Tinnitus:
Seeing It, Assessing It & Lessening It

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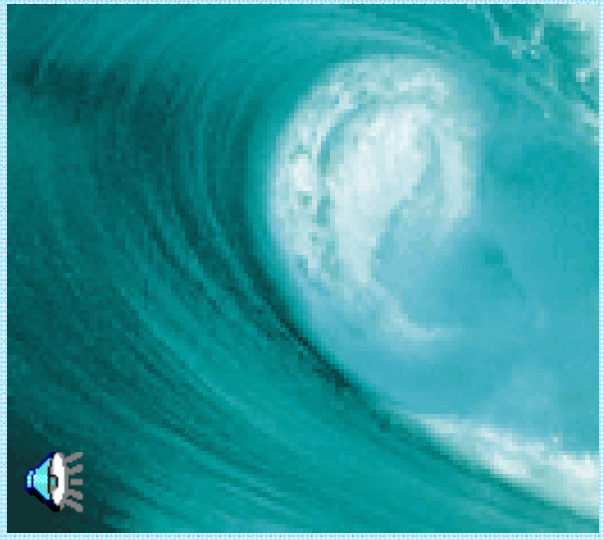
Tinnitus
Malady of the 21st Century

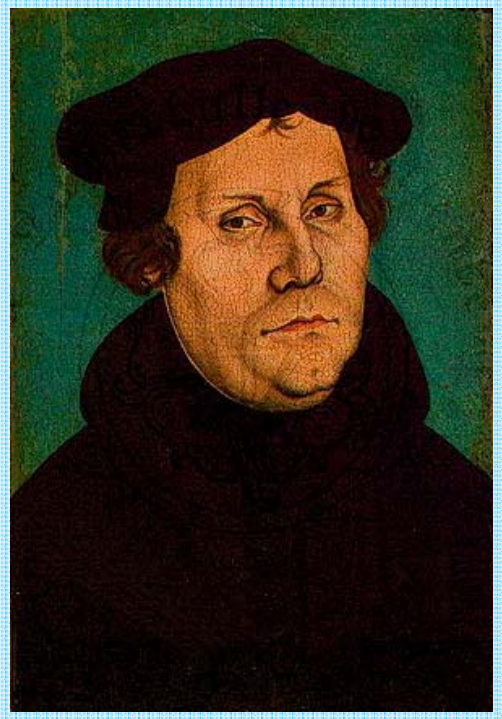


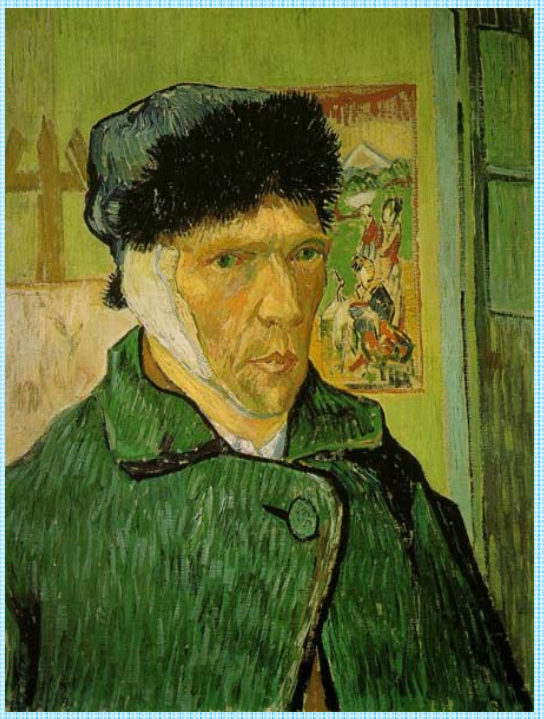
Tinnitus Terminology

- **Tinnitus: a subjective phantom perception of sound in head or in the ears without any external source**
- **Somatosound: acoustic events generated in head or neck regions due to blood flow, myogenic activity, vascular pulsation, myoclonus, patulous Eustachian tube, etc. (Jasterboff, 1990, 1995, Hazell, 1995).**

Tinnitus and its Prevalence

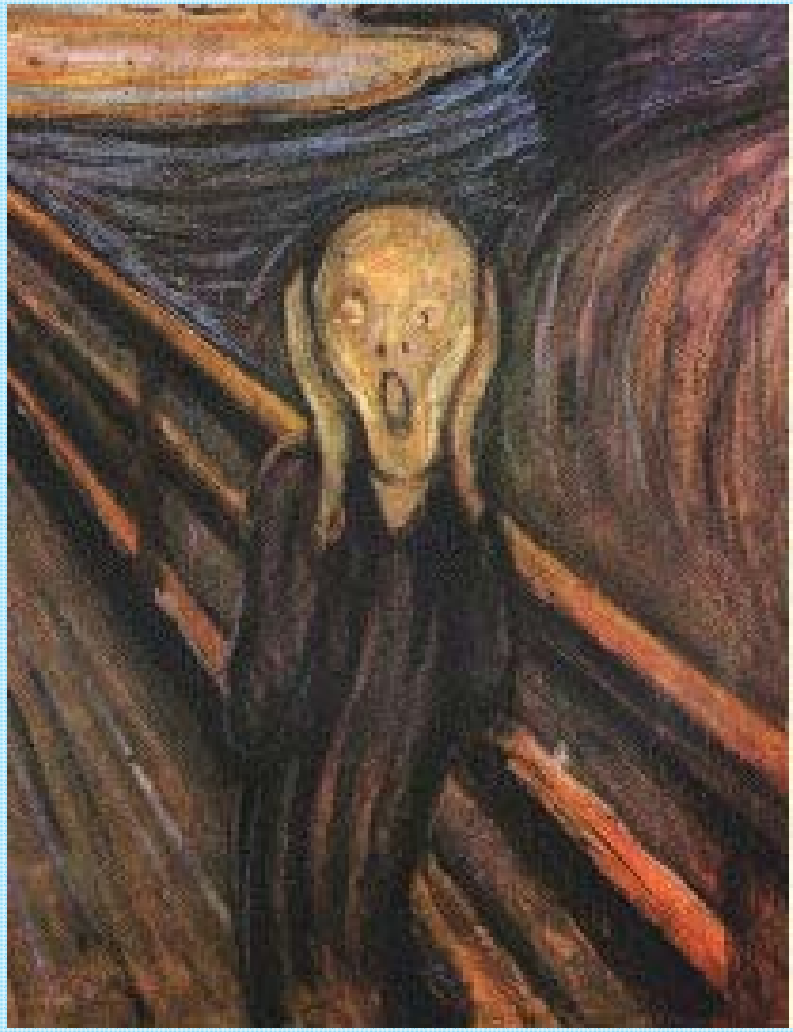
Martin Luther, Ludwig van Beethoven & Vincent van Gogh





All had Tinnitus!

Tinnitus Classification

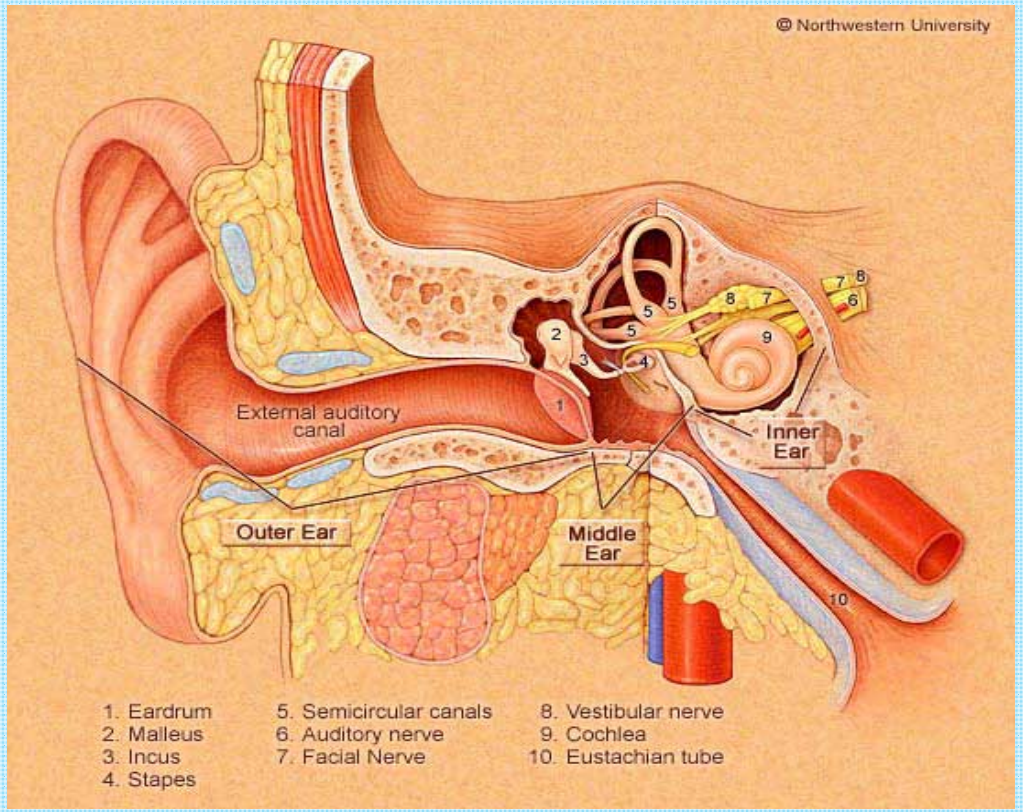


Tinnitus Types (Danesh, 2004)

SUBJECTIVE	Only patient hears it
OBJECTIVE	Both patient and clinician can hear it.
EVOKED	Patients can hear and/or stop hearing it on their own decision
SUBOBJETIVE	Neither the patient nor clinician can hear it without appropriate tools!

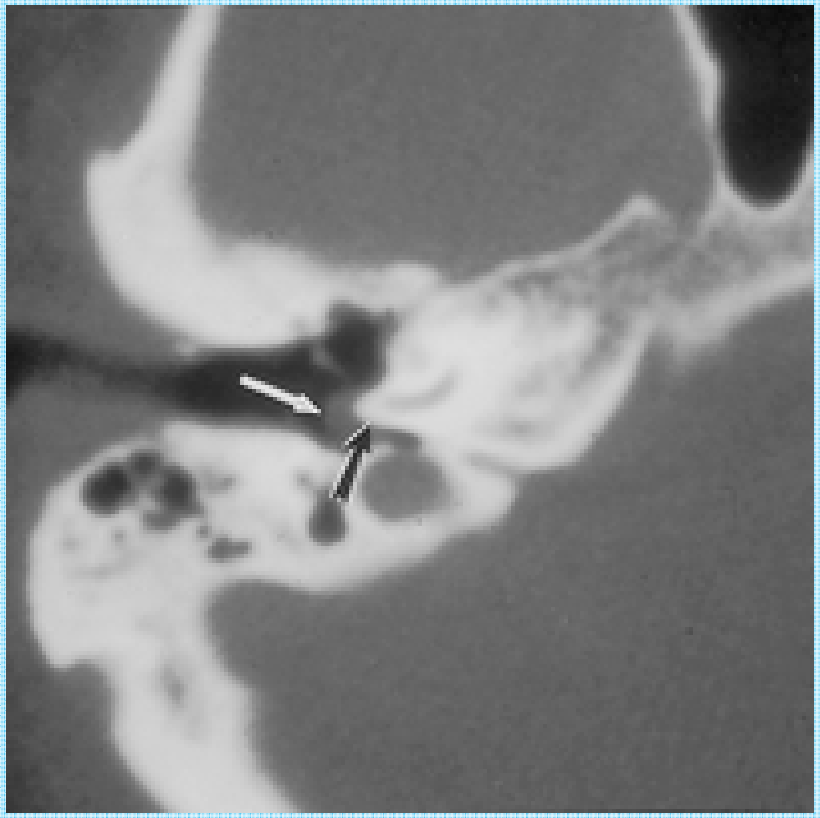
Origins of Tinnitus

- Outer ear
- Middle ear
- Inner ear
- 8th CN
- Brainstem
- Cortex



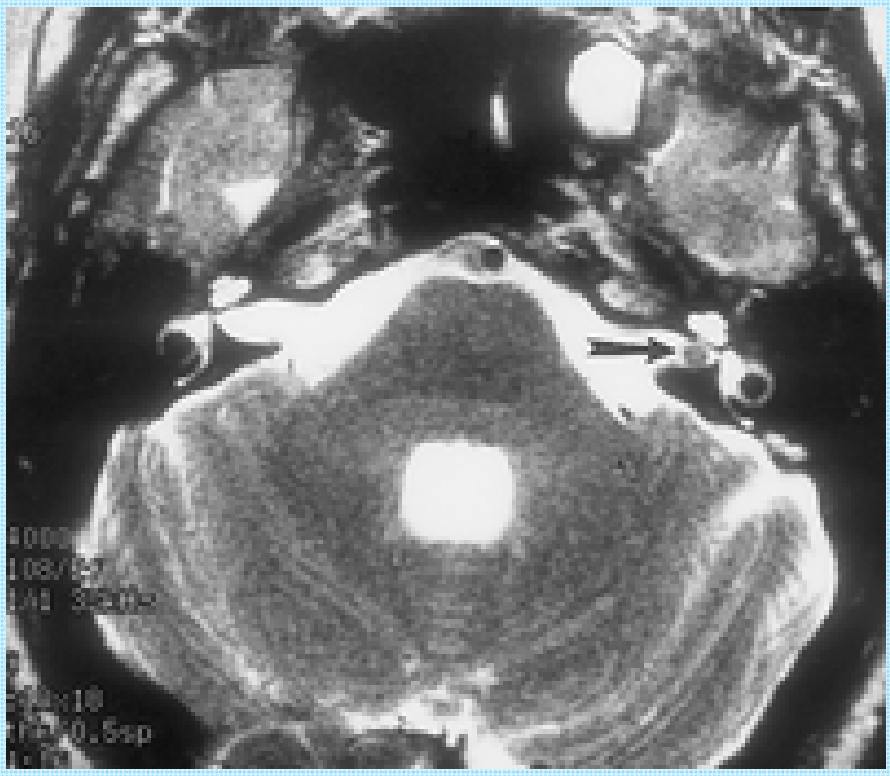
Objective Tinnitus

White arrow (Glomus Tympanicum), Black arrow (promontary)



Source: Weissman JL. Hearing loss. Radiology 1996; 199:593-611

Tinnitus due to Left Vestibular Schwanoma



Source: Weissman JL. Hearing loss. Radiology 1996; 199:593-611

Intralabyrinthine Schwannoma

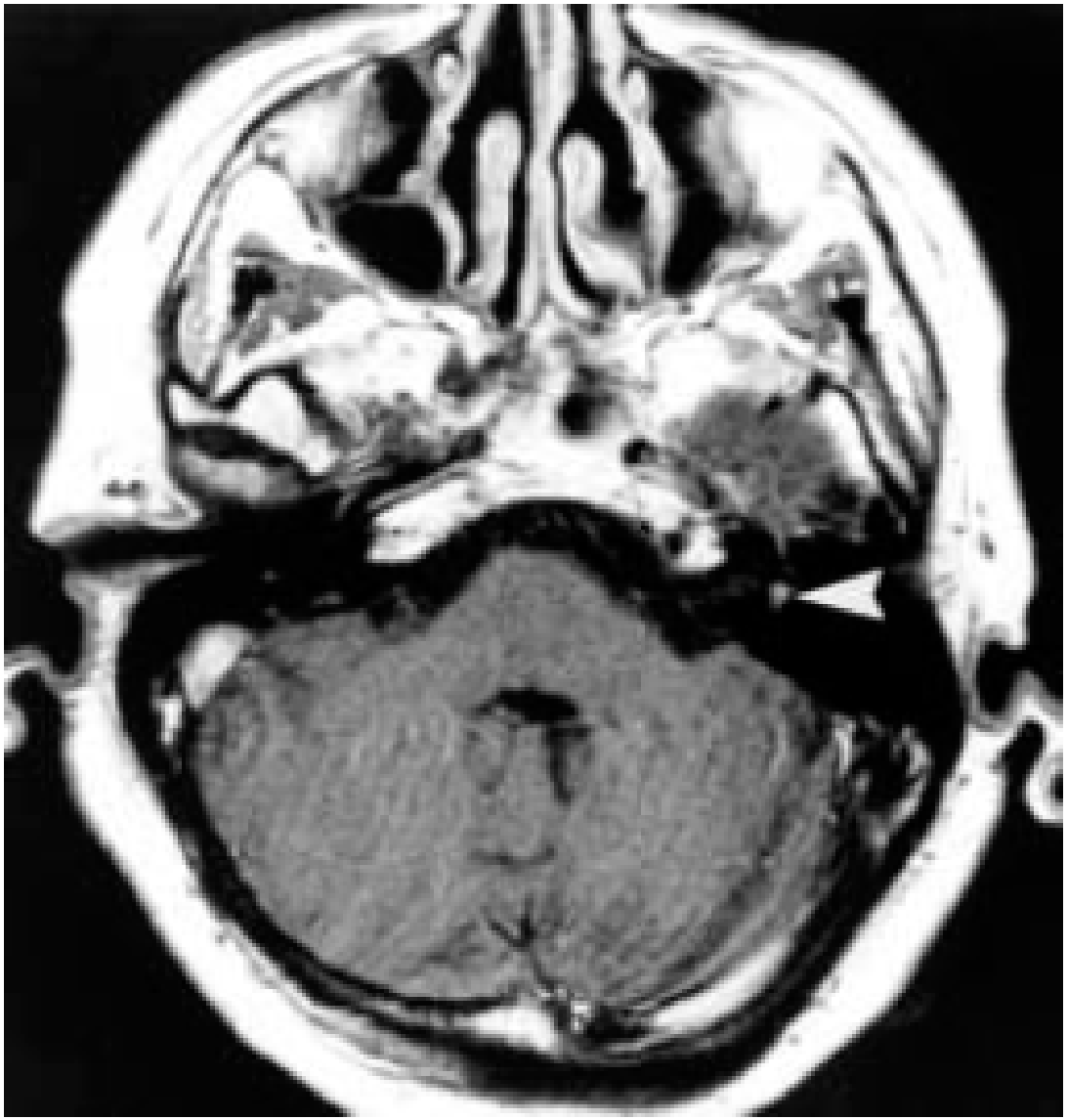
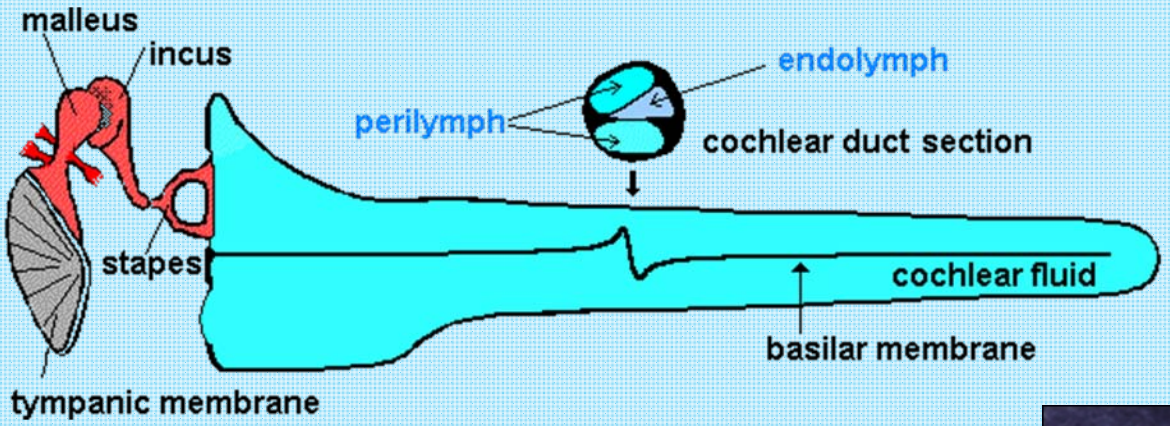
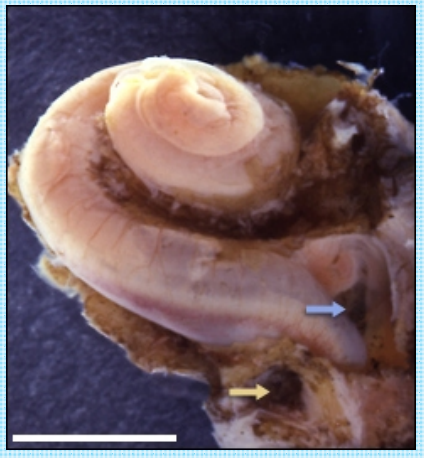


Fig. 1 – Axial gadolinium-enhanced T1-weighted MR image demonstrating a discrete enhancing schwannoma filling the labyrinth on the left side.

MR Findings in Intralabyrinthine Schwannomas, *Clinical Radiology, Volume 57, Issue 5, May 2002, Pages 355-358*
Mary-Louise Montague, Ameet Kishore, Donald M. Hadley and Brian F. O'Reilly

Vulnerability of the basal turn of the cochlea?



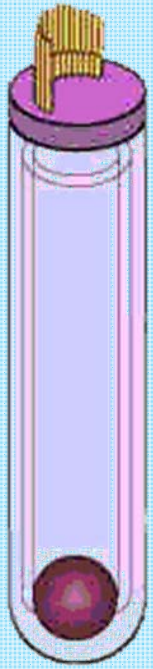


http://www.vimm.it/cochlea/cochleapages/overview/history.htm

Tinnitus Theories

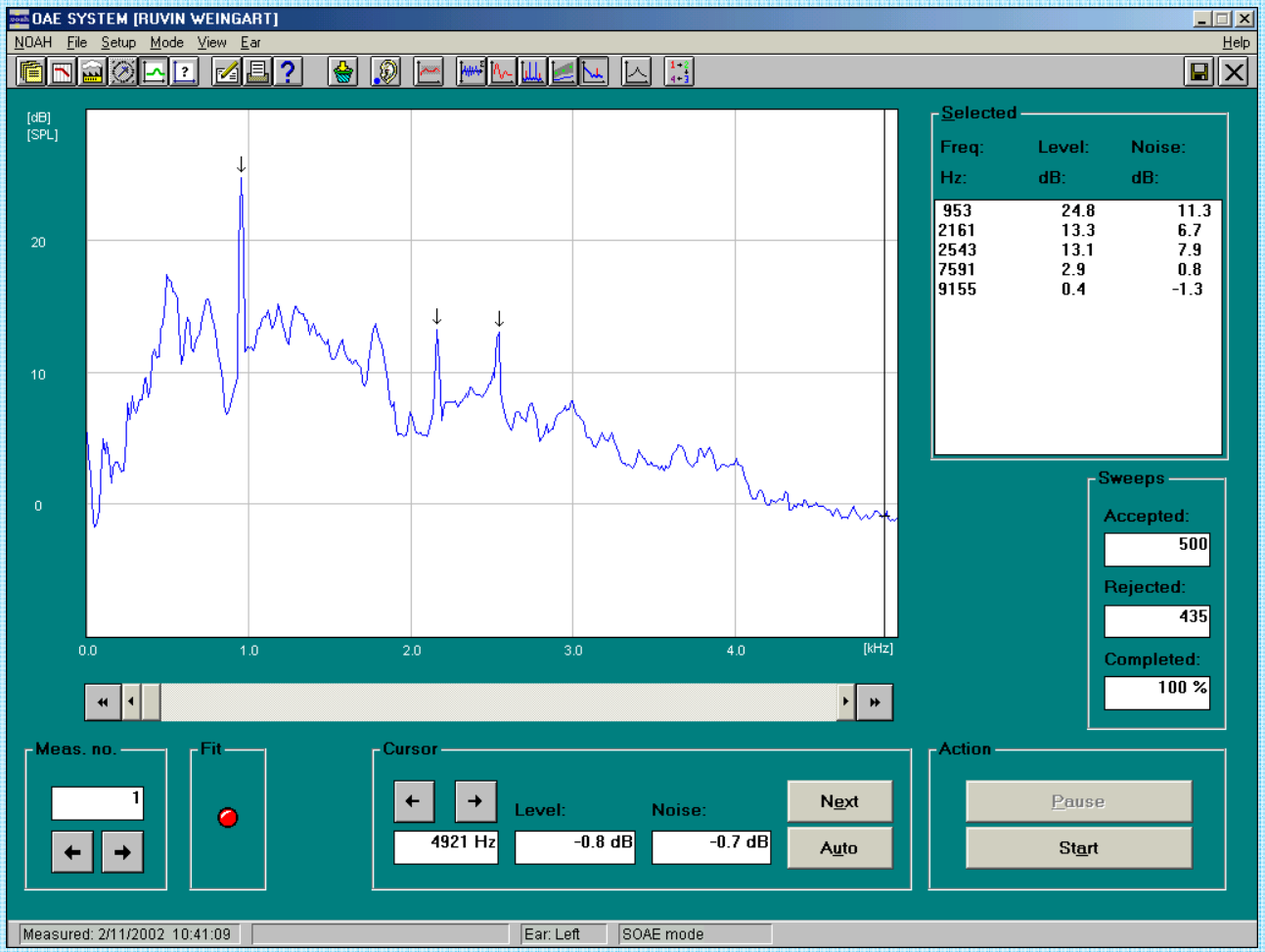
- *SOAEs*
- *Edge theory*
- *Discordant theory*
- *Role of Calcium and N- methyl-D aspartate (NMDA) receptors*
- *The dorsal cochlear nucleus*
- *Auditory plasticity theory*
- *Crosstalk theory*
- *And many more….*

Tinnitus
Outer Hair Cell motility and spontaneous otoacoustic emissions



SOAE

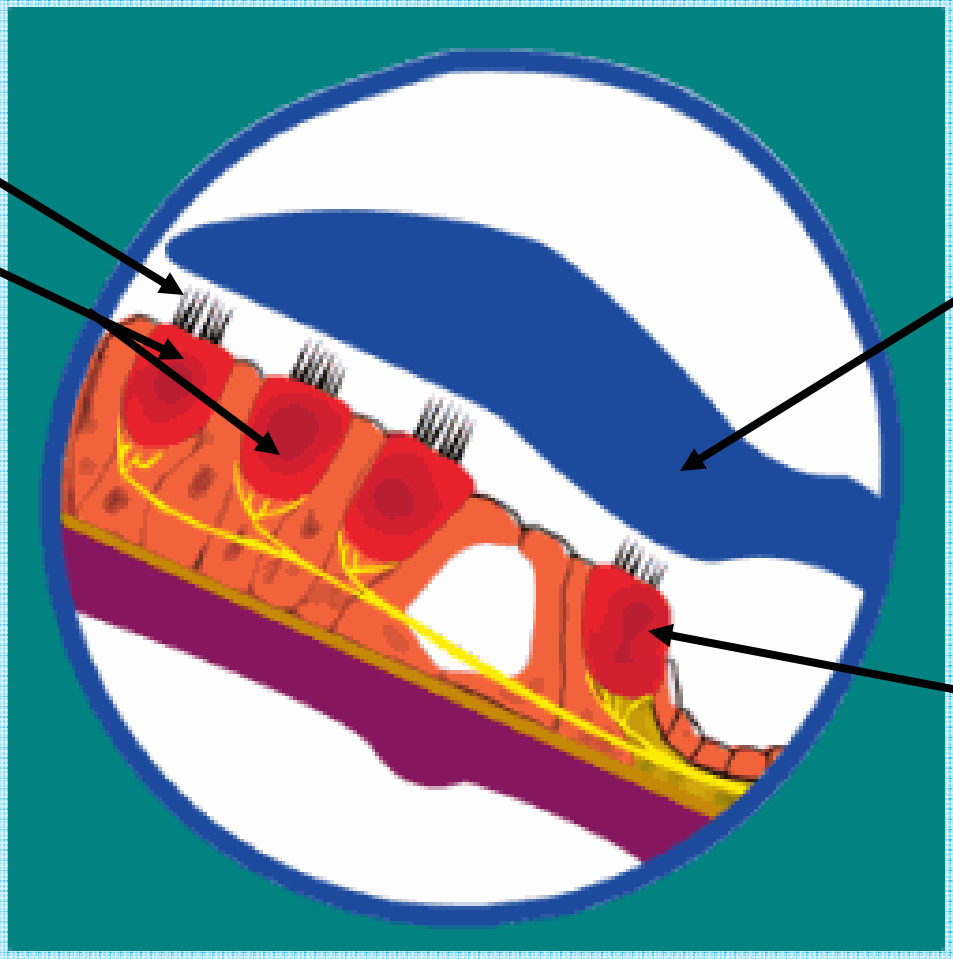
Multiple SOAE, Left Ear, 82 years old, suffering from unilateral tinnitus for 12 years.



SOAE and Tinnitus

- The prevalence of SOAE-related tinnitus is estimated to be around 4% in patients with tinnitus (Penner, 1992).

Decoupling of stereocilia and Tinnitus?



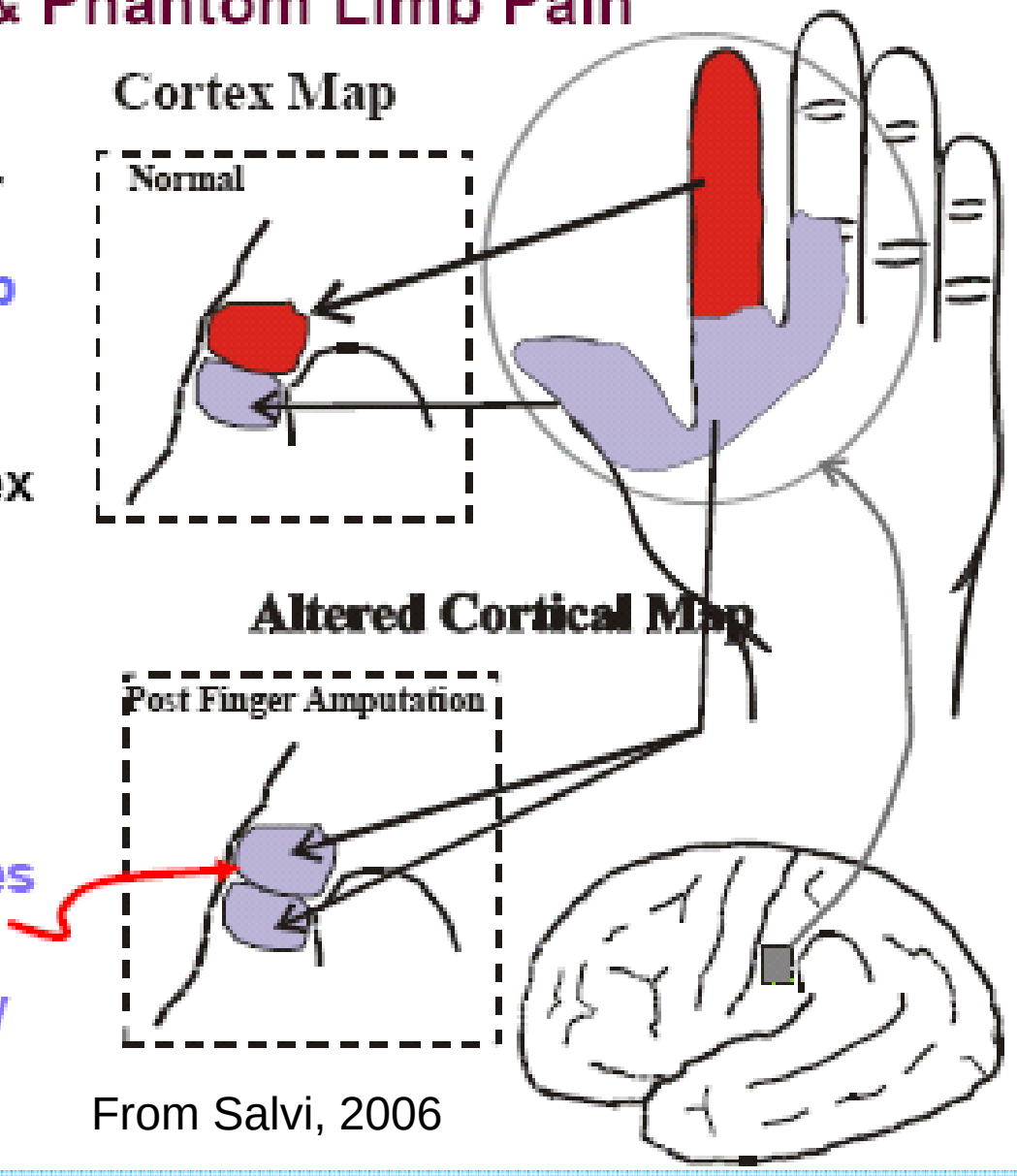
Tinnitus as a crossmodal phenomenon.

- Tinnitus can be modulated and triggered by stimuli and inputs from other sensory modalities or sensorimotor systems. Cacace (2003)
- Interaction between the dorsal cochlear nucleus and somatosensory system

Cortical Plasticity & Phantom Limb Pain

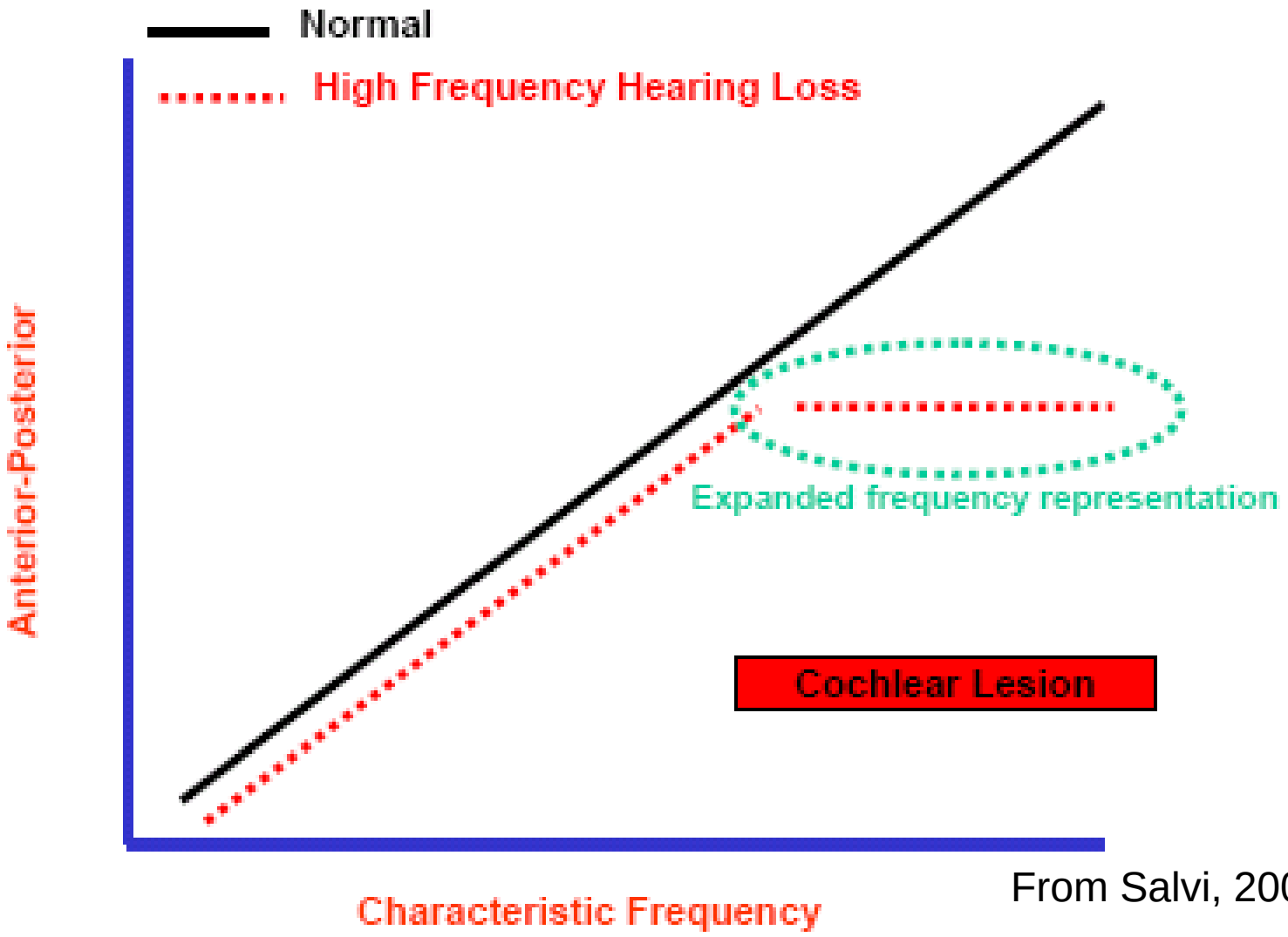
Amputation of Finger

- Index finger & thumb normally activate restricted regions of somatosensory cortex
- Amputation of index finger causes expansion of thumb region
- thumb region invades cortical region normally activated by index finger



From Salvi, 2006

Hypothesis-Tinnitus May Arise Reorganization of the Central Auditory System –"Plasticity"



From Salvi, 2006

Plasticity and Tinnitus

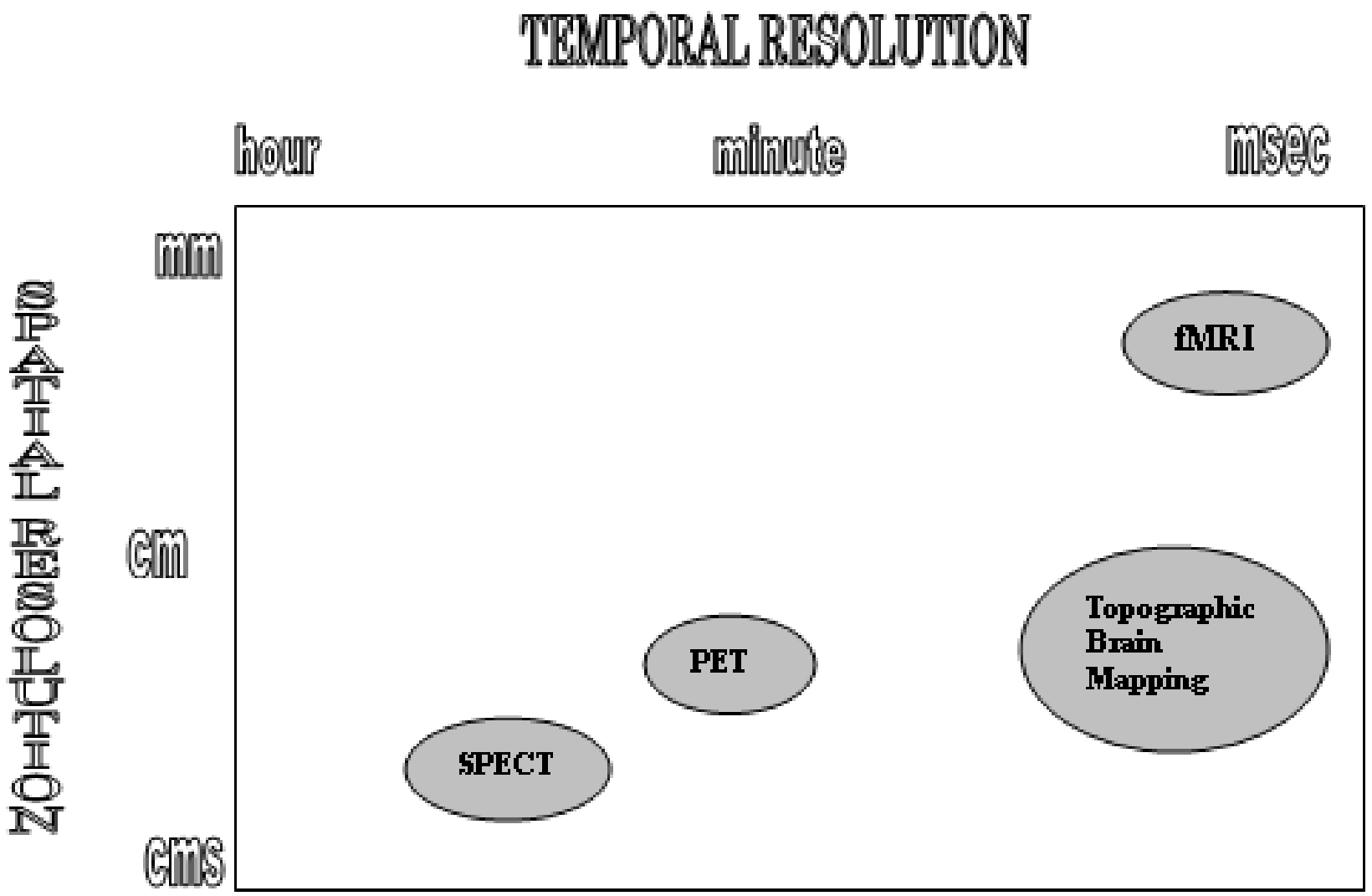
- Tinnitus results from normal compensatory changes in the hearing mechanism, rather than irreversible ear damage.

Tinnitus Mechanisms continued:

Neuro-Imaging/Mapping Techniques employed in the studying of Tinnitus

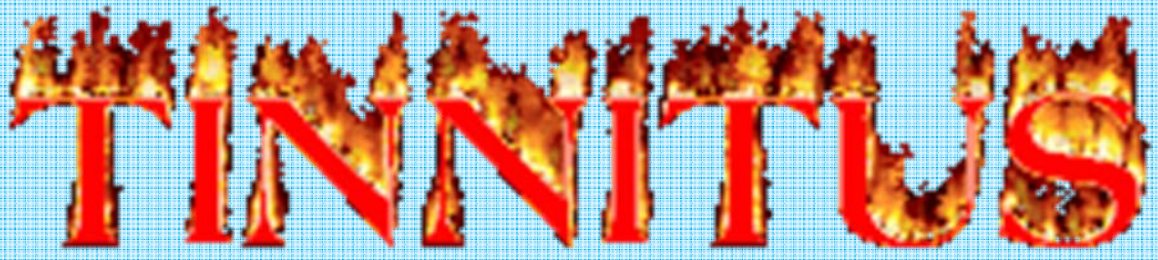
Neuro-Imaging/Mapping Techniques

1. **Functional: fMRI, PET, SPECT, MEG, EEG, and Topographic brain mapping and source localization methods.**
2. **Anatomical: CT, MRI**



Spatial and Temporal properties of functional neuroimaging techniques (Danesh et al, 2003, Tinnitus, Seeing of the Unseeable).

Functional Imaging of

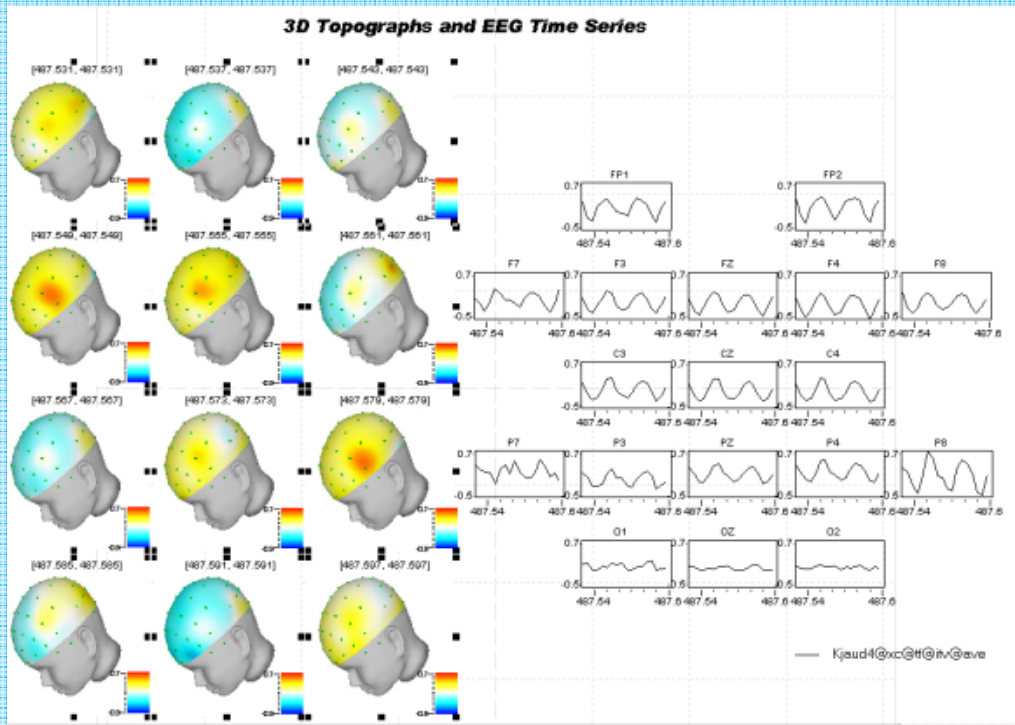


Evoked Potential Studies and Tinnitus

- No difference between CAP (Moeller, et al. 1992)
- Shorter Wave V in patients with Tinnitus (Moeller, et al. 1992)
- Enhanced CNV amplitude in patients with Tinnitus (Shiraishi, et al. 1991)
- Smaller N1, P2, P3 amplitudes in subjects with Tinnitus (Attias, et al. 1993).

Tinnitus and Topographic Brain Mapping

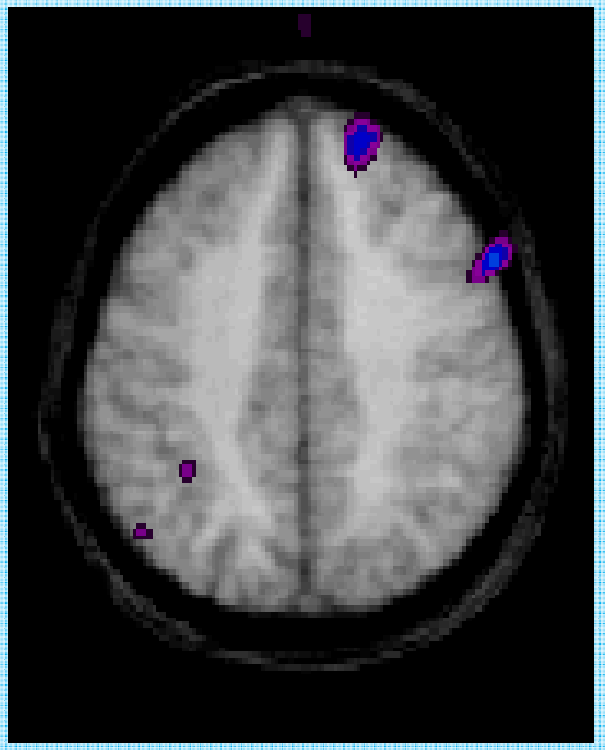
- No published study, presently.
- Can compare EEG and ERP activity and develop topographic brain maps.



PET

- **PET allows to objectify subjective symptoms such as chronic pain or tinnitus.**

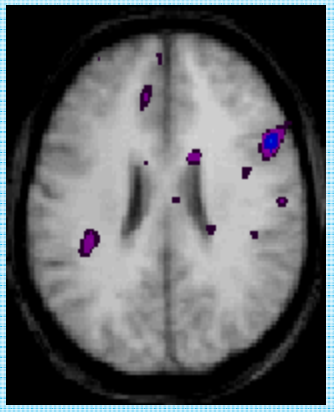
How are the functional neuroimaging techniques used in Tinnitus studies?

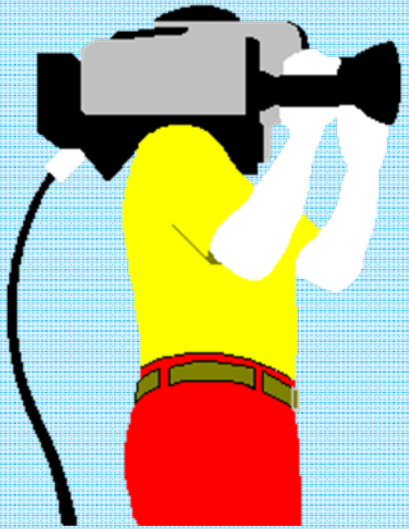


Dr. Frank Mirz Tinnitus Lab, Copenhagen-Denmark

Normal State

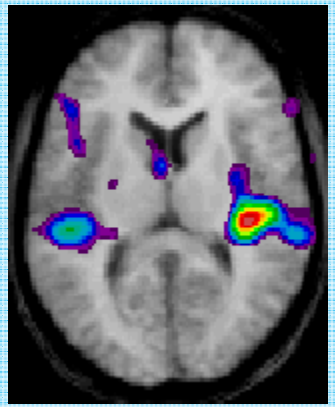
(No Tinnitus)





Evoked Tinnitus!

Altered Tinnitus



Applications of Functional Imaging of Tinnitus

- To study evoked Tinnitus that includes:
  - Gaze-evoked tinnitus
  - Cutaneous-evoked (hands or external ear) tinnitus
  - Finger-movement-evoked tinnitus
  - Oral-facial/Jaw movement evoked tinnitus
- To study the effects of acoustical maskers and/or medications (e.g., lidocaine injection) on tinnitus
- Evaluation of the steady-state activities.

Evoked-Tinnitus Classification

- **Visual-motor evoked (e.g., Gaze-evoked tinnitus)**
- **Somatosensory-evoked tinnitus/Cutaneous-evoked (fingers or external ear) tinnitus**
- **Finger-movement-evoked tinnitus Somatomotor-evoked tinnitus**
- **Orofacial/Jaw movement evoked tinnitus**
- **Cranio-cervical manipulations of head and neck**
- **Applying electrical stimulation to the median nerve and hand region**

Underlying factors of evoked tinnitus

- **Peripheral deafferentation**
- **Crossmodal reactive sprouting of neurons to denervated synaptic sites (Wall et al.,1987) (Hypotheses)**
- **Non-classical auditory pathways become *re*activated as an expression of neuroplasticity (Moller and Rolins, 2002) (Speculation)**

What are the other underlying factors contributing to the generation of evoked tinnitus?

- Regeneration and new synapse formation in the CNS
- Ephaptic Transmission/Interactions
- Plastic changes in the CNS due to atypical connections between the auditory and sensory-motor systems.
- Crossmodality

PET Findings in cases with gaze-evoked tinnitus (Giraud et al., 1999)

- Four adults with gaze-evoked tinnitus following deafferentation of the 8th CN.
- Increased activity in temporal-parietal association areas (bilateral).

PET Findings in cases with orofacial-evoked tinnitus:

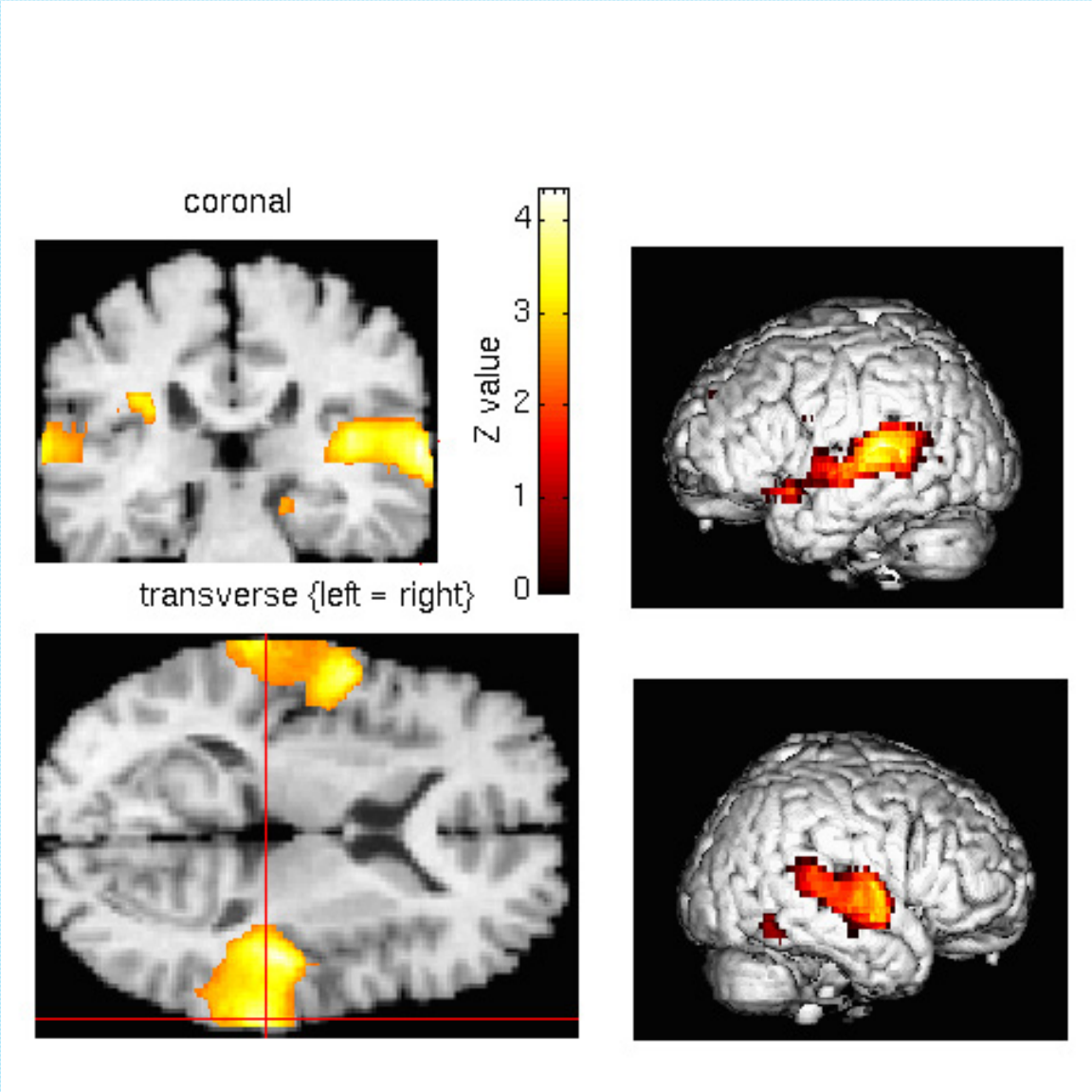
Lockwood, Salvi, Coad, etal., 1998.)

PET Findings in cases with orofacial-evoked tinnitus: Lockwood, Salvi, Coad, etal., 1998.)

- Two groups: with and without tinnitus
- Monaural tonal stimulation
- OFM-induced loudness changes of tinnitus affected the **auditory cortex contralateral to the ear in which tinnitus was perceived**, whereas unilateral cochlear stimulation caused bilateral effects, suggesting a retrocochlear origin for their tinnitus
- Activation in MGB, contralateral temporal lobe and contralateral hippocampus

Unilateral tonal stimulation and PET

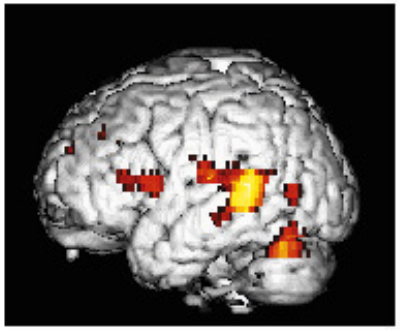
(bilateral activation)



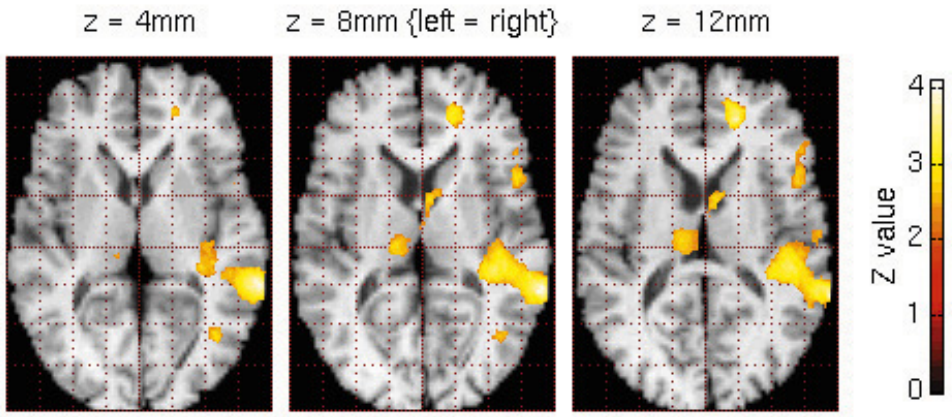
Source: Alan H. Lockwood, Richard J. Salvi et al., (1998).

Lockwood et al., 1998

- Their findings suggested that the unilateral nature of blood flow patterns, as shown by PET, indicates that tinnitus is originated in the central auditory system and not in the cochlea.



Unilateral activation with OFM in tinnitus subjects

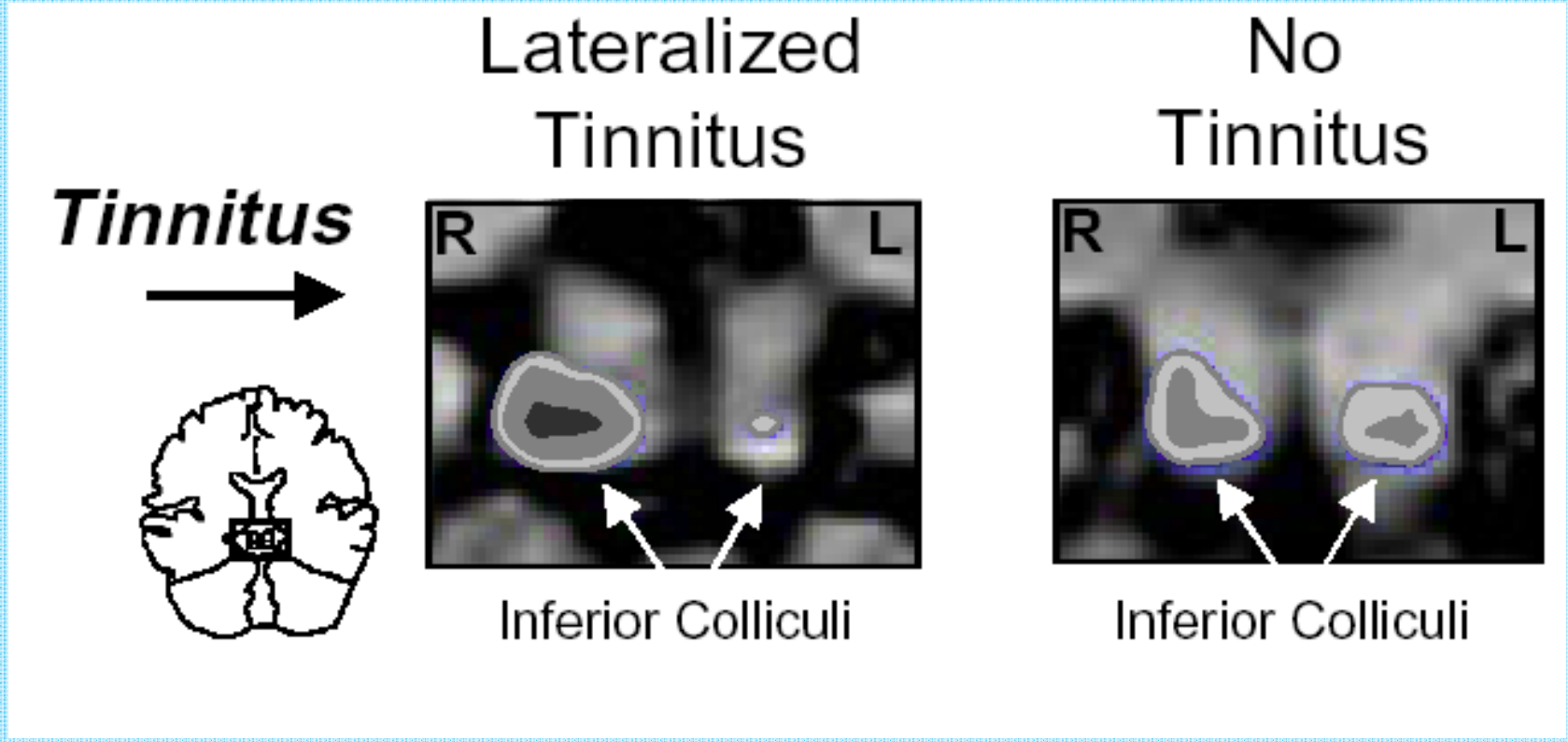


Source: Alan H. Lockwood, Richard J. Salvi, Mary Lou Coad, Mary Towsley, David Wack, Brian Murphy (1998).

fMRI findings in a case with Cutaneous-evoked Tinnitus

- Cutaneous-evoked tinnitus following de-afferentation of the 8th cranial nerve followed by or associated with de-efferentation of the facial nerve.
- Stroking back side of the hand or touching the finger tips resulted in tonal tinnitus
- fMRI revealed **activation in the contralateral temporal-parietal junction** at the superior portion of the lateral fissure and the lower portion of the parietal operculum.

Cacace, Cousins, Parnes, etal., 1999.



fMRI study: Asymmetric activity of inferior colliculus in an individual with normal hearing and lateralized tinnitus. Asymmetric activity was normalized after lidocaine injection and it increased after the drug effects vanished.

Melcher et al., 2000.

Evoked Tinnitus
Case Presentation I

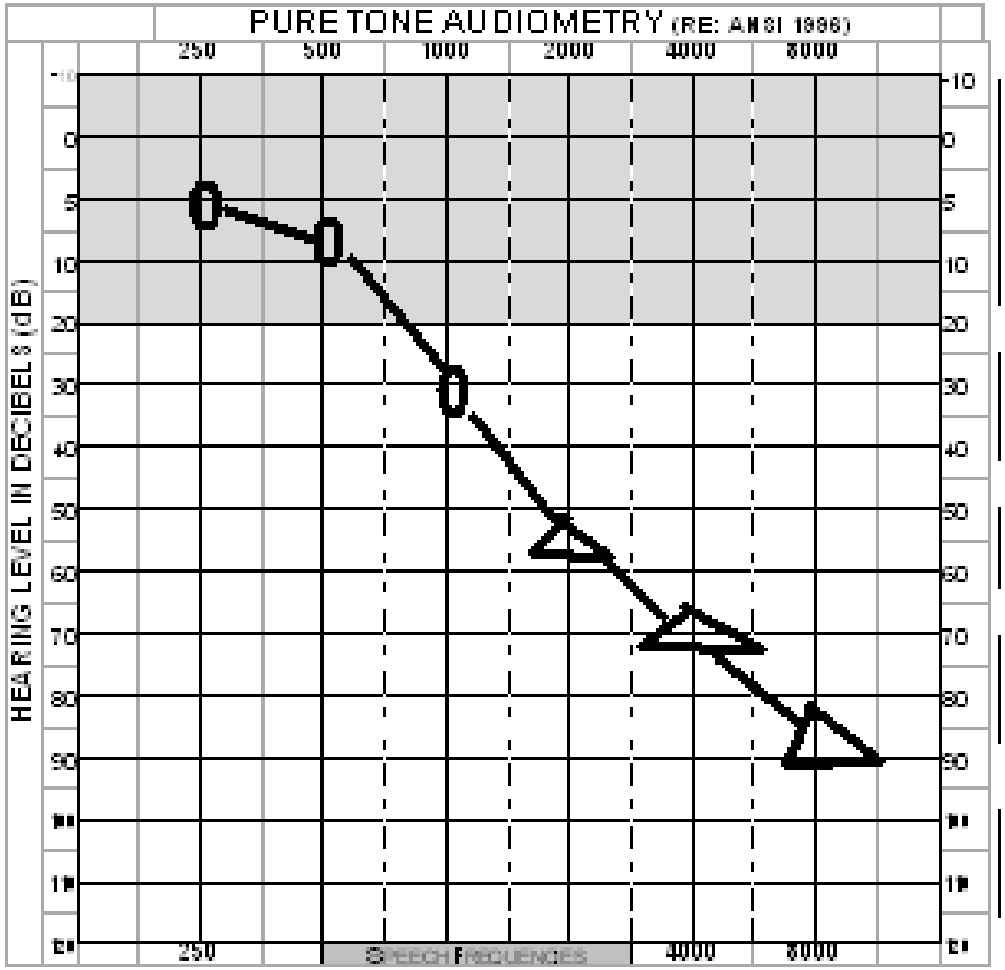
- Female
- Normal audiological/otological findings
- Extension and flexion of neck muscles from anterior to postero-superior position (chin tucks) resulted in high pitched tinnitus.

Case I
Evoked Tinnitus

Evoked Tinnitus
Case Presentation II

- **Female**
- **Moderate sudden SNHL, AD**
- **Tinnitus at 250Hz, 4 dB SL**
- **Candidate for habituation/masking therapy**
- **Unilateral digital dual channel/memory ITC**
- **Completely masks out tinnitus**
- **Has developed “evoked tinnitus”**
- **Rotation of the head in horizontal planes at 90degrees generates a high pitched transient tinnitus.**
- **Extralemniscal (non-classical) auditory pathway stimulation.**

Case II, Unilateral Sudden SNHL, AD, Unknown Etiology



Complete Neck Rotation results in Evoked Tinnitus.

Use of MEG in the studying of Tinnitus

Detection of Tinnitus by MEG using Coherence Imaging

Image Results

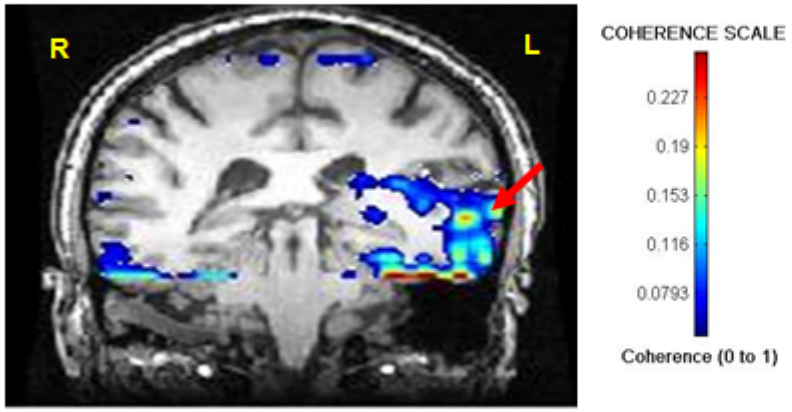


Fig 1. MEG Coherence analysis of spontaneous activity while a patient perceived his tinnitus. MRI shows localization of activated region in the Left Auditory Cortex. Red indicates cortical areas that are highly coherent with all other brain regions. This patient had unilateral tinnitus in the right ear.

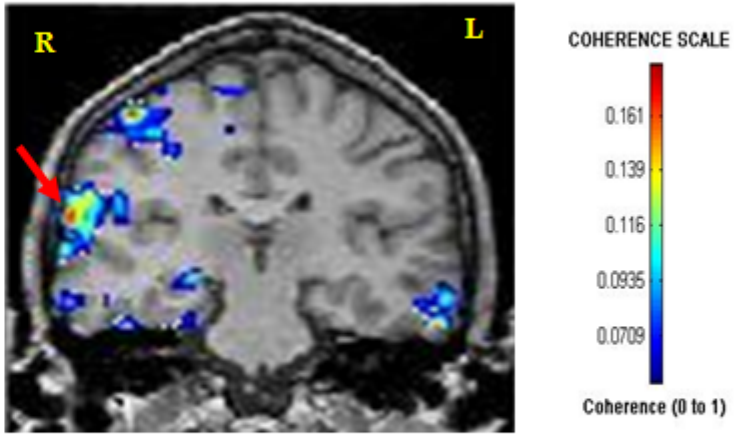


Fig 2. This patient has bilateral tinnitus. High coherence seen in the Right Auditory cortex even though he states both ears are ringing. This implies a network that is more active during rest in the auditory cortex of the right hemisphere than in the left.

Susan M Bowyer , et al 2008

Detection of Tinnitus by MEG using Coherence Imaging

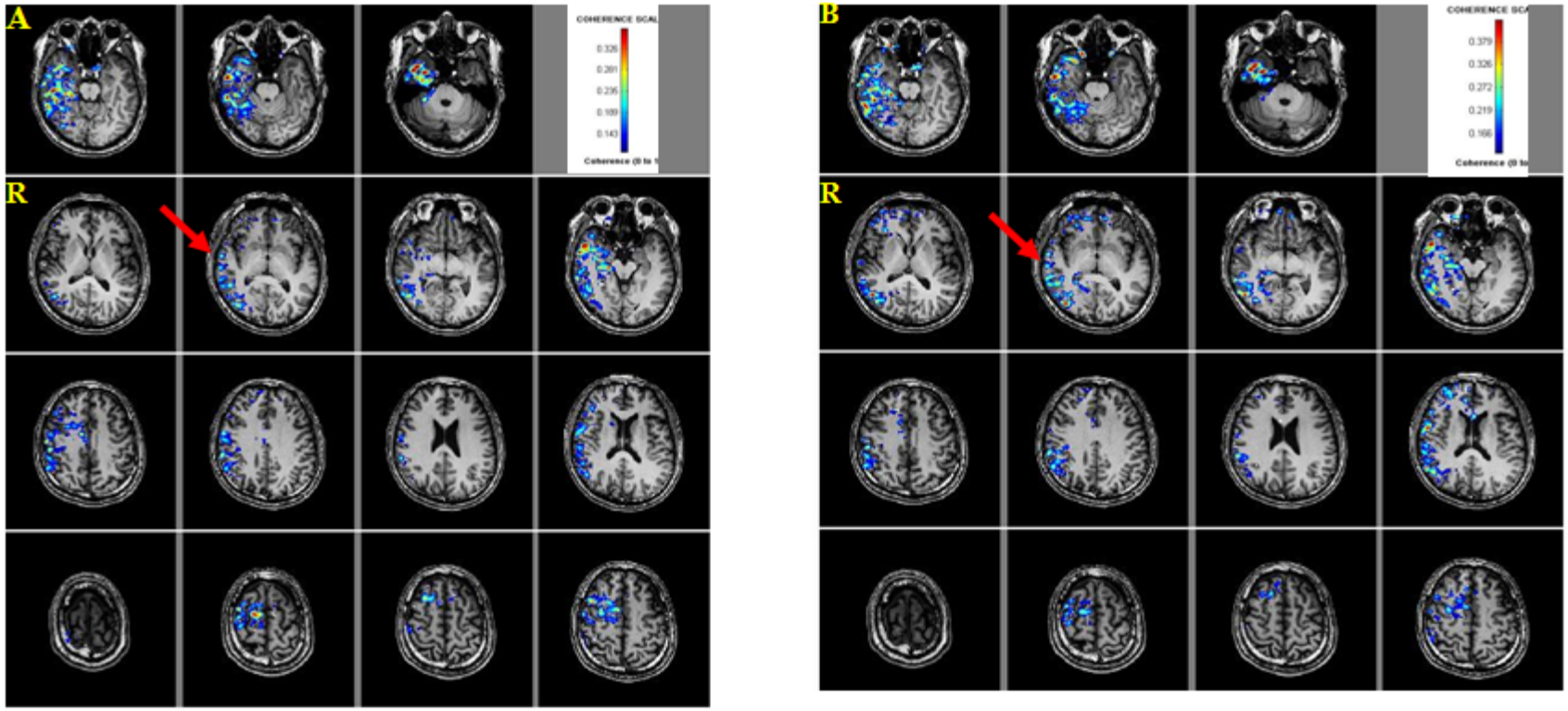


Fig 3. Cortical activity in the 1-50 Hz range is seen in 2 conditions A) eyes open, B) eyes closed in the right auditory cortex. Note high coherence is seen in the right auditory cortex in both conditions. This patient had unilateral tinnitus in the left ear.

Susan M Bowyer , et al 2008

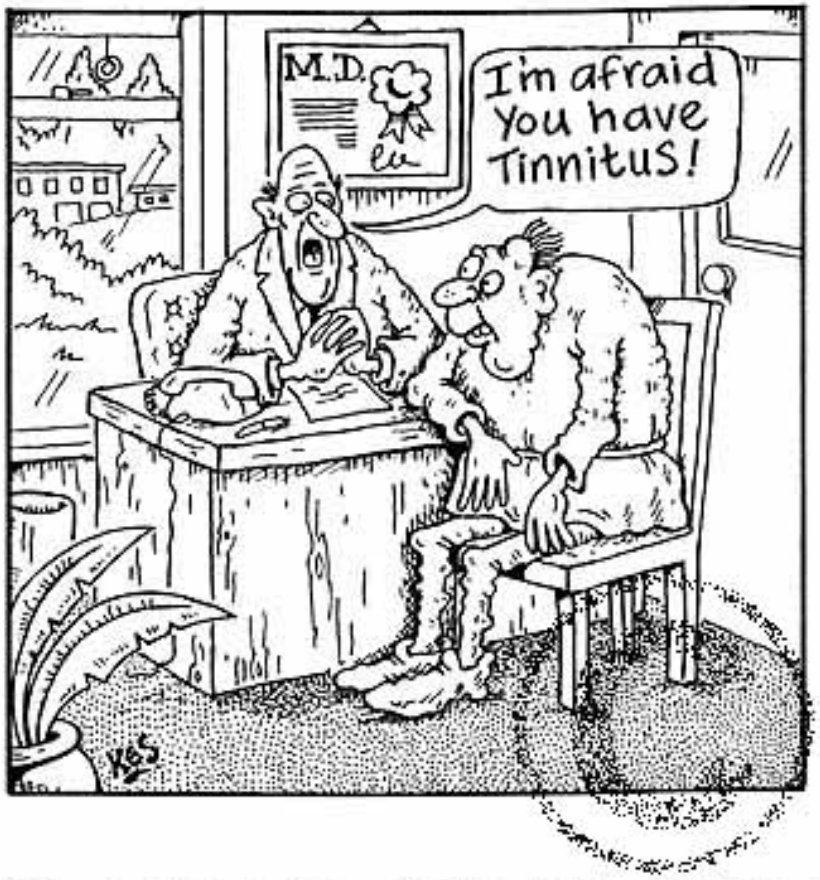
Tinnitus Assessment

- Tinnitus Self Assessment Questionnaires
- Psychoacoustic Evaluation
  - Tinnitus Pitch Match
  - Tinnitus Loudness Match
  - Minimal Masking Level
  - Residual Inhibition
- Loudness Discomfort level
- Hyperacusis Self Assessment Questionnaires

Tinnitus Self Assessment Questionnaires

- THI (Newman et al., 1996)
- TRQ(Wilson et al., 1991)
- Iowa Set of Questionnaires (Dr. Rich Tyler)
  - **Iowa Tinnitus Handicap Questionnaire**
  - **Iowa Tinnitus Activities Questionnaire**
- Sound Therapy Option Profile (STOP): A Tool for Selecting Devices Used in Tinnitus Treatment 9/4/2006 Craig W. Newman, Ph.D. & Sharon A. Sandridge, Ph.D., Cleveland Clinic, Cleveland

Tinnitus Management
A multidisciplinary effort!



Quasimodo visits his doctor

"Hell's Bell's, Hell's Bells."

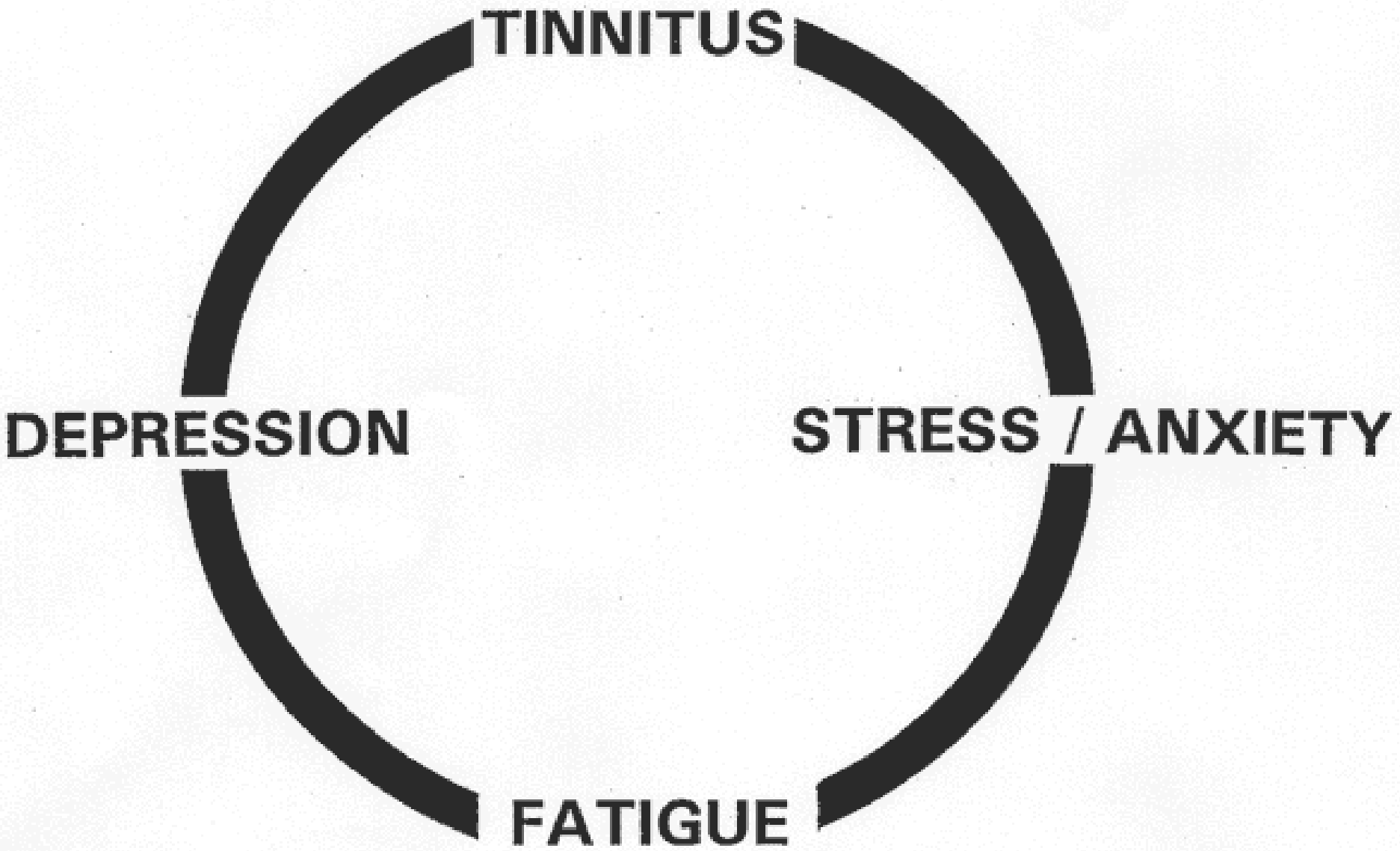
Tinnitus Treatments!

- Turn off my tinnitus! (Where is that “magic pill”?)

Accompanying symptoms

- Stress
- Anxiety
- Depression
- Fear
- Insomnia
- Fatigue
- …

Figure 1. A Vicious Circle of Symptoms



Source: Folmer, R. (2001)

Comments made by some clinicians to their tinnitus patients about tinnitus treatment (Danesh, 2002 Tinnitus study)

- “Go and live with it!”
- “Nothing can be done!”
- “If I knew how to cure it, I will be a rich person!”
- “I could cure you if you had cancer!”
- “Fifty percent of the people with tinnitus like yours commit suicide!!”

Tinnitus Treatment Options

*** Amplification (Hearing Aids)**
*** Biofeedback**
*** Cochlear Implants/Electrical Stimulation**
*** Cognitive Behavioral Therapy**
*** Tinnitus Reaction Modification**
*** Drug Therapy**
*** Masking/Habituation Therapy**
*** Tinnitus Retraining Therapy**
*** TMJ Treatment**
*** Alternative Treatments**
*** Surgery**

Source: www.ata.org

Tinnitus Evaluation

1. Tinnitus Pitch Match
2. Tinnitus Loudness Match
3. Minimal Masking Level
4. Residual Inhibition
5. Loudness Discomfort Level

Tonal vs noise, most troublesome component, RI: pure tone, NBN, or WN

Environmental Masking

- Useful to mask out mild tinnitus which is bothersome in quiet
- Electronic soothing sound generators
- Burn your own CD
- Audocity and other softwares/sharewares
- Home environmental maskers (fans etc.)
- Broad-band noise, static FM stations
- Required noise level is usually soft which does not disturb family members

Wearable Masking/Noise generator Devices

Tinnitus Control Instrument

Sound Generators/Tinnitus Maskers

Noise Generators/Tinnitus Maskers

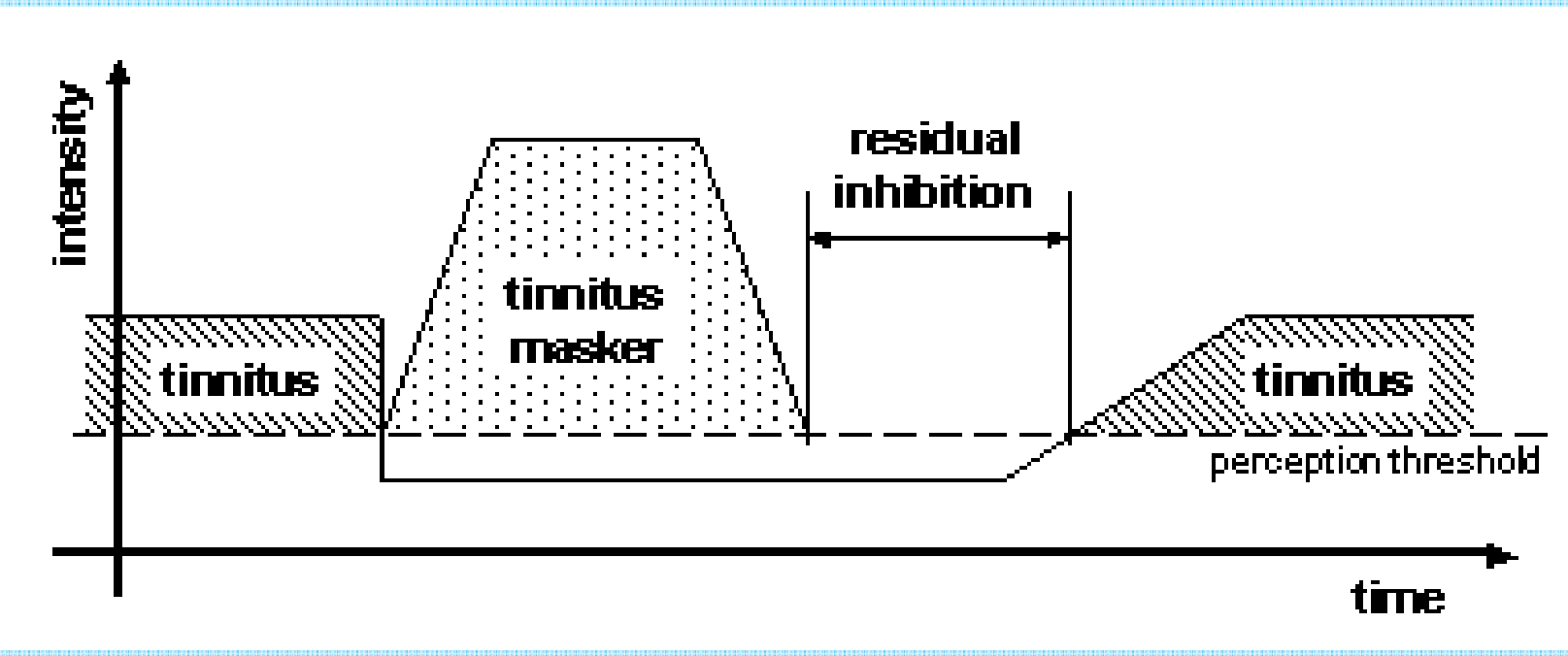
Tinnitus Device

Low-Level Ultrasound Bone Conduction Device

Residual Inhibition

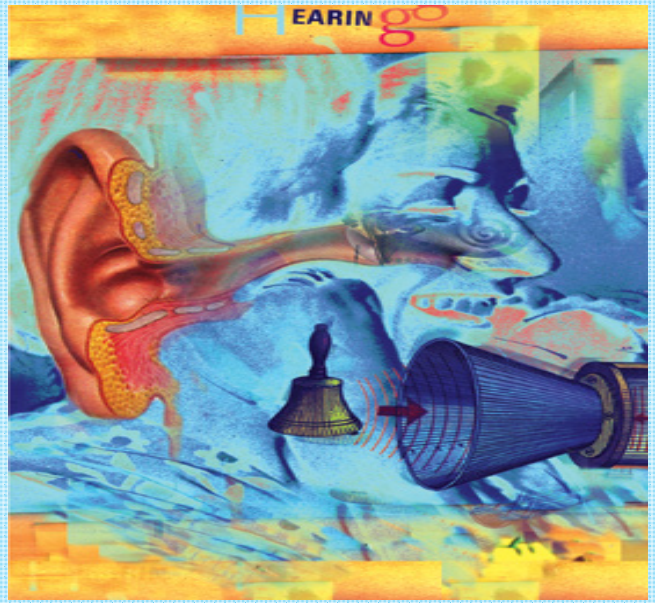
- Residual inhibition is the natural process of the nervous system becoming desensitized to external stimuli over time.

Residual Inhibition



Tinnitus Management with Amplification

- Bilateral Hearing Loss plus bilateral tinnitus
- Unilateral hearing loss/tinnitus



Inventor Thomas A. Edison

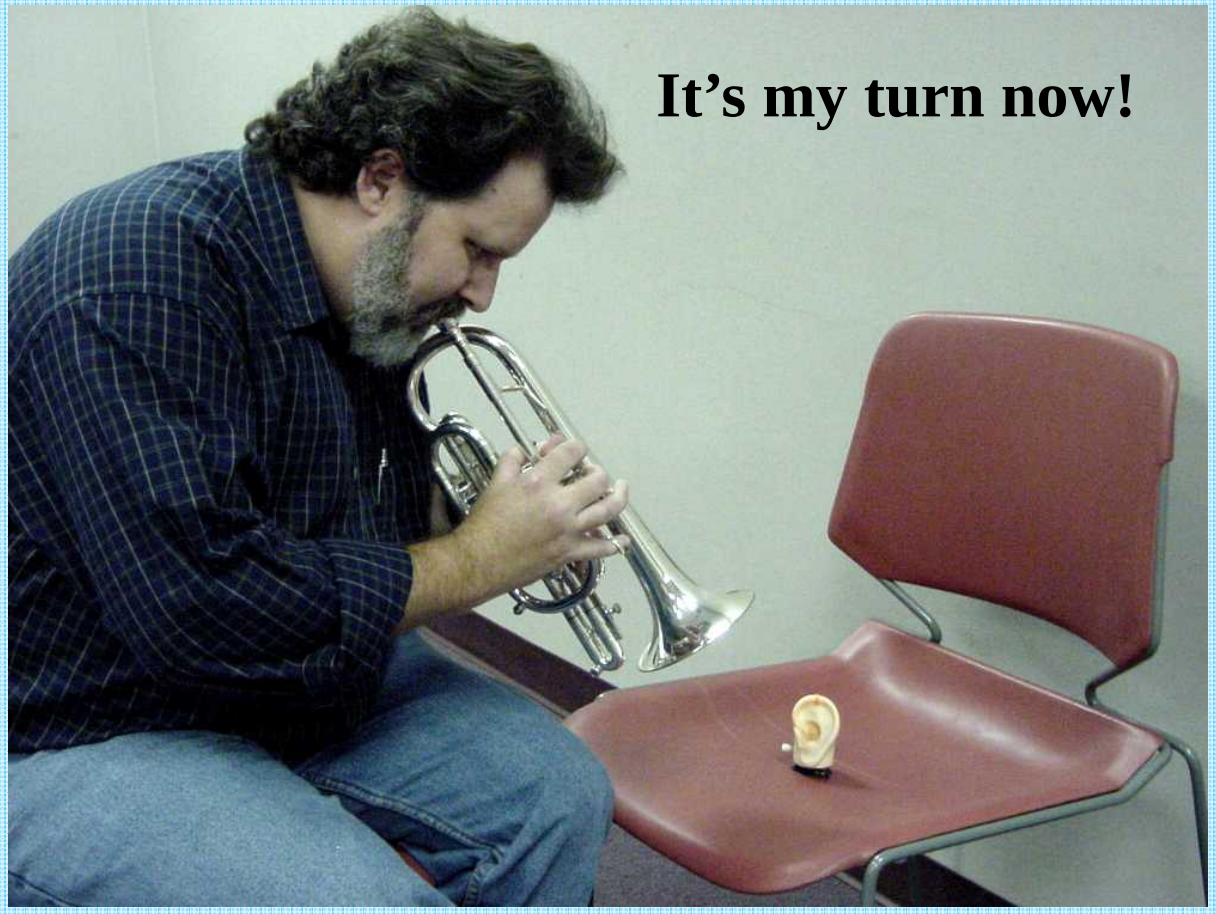
Management of Unilateral Sensorineural Hearing Loss Associated with Tinnitus (Partial List) (Andreassen & Danesh, 2007)

GENDER	AGE	ETIOLOGY	EAR/ HL	MANAGEMENT	RESULTS
F	47	Idiopathic Sudden Hearing Loss	RE Mod/ Severe	Hearing Aid plus Habituation Therapy	Complete Masking
M	57	Idiopathic Sudden Hearing Loss	RE Severe	Hearing Aid plus Habituation Therapy	Complete Masking
F	73	Meniere's Disease	LE Severe	Amplification plus Habituation Therapy	Sig. Less Consciousness
M	36	Idiopathic Sudden Hearing Loss	RE Mild	Amplification plus Habituation Therapy	Sig. Less Consciousness
F	58	Idiopathic Sudden Hearing Loss	RE Mod	Amplification plus Habituation Therapy	Complete Masking

Tinnitus Sound Therapy

- http://www.uihealthcare.com/depts/med/otolaryngology/clinics/tinnitus/treatment.html#Sound
- University of Iowa

Tinnitus Management: Retraining and Habituation



Habituation

- “Habituation” is defined as the disappearance of a reaction to a stimulus.

Goal

- The goal of habituation therapy is to make tinnitus an unimportant signal even though it is still there.

Habituation Protocol

- 1. Remove negative connotation toward tinnitus
- 2. Alleviation of Fear from tinnitus
- 3. Improve understanding and control to remove negative connotations
- 4. patient education
- 5. spend time with your patient
- 6. show sympathy but not pity!

Habituation Therapy

- enriched environmental sounds,
- enhancement of environmental sounds with amplification,
- introduction of broadband noise produced by low intensity white noise sound generators.

Retraining

- Retraining therapy involves reprogramming or resetting brain networks which are selectively picking up 'music of the brain' in the auditory system.

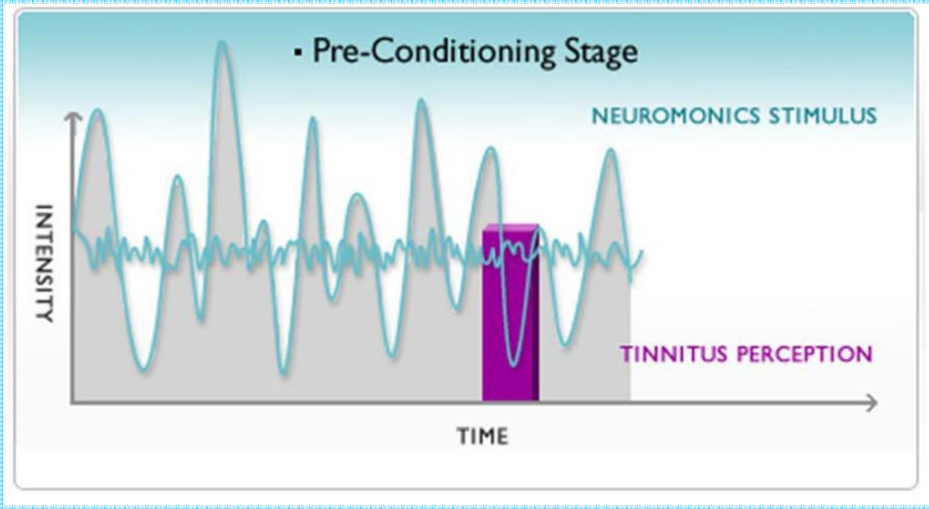
The Goal of Retraining

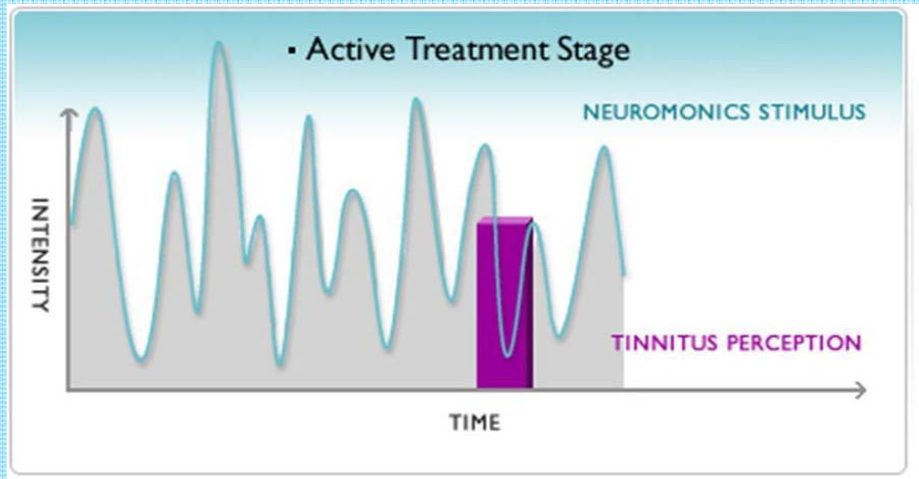
- the goal is to get rid of tinnitus reaction, rather than tinnitus perception

Retraining

- 1. To gradually reduce the strength of the REACTION against tinnitus
- 2. Provide a continuous sound
- 3. The presence of any continuous stimulus results in a process called habituation, whereby the individual responds less and less to the stimulus

Neuromonics

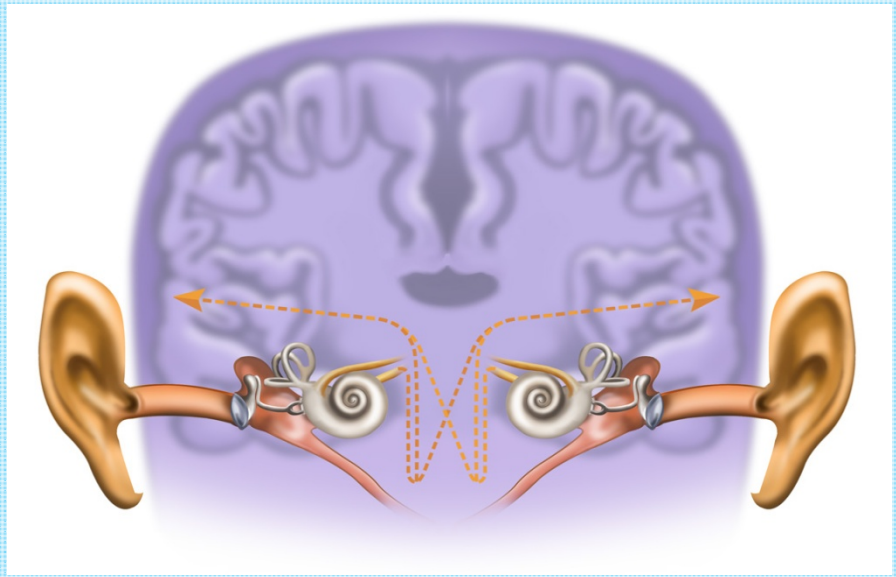




Tinnitus Pathogenesis

Audiological

•Hearing loss uncovers noise floor



Neurological

• Conditions a limbic system enhancement

• Neurological starvation leading to rewiring

• Alterations in processing patterns e.g. gain changes

• Decreased sound tolerance

Psychological

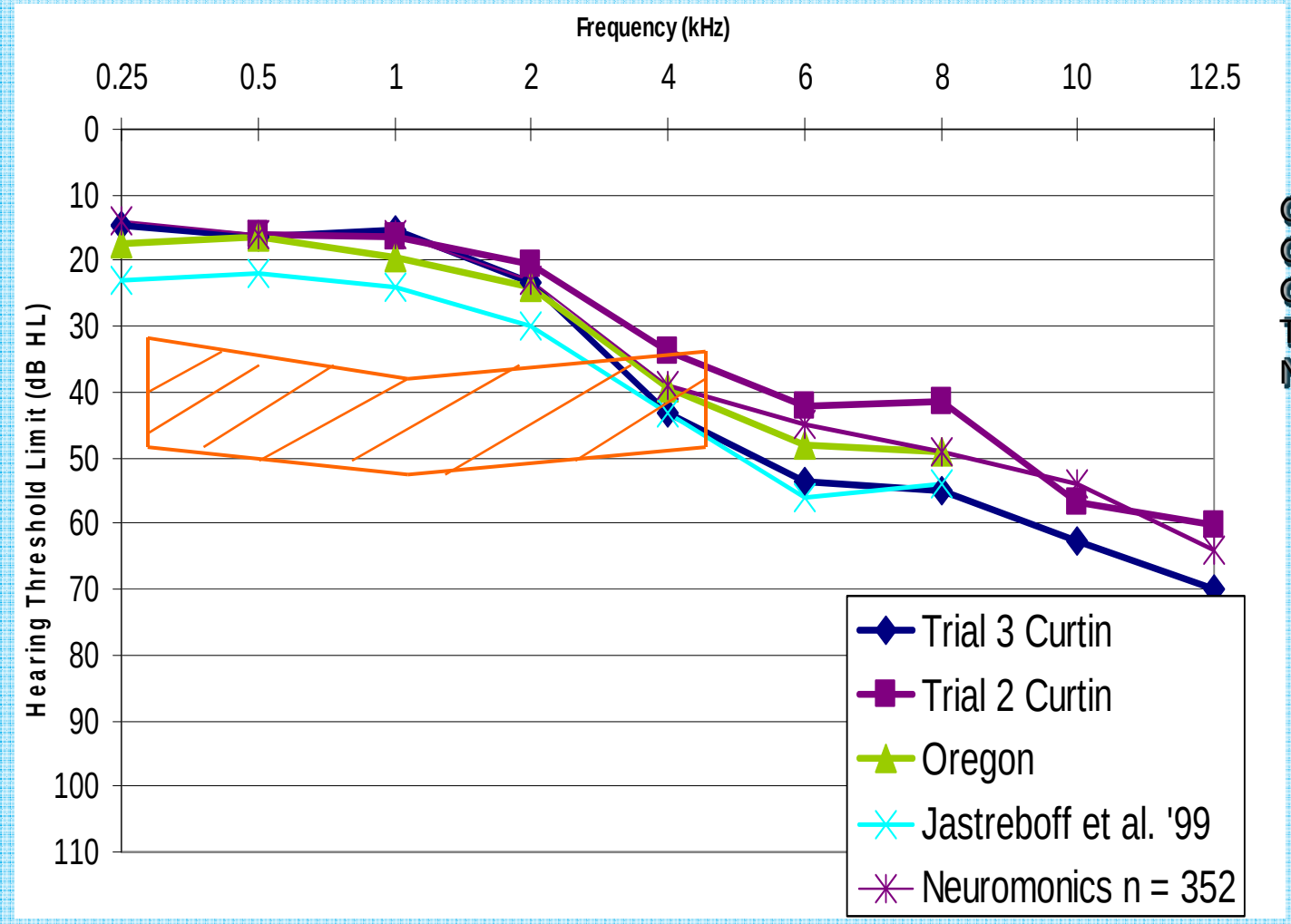
• Sleep & concentration disturbance

• Lack of control

• Fear and anxiety

• Stress increases ANS arousal

Mean Tinnitus Clinic Thresholds



Curtin T2: N. = 160 ears
Curtin T33: N. = 134 ears
Oregon: N.= 1033 ears
TRT: N.= 1616 ears
NTT: N.= 704 ears

Oregon data: Henry, J., Meikle, M., & Gilbert, A. (1999).
TRT data: Jastreboff, Sheldrake, & Jastreboff, (1999).

What is Neuromonics Tinnitus Treatment?

1

Novel (patented) acoustic therapy

1

Individually prescribed (with compensation for hearing loss)

Delivered via a purpose-built digital Processor

2

6 month program of support, monitoring, collaborative counseling and education from a specialist clinician

Development Process to Date

- Conceived in Western Australia 17 yrs ago, at Curtin University of Technology
- Iterative development process:
  - 4 randomized controlled studies over > 200 subjects
- > 2500 private practice patients since April 2004
- Delivery system evolved substantially
  - Regulatory clearance in Aust, NZ, Singapore & USA
- Accredited Providers; >30 clinics in Australasia, & >50 clinics in USA, incl. The Cleveland Clinic/ other major specialist tinnitus clinics

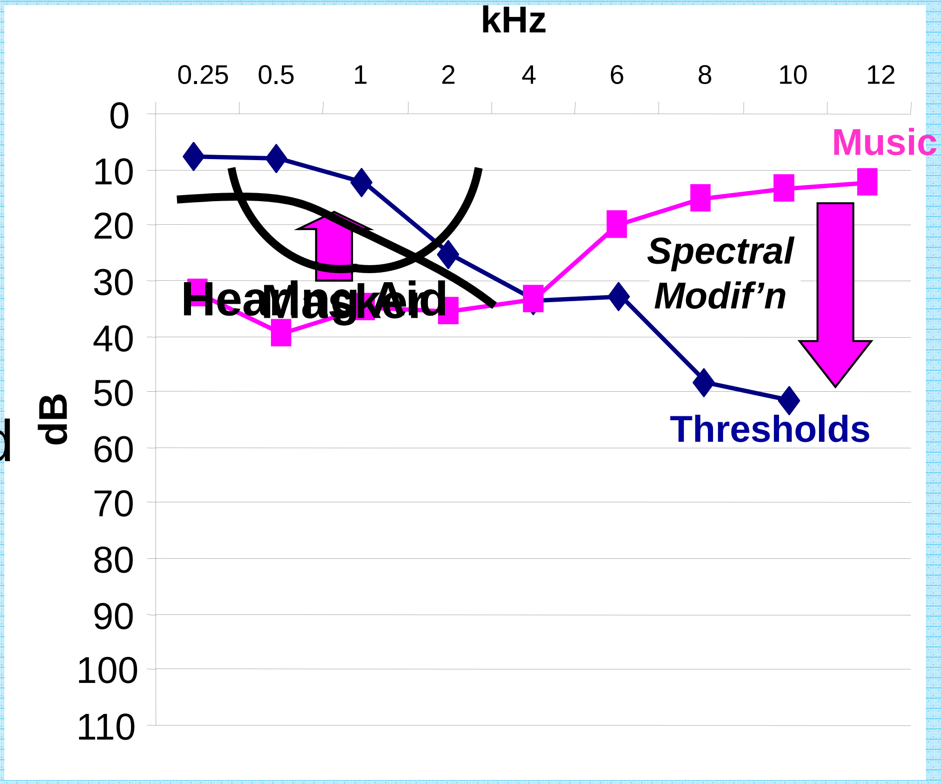
Davis, 2008

Customisation: Spectral Modification

- Typical tinnitus sufferer has hearing loss >4kHz
- Masking/music also generally provide little stimulus above 4kHz…
- …unless uncomfortably loud in speech range
- …particularly for those with decreased sound tolerance

- **Hearing aids** have low frequency bias
  - limited in frequency range
  - problematic with decreased sound tolerance
  - can't help with sleep or relaxation

- Customization ensures:
  - max stimulation of auditory pathways
  - compensation for asymmetry
  - control of inter-aural phase relationships
  - min listening volume



Spectral Composition of Music vs. Hearing Thresholds of Typical Clinic Patient Sample

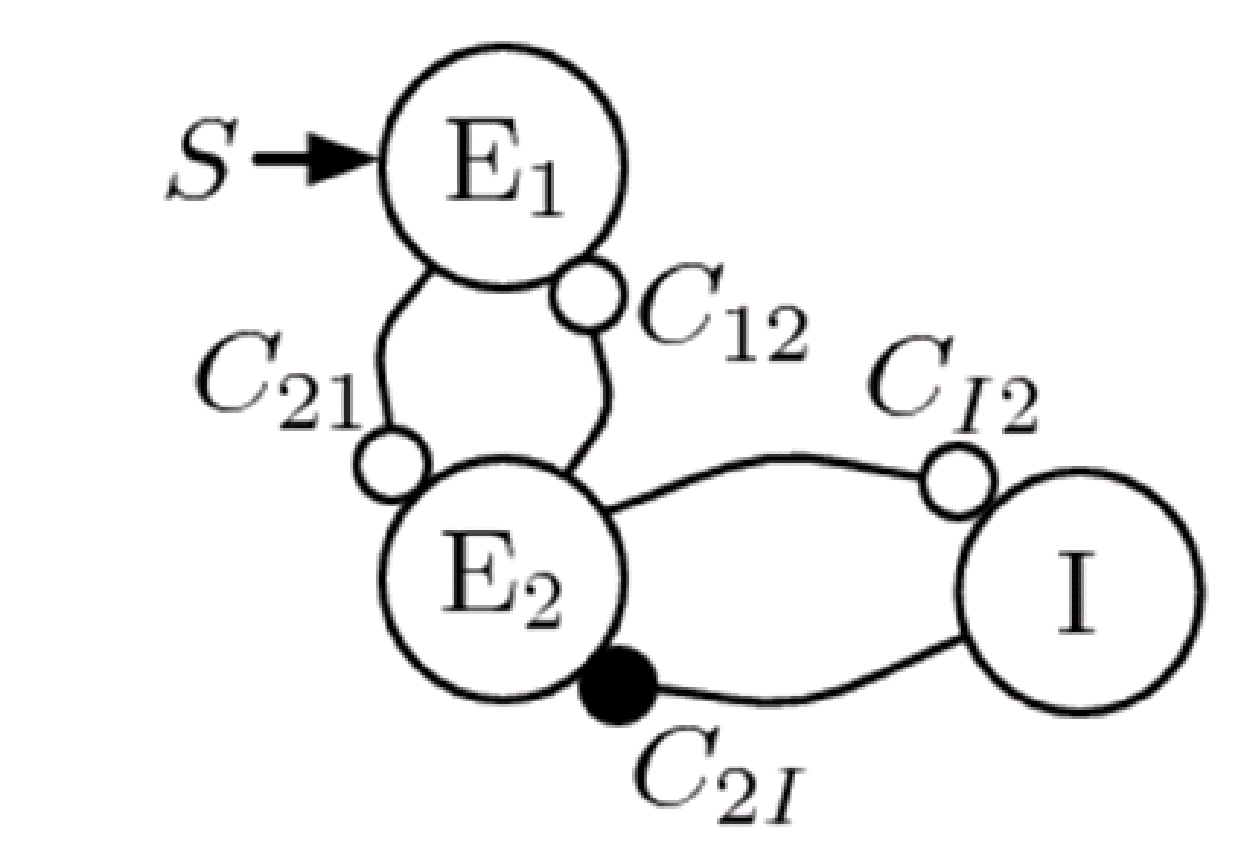
Davis, 2008

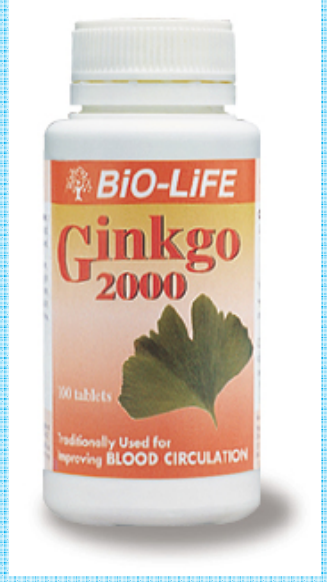
Take Home Messages

- Tinnitus and decreased sound tolerance are related to neuro-plastic changes in response to hearing loss and negative cognitions
- First quantify patient's individual needs &severity
- Only management required for a mild problem
- When more severe, a comprehensive rehab program is required to address all underlying factors
- Range of options: acoustics & counselling = best practice
- Hearing aid candidacy in only 20-30 % of cases
- TRT can be effective when done comprehensively
- Neuromonics is a newly available treatment option
- For any clinic, counselling and relaxation training is critical
- Evidence based practice, including post-therapy measures

A neural Network Model for Tinnitus

Fujimoto, Nagashino, Kinouchi, Danesh *and* Pandya (2006)





Antioxidants, herbs, vitamins.

Tinnitus Treatments

- **Psychological Approaches**
  - Biofeedback/Neurofeedback
  - Relaxation therapy
  - Meditation
  - Hypnotherapy
  - Yoga

Biofeedback and Neurofeedback

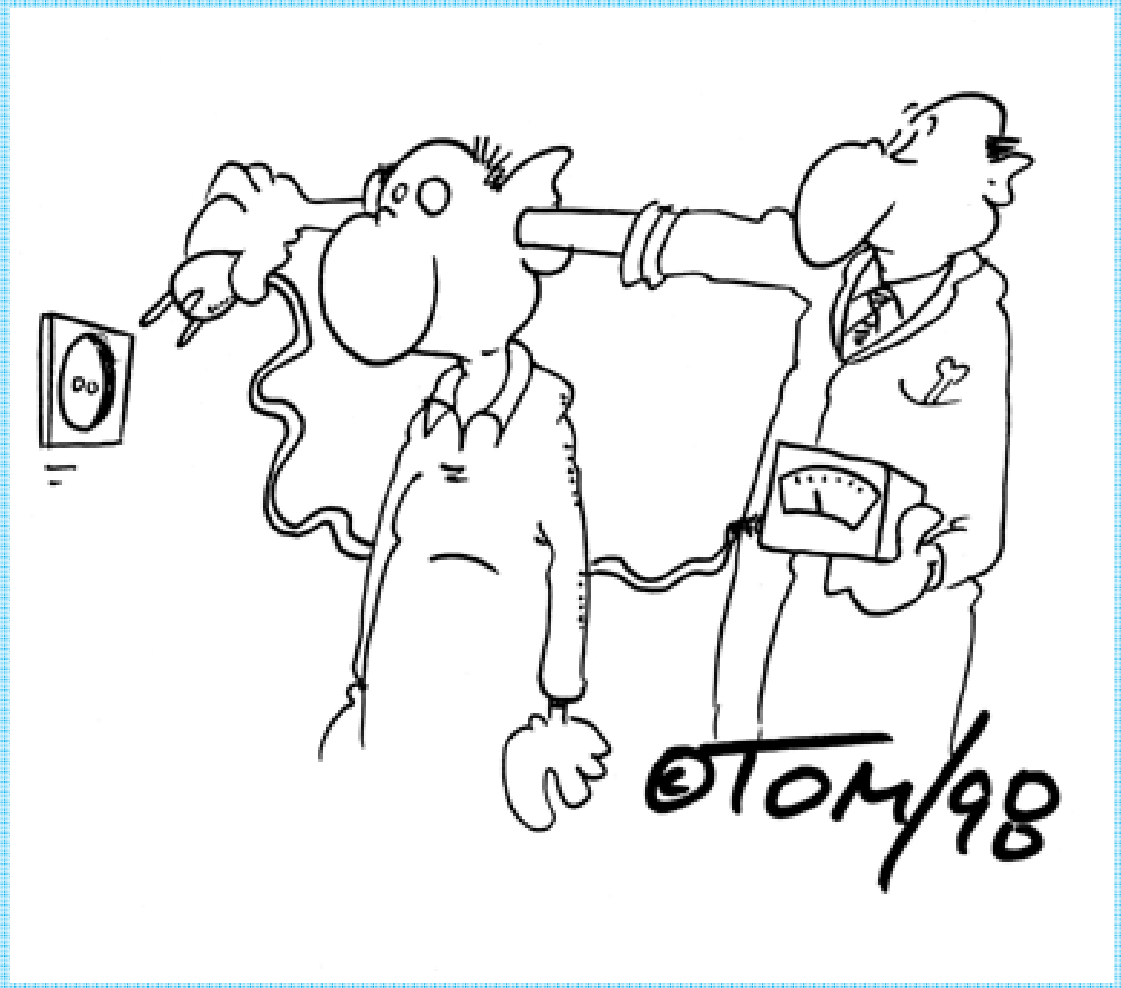
- Biofeedback is a learned ability to control physiologic processes such as body temperature or heart beat. Neurofeedback is a form of biofeedback which controls the electrical activity of the brain such as frequency, location or amplitude of specific EEG activity.
- Studies show down regulation of the amplitude of beta-activity.

Gosepath et al (2001)

Electrical Stimulation

- Both DC and AC have been used (mainly AC)
- DC (direct current) to round window or promontory could reduce tinnitus
- DC may produce permanent tissue damage
- AC (alternating current) External stimulus on promontory transtympanically and transcutaneously in pre and post auricular regions

Electrical Suppression of Tinnitus!



LASER and Tinnitus Treatment

Picture of a Patient being treated at the Mastoid with Low Level Laser as part of the overall treatment protocol.

http://www.tinnitus.us/treatmentoftinnitus.html

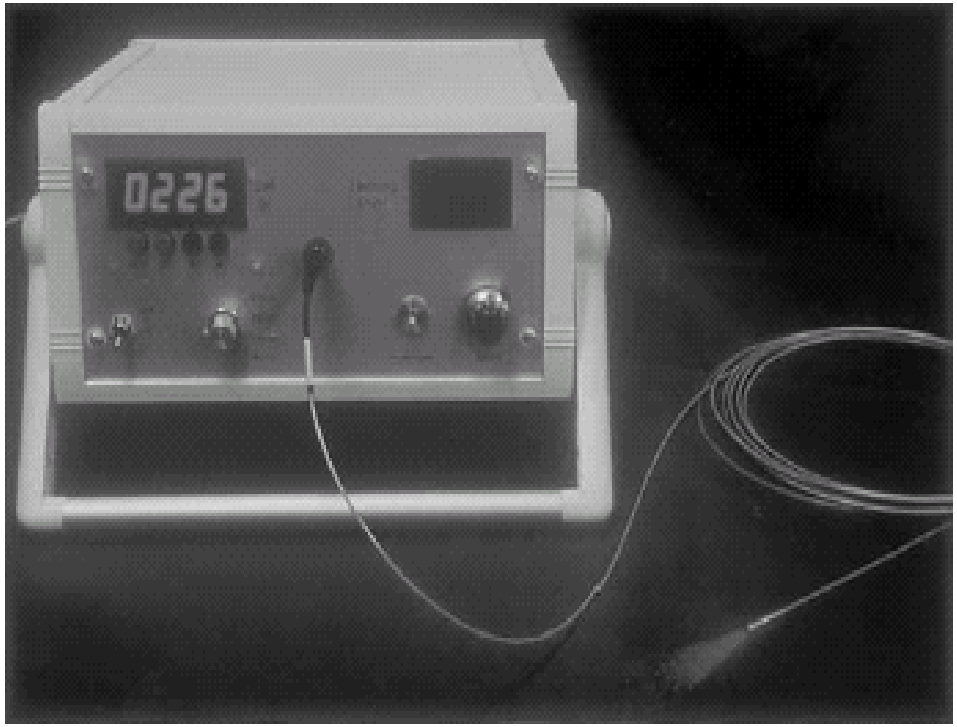


Fig. 1 The new-developed TCL-system with four different diode lasers ($\lambda = 635$ nm-830 nm) and integrated power meter. The laserlight is delivered in the centre of the laser unit through the attached microlens laser fibre. The irradiation is activated by a timer

Fig. 2 The new-developed head-set applicator for the TCL-system. A synthetic headband-construction is adjusted and fastened to the upper head of the patient. The microlens laser fibre is positioned within the external auditory meatus nearby the tympanic membrane (in defined position) and is immobilised by a micro-tripod with ear speculum at the lateral site

S. Tauber · W. Beyer · K. Schorn · R. Baumgartner

Transmeatal cochlear laser (TCL) treatment of cochlear dysfunction: A feasibility study for chronic tinnitus

Laser and Tinnitus Studies

- Nakashima et al (2002):No significant difference was observed between the active and placebo laser groups with regard to outcome of loudness, duration, quality, and annoyance of tinnitus. Transmeatal low-power laser irradiation with 60 mW is not effective for the treatment of tinnitus.
- Tauber et al. (2003) used transmeatal cochlear laser therapy. After a follow-up period of six months tinnitus loudness was attenuated in 13 of 35 irradiated patients, while two of 35 patients reported their tinnitus as totally absent (some success).

Tinnitus Summary

- No absolute cure yet
- A variety of etiologies
- Many underlying factors
- Many ways to treat eat
- Absolutely Manageable!

Thank You

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