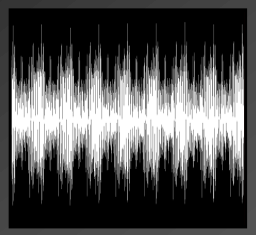
?

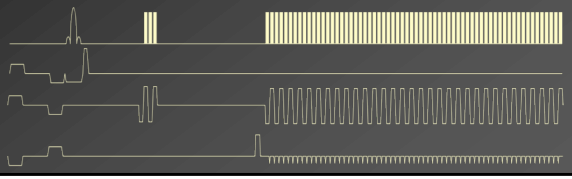
Vibrations in MRI:

The Bad & The Good

Magnetic Resonance rocks !



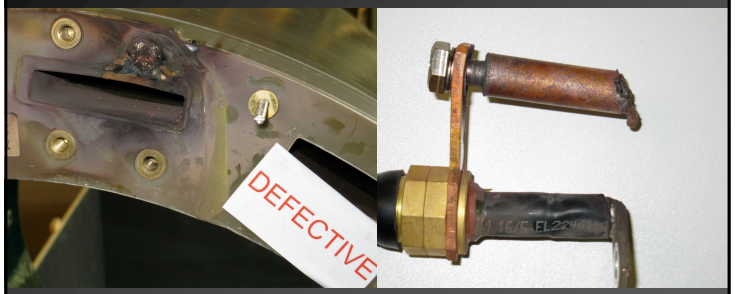




E(cho) P(lanar) I(maging)

... and can heat up!

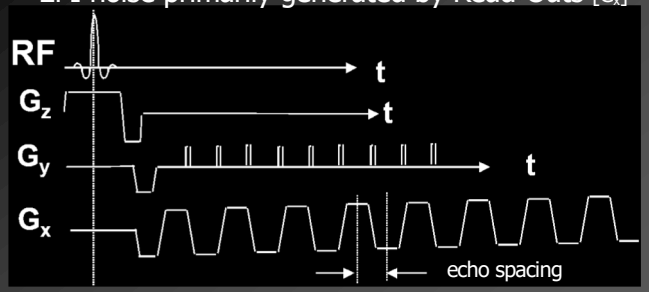
Read-Out of EPI: often in x-direction



"melt-down" from high currents on unstable contacts

Determinants of EPI Noise

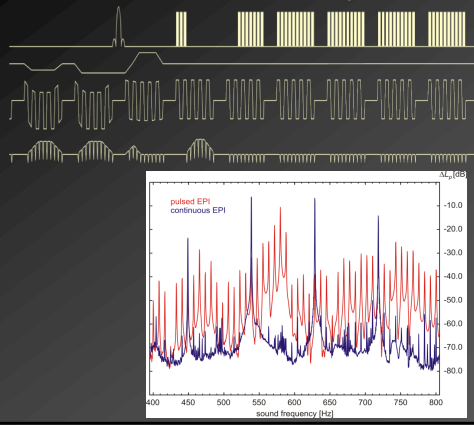
- EPI = loud(est) MR pulse sequence (up to 120 dB)
- EPI noise primarily generated by Read-Outs [G_x]



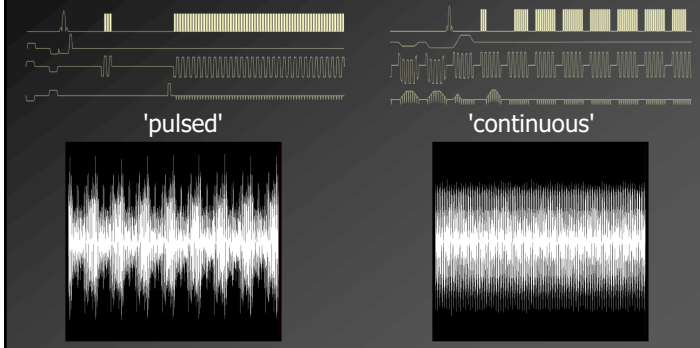
→ just to the disadvantage* for FMRI ?

*Haller et al., *Magma* 2005 / *Brain Res* 2009

$C_{ontinuous}$ EPI = $L_{ow}I_{mpact}N_{oise}A_{cquisitions}$

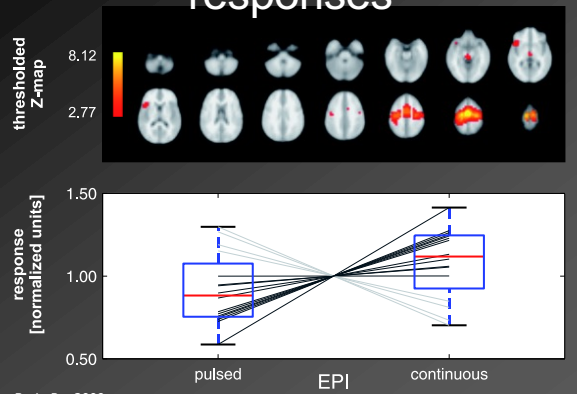


Lowering EPI Noise ...



Seifritz et al., *NeuroImage* 2006 (courtesy of K. Scheffler)

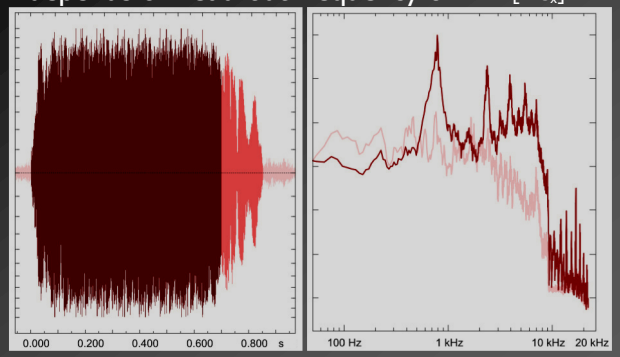
... can increase FMRI responses



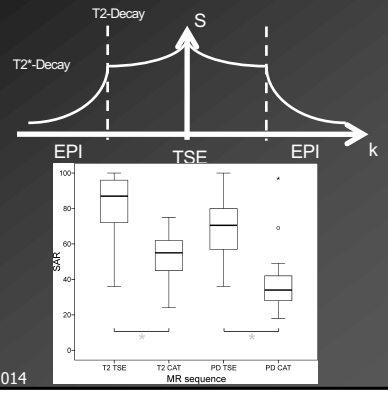
Haller et al., *Brain Res* 2009

Fundamental Frequency Peak of EPI

- depends on read-out frequency of EPI [$\pm G_x$]

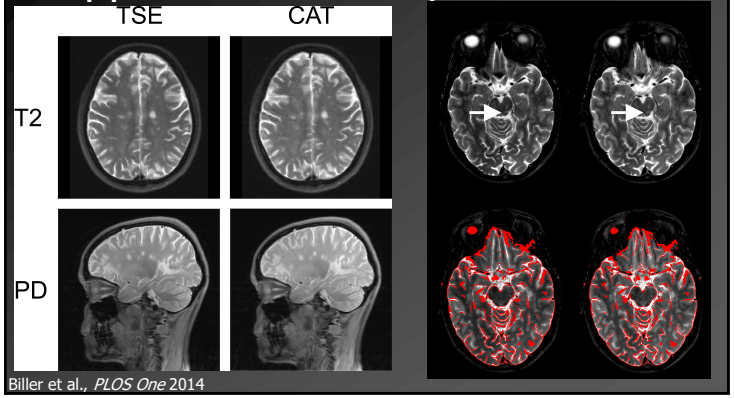


Interlude 1: Combined EPI / TSE Acquisitions to reduce SAR

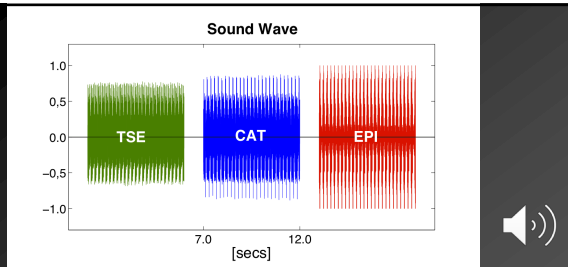


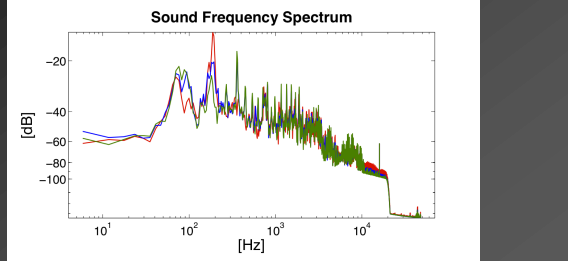
Biller et al., *PLOS One* 2014

Combined EPI / TSE Acquisitions: Application to Multiple Sclerosis

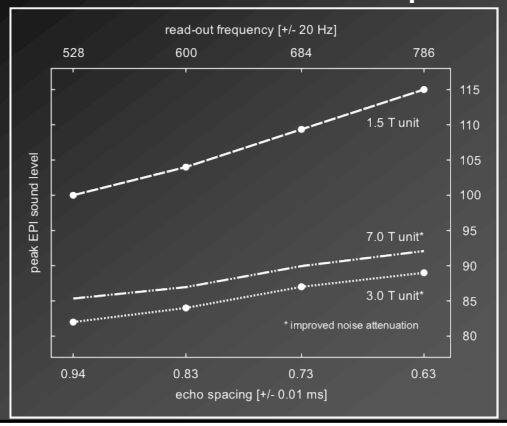


Biller et al., *PLOS One* 2014



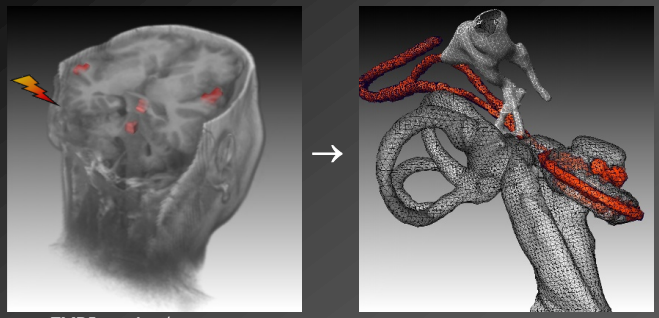


EPI Noise and Echo Spacing



FMRI-Audiometry – What for ?

Neurofibromatosis Typ II (NF II) cochlear implant (CI) *in situ*



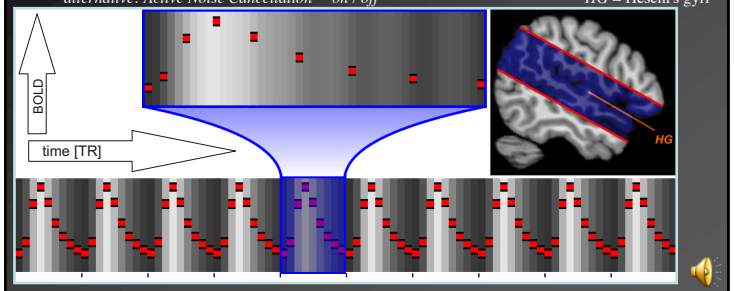
*FMRI-testing**

*Bartsch et al., *RoeFo* 2002

FMRI-Audiometry (I)

- EPI Read-Out [■] evokes auditory activations*
- omissions of [■] yield detectable BOLD-fluctuations#

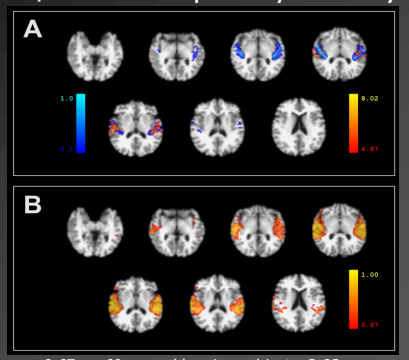
alternative: Active Noise Cancellation ° on / off *HG* = Heschl's gyri



Bartsch et al.,* *Riv Neuroradiol* 2003/# *NeuroImage* 2007; ° Chen et al., *IEEE Trans Biomed Eng*

FMRI-Audiometry (II)

- Validation / relation to primary auditory cortex (PAC)



(A) $p_{(FP)} \leq 0.05$ vs. (B) $p_{(TP)} \geq 0.67$, n=60 normal hearing subjects, 3-83 yrs

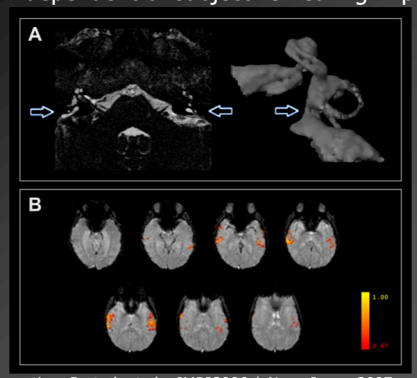
FMRI-Audiometry (III)

subjects	no complete deafness	FMRI-sensitivity	complete deafness	FMRI-specificity
normal hearing / awake (n = 60)	n = 60	97 %	none	-
SNHL / awake (n = 36)	n = 33 (at least unilateral residual hearing)	94 %	n = 2	100 %
SNHL/ sedated (n = 12, propofol)	n = 9 (at least unilateral residual hearing)	≥ 78 %	none	-

Bartsch et al., *DGNR* 2007 (Kurt-Decker-Price)

FMRI-Audiometry prior to Cochlear Implantation

= fast & independent of subjective hearing impression !

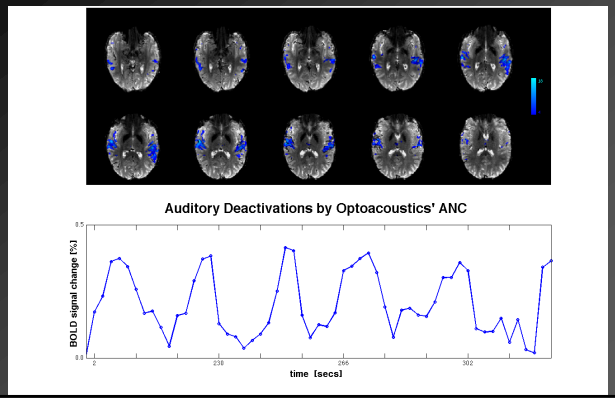


*LVAS+Mondini malformation; Bartsch et al., *JMRI* 2006 / *NeuroImage* 2007

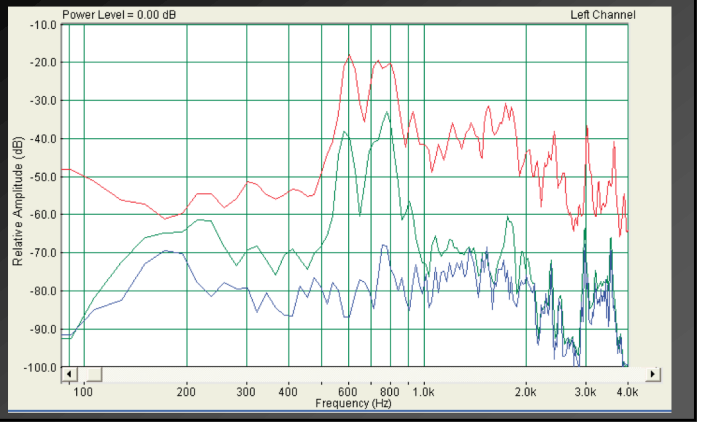
Disadvantages of Read-Outs and their Omission

- Auditory Discomfort *(related to Read-Outs)*
- Startle Movements *(related Read-Outs)*
- Sparse Sampling *(related to Read-Out Omissions)*
- Ear-unselective *(both)*

Alternative to Read-Out Omissions: FMRI-Audiometry by Active Noise Cancellation



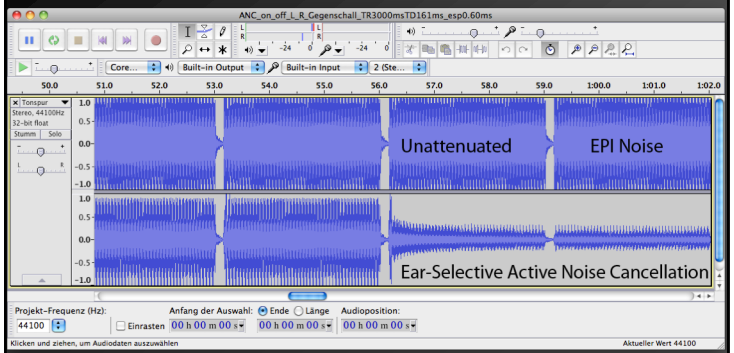
EPI, Passive & Passive + Active NC



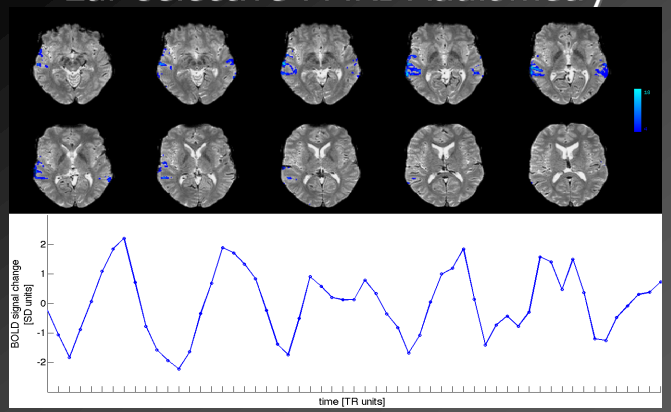
Advantages of ANC

- Patient / subject comfort
- Minimizes startle movements
- Facilitates transmission of auditory stimuli
- Continuous recording, no sparse sampling
- Ear-selective application possible

Ear-selective ANC

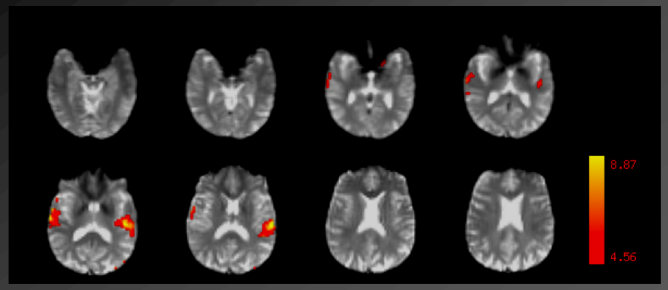


Ear-selective FMRI-Audiometry



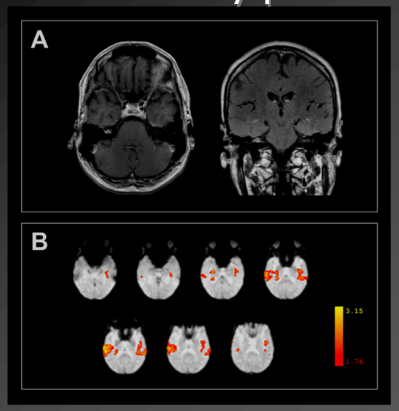
Curiosities: "Factitious" Disorders

FMRI-Audiometry: Münchhausen syndrome + Münchhausen-by-proxy



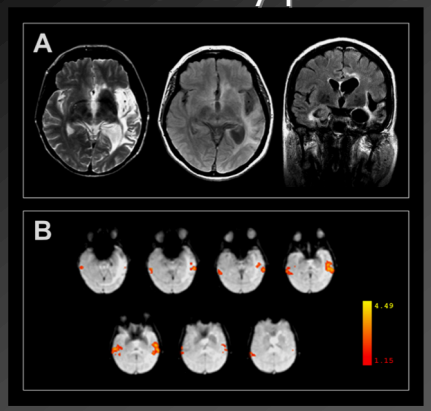
GLM-voxel corrected $p_{(FP)} \leq 0.05$; convern is FPs !

FMRI-Audiometry prior to CI



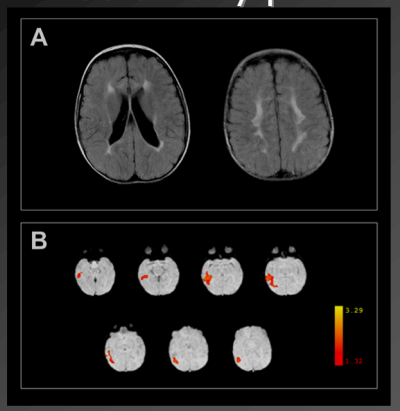
benign Feiling-Gardner NF II *(as opposed to Wishart phenotype: <20a with rapid progression)*

FMRI-Audiometry prior to CI



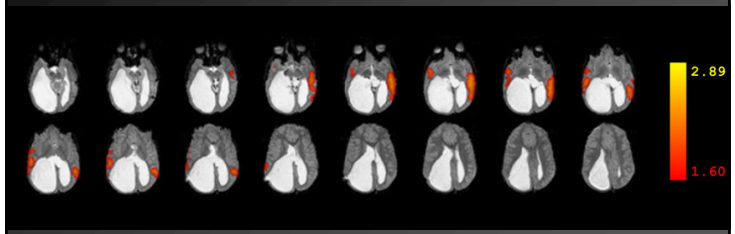
h/o herpes-simplex-encephalitis

FMRI-Audiometry prior to CI



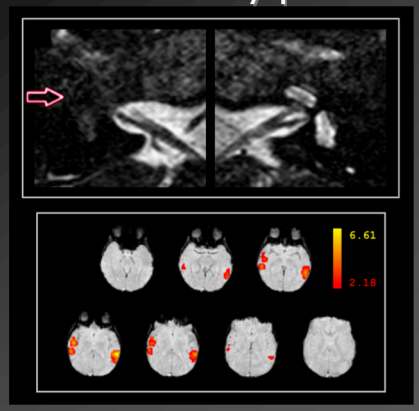
periventricular leukomalacia (PVL) under propofol sedation

FMRI-Audiometry prior to CI



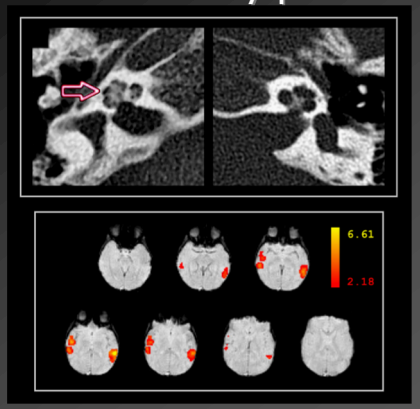
cerebral malformation (with glioependymal cysts) under propofol sedation

FMRI-Audiometry prior to CI



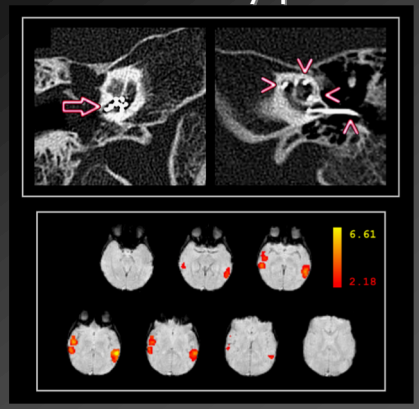
h/o bacterial meningitis under propofol sedation

FMRI-Audiometry prior to CI



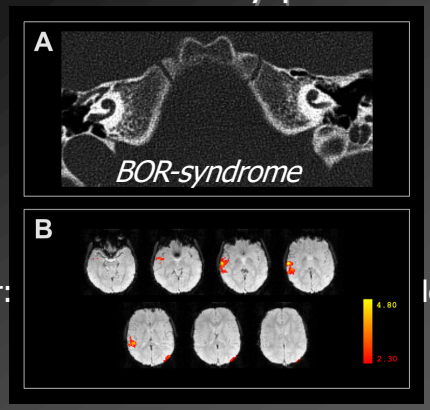
h/o bacterial meningitis under propofol sedation

FMRI-Audiometry prior to CI



h/o bacterial meningitis under propofol sedation

FMRI-Audiometry prior to CI

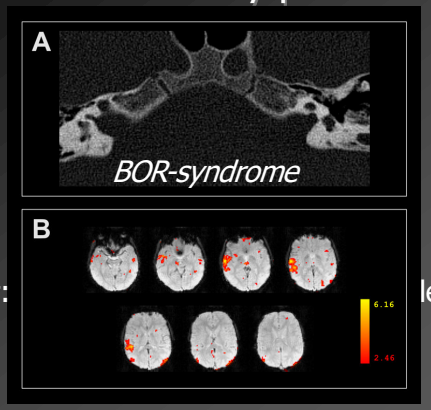


right ear: deaf

left ear: ?

GLM cluster FWER-corrected $p_{(FP)} \leq 0.05$; BOR = branchio-oto-renal malformations

FMRI-Audiometry prior to CI

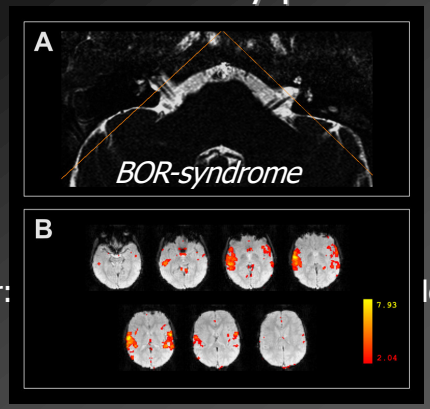


right ear: deaf

left ear: ?

GLM-MM $p_{(TP)} \geq 0.67$; BOR = branchio-oto-renal malformations

FMRI-Audiometry prior to CI



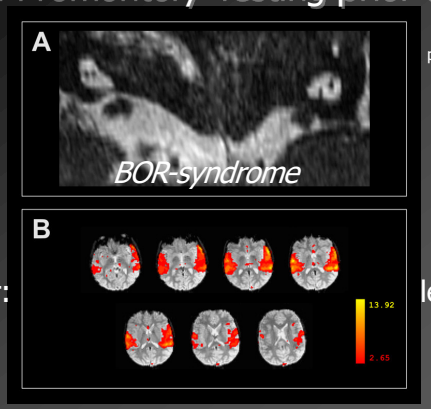
right ear: deaf

left ear: ?

PICA-MM $p_{(TP)} \geq 0.67$; BOR = branchio-oto-renal malformations

Interlude 2: FMRI-Promontory Testing prior to CI

cochlear nerve present at all?



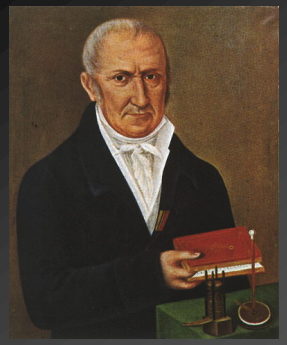
right ear: deaf !

left ear: not !

PICA-MM $p_{(TP)} \geq 0.67$, *right* extratympanic stimulation; BOR = branchio-oto-renal malformations

History of Promontory Testing (PT)

Alessandro Volta

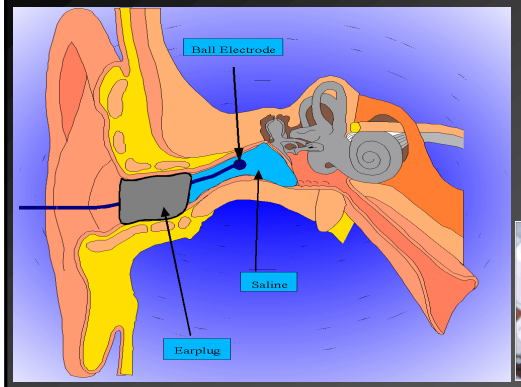


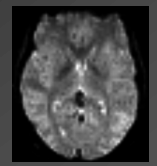
self-test ~ 1800



*1745, suffering from presbyacusis ?

Extra- vs. Transtympanic PT

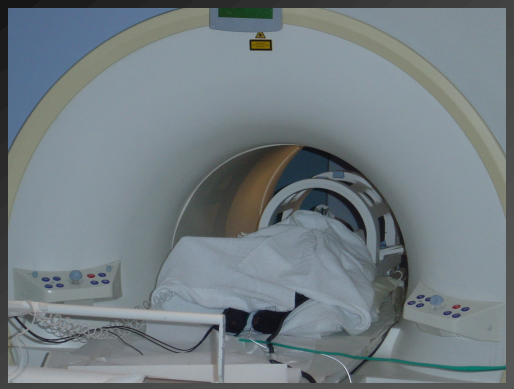






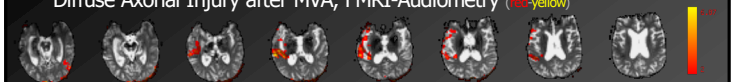
Hofmann et al., *AJNR* 1999; Obler et al., *MRM* 1999

Extratympanic PT prior to CI

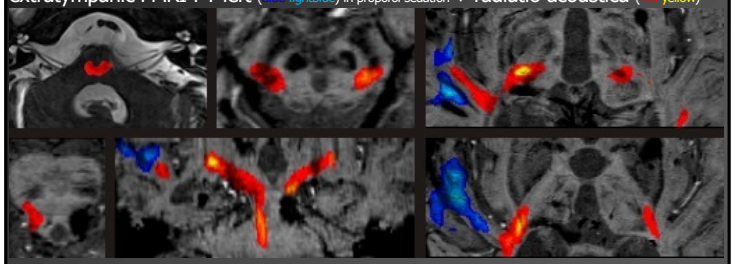


Combining Functional & Diffusion-weighted EPI

Diffuse Axonal Injury after MVA, FMRI-Audiometry (red-yellow)

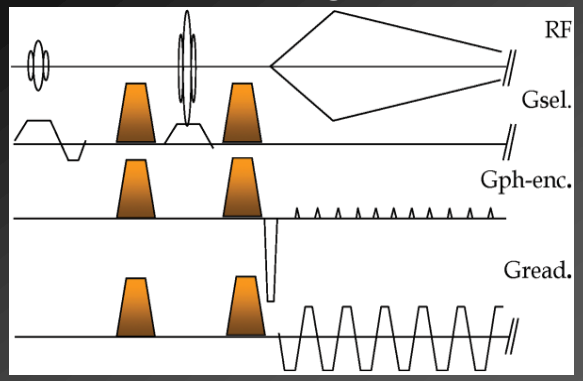


extratympanic FMRI-PT left (blue-lightblue) in propofol sedation + radiatio acoustica (red-yellow)



Bartsch et al., 2009 (in Johansen-Berg / Behrens: Diffusion MRI, *Elsevier*)

Diffusion-weighted EPI



Le Bihan et al., JMRI 2006

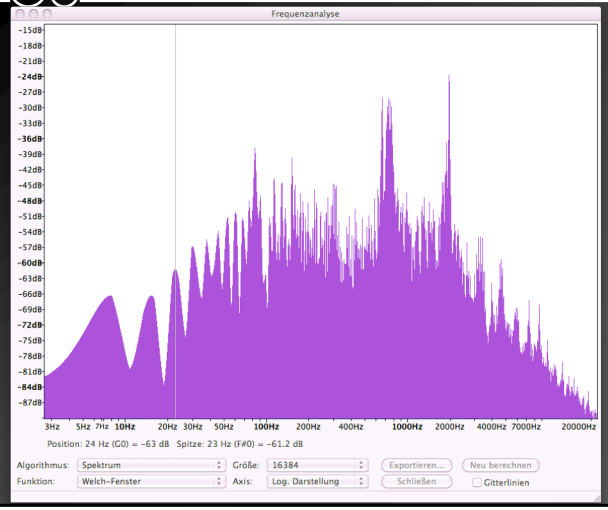
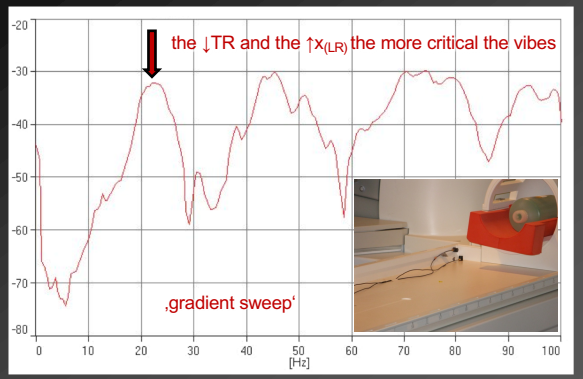
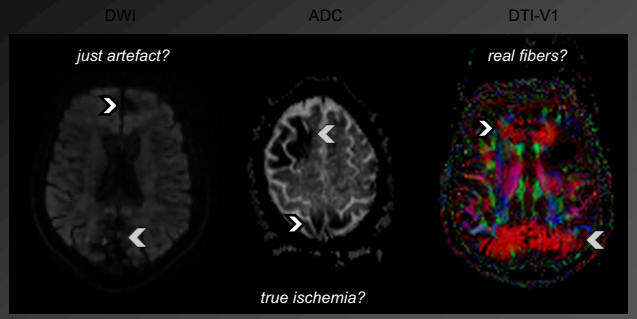


Table Vibrations *by diffusion gradients*



Hiltunen et al., NeuroImage 2006

„Bad-Vibes" in Diffusion-EPI:

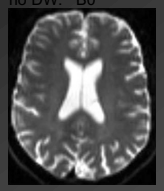


Gallichan et al., Hum Brain Mapp 2009

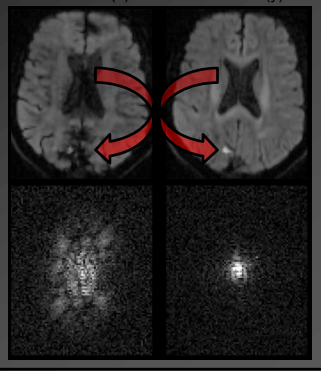
„Bad-Vibes“: False-negative Diffusion-EPIs

3 Tesla, b = 1000s/mm²
acute embolic stroke
clinically silent

no DW: B0



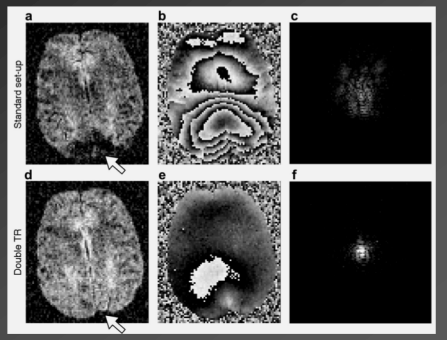
DW: L>>R (x) A>>P (y)



Gallichan et al., ISMRM & Hum Brain Mapp 2009

„Bad-Vibes”: Avoiding the Artefact

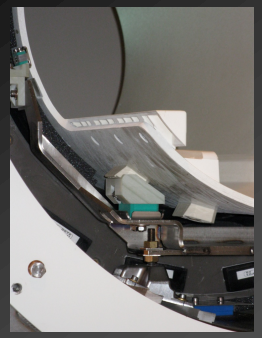
- Data Acquisition:
  - increase TR
  - scan full k-space
    (no partial Fourier, TE↓ by PPI)
  - NE1+2 ?

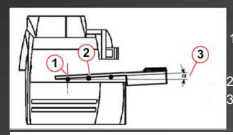


Gallichan et al., ISMRM & Hum Brain Mapp 2009

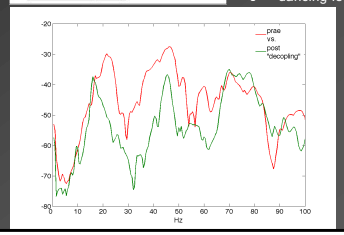
„Bad-Vibes”: Avoiding the Artefact

- Scanner / Table Upgrades





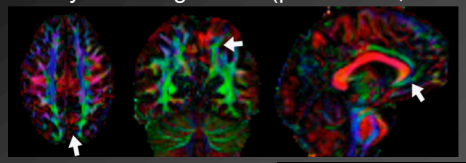
1: anterior rolls on the body-coil (isocenter)
2: middle rolls
3: elevation angle *
➔ ‘dancing feet’



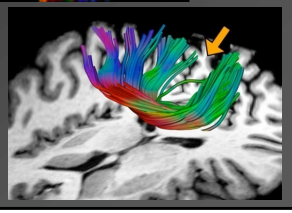
* by courtesy of Siemens Medical Solutions

„Bad-Vibes“: Eliminating the Artefact

- mathematically: --cni flag in dtifit (part of FSL; www.fmrib.ox.ac.uk/fsl/)

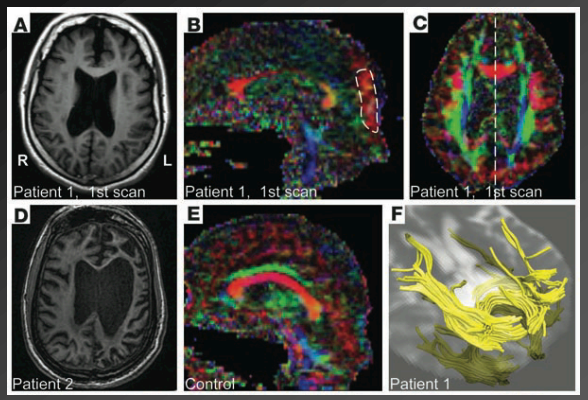


$$\begin{pmatrix} \ln(S_1) \\ \ln(S_N) \end{pmatrix} = \begin{pmatrix} -b_{xx,1} & -b_{yy,1} & -b_{zz,1} & -2b_{xy,1} & -2b_{xz,1} & -2b_{yz,1} & 1 & \ln(A(r_{x,1})) \\ -b_{xx,N} & -b_{yy,N} & -b_{zz,N} & -2b_{xy,N} & -2b_{xz,N} & -2b_{yz,N} & 1 & \ln(A(r_{x,N})) \end{pmatrix} \begin{pmatrix} D_{xx} \\ D_{yy} \\ D_{zz} \\ D_{xy} \\ D_{xz} \\ D_{yz} \\ \ln(S_0) \\ k \end{pmatrix}$$



Gallichan et al., ISMRM & Hum Brain Mapp 2009

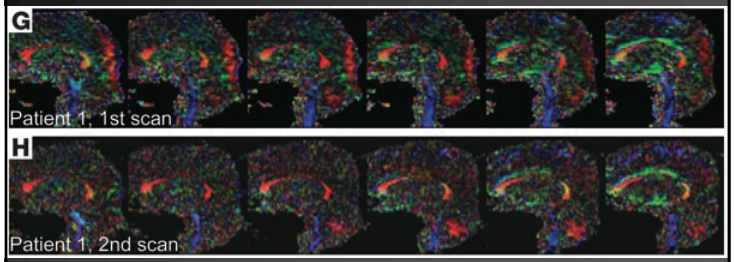
„Bad-Vibes“: Misinterpretation of the Artefact



Voss et al., JCI 2006 *(impact factor 14 !)*

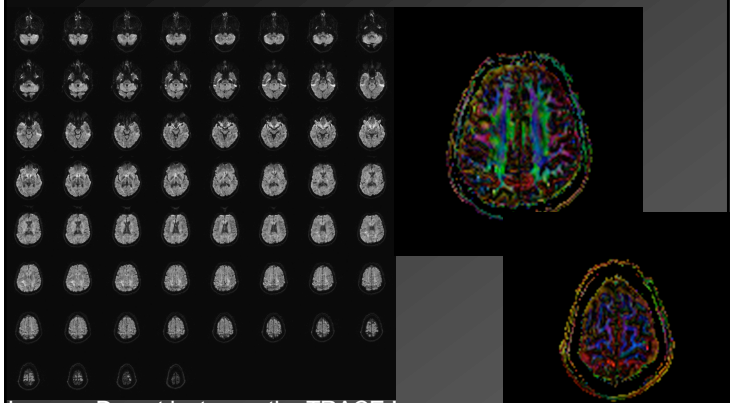
„Bad-Vibes“: Misinterpretation of the Artefact

transitional stage of axonal regrowth –
the fall of a medical dogma ?



Voss et al., JCI 2006 *(impact factor 14 !)*

Is Our Scanner Affected ??



Lesson: Do not just save the TRACE !

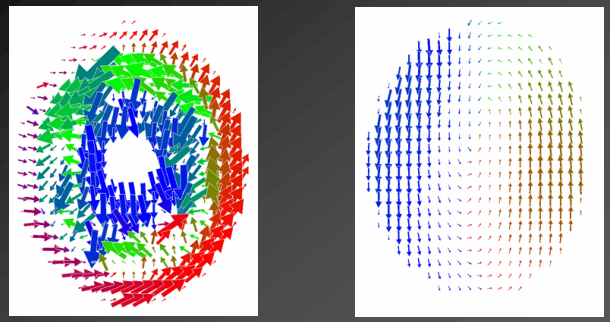
„Bad-Vibes“ in Diffusion-EPI can:

- ***mask*** *diffusion abnormalities / ischemic strokes*
- ***mimic*** *diffusion abnormalities / ischemic strokes*
- *cause* ***false-positive*** *DTI results / fibre trackings*

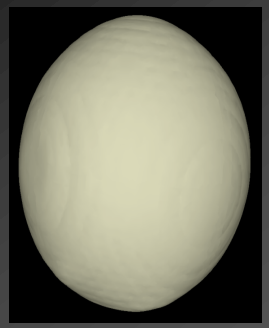
but can such vibes be used ?

T$_{able-}$R$_{esonance-}$E$_{lastography\ with}$ MR =
„Turning the Bad into Good Vibes“

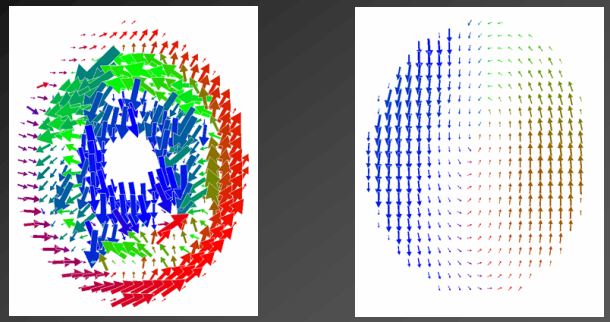
How stiff is our Brain ?



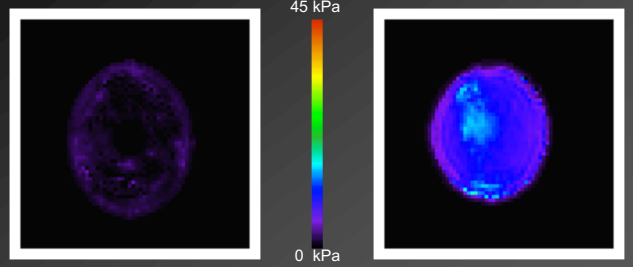
How do *you* like your egg ?



Soft- *or* **Hard**-*Boiled* ?



A Case for MR-Elastography …



… or brute force !



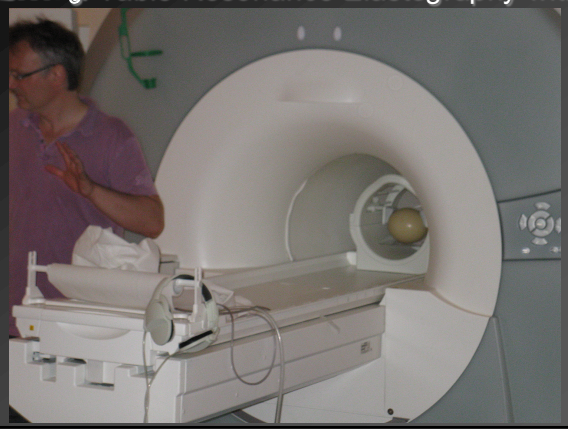


MR-Elastography

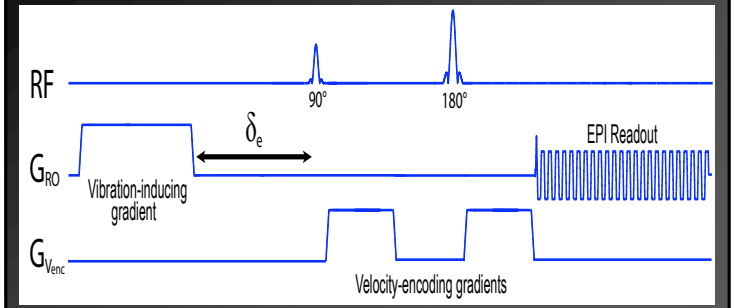


www.elastography.de; Uffmann et al., ISMRM 2004

TREMR: Table Resonance Elastography with MR

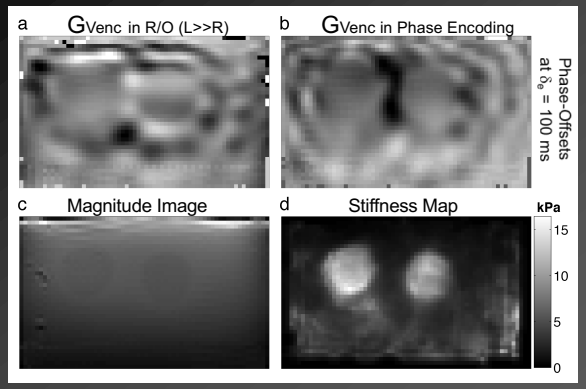


TREMR: The Pulse Sequence



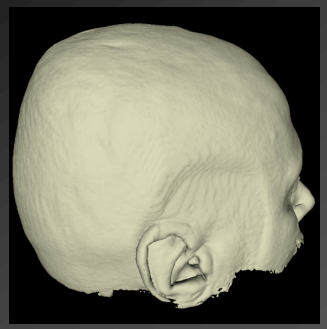
Gallichan et al., Magn Reson Med 2009

TREMR: Gelatin Phantom



Gallichan et al., Magn Reson Med 2009

TREMRing the Brain ?



How stiff is our Brain ?

DON'T PANIC !



The Ultimate Answer: "That's it. That's all there is."

"I always thought something was fundamentally wrong with the…"

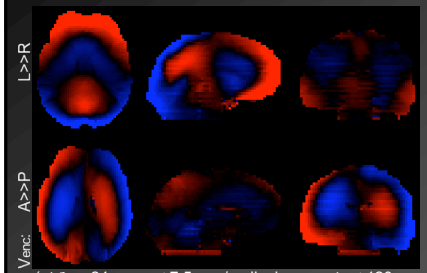
brain ?

Adams, 1980 & 1993

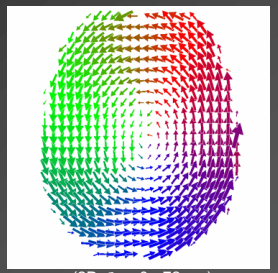
TREMR: Normal Brain

Unwrapped Median Phase

Velocity Vectors



(at δ_e = 24 ms; v ≤ 7.5 mm/s, displacements ≤ 120µm
a ≤ 1.2 m/s² < *g*/8; bungee: ~2*g*, formula I: ~5*g* !)

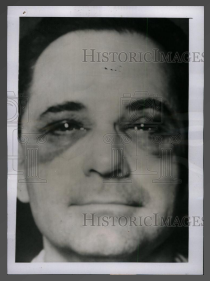


(2D, δ_e = 0 - 72 ms)

Gallichan et al., Magn Reson Med 2009

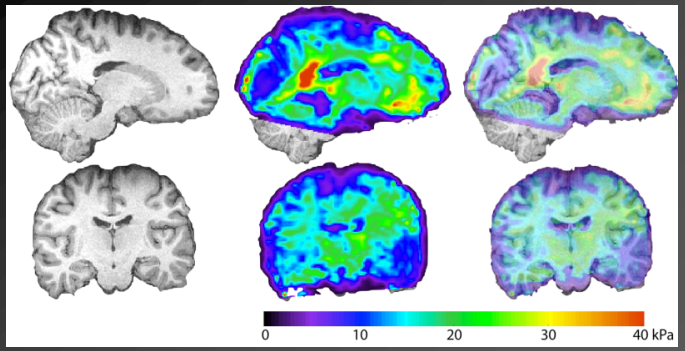
TREMR: No Need to be Afraid!





(at δ_e = 24 ms; v ≤ 7.5 mm/s, displacements ≤ 120µm
a ≤ 1.2 m/s² < *g*/8; bungee: ~2*g*, formula I: ~5*g* !)

TREMR: Normal Brain



Gallichan et al., Magn Reson Med 2009

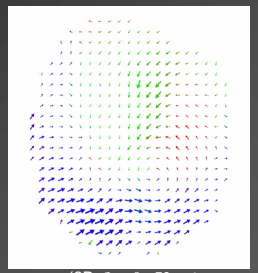
TREMR: Pathology?

Phase Images



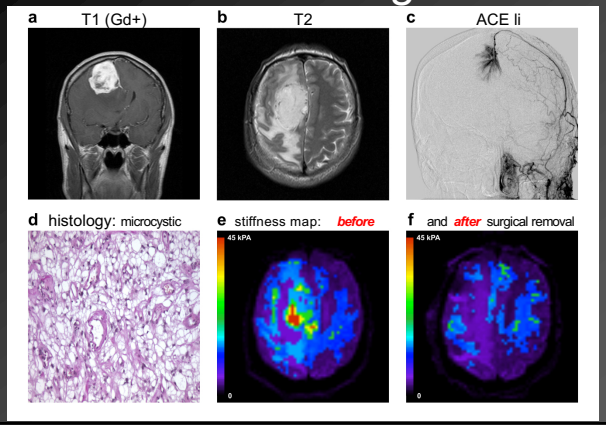
(L>>R)

Velocity Vectors

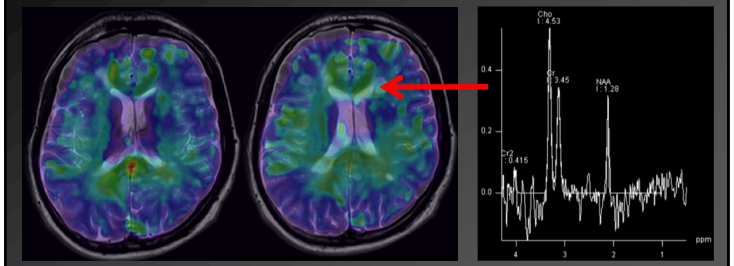


(2D, δ_e = 0 - 72 ms)

TREMR: Meningeoma

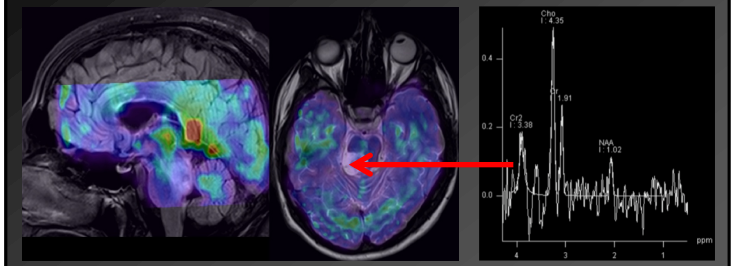


TREMR: MS-Plaques



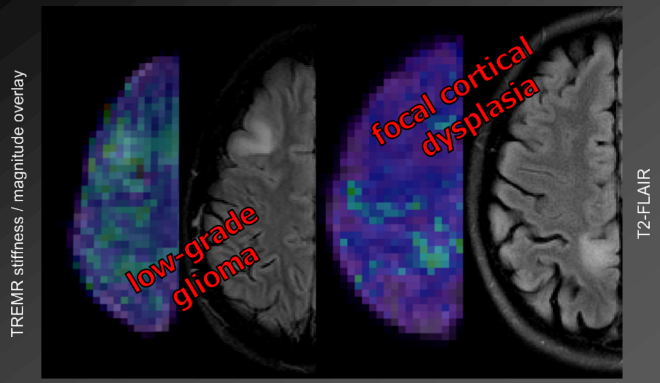
TREMR stiffness map on T2-TSE (overlay)

TREMR: Tectal Glioma

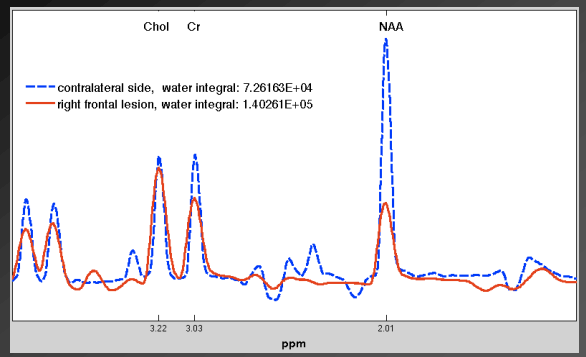


TREMR stiffness map on FLAIR / T2-TSE (overlay)

Which one is the Tumor ?



Doesn't MR-Spectroscopy solve this ?

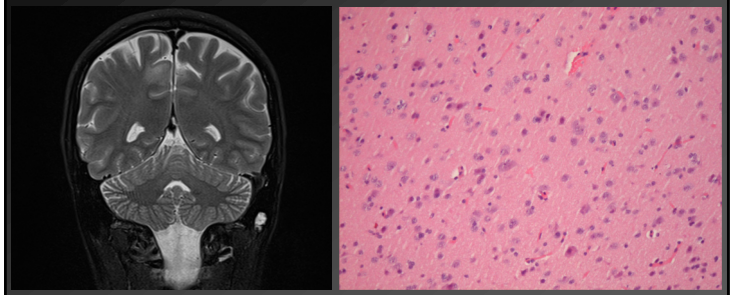


early NAA-reductions in low-grade gliomas

Histology of FCDs ?

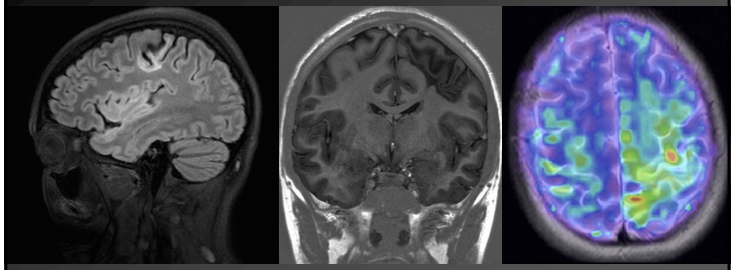
FCD

Hematoxylin-Eosin Stain



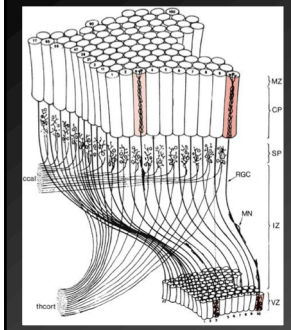
… is largely reminiscent of cortical tubers in tuberous sclerosis !

Tumor ? Or Infarction ??

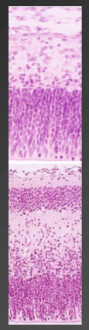


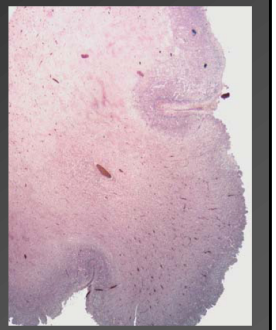
Another stiff FCD !

Why are FCDs stiff ?



protocortex*

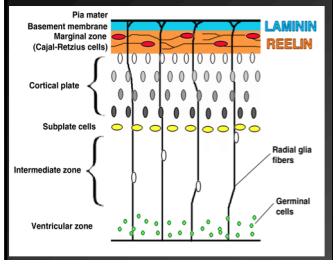


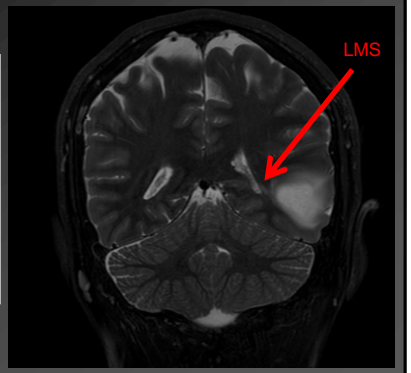


TSC

*Rakic, Science 1988; Taylor et al., JNNP 1971; Yasin et al., Acta Neuropathol 2010

And what about DNETs ?





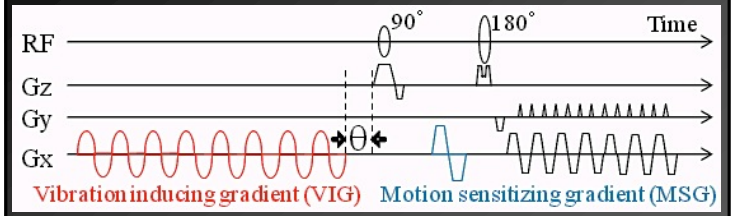
… we don't know yet.

TREMR: Limitations

- by-product of vibrations from MR gradient switching
- glitches in unwarpped phase data
- stiffness maps: semiquantitative, limited resolution, “smooth”
- table vibrations limited to 15-30 Hz resonance, yet these seem be sufficient even after “decoupling”

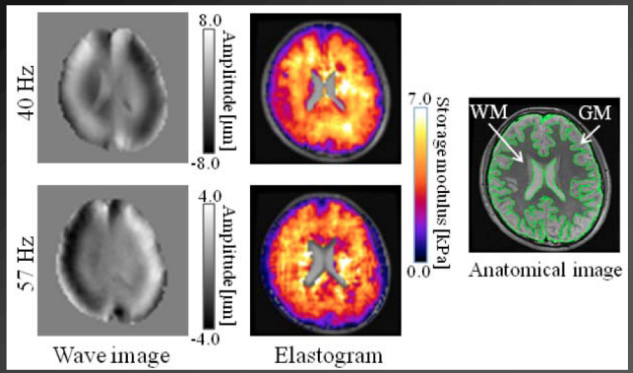


TREMR: The New Pulse Sequence



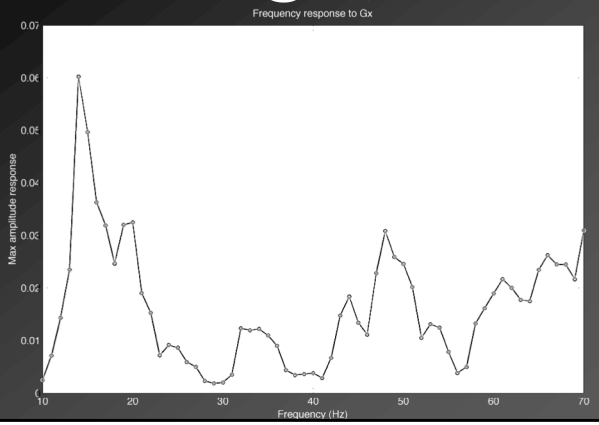
Suga et al., ISMRM 2012

TREMR: The New Pulse Sequence

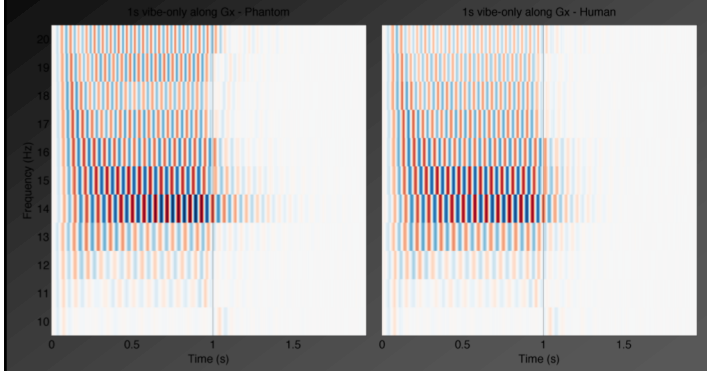


Suga et al., ISMRM 2012

Vibe-Peaks @ 14, 48 & 70 Hz

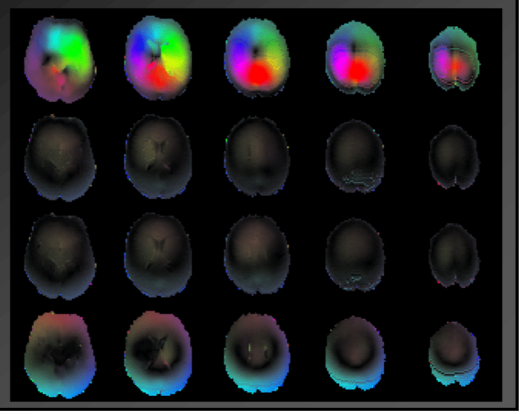


Vibes @ 14 Hz: Phantom vs. Head

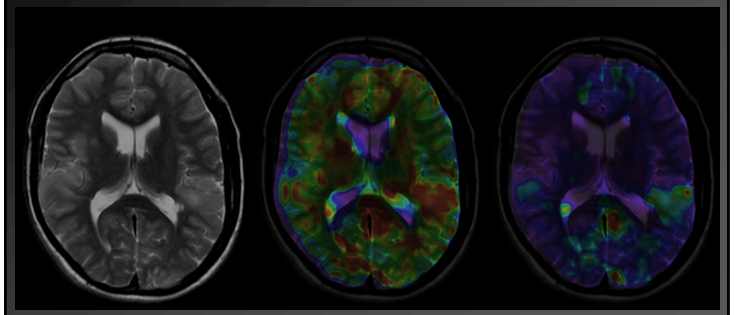


TREMR: New vs. Old

- *14 Hz*
- *48 Hz*
- *70 Hz*
- *Trapez. 20 Hz*

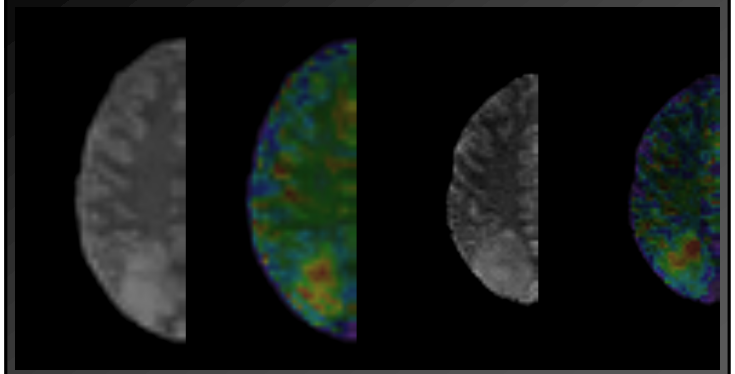


TREMR in Tuberous Sclerosis



T2-w TSE trap. TREMR 14 Hz TREMR

Are Gliomas Always Soft ?



Astrozytom WHO Grad III *(3.0 x 3.0 x 6.0 mm vs. 2.4 x 2.4 x 2.4 mm)*

"Take-Home" Messages: Mechanical Vibes

Table Vibrations for TREMR

Mono-/multifrequent Exc., reproducible

1 **2**

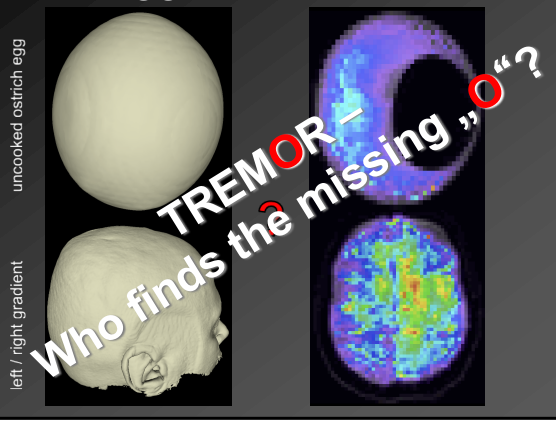
3 **+**

No „differentia specifica" between FCDs and glioma! Are there „soft" FCDs?

Relevance:

surgical strategy – „supporting suture" vs. sonographic aspiration?

The Egg of the Columbus



Finally…

