# Basics of Audiometry

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## Overview

***Psychoacoustic measurements***

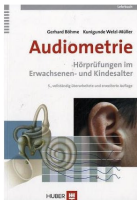
- Acoustics
- Pure tone audiometry
- Speech audiometry

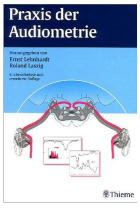
***Objective Methods:***

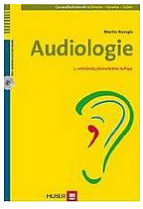
- Otoakoustic emissions (OAE)
- Acoustically evoked potentials (AEP, ERA)
- Tympanometry

- 10 min per topic, longer only pure tone and speech audiometry
- Applications of OAE and AEP: PD S. Brockmeier

## Textbooks on audiology




- Several text books are available
- You should own one in its newest edition

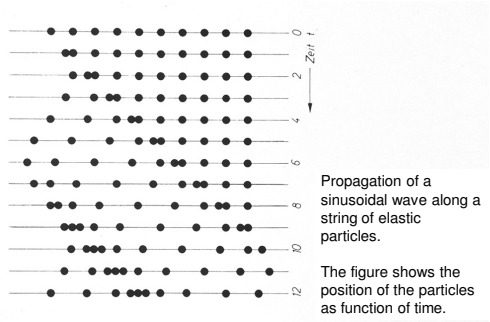
- In this presentation: page numbers in lower right corner refer to pages in Kompis M, "Audiologie", Hans Huber Verlag, 2nd edition 2009

# Basics of acoustics and auditory perception

Acoustics = the science covering mechanical vibrations, wave propagations, generation and measurement in gases, liquids and solid materials

Text book: chapter 1

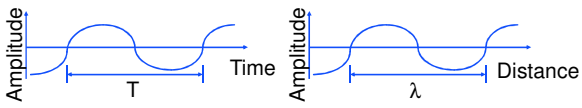
# Longitudinal wave propagation




Propagation of a sinusoidal wave along a string of elastic particles.

The figure shows the position of the particles as function of time.

# Time and place dependency



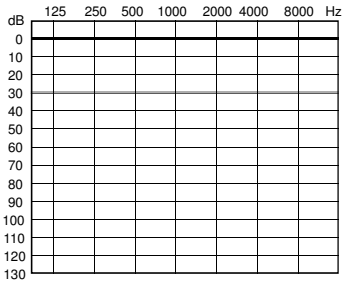

- Period T (s)
- Frequency f = 1/T (Hz)
- Wave length λ (m)
- Wave number k = 1/λ (1/m)

## Physics and perception

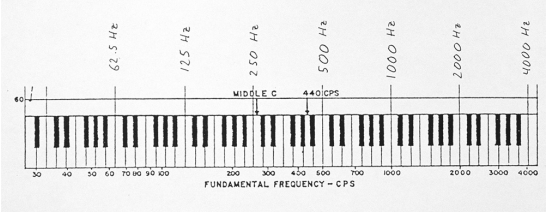
Amplitude corresponds to Loudness

Frequency corresponds to pitch

## Audiogramm




## Logarithmic perception of frequencies




Logarithmic (dur)

Linear (Nasca)

## dB = Logarithmic scale

- dB = dezibel = 1/10 Bell
- relative measure: requires an anchor

- Calculation:

$L_{dB} = 10 \cdot \log_{10} (P_1/P_0)$ *(Power or energy)*

$= 20 \cdot \log_{10} (A_1/A_0)$ *(Amplitude)*

## dB = logarithmic scale

**10 dB**

= factor of 10 in power / energy

= approx. factor of 2 in subjective loudness

## Using logarithms

→ x 100 → x 2.5 → x 0.1 → **= 25 x**

+ 40 dB + 8 dB -20 dB **= 28 dB**

## References: how is „0 dB“ defined?

- dB SPL = Sound Pressure Level: 20uPa
- dB HL = Hearing Level: normal hearing
- dB SL = sensation level: Threshold of subject

*Complex (broadband) sounds:*

- Often dBA = A-weighted leve

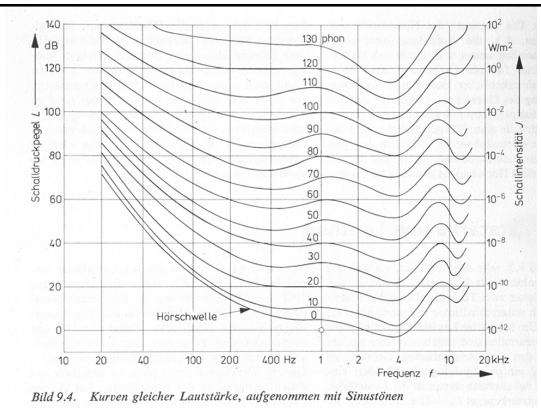
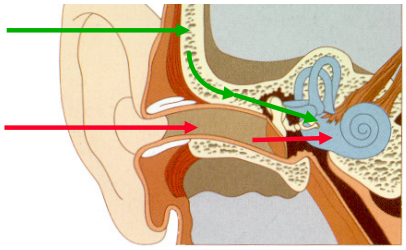



*Bild 9.4. Kurven gleicher Lautstärke, aufgenommen mit Sinustönen*

## Air conduction and bone conduction



# Pure tone audiometry

= the measurement of the hearing thresholds as a function of the frequency

# Importance and some characterictsics of pure tone audiometry

***Impoartance:***

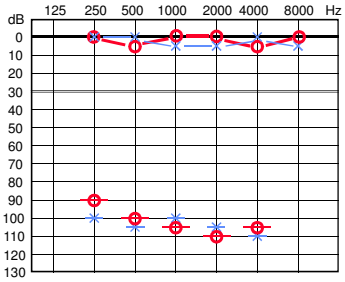
- Most important „tool“ in Audiologie
- Fast assessment of a a hearing loss

***Some characteristics:***

- Fast (10-30 Min)
- Psycho-acoustic --> there is a subjective element

***An audiologic examination without an audiogram is considered incomplete***

# Normal audiogram



## Audiometric symbols (CH, international)

| | Left ear: | | Right ear: | |
|---|---|---|---|---|
| | *No masking* | *masking* | *No masking* | *masking* |
| Air conduction (AC): | × | □ | ○ | △ |
| Bone conduction (BC): | › | ⊐ | ‹ | ⊏ |
| Uncomfortable level: | ⟊ | | ⊖ | |

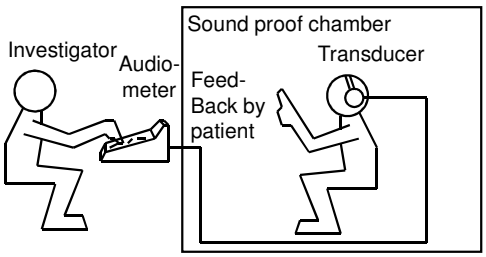
Note: AC: right = red = round
BC: right: open to the right

## Audiometric symbols (D)

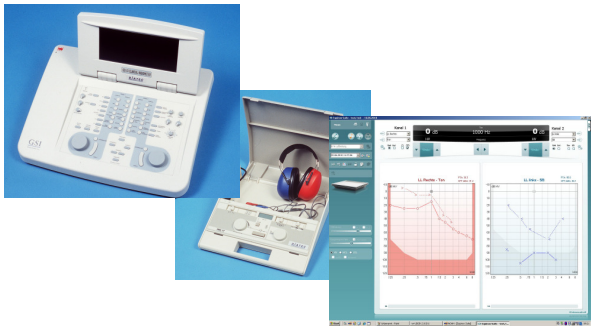
| | Left ear: | Right ear: |
|---|---|---|
| | *With and without masking* | *With and without masking* |
| Air conduction (AC): | × | ○ |
| Bone conduction (BC): | ‹ | › |
| Uncomfortable level: | //// | //// |

Note: AC: right = red = round
BC: Left: looks like letter "L"

## Audiometry: A schematic view

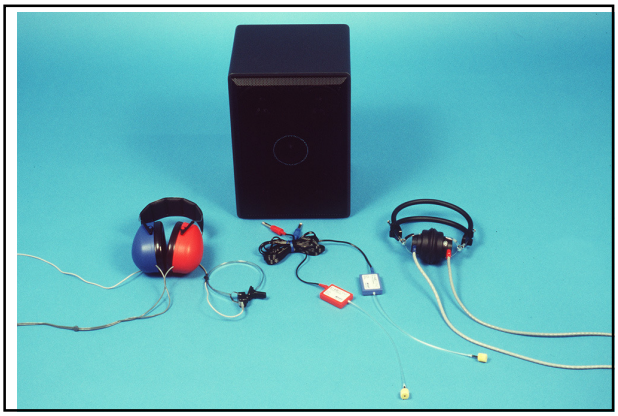


## Audiometer

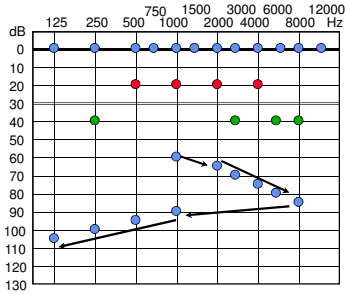


## Transducers

- Head phone
- Insert phone (“ear phones”)
- Bone vibrator
- loudspeaker (for sound field measurements)



# Frequencies tested



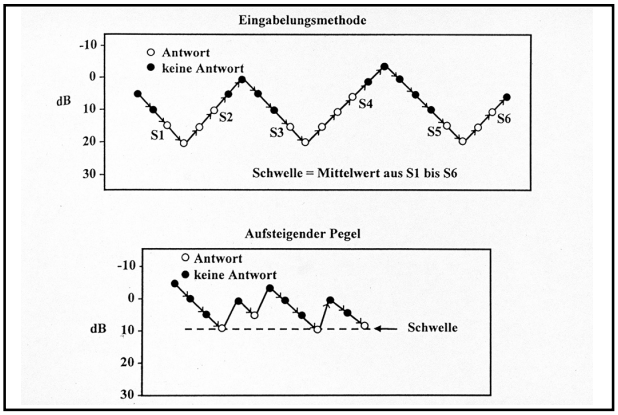

available

very important

important

Order of measurements

S. 48-50




# Percent hearing loss

## CPT-AMA (council of physical therapy – American medical association)

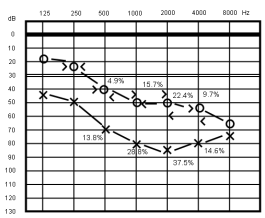



**Tabelle 3.4:** Tabelle zur Berechnung des prozentualen Hörverlusts aus dem Reintonaudiogramm nach CPT-AMA

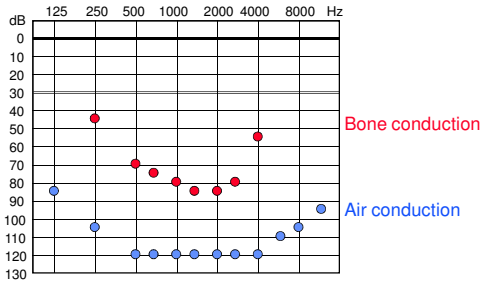
| Hörverlust | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz |
|---|---|---|---|---|
| Bis 5 dB | 0.0 % | 0.0 % | 0.0 % | 0.0 % |
| 10 dB | 0.2 % | 0.3 % | 0.4 % | 0.1 % |
| 15 dB | 0.5 % | 0.9 % | 1.3 % | 0.3 % |
| 20 dB | 1.1 % | 2.1 % | 2.9 % | 0.9 % |
| 25 dB | 1.8 % | 3.6 % | 4.9 % | 1.7 % |
| 30 dB | 2.6 % | 5.4 % | 7.3 % | 2.7 % |
| 35 dB | 3.7 % | 7.7 % | 9.8 % | 3.8 % |
| 40 dB | 4.9 % | 10.2 % | 12.9 % | 5.0 % |
| 45 dB | 6.3 % | 13.0 % | 17.3 % | 6.4 % |
| 50 dB | 7.9 % | 15.7 % | 22.4 % | 8.0 % |
| 55 dB | 9.6 % | 19.0 % | 25.7 % | 9.7 % |
| 60 dB | 11.3 % | 21.5 % | 28.0 % | 11.2 % |
| 65 dB | 12.8 % | 23.5 % | 30.2 % | 12.5 % |
| 70 dB | 13.8 % | 25.5 % | 32.2 % | 13.5 % |
| 75 dB | 14.6 % | 27.2 % | 34.0 % | 14.2 % |
| 80 dB | 14.8 % | 28.8 % | 35.8 % | 14.6 % |
| 85 dB | 14.9 % | 29.8 % | 37.5 % | 14.8 % |
| 90 dB | 15.0 % | 29.9 % | 39.2 % | 14.9 % |
| Ab 95 dB | 15.0 % | 30.0 % | 40.0 % | 15.0 % |

right 4.9 % + 15.7 % + 22.4 % + 9.7 % = 52.7 %

left13.8 % + 28.8 % + 37.5 % + 14.6 % = 94.7 %

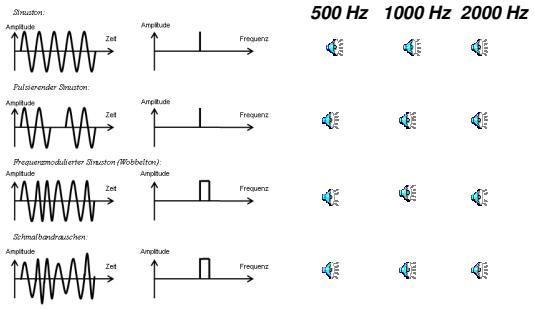
S. 54/55

## Audiometer limits

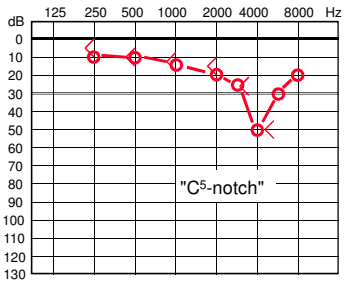



S. 51/52

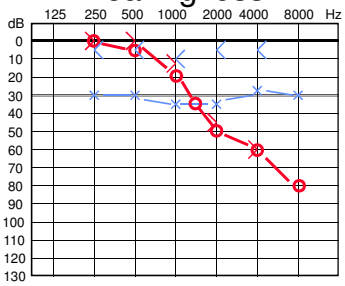
## Some signals used in audiometrie




## Acoustic trauma



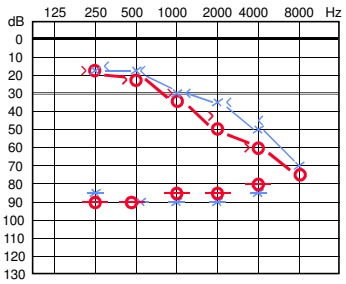
## Conductive, sensorneural or mixed hearing loss



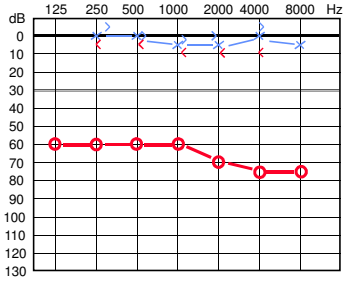

## Measuring the uncomfortable level

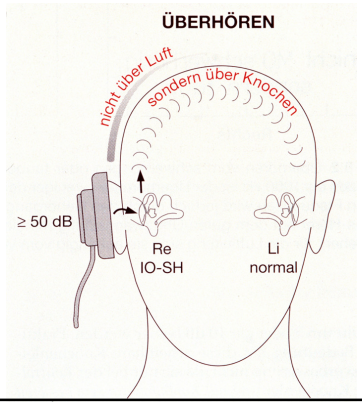
- Instruction: „Hold you hand up, when the sound becomes uncomfortably loud”
- Test signal: Pure tone or narrow band noise, *not* pulsed!
- Relatively fast increase in level
- Repeat twice

## Recruitment and the unconfortable level



## Deafness in right ear - shadow curve

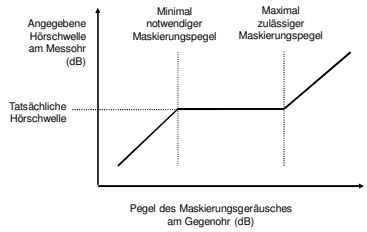



## Masking

- **Masking Signal:** Narrow band noise in contralateral ear
- **When necessary:** As soon as you might measure the shadow curve (actual hearing in the contralateral ear)
- **Problem:** Masking level must be neither too low nor too hign
- Different masking paradigms exist,
  you should KNOW ONE OF THEM WELL

## Prinzip der gleitenden Vertäubung




## Speech audiometry

= Evaluation of speech understanding using standardized tests

## Some speech tests used in Switzerland

**Test in quiet:**

- German:
  - Freiburger Wörter
  - Freiburger Zahlen
- French:
  - Mots dissylabiques
  - Mots monodissylabiques
- Italian:
  - Bocca e Pellegrini: Parole
  - Bocca e Pellegrini: Numeri

**Test in Noise:**

- Basler Satztest
- Words in noise (WIN)
- And several more…

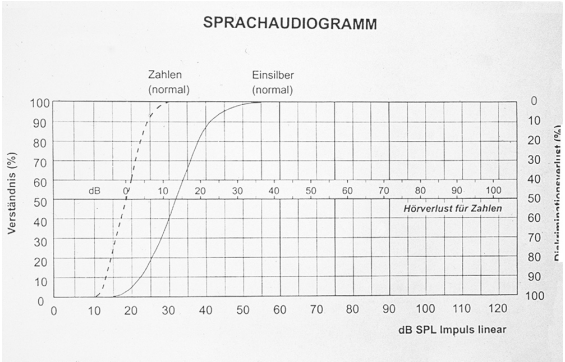
## Freiburger Zahlentest - Schweizeraufsprache 1987 nach F. Keller

| dB | Grp. | | | | | | | | | | | % re | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 98 | 22 | 54 | 19 | 86 | 71 | 35 | 47 | 80 | 63 | | |
| | 2 | 53 | 14 | 39 | 68 | 57 | 90 | 85 | 31 | 72 | 46 | | |
| | 3 | 51 | 36 | 43 | 17 | 99 | 45 | 82 | 24 | 60 | 48 | | |
| | 4 | 67 | 83 | 55 | 13 | 28 | 92 | 34 | 70 | 49 | 76 | | |
| | 5 | 62 | 58 | 23 | 16 | 41 | 37 | 89 | 30 | 95 | 74 | | |
| | 6 | 32 | 65 | 83 | 50 | 91 | 27 | 18 | 44 | 79 | 56 | | |
| | 7 | 59 | 77 | 62 | 40 | 96 | 73 | 19 | 84 | 38 | 25 | | |
| | 8 | 93 | 78 | 13 | 66 | 57 | 39 | 80 | 75 | 62 | 24 | | |
| | 9 | 88 | 42 | 65 | 23 | 76 | 15 | 94 | 87 | 29 | 60 | | |
| | 10 | 33 | 18 | 64 | 52 | 97 | 45 | 30 | 69 | 26 | 78 | | |

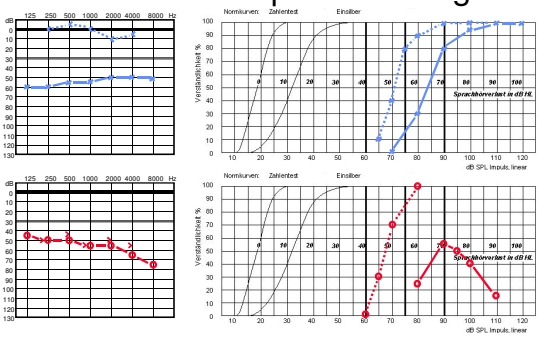
## Freiburger Wörtertest - Schweizeraufsprache 1987 nach F. Keller

| dB | Grp. | | % re |
|---|---|---|---|
| | 1 | Nuss, Wolf, Braut, Kern, Fang, Klotz, Hund, Stück, Zahl, Ring, Lärm, Geiz, Durst, Bach, Schreck, Spott, Aas, Teig, Hanf, Stich | |
| | 2 | Holz, Russ, Mark, Stein, Glied, Fleck, Schloss, Fall, Busch, Werk, Dach, Eid, Knie, Traum, Pass, Kunst, Mönch, Bart, Los, Schiff | |
| | 3 | Blatt, Stift, Hohn, Zweck, Aal, Furcht, Leim, Dorf, Tal, Keil, Schutz, Wind, Maus, Klee, Schlitz, Bank, Stock, Wuchs, Ref, Gras | |
| | 4 | Schnee, Laub, Wurst, Fass, Griff, Pest, Mund, Kopf, Reiz, Heft, Grad, Frist, Oel, Fuss, Drang, Schleim, Takt, Kinn, Stoss, Ball | |
| | 5 | Ziel, Punkt, Fest, Schein, Darm, Torf, Lamm, Wehr, Glas, Huf, Spiess, Pfau, Block, Arm, Neid, Stroh, Wurf, Rest, Blick, Schlag | |
| | 6 | Seil, Pfand, Netz, Fluss, Schild, Ochs, Draht, Hemd, Schmutz, Tau, Rat, Milch, Rost, Kahn, Tier, Durst, Brot, Haar, Feld, Schwein | |
| | 7 | Spiel, Moos, Lachs, Glut, Erz, Baum, Sand, Reich, Kuh, Wort, Schiff, Hecht, Buch, Hang, Fels, Schopf, Kranz, Teich, Star, Dienst | |
| | 8 | Duft, Band, Kost, Ski, Feind, Herr, Pflug, Tal, Gift, Raum, Zeug, Ernst, Fach, Groll, Speck, Sitz, Moor, Last, Krach, Schwung | |
| | 9 | Specht, Eis, Funk, Rahm, Weg, Thron, Rind, Spass, Klotz, Ble, Markt, Schilf, Hut, Korb, Zank, Lauf, Kies, Dank, Schnur, Pech | |
| | 10 | Horn, Pfeil, Kamm, Gips, Turm, Spiess, Recht, Sprung, Zopf, Schall, Stau, Bass, Fell, Pracht, Mais, Gramm, Sieb, Ohr, Lump, Dreck | |
| | 11 | Bild, Ast, Frosch, Ruhm, Herz, Mond, Gain, Bau, Sicht, Huhn, Kreis, Lack, Pferd, Schacht, Pelz, Teil, Witz, Rand, Stuhl, Zorn | |
| | 12 | Brett, Saft, Schuss, Pilz, Ort, Kraut, Schwert, Gleis, Tag, Vieh, Spalt, Sohn, Druck, Held, Bahn, List, Flug, Narr, Kork, Reis | |
| | 13 | Staub, Tracht, Herd, Licht, Not, Wein, Fluch, Kalk, Lehm, Grund, Fass, Schmied, Amt, Ross, Puls, Meer, Graf, Bier, Schweiss, Dolch | |
| | 14 | Schritt, Ruf, Gas, Wert, Brust, Korn, Dieb, Schrei, Pfahl, Blech, Faust, Rang, Pult, Nest, Heu, Schicht, Zoll, Stand, Lohn, Angst | |
| | 15 | Knecht, Schaf, Lust, Berg, Zeit, Schlamm, Docht, Preis, Kind, Uhr, Mal, Speer, Sinn, Fluss, Rock, Haupt, Gang, Trieb, Schmalz, Boot | |
| | 16 | Bund, Stiel, Wachs, Reim, Tor, Geld, Luft, Stuck, See, Trotz, Pfad, Heil, Brief, Arzt, Haus, Bund, Fracht, Stern, Loch, Zahn | |
| | 17 | Fink, Schlauch, Stab, Reh, Floss, Him, Fuchs, Beil, Napf, Teer, Stolz, Art, Wurm, Ding, Trab, Kleid, Bett, Schatz, Wut, Pflock | |
| | 18 | Schnitt, Bucht, Land, Helm, Bock, Scherz, Keil, Rast, Gruss, Wohl, Plan, Krieg, Abt, Pfiff, Bein, Sturm, Tee, Mann, Frost | |
| | 19 | Frucht, Leib, Zins, Fee, Schar, Gold, Wunsch, Malz, Ton, Stier, Dachs, Heer, Bauch, Kreuz, Akt, Glück, Pfund, Sekt, Molch, Rad | |
| | 20 | Fleisch, Gneiss, Welt, Rohr, Park, Flut, Saum, Schmerz, Hand, Most, Schuh, Film, Damm, Zeit, Koch, Bad, Spruch, Leid, Biss Axt | |

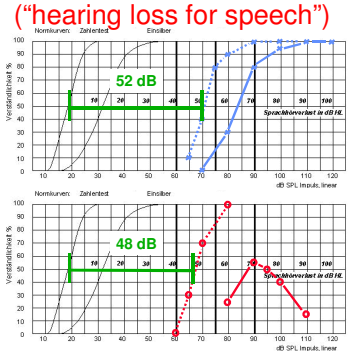
## SPRACHAUDIOGRAMM



# Pure tone and speech audiogram

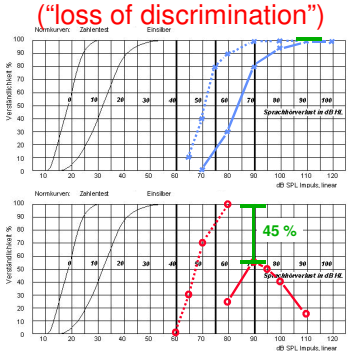



# Important term: Sprachhörverlust ("hearing loss for speech")




S. 101

# Important term: Diskriminationsverlust ("loss of discrimination")




S. 101

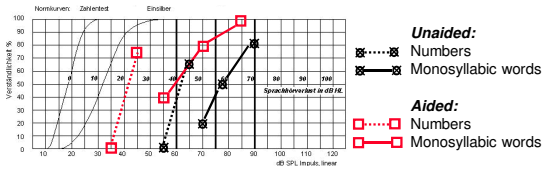
## Important terms

- Hearing loss for speech:
  - Difference between measured level for 50% speech understanding of numbers and the average value for normal hearing subjects (reading the middle of the speech audiogram).
- Loss of discrimination:
  - Difference between maximal monosyllabic word understanding (at best level!) und 100 %

S. 101

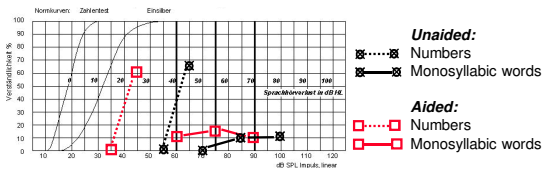
## Is the number test useful at all?

- Patient with good speech understanding




## Is the number test useful at all?

- Patient with poor speech understanding (CI candidate, useful hearing only below 750 Hz)



## Is the number test useful at all?

- Provides relatively little additional information in cooperative patients with relatively good hearing

***But:***

- Provides a lot of information in patients with poor speech understanding
- Is a very fast tool for quality control and to check the plausibility of your measurement (Aggravation, simulation, malingering)

## Freiburger monosyllabic words (N=20, p=0.9)

***Binomial distribution:***

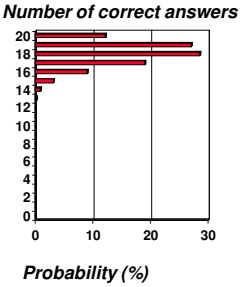
$$P(x)=\binom{N}{x}\cdot p^x\cdot(1-p)^{N-x}$$

P(x): probability for exactly x correct answers

N: Number of test items

p: probability of correct understanding of one number

„N over x“ = N! / (x! · (N-x)!)




## Freiburger monosyllabic words (N=20, p=0.5)

***Binomial distribution:***

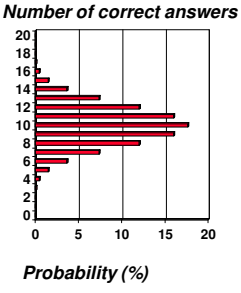
$$P(x)=\binom{N}{x}\cdot p^x\cdot(1-p)^{N-x}$$

P(x): probability for exactly x correct answers

N: Number of test items

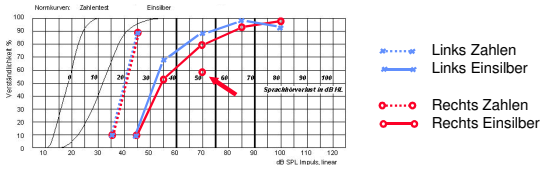
p: probability of correct understanding of one number

„N over x“ = N! / (x! · (N-x)!)



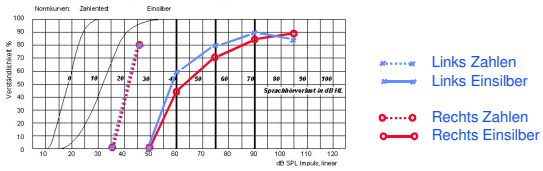
## Living with large variations

- It's not the fault of the investigator or the patient
- Individual values are far off → remeasure
- Do not over-interprete small gains
- Never shorten the lists around 50% speech understanding to be faster




## Sozialindex: % Hearing loss

- Freiburger Wörter: Average loss at 60, 75, 90 dB
- Example right ear: (55% + 30% + 15%) / 3 = 33.3%
- Example left ear: (40% + 20% + 10%) / 3 = 23.3%
- French: use monosyllabic words at 55, 70, 85 dB




## Electric Response Audiometry (ERA)

= Electrical response of the central nervous system to acoustic stimuli

Book chapter 11

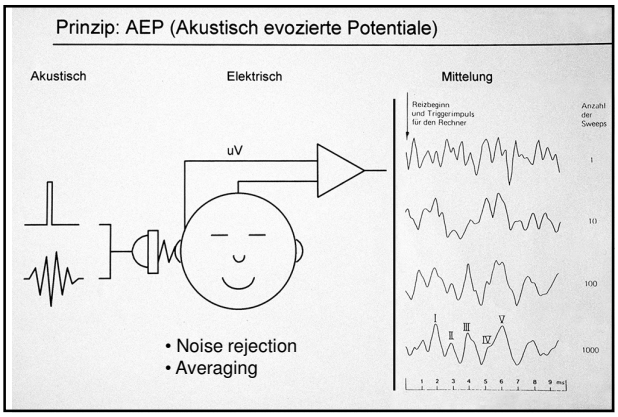
# Abbreviations and terms

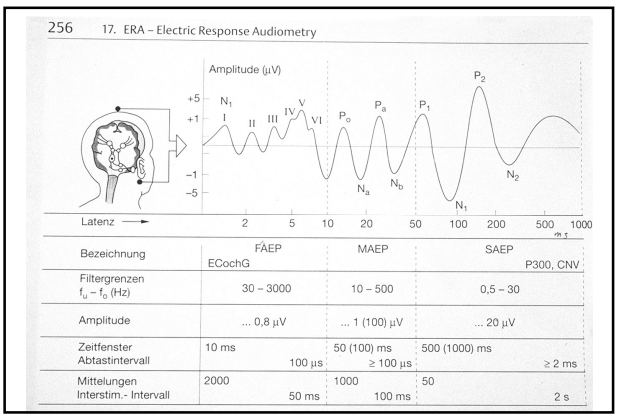
***For the measurement procedure:***

- ERA = Electric response audiometry
- ERA = Elektrische Reaktions Audiometrie

***For the potentials:***

- AEP = Acoustically evoked potential
- AEP = Auditorisch evozierte Potentiale




| Bezeichnung | FAEP ECochG | MAEP | SAEP P300, CNV |
|---|---|---|---|
| Filtergrenzen $f_u - f_o$ (Hz) | 30 – 3000 | 10 – 500 | 0,5 – 30 |
| Amplitude | ... 0,8 µV | ... 1 (100) µV | ... 20 µV |
| Zeitfenster<br>Abtastintervall | 10 ms<br>100 µs | 50 (100) ms<br>≥ 100 µs | 500 (1000) ms<br>≥ 2 ms |
| Mittelungen<br>Interstim.- Intervall | 2000<br>50 ms | 1000<br>100 ms | 50<br>2 s |

# Different acoustically evoked potentials (AEP)

- Early or short latency response AEP (1ms - 10 ms)
  - Most frequently used
  - Broadband hearing threshold
  - Vigilance independent
- Middle latency response AEP (10 ms - 100 ms)
  - Partly myogenic source
  - Variable in children
- Late or long-latency response AEP (100 ms - 1 s)
  - Cognitive effects
  - Vigilance dependent

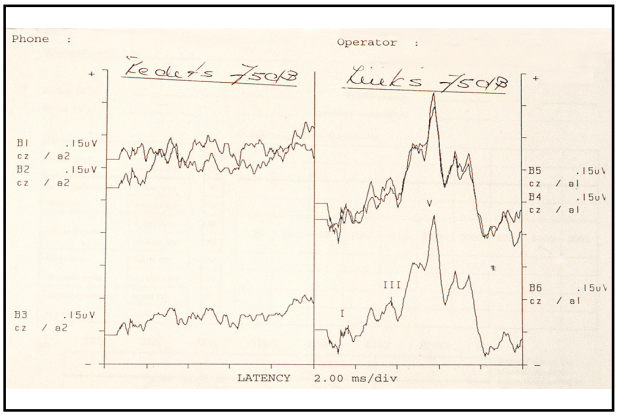
# Early or Short latency response acoustically evoked potential

***Still more names and abbreviations:***

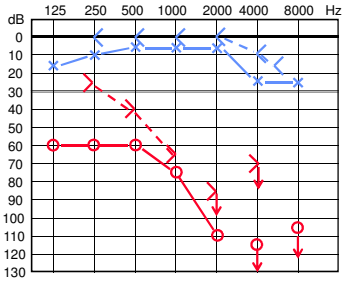
Potentials:
- Frühe auditorisch evozierte Potentiale (FAEP)
- Auditory brainstem response (ABR)

Measurement:
- Hirnstammaudiometrie
- Brainstem electric response audiometry (BERA)

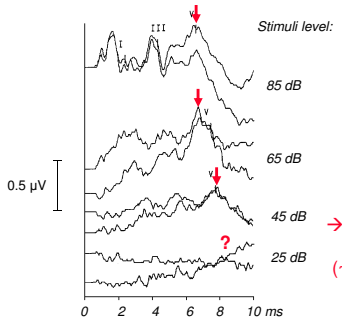
Book section 11.1



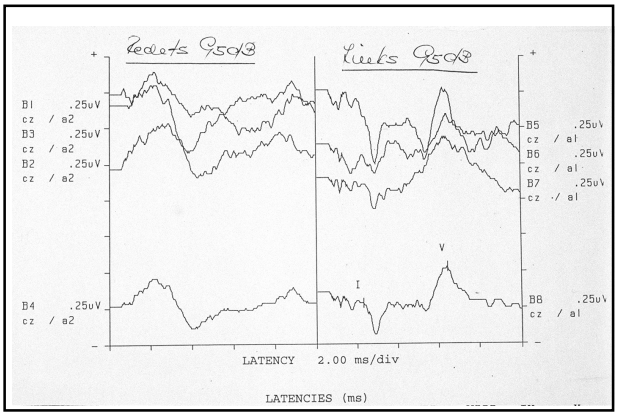
## Asymmetric hearing loss



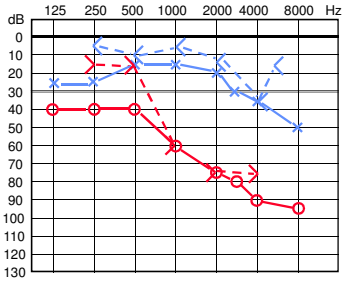

## Short latency response AEP




→Hearing threshold at 30-40 dB (~2000 – 4000 Hz)



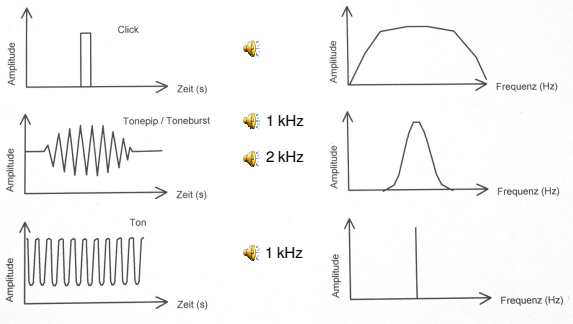
## Acoustic neuroma (right side)




## ABR application range: Examples

- **Children:**
  - To determine or to conform hearing threshold (e.g. after fail in newborn hearing screening using OAE!)
  - Auditory neuropathy
- **Adults:**
  - Suspected malingering or hysterical deafness (Simulation and aggravation)
  - Retrocochlear pathologies
  - Before cochlea implantation
  - Subjects who are unable to cooperate in audiometry

## Signale im Zeit und Frequenzbereich



## Frequency specific ERA

(Book chapter 11.2)

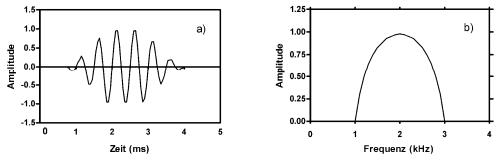
- **Generally:**
  - Long measurement times
  - Little information for frequencies below 1000 Hz
  - Used moderately
- **Method:**
  - BERA with tone-pips
  - Notched Noise ERA
  - Auditory steady state potentials (ASSR)

## 3 methods for frequency dependent ERA

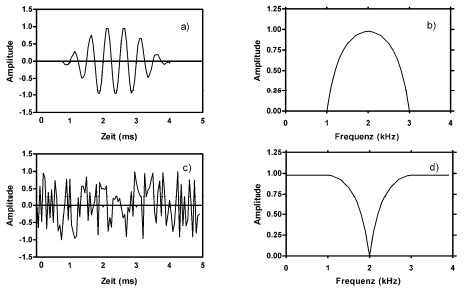
(Book chapter 11.2)

- **ERA with tone-pips instead of clicks:**
  - Limited frequency specificity
  - Long duration of measurement
- **Notched Noise ERA:**
  - Better frequency specificity
  - Still long duration of measurement
- **Auditory steady state potentials (ASSR)**
  - Simultaneous measurement of several frequencies is possible
  - Could become method of choice in the future

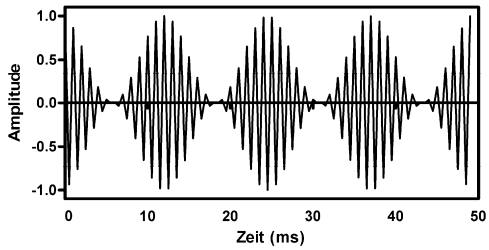
## ERA with tone-pips



## Notched-noise ERA

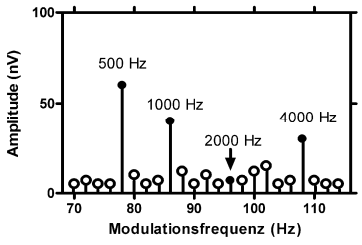



## ASSR / M.A.S.T.E.R.



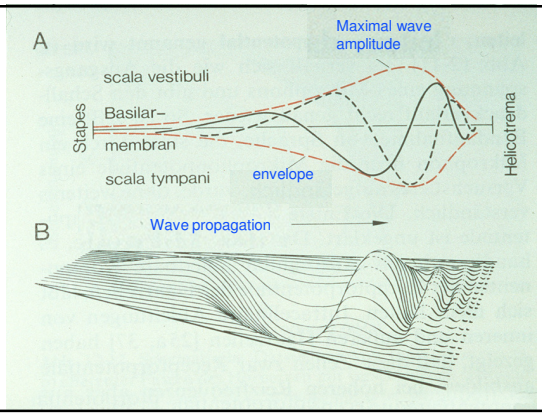

S. 166 f

## ASSR / M.A.S.T.E.R.

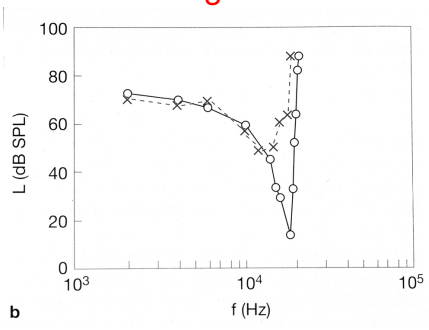


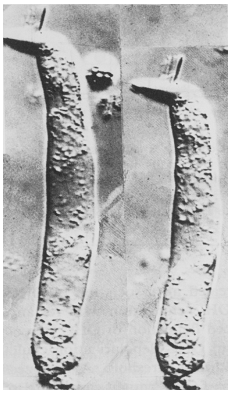

S. 166 f

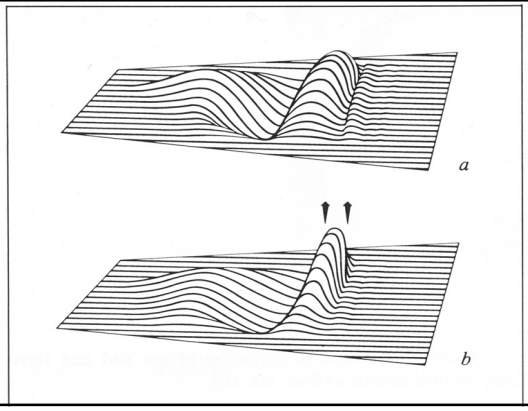
# Otoacoustic emissions (OAE)




## Tuning curves





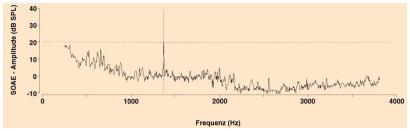



## Types of OAE

- *SOAEs*
  = spontaneous otoacoustic emissions
- *TEOAE*
  = transiently evoked otoacoustic emissions
- *DPOAE*
  = distortion product otoacoustic emissions
- (*SEOAE*= simultaneously evoked OAE)

## SOAE - spontaneous OAE

- How to measure: Microphone in external auditory canal
- sound level: -30 to +20 dB SPL




- Present in:
  - (almost) only in normal, hearing ears
  - women: 52%, men: 30%
  - under 2 years: 68%
  - over 50 years: 20%

## Application of spontaneous OAE

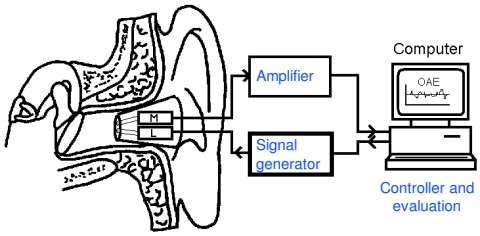
- tinnitus objectification:
  - no (or rarely)
- low incidence (too rare)

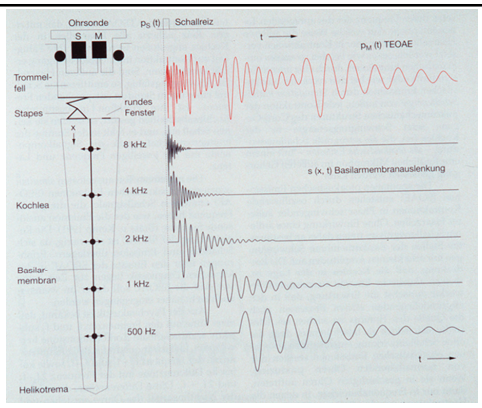
→ marginal clinical use

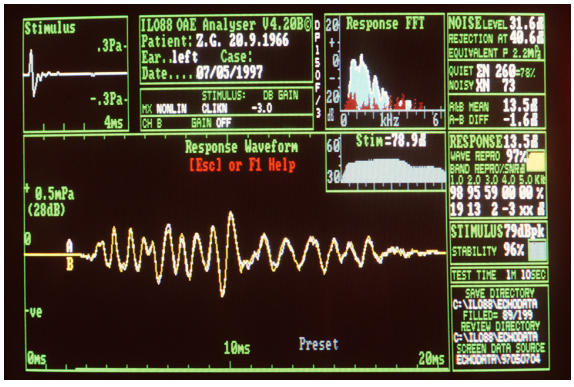
## TEOAE
## = transiently evoked OAE

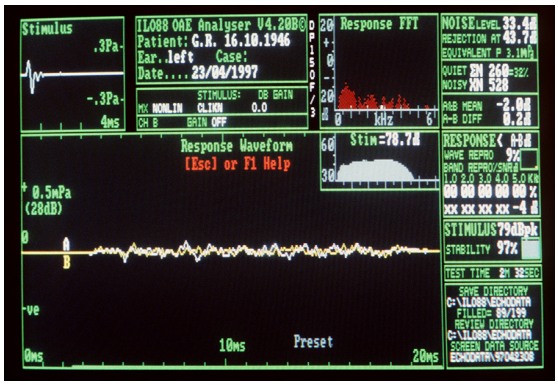
- How to measure: click into ear and measurement of response
- sound level: approx. 10 dB SPL (infant 20 dB)
- Present in: normal hearing and hearing loss less than 20-30 dB

# Principle of OAE measurement



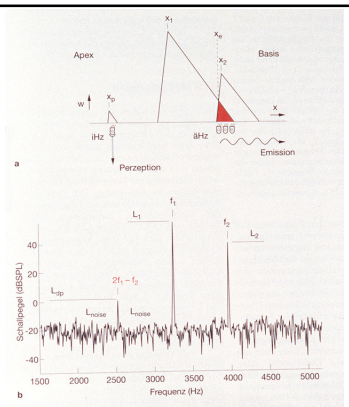



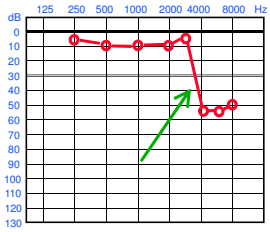



# DPOAE
# = distortion product emissions OAE

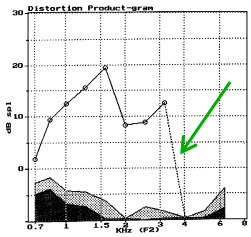
- How to measure: 2 Sinus tones into ear and measurement of distortion
- Present in: normal hearing and hearing loss below approx. 30-50 dB



## DPOAE-Measurement: Example




Audiogram




DP-Gram

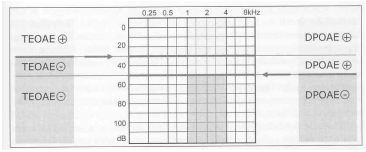
## Comparison TEOAE - DPOAE

*TEOAE*

- Up to 20-30 dB hearing loss
- poorer frequency sensitivity

*DPOAE*

- Up to 30-50 dB hearing loss
- better frequency sensitivity




## OAE: What do we actually measure?

- Middle ear function (2x sound transmission)
- Active functioning of inner ear

*NOT* hearing as an entity

## Application of OAE

- Screening of newborns
- Verification of subjective hearing test
  - in children (frequent!)
  - in adults

## Tympanometry

Acoustical impendence measurement of tympanic membrane

Book: chapter 9

## Acoustical impedance

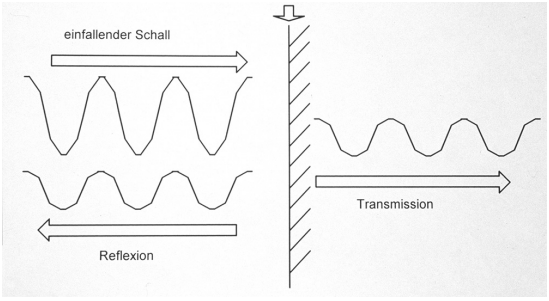
- ***Definition:*** ratio of:

  sound pressure amplitude : motion amplitude

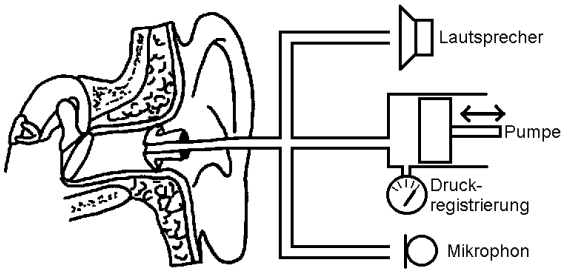
  (low acoustical impendence = soft medium
  high acoustical impendence = stiff medium)

- Medium characteristic, not signal characteristic

## Sudden change acoustical impedance

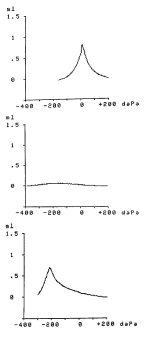



## Schematic view of tympanometry

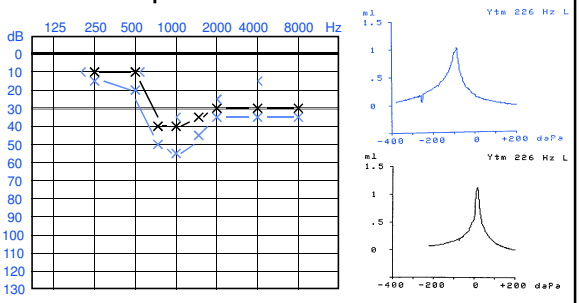



## Tympanogram : Types

- Type A: normal
- Type B: effusion
- Type C: low pressure



## Low pressure in middle ear




## Tympanometry: Characteristics and limits

- Fast (< 1 min)
- Non-invasive
- Provides useful information about middle ear

***requirements:***

- Free external ear channel, intact tympanic membrane
- measuring probe can be properly placed

## Thank you for your attention