low-pitched sounds***.
- when hearing *differs* between ears (or between air and bone conduction), intense tones presented to one ear may be heard in other ear; H: **masking sound** presented to ear not being tested.



The normal auditory threshold forms a curved line when plotted against a physical sound pressure level scale (dB SPL, red curve and red scale on the right). A scale with corresponding correction factors is used clinically (dB HL, green scale on the left), and the normal auditory threshold (green) is plotted as a horizontal line. The dB HL scale directly indicates hearing loss relative to a normal population (0 dB HL).

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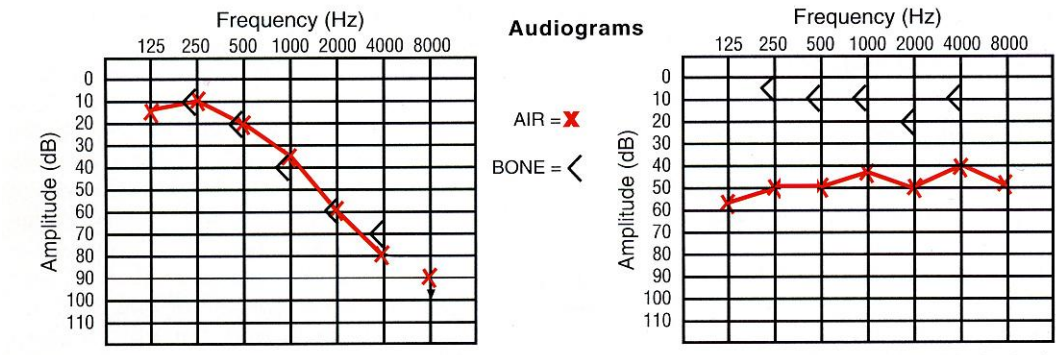
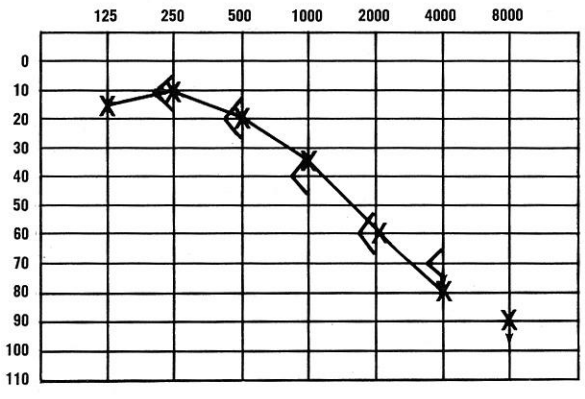


Air and bone conduction affected equally. Loss mainly in higher tones. Typical of presbycusis

Pure conduction loss. Typical of uncomplicated otosclerosis



CONVENTIONAL AUDIOGRAMS
ISO–1964

FIGURE 1. Audiogram typical of presbycusis (hearing loss due to age). Air and bone conduction are equally affected, and loss is mainly in higher tones. No improvement can be expected from surgery.

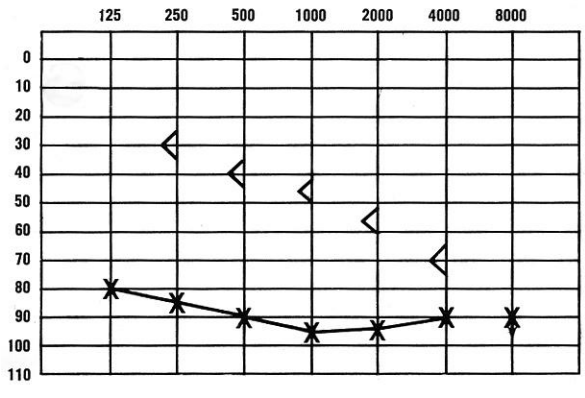


FIGURE 2. Severe mixed hearing loss. Although a great differential exists between air conduction and bone conduction, considerable high-tone deafness is inescapable, regardless of the results of surgery.

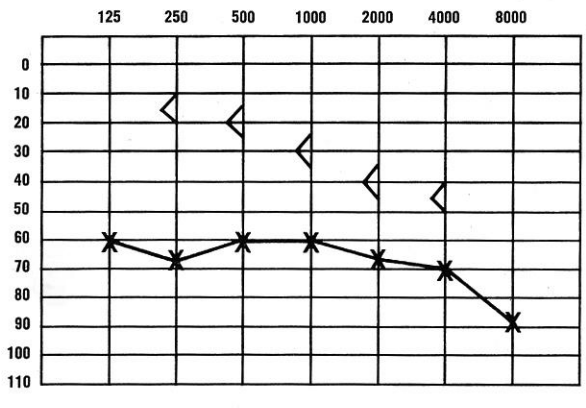


FIGURE 3. Moderately severe mixed hearing loss. Hearing may be considerably improved by surgery, but perception of the higher frequencies may be inadequate.

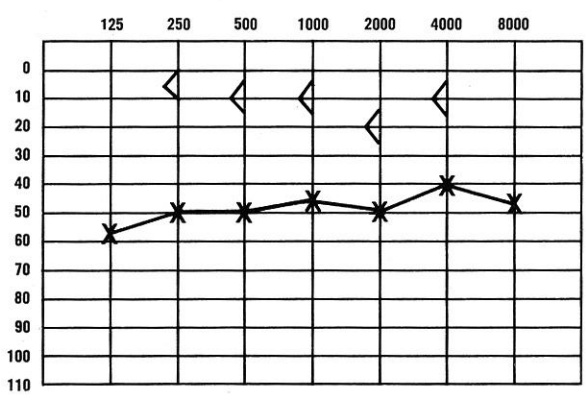
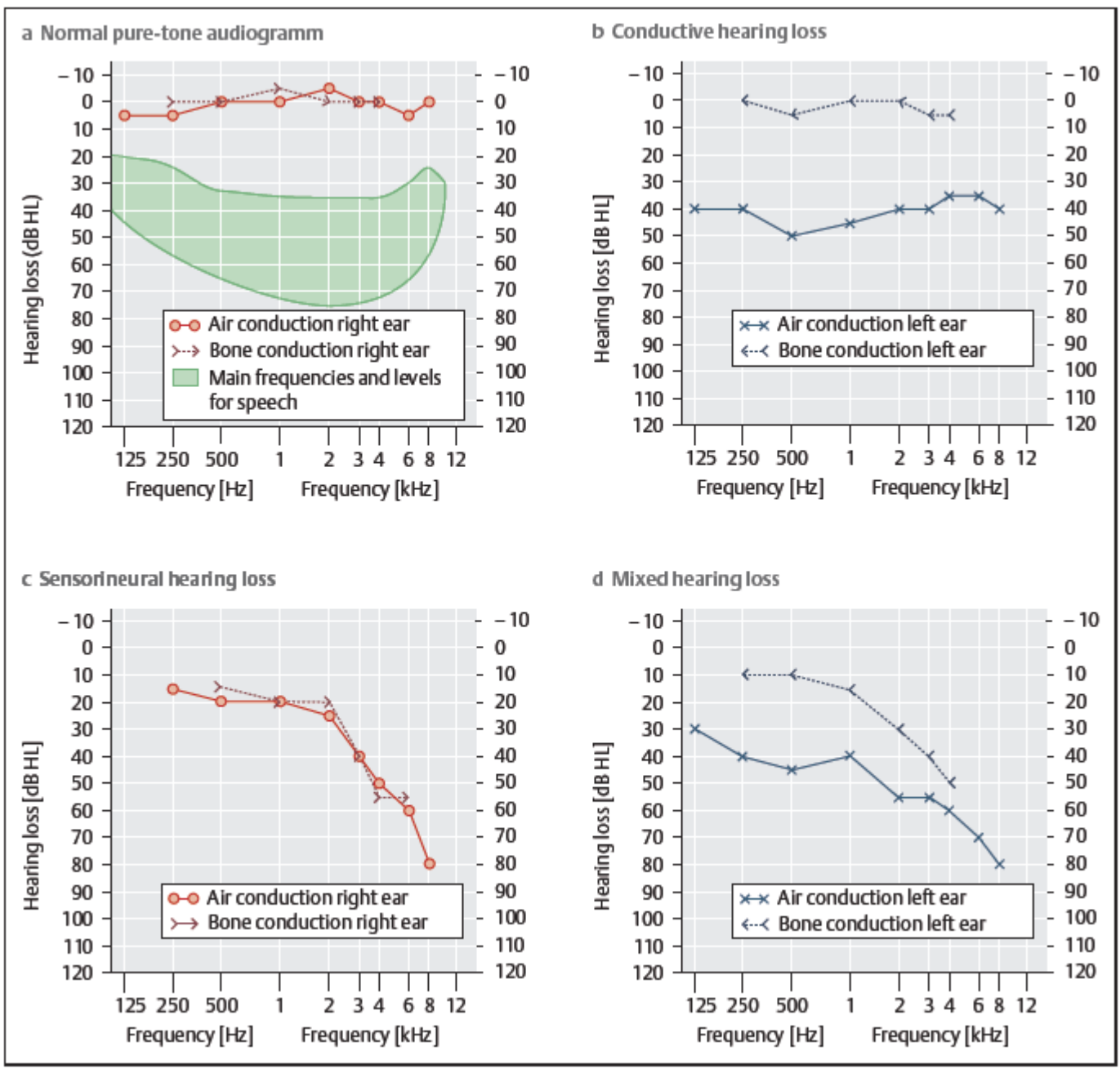


FIGURE 4. This audiogram illustrates a pure conduction loss because of uncomplicated otosclerosis. In such a case, surgery should give excellent results.



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PEDIATRIC ASPECTS

According to age:

< 6 months - **behavioral observation audiometry**;

6 months ÷ 2.5 years - **visual reinforcement audiometry**;

> 2.5 years - **play audiometry**;

older children - **standard testing** with hand raising.

N.B. child cooperation is adequate for objective audiometry since 3-4 years of age!

- perform ***audiometric SCREENING*** at 5, 8, 10, 12 (± 15, 18) years.

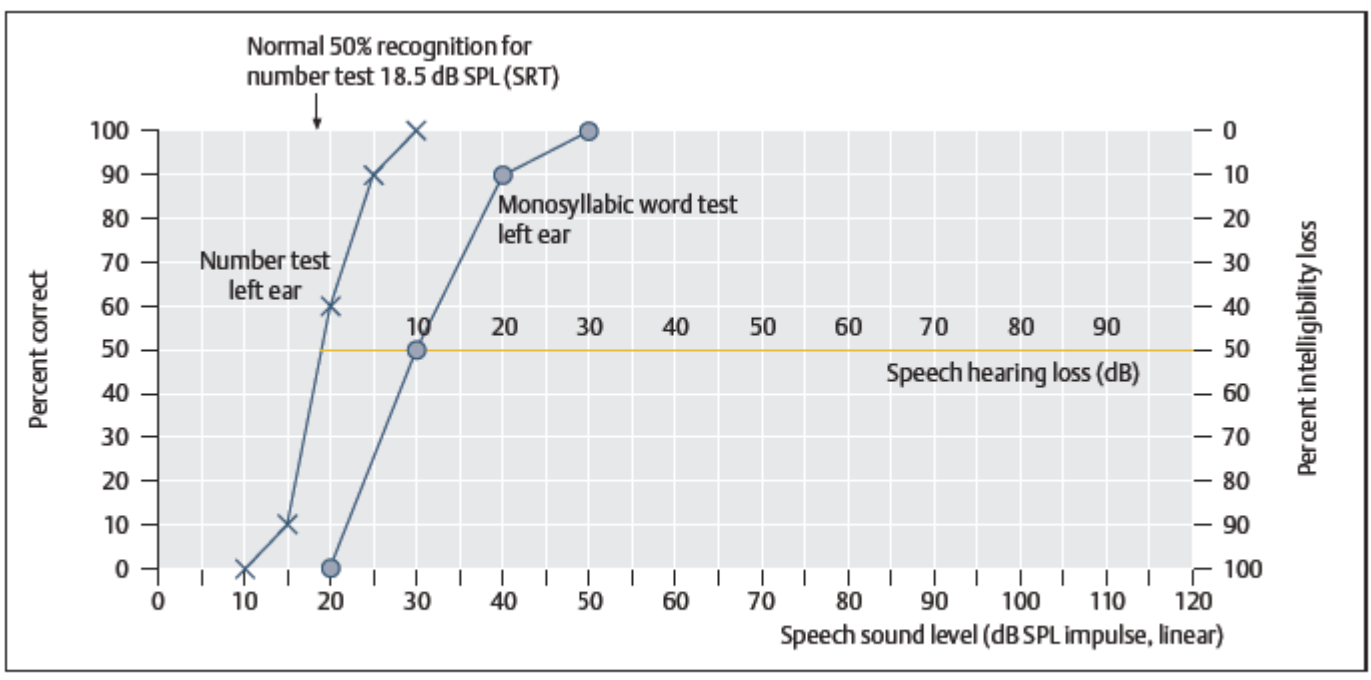
  Failure of audio-metric screening - inability to hear in either ear sounds of 1000 Hz or 2000 Hz at 20 dB, or 4000 Hz at 25 dB → formal full-scale audiometry.

- ***FULL-SCALE audiometry*** should be given to all children prior to beginning school!!!

SPEECH AUDIOMETRY

1. **Speech reception threshold (SRT)** - intensity at which speech is recognized as meaningful symbol.
   - determined by presenting list of words (usually words with two equally accented syllables) at specific intensities (500, 1000, 2000 Hz) and noting intensity at which patient repeats 50% of words correctly.
   - results should be consistent with pure-tone audiometry (if not, nonperipheral hearing disturbance is more likely).

2. **Speech discrimination (s. word recognition score)** - ability to discriminate among various speech sounds or phonemes (indication of person's ability to understand speech under ideal listening conditions).
   - determined by presenting 50 phonetically balanced one-syllable words, containing phonemes in same relative frequency as in conversational English, at intensity of 25-40 dB above SRT.
   - percentage of words correctly repeated by patient is **speech discrimination score** (normally 90-100%).
   - ***conductive hearing loss*** - score remains in *normal* range;
     sensorineural hearing loss (impaired analysis of speech sounds by inner ear and 8th nerve) – score is *reduced* (score is poorer in **neural** than in **sensory** hearing loss).



Normal speech recognition curves for monosyllabic test words (o) and four-syllable number words (x) of the type used in the Freiburg Speech Test. Plotted with sound level on the abscissa.

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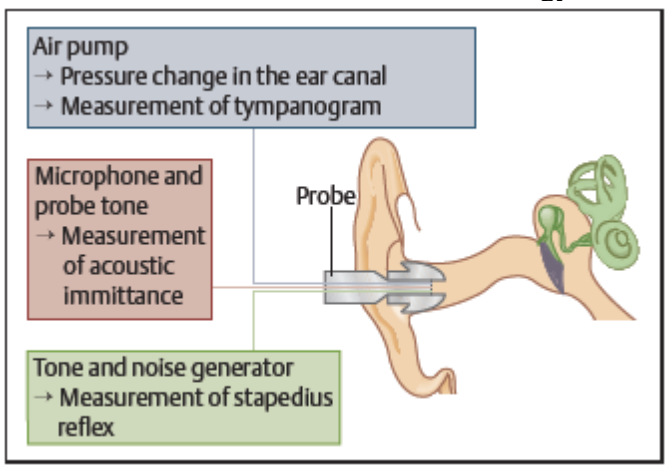
TYMPANOMETRY (ACOUSTIC IMPEDANCE)

- measures ***immittance***, i.e. ***impedance (compliance) of middle ear to acoustic energy***.

- while patient remains quiet, probe (containing sound source and microphone) is placed in ear canal to measure how much acoustic energy is **absorbed** (passes through) or is **reflected** by middle ear.



The external auditory canal is hermetically sealed with a probe that has various access ports. The acoustic impedance is measured with a probe tone (usually 220 Hz). An air pump generates a positive or negative pressure in the ear canal (tympanogram), and additional tones or noise evoke a stapedius reflex. The reflected portion of the probe tone is fed to a measuring instrument by an integrated microphone and plotted as a tympanogram.

Source of picture: Rudolf Probst, Gerhard Grevers, Heinrich Iro "Basic Otorhinolaryngology" (2006); Publisher: Georg Thieme Verlag; ISBN-10: 1588903370; ISBN-13: 978-1588903372 >>

- normally, maximal compliance of middle ear occurs when pressure in ear canal equals atmospheric pressure, i.e. normal ear shows smooth bell-shaped curve.
- when pressure in middle ear is relatively negative (as in eustachian tube obstruction and middle ear effusion), maximal compliance occurs with negative pressure in ear canal + very little movement of tympanic membrane is registered (flattened curve).
  Tympanometry is used to *screen children for middle ear effusions*! (detects fluid with 90% sensitivity and 75% specificity)
- disrupted ossicular chain (as in necrosis or dislocation of long process of incus) - middle ear is excessively compliant.
- fixated ossicular chain (as in stapedial ankylosis in otosclerosis) - compliance ↓ or normal.

Type A tympanogram with little negative pressure - normal middle ear and eustachian tube function.

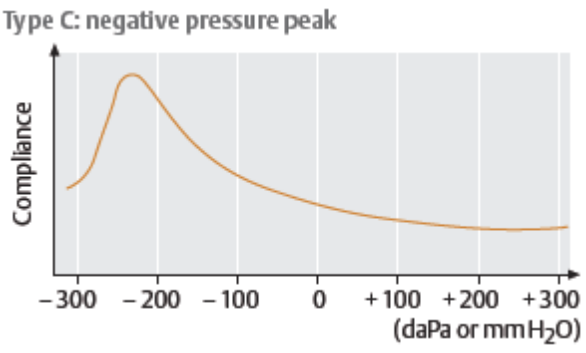
a The normal tympanogram has a prominent, sharp peak between + 100 and – 100 daPa.

Type B tympanogram with low volume - middle ear fluid.

b The type B tympanogram is flat or has a very low, rounded peak. This indicates immobility of the tympanic membrane, which may be due to fluid in the middle ear or tympanic atelectasis.

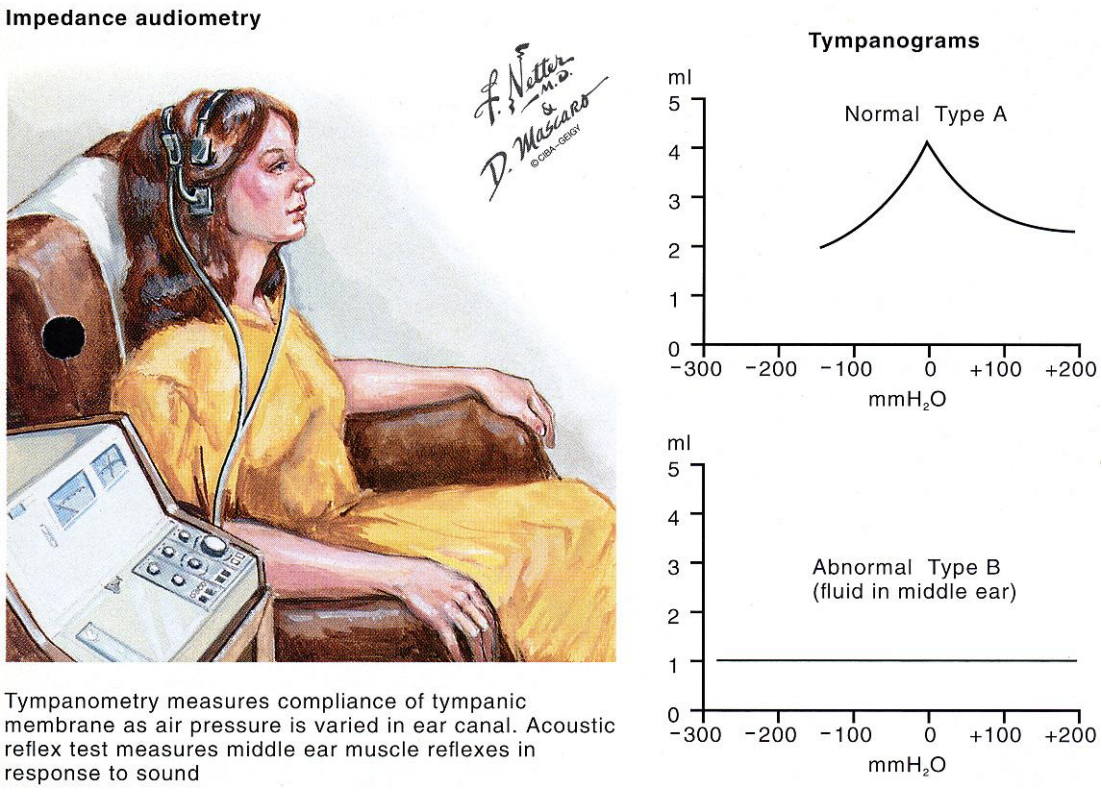
Type B tympanogram with large volume - patent tube or perforation; small volume with visible perforation on exam - eustachian tube edema; volume of 4-5 mL suggests patent eustachian tube.

Type C tympanogram with high negative pressure - eustachian tube inflammation and dysfunction.



c The type C tympanogram has a peak in the negative pressure region below – 100 daPa, consistent with impaired middle ear ventilation.

Type D tympanogram - flaccid tympanogram with high negative pressure or ossicular discontinuity.



Tympanometry measures compliance of tympanic membrane as air pressure is varied in ear canal. Acoustic reflex test measures middle ear muscle reflexes in response to sound

Source of picture: Frank H. Netter "Clinical Symposia"; Ciba Pharmaceutical Company; Saunders >>

STAPEDIAL REFLEX TESTING

- detects ***changes in compliance*** produced by ***reflex contraction of STAPEDIUS muscle***.

- acoustic reflex is initiated by presenting tone of varying intensities to ear being evaluated (or to opposite ear) – reflex appears as notch on tympanometry graph.
- typically, threshold for response is in range of 85 dB for midfrequency stimulus (elevated or absent thresholds are synonymous with middle ear dysfunction).
- reflex is absent in 5% normal population.
- evaluates **CN7** & **ossicles** function – perform if tympanogram is normal but you still suspect middle ear disorder (abnormal in otosclerosis, CN7 palsy)
- can confirm voluntary threshold responses and may indicate that patient is malingering.
- *reflex adapts/decays* (esp. below 2000 Hz) *in NEURAL hearing loss* (vs. SENSORY hearing loss).

OTOACOUSTIC EMISSIONS (OAE)

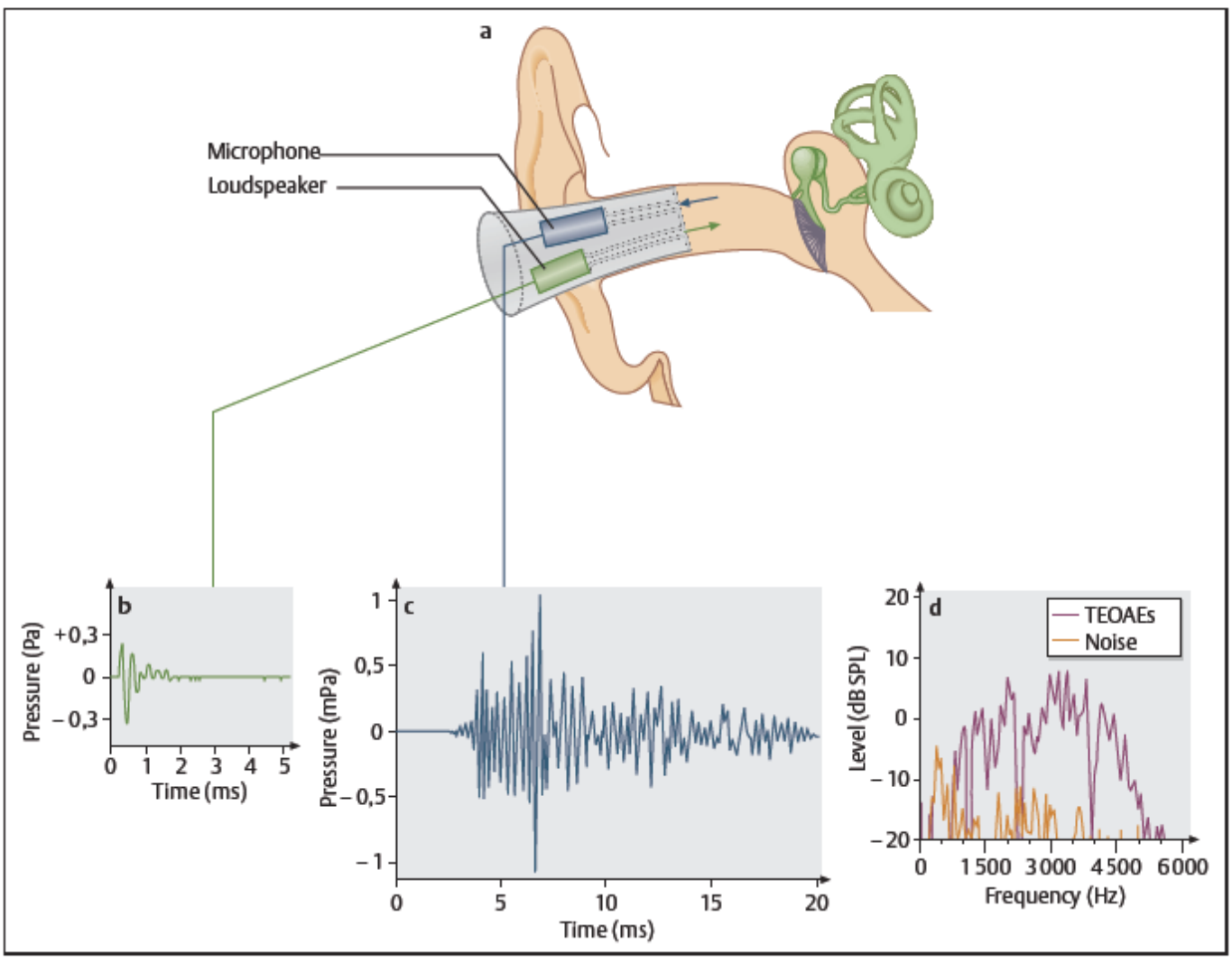
- sounds generated by motile outer hair cells in **healthy cochlea** (i.e. sounds that issue from external acoustic meatus as result of vibrations originating within cochlea).

- measured by placing in ear canal sound source to present stimulus and microphone to record response.
- absent otoacoustic emissions indicate damaged cochlea; middle ear diseases (such as otitis media) also eliminate otoacoustic emissions.

Used in **infant hearing screening**!

- categories:
  1) **SPONTANEOUS otoacoustic emissions** - limited clinical application because are recorded only in approximately half of population.
  2) **EVOKED otoacoustic emissions**

Fig. Transient evoked otoacoustic emissions (TEOAEs)



a Setup for measuring TEOAEs: measuring probe with microphone and loudspeaker.
b Waveform of the stimulus, which lasts approximately 2 ms. Note that the scale of the stimulus sound pressure (Pa) is 1000 times greater than the scale for the sound pressure responses recorded in the ear canal (see **c**).
c The waveform recorded 2.5 ms after initiation of the stimulus reflects the time course and amplitude of the sound pressure of the TEOAEs.
d Spectrum of the evoked response (from **c**), indicating the frequency distribution of the TEOAEs (purple). The orange trace represents noise.

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BAER s. BAEP (Brain Stem Auditory Evoked Responses s. Potentials)

- *registers action potentials along auditory pathways* (CN8 ÷ auditory cortex).

- stimulus - monaural click 65 dB above patient's hearing threshold.
- recorded between ***vertex of scalp*** and ***mastoid process*** (or ***earlobe***).
- **attention of subject is not required**! – perfect for non-cooperative patients (e.g. children, coma, malingering).
- BAER results may be inaccurate in patients who have no high-frequency hearing (*audiometry is recommended before BAER!*).
- very low voltage – 1000-2000 responses are recorded so that BAER can be extracted by averaging from background noise. also see p. D25 >>

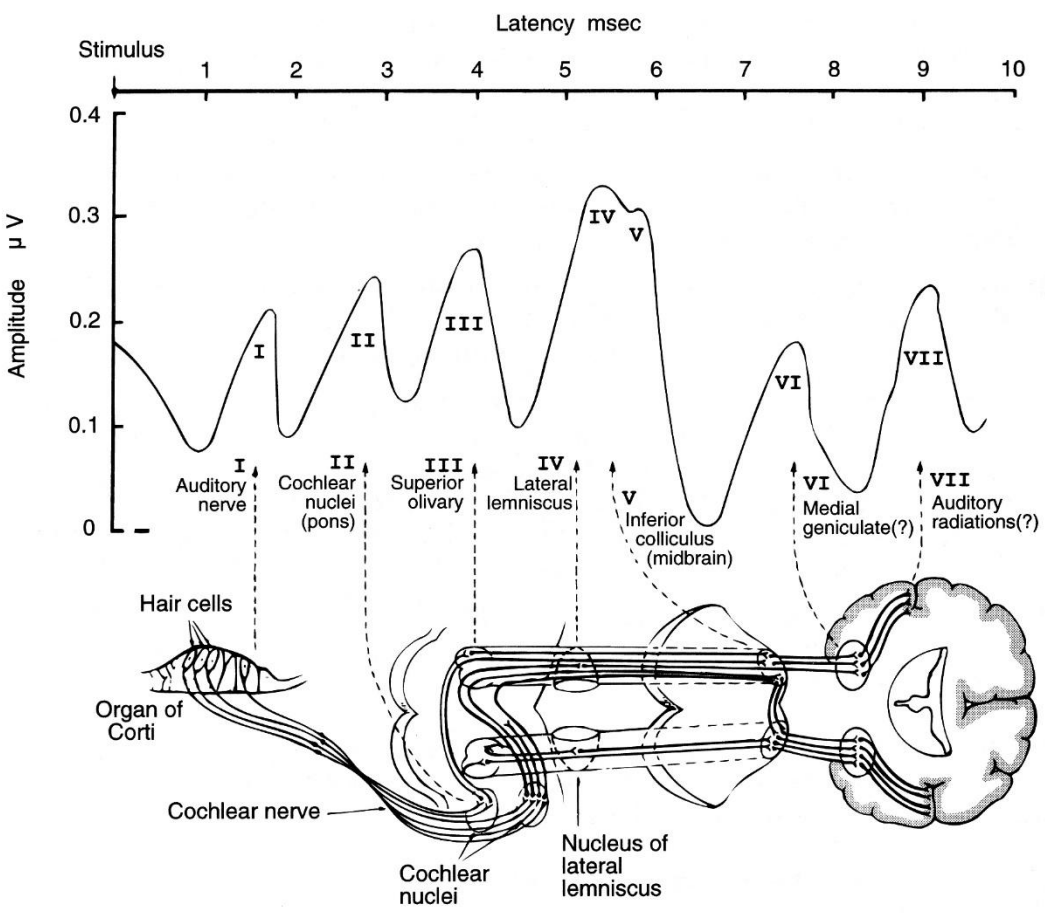
Series of up to seven components that occur within 10 msec of click stimulus:

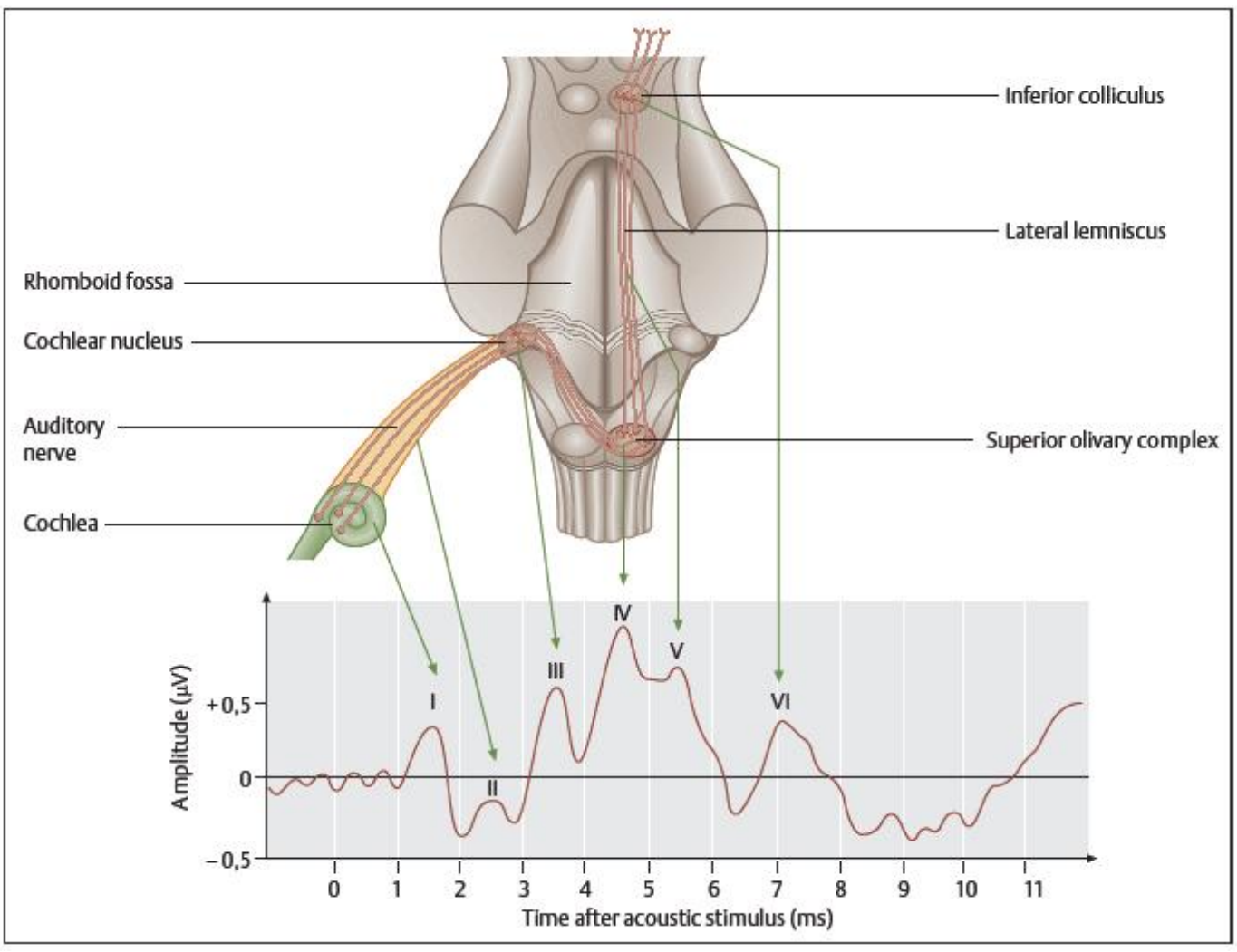
- **wave I** and early part of **wave II** - *auditory nerve* action potential.
- **wave II** - *cochlear nucleus*.
- **wave III** - *superior olive*.
- **wave IV** - *lateral lemniscus*.*
- **wave V** - *inferior colliculus*.
- **waves VI and VII** are inconsistent and of *uncertain origin* - little clinical utility.

N.B. most consistent are **waves I, III, V** (CN8, superior olive, inferior colliculus).

*because **lateral lemniscus** contains *second order* neurons from cochlea and *third and fourth order* neurons from superior olive, it contributes to three waves.

- although brain stem auditory pathways decussate at multiple levels, ***unilateral*** abnormalities of ***waves III and V*** are most often associated with ***ipsilateral*** brain stem disease.
  Alarm: if BAER > 1 msec
- every wave has its own specific shape and latency (bilateral symmetry is also very important) – lesion localization:





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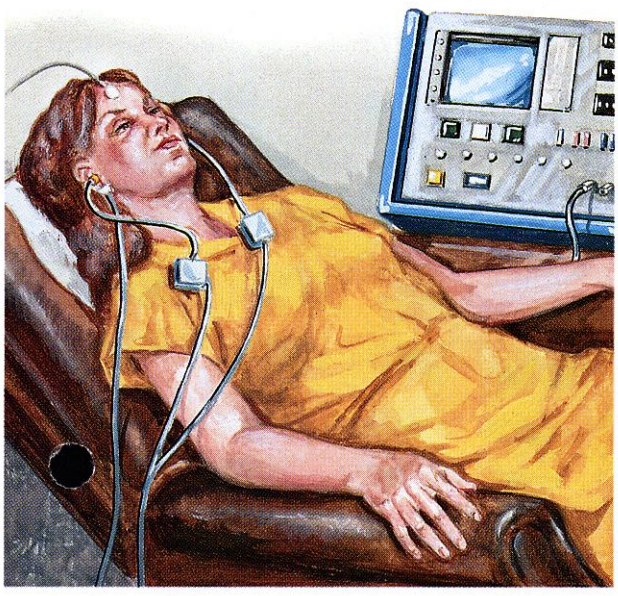
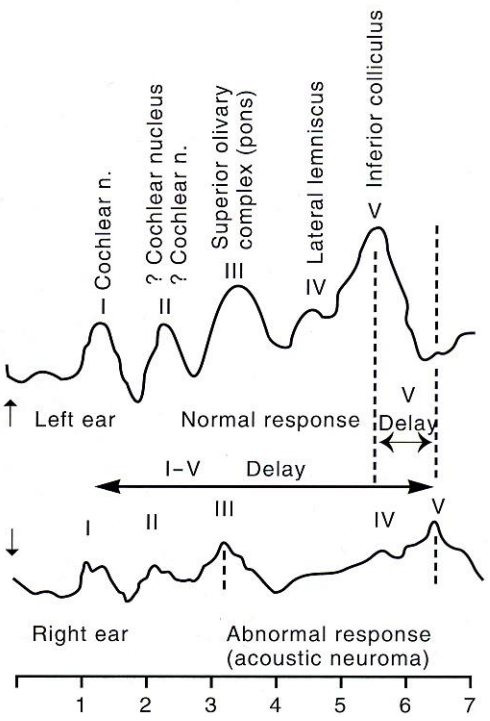
BAER is used to:

1. Rule out ***acoustic neuroma*** (sensitivity ≈ 90%; higher than CT!) – possible BAER variants:
   a) prolongation of I-III interpeak interval (conduction delay between distal eighth nerve and lower pons).
   b) preservation of wave I with loss of subsequent components.
   c) loss of all BAER waveforms.

Brainstem auditory evoked response

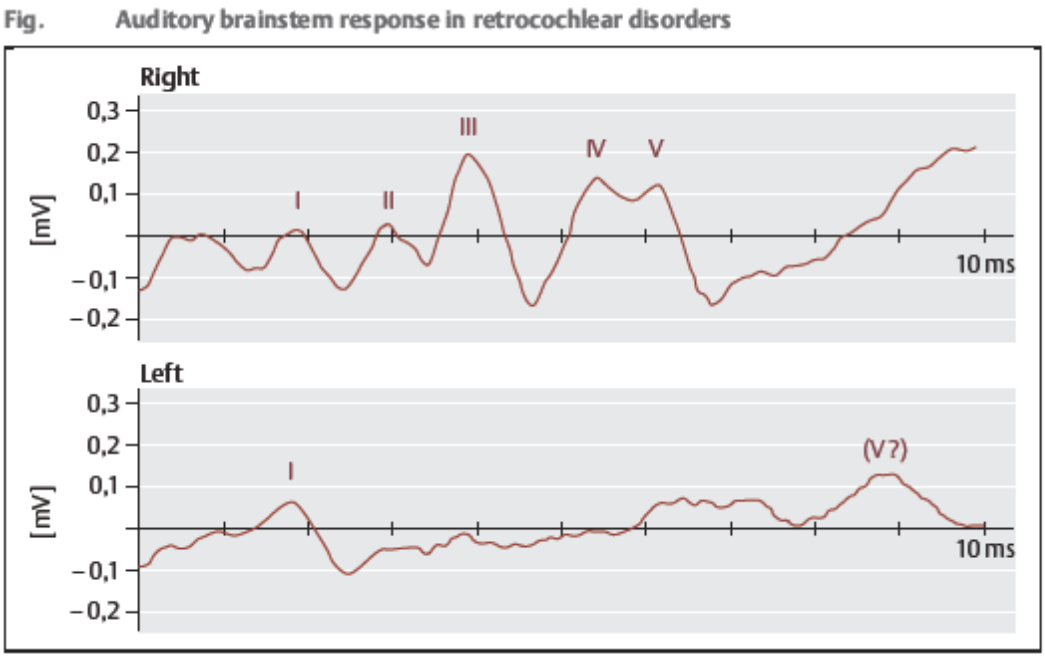




Identifies and locates defects along central auditory pathway. Patient wears earphones, which direct acoustic stimuli via electrodes over ears and parietal area

Source of picture: Frank H. Netter "Clinical Symposia"; Ciba Pharmaceutical Company; Saunders >>

Fig. Auditory brainstem response in retrocochlear disorders



Auditory evoked brainstem potentials in a patient with a left-sided retrocochlear hearing disorder. The *right side* shows normal ABR potentials with a normal latency On the *left side*, only potential I is clearly defined. The potentials were evoked with a brief click stimulus approximately 90 dB above the hearing threshold.

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2. Evaluate hearing acuity in ***noncooperative patients*** (threshold for eliciting wave V is determined).

3. Detecting ***intrinsic brainstem lesions*** involving auditory pathways (e.g. multiple sclerosis, brainstem glioma, brainstem infarcts, olivopontocerebellar degeneration).

4. Evaluate brainstem status in ***coma*** (as prognostic indicator; esp. after head trauma)
   - BAER is resistant to alteration by systemic **metabolic abnormalities or medications** (e.g. barbiturate levels sufficient to produce isoelectric EEG leave BAER essentially unchanged, as do hepatic and renal failure);
   - BAER is always abnormal in **structural lesions**.

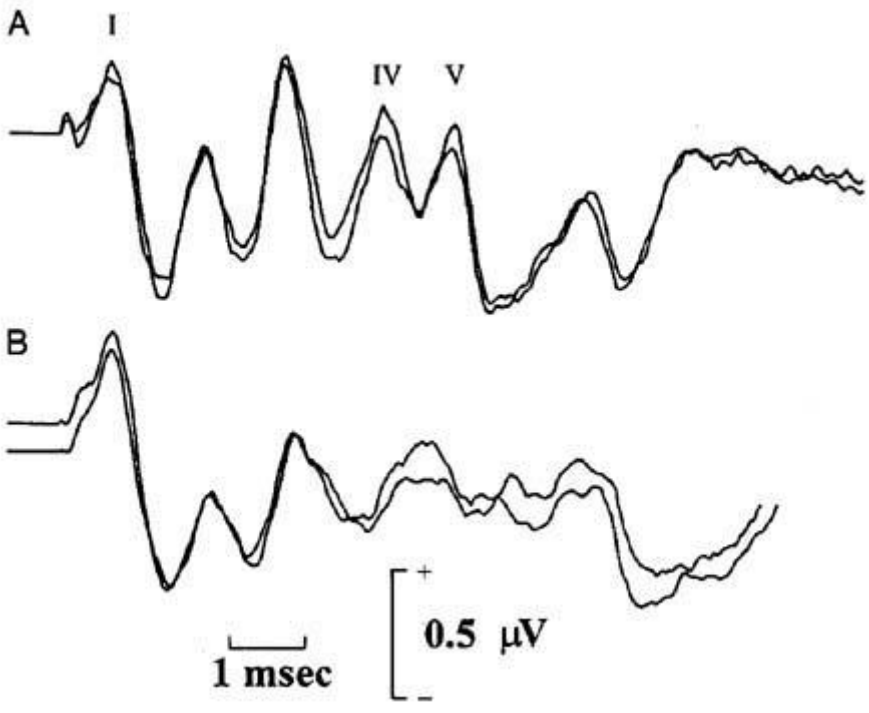
BAER is normal in coma due to ***metabolic / toxic disorders*** or ***bihemispheric disease*** but abnormal in presence of ***brainstem pathology***

5. Confirm ***brain death*** - BAER should be absent apart from wave I and early part of wave II, which are generated peripherally.
   - in many patients with suspected brain death, however, all BAER components (incl. wave I) are absent - not possible to exclude other causes (such as technical factors of deafness) for absent response.

Abnormal BAER result is indication for MRI (T1-weighted, with contrast) of posterior fossa (i.e. BAER need not be obtained if MRI is planned).

A, normal subject:

B, structural lesion of upper pons (waves IV and V markedly attenuated):



ELECTROCOCHLEOGRAPHY (ECOG)

- variant of BAER in which needle electrodes are placed in ear drum to obtain better definition of cochlear potential.

1) **cochlear microphonic** - generated by OUTER HAIR CELLS in basal turn of cochlea - response to alternating current that mirrors waveform of low to moderately intense sounds; usefulness has been questioned because of difficulty in interpreting responses.
2) **summating potential**
3) **action potential**.

- **electrodes** must be placed *on or through tympanic membrane* (surface electrodes, such as those used in BAER, cannot record these potentials).

IMAGING

MIDDLE EAR

X-ray special projections (to avoid superimposition of important structures):

Schüller view – along ear canal – demonstrates mastoid air cells.
Stenvers view – angled 45° forward – demonstrates petrous ridge & apex.

High-resolution thin-slice CT (bone windows) – main imaging modality!!!!

MRI, angiography – only for pulsatile tinnitus, suspected tumors (esp. vascular).

INNER EAR

High-resolution thin-slice CT (bone windows) – for labyrinthine disorders!!!!

MRI – for CN8 (e.g. retrocochlear) disorders.

DIAGNOSTIC TYMPANOTOMY

- under operating microscope, by *incising canal skin* and reflecting skin and membrane as flap.
- most often combined with **surgical correction**.

VESTIBULAR EVOKED MYOGENIC POTENTIALS (VEMP)

- stimulation of sacculus (by acoustic clicks) and registration of evoked muscle potentials (e.g. sternocleidomastoideus).

BIBLIOGRAPHY for ch. "Otology" → follow this LINK >>