



Neuroradiologische Einsichten

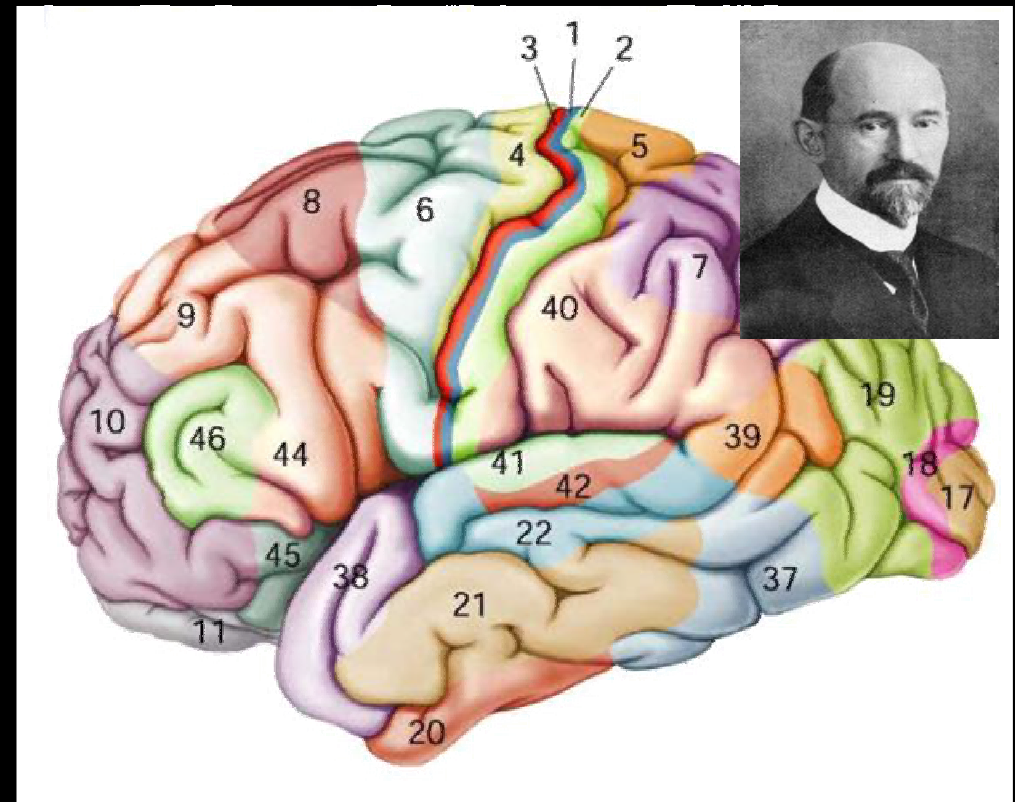
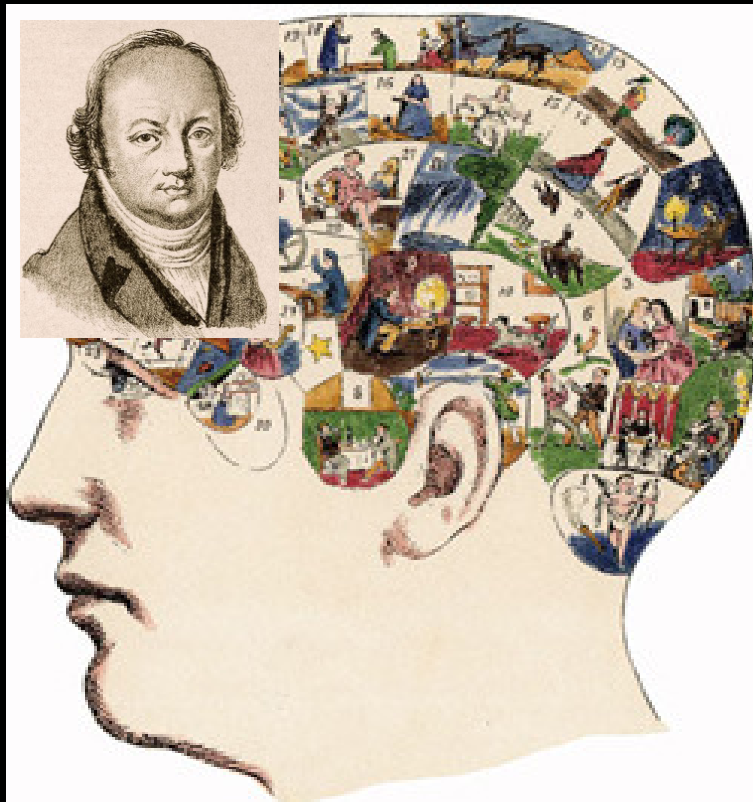
Motorisches Lernen

Christoph Stippich

Abteilung Diagnostische & Interventionelle Neuroradiologie

Das menschliche Gehirn

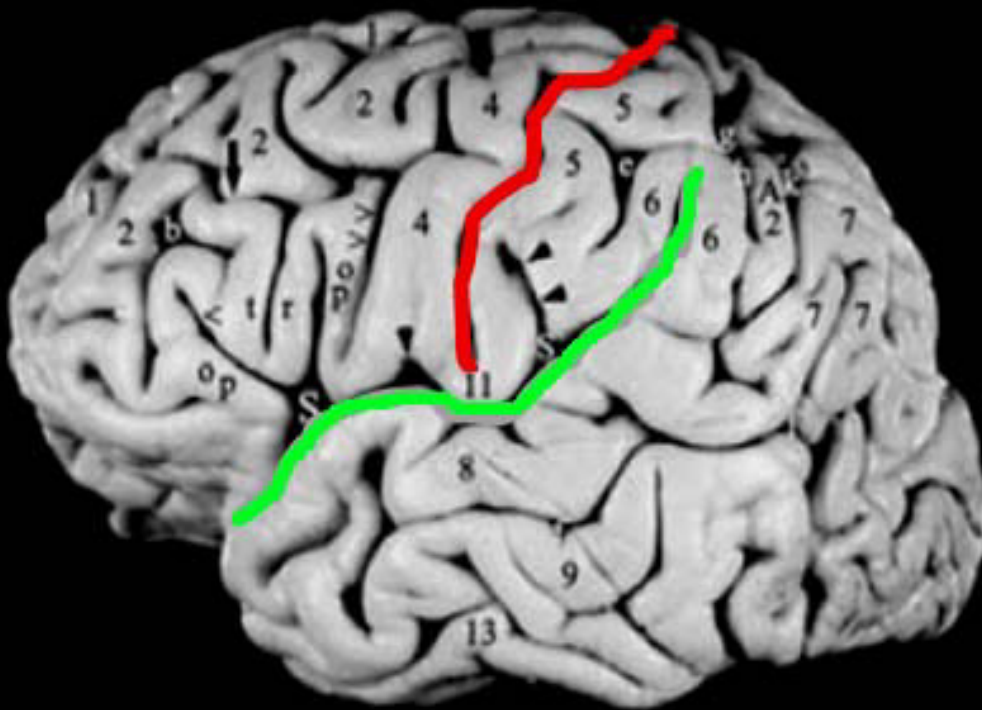
Funktion, mikro- & makroskopischer Aufbau



Franz-Josef Gall (1758-1828) „Das Gehirn ist Sitz aller mentaler Funktionen“ (Phrenologie)
Korbinian Brodmann (1868-1918) zytoarchitektonische Kartierungen - Brodmann Areale

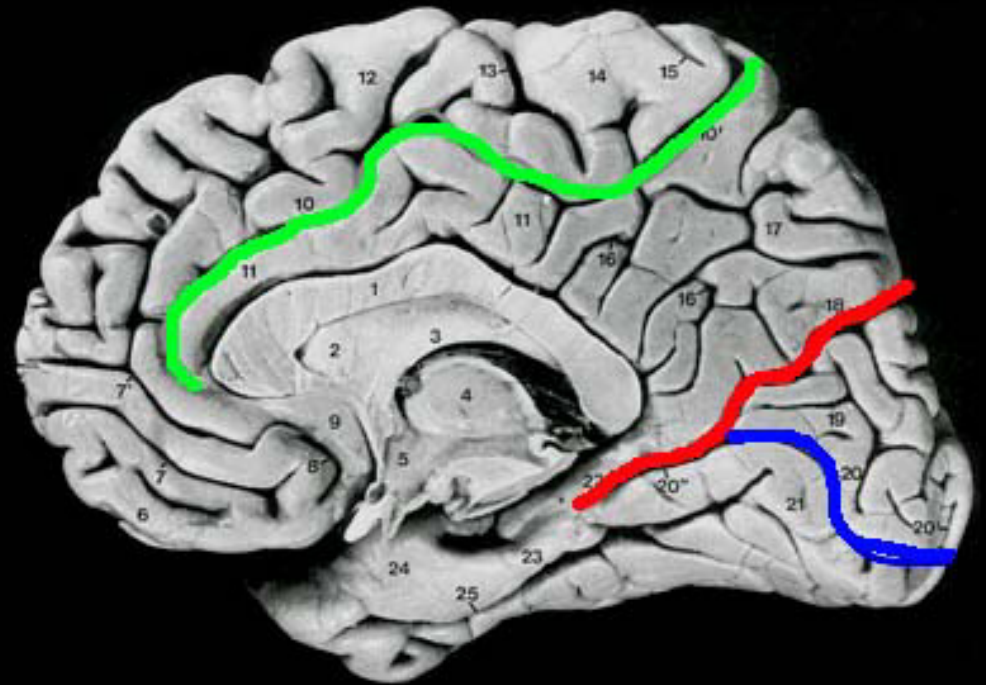
Hirnoberfläche

Wichtige Sulci



Seitansicht

S. centralis, S. lateralis (Sylvi)

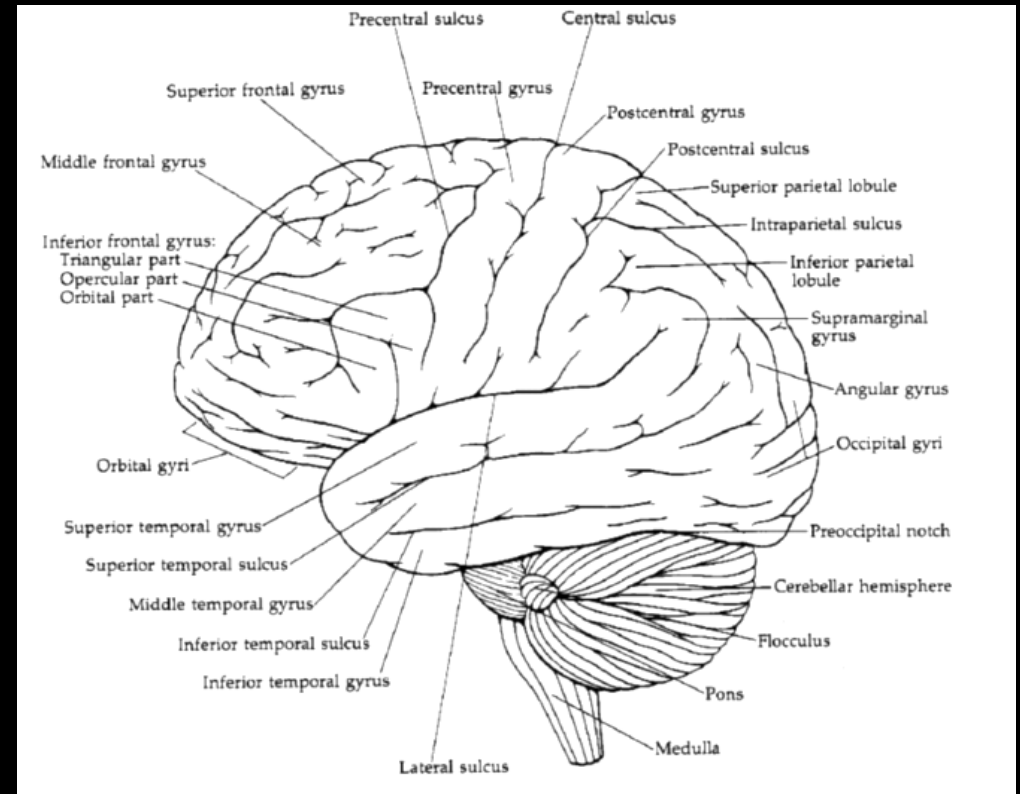


Medialansicht

S. cinguli, S. parietooccipitalis, S. calcarinus

Hirnoberfläche

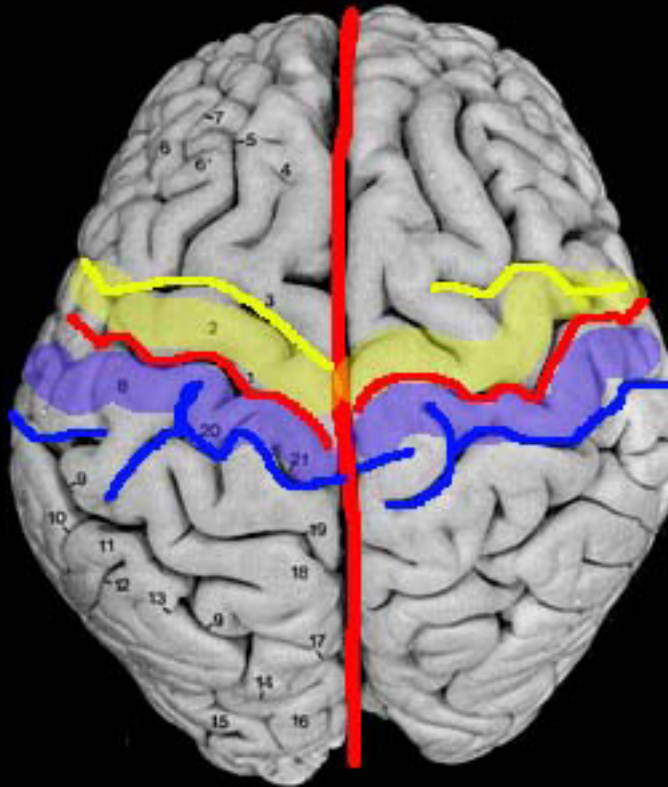
Lappen, Windungen & Sulci



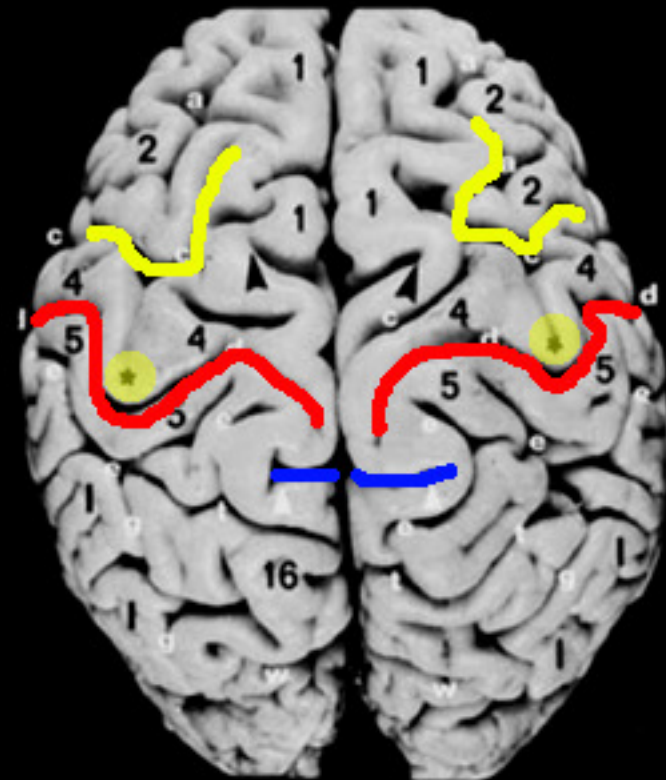
Landmarken, Lateralansicht

Hirnoberfläche

Zentralregion



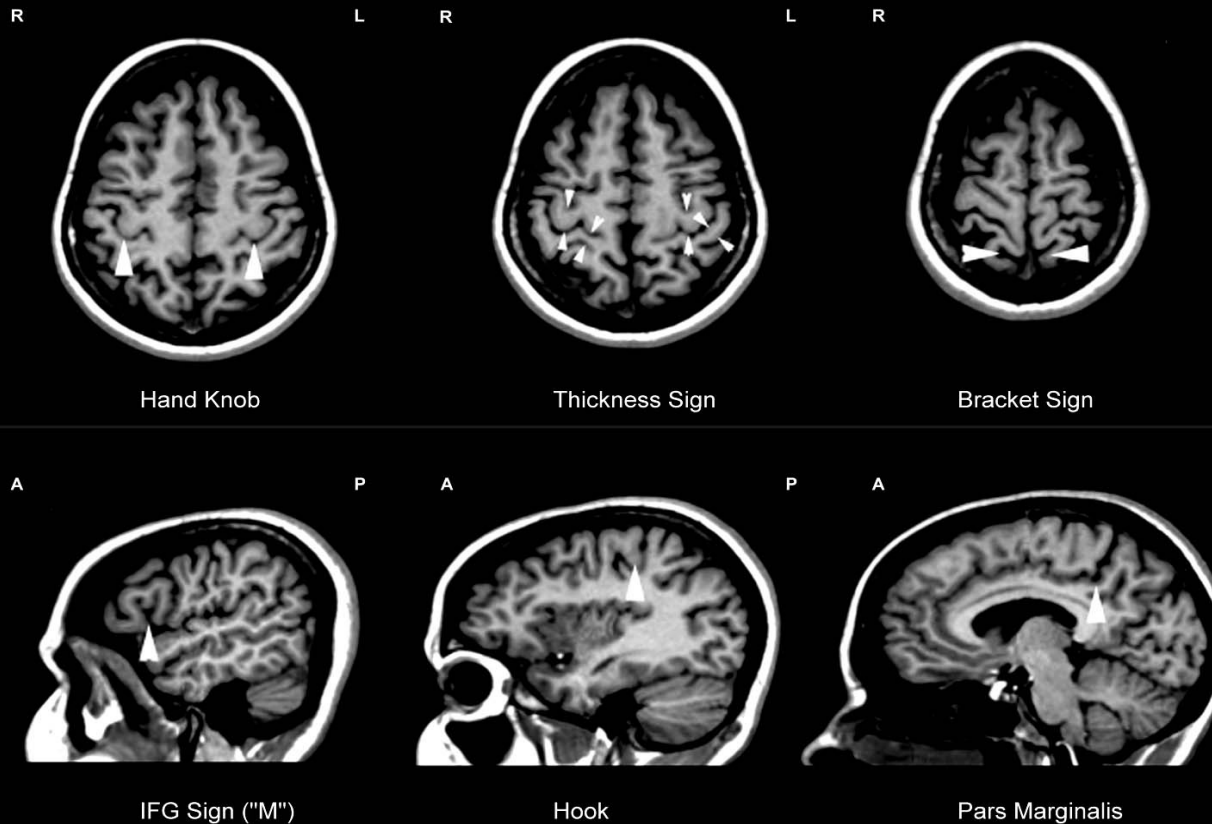
Fissura longitudinalis
G. precentralis, G. postcentralis



Sulcus centralis
S. frontalis sup. / S. precentralis, S. cinguli

Schnittbildanatomie

Morphologische Landmarken

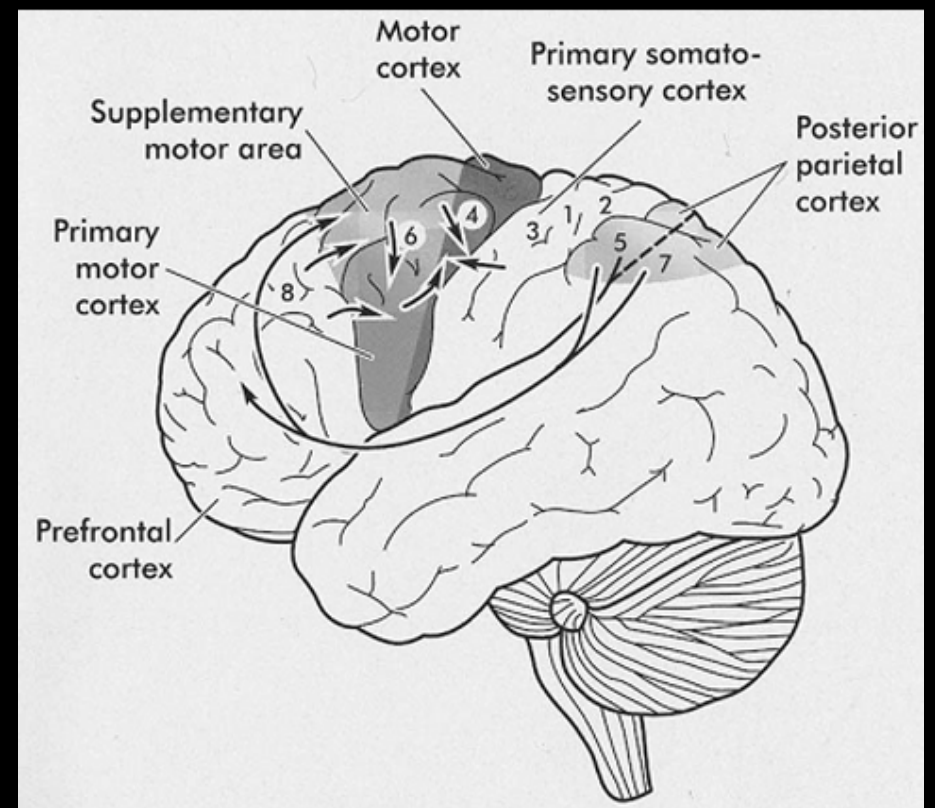
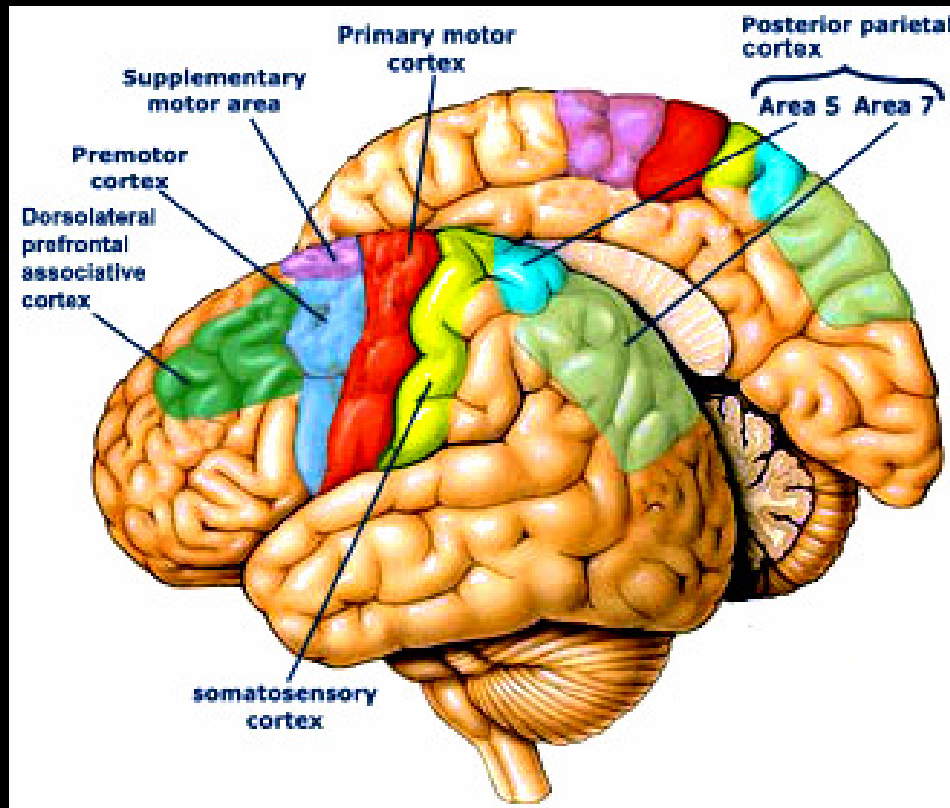


Landmarken der Zentralregion

Stippich C. (Ed.), *Clinical functional MRI*, Springer Verlag 2007

Motorisches System

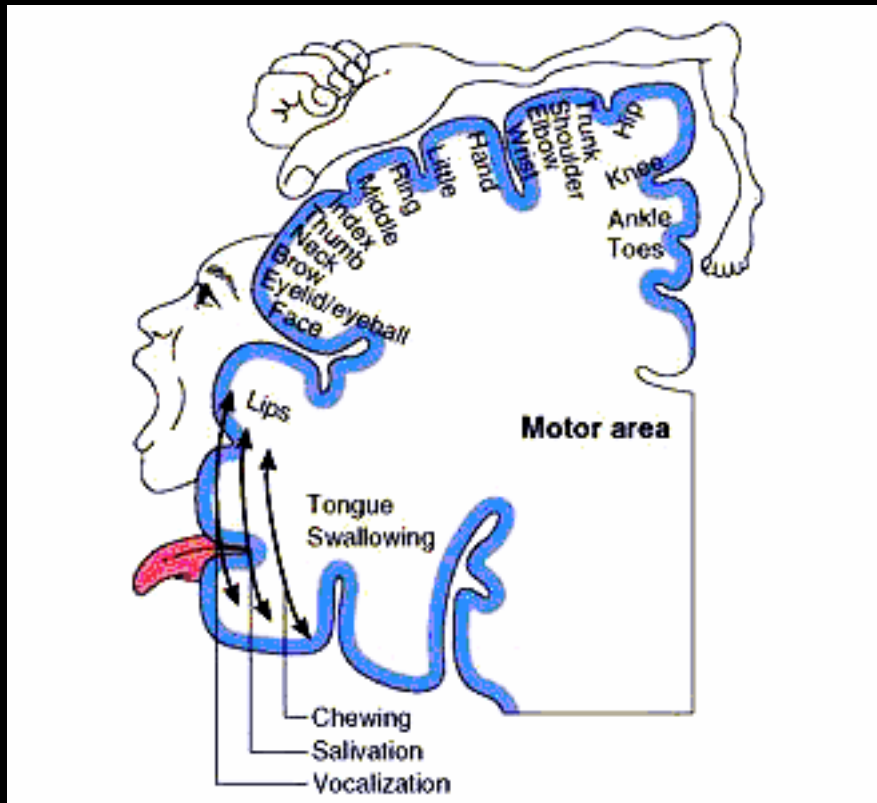
Kortikales motorisches Netzwerk



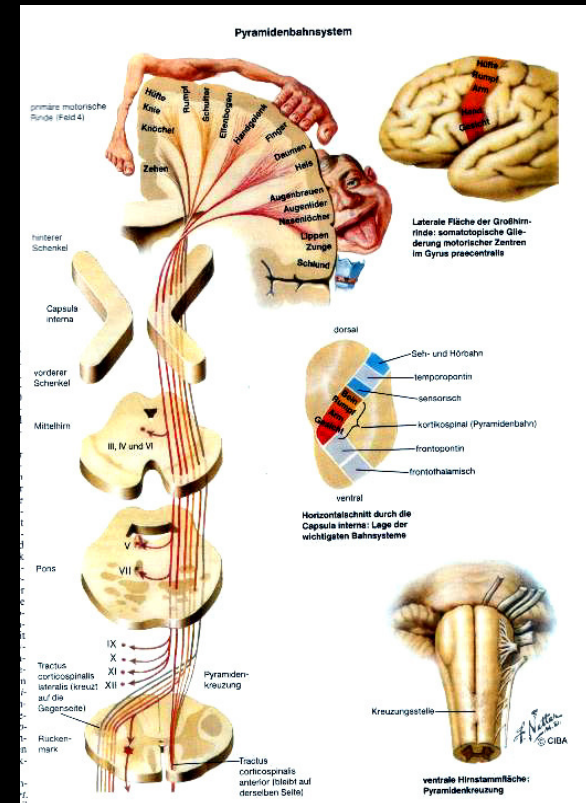
M1 – BA 4 (rot), PMA – BA 6 (blau), SMA – BA 6 (pink), S1- BA 1,2,3 (gelb); from: <http://thebrain.mcgill.ca>

Motorisches System

M1 Somatotopie & Efferenzen



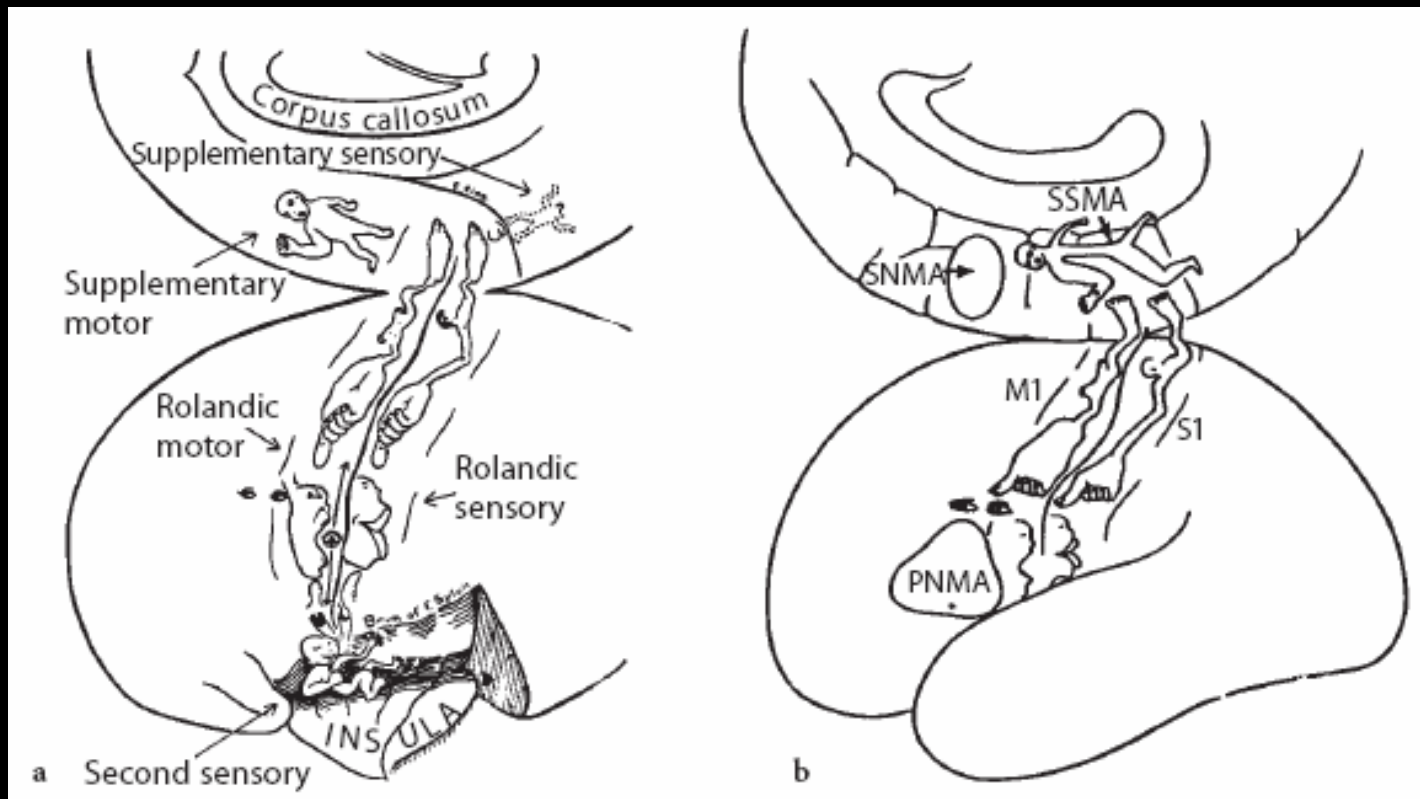
Motor Homunculus



Tractus Corticospinalis

Motorisches System

M2 Somatotopie

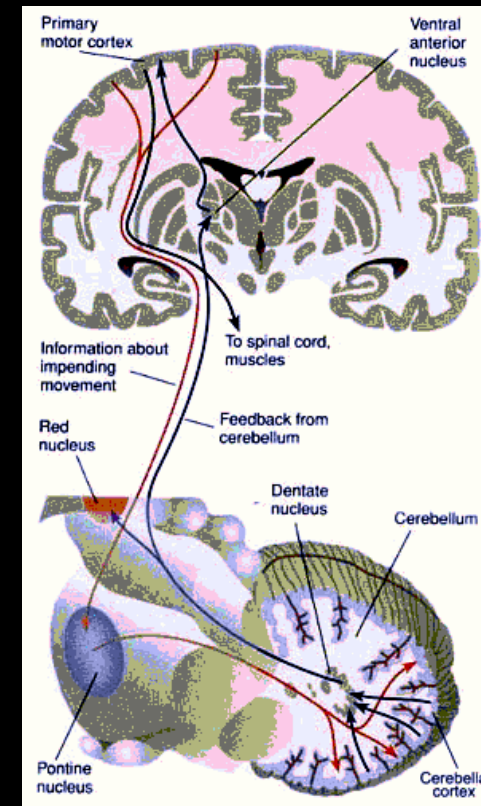
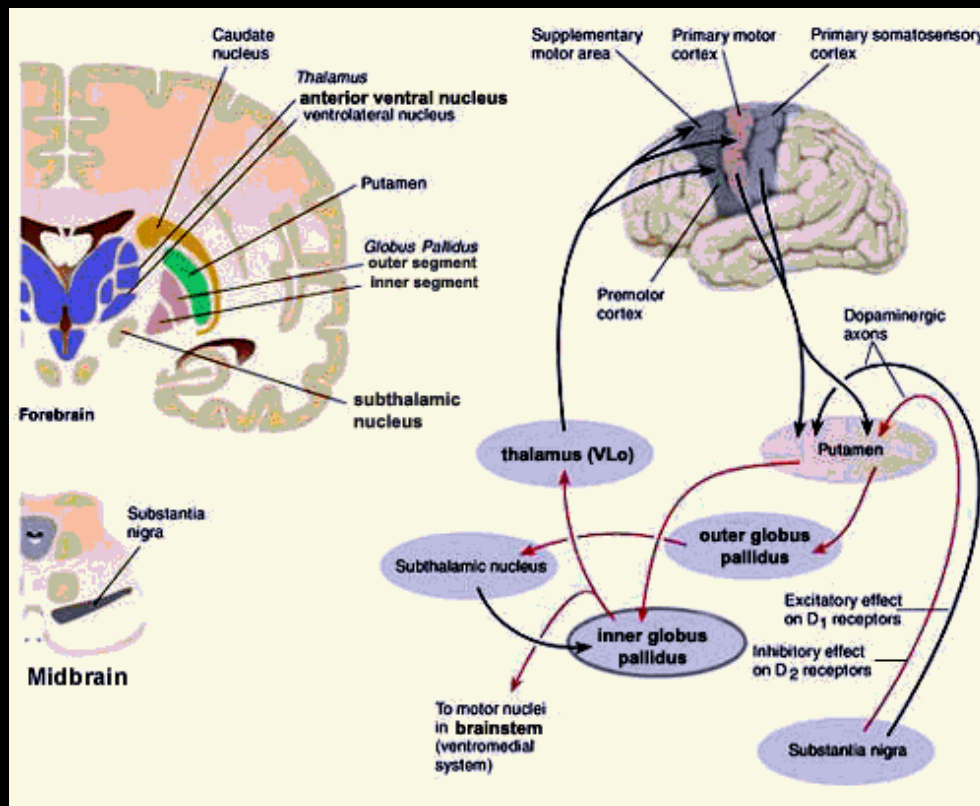


SMA

Pre-SMA

Motorisches System

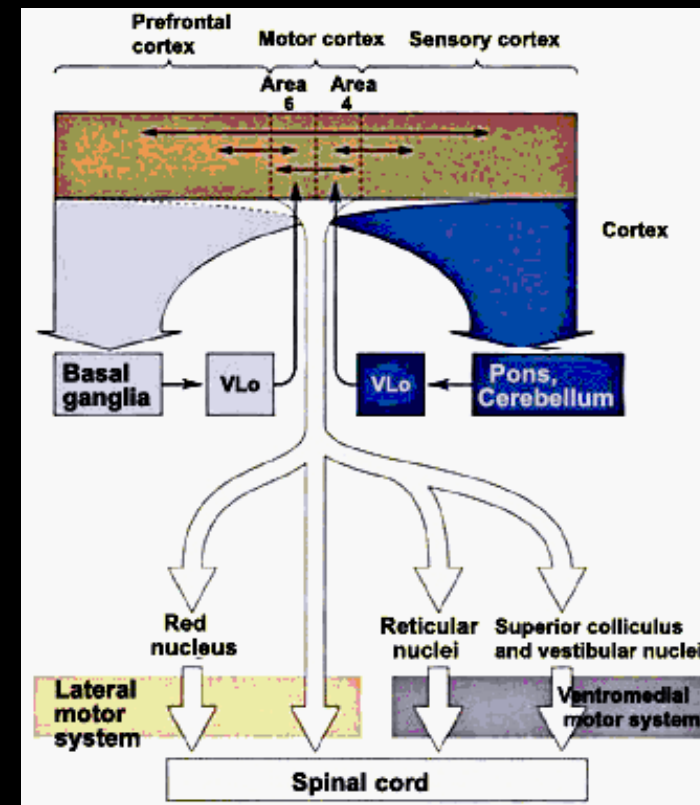
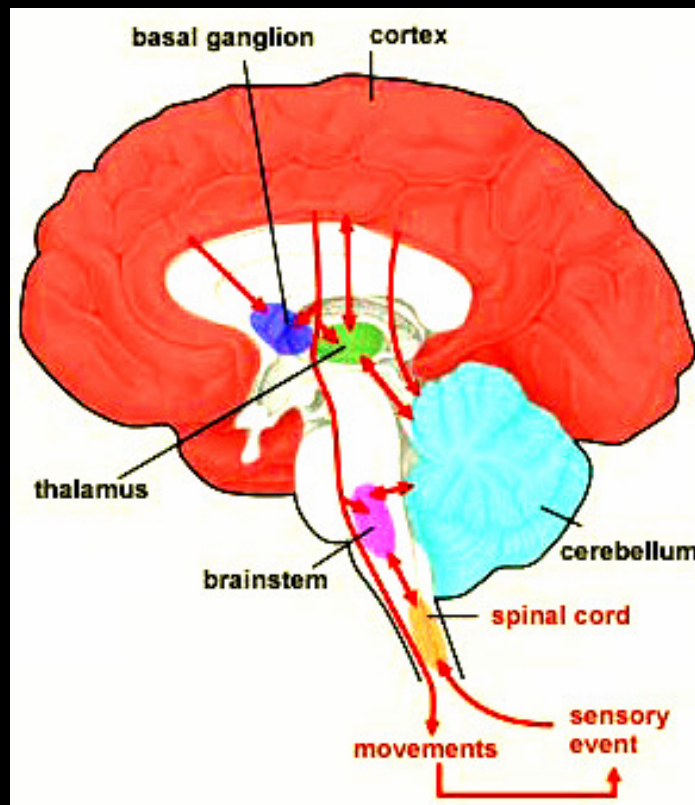
Basalganglien & Zerebellum



Basalganglien: Frontale, prefrontale & parietale Areale – Basalggl. – ,Thalamus - SMA; bahnen & filtern
Zerebellum: motorische & somatosensile information; Integration, Modulation, Koordination, Kalibrierung, prozedurales Gedächtnis
from: <http://thebrain.mcoill.ca>

Motorisches System

Aktivierungs-Sequenz



Auswahl (**Achtung !**): Parietal- & Frontallappen, subkortikale Strukturen; Planung (**Fertig !**): PMA & SMA; Ausführung (**Los !**): subkortikale Strukturen, PMA / SMA, M1; from: <http://thebrain.mcgill.ca>

Motorisches System

Willkürbewegungen (Kortex)

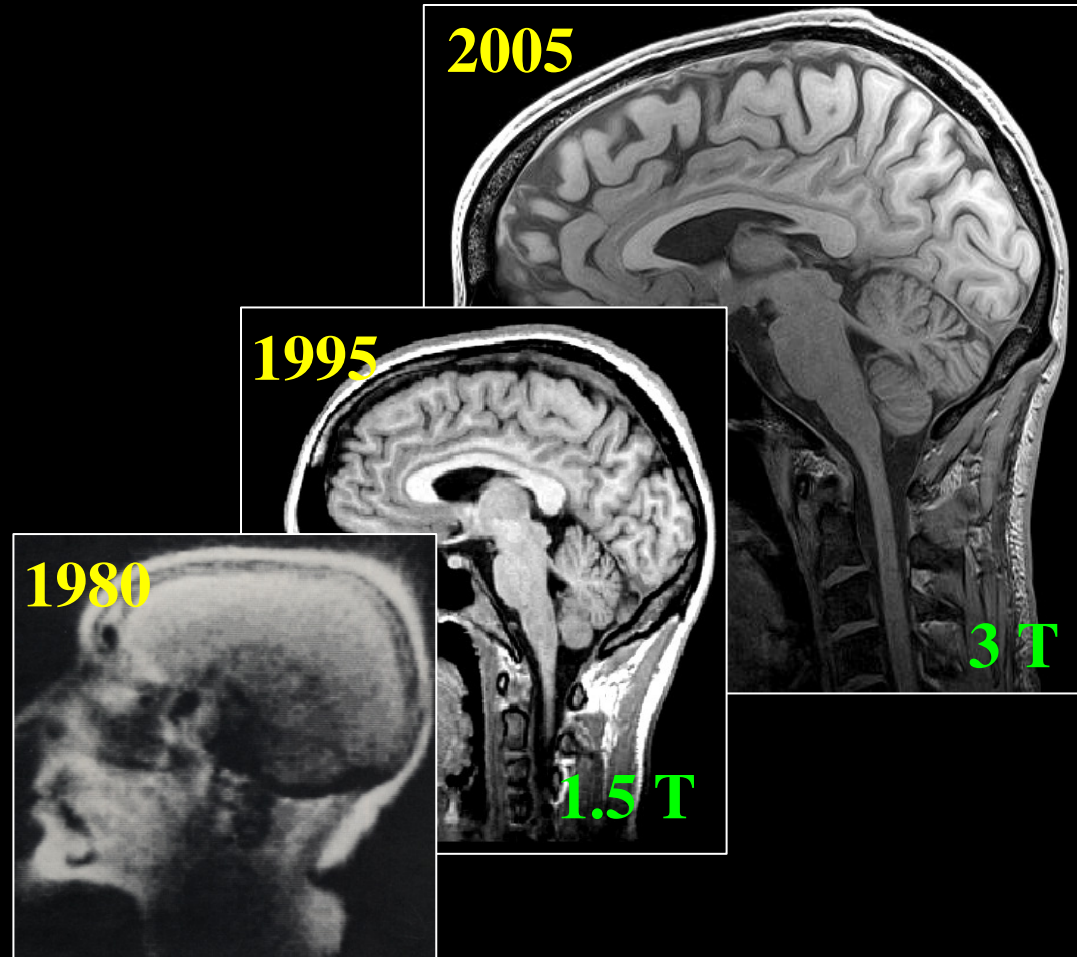
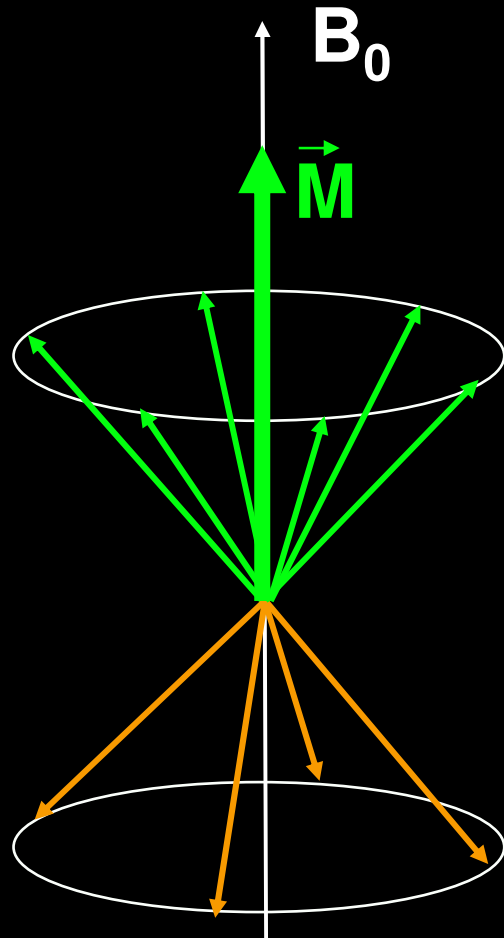
- 3 Schritte: Auswahl, Planung, Ausführung (Achtung–Fertig–Los!)
- Primärer Motorkortex (M1, BA4); Ausführung, Somatotopie
- Prämotorische Rinde (PMA, BA6); Integration sensorischen Inputs, Bewegungskontrolle
- Supplementärmotorische rinde (SMA, BA6); Planung komplexer Bewegungsabläufe, Koordination beider Körperseiten, v.a. Hände
- Komplexe Interaktion zwischen Kortex, Basalganglien, Thalamus, Zerebellum & Rückenmark

Motorisches System

Willkürbewegungen (subkortikale Strukturen)

- Basalganglien: Komplexe Funktionsschleife: frontale, prefrontale & parietale Areale – Basalganglien – Thalamus - SMA: Bahnung & Filterung der Info zur SMA
Beteiligt: Gedächtnis, Kognition, Emotion
- Zerebellum: Durchgang aller motorischen und somatosensiblen Impulse, : Integration & Modulation, motorisches Lernen, prozedurales Gedächtnis
Koordination verschiedenen Körperteile
Kalibrierung der neuronalen Muskelaktivierung

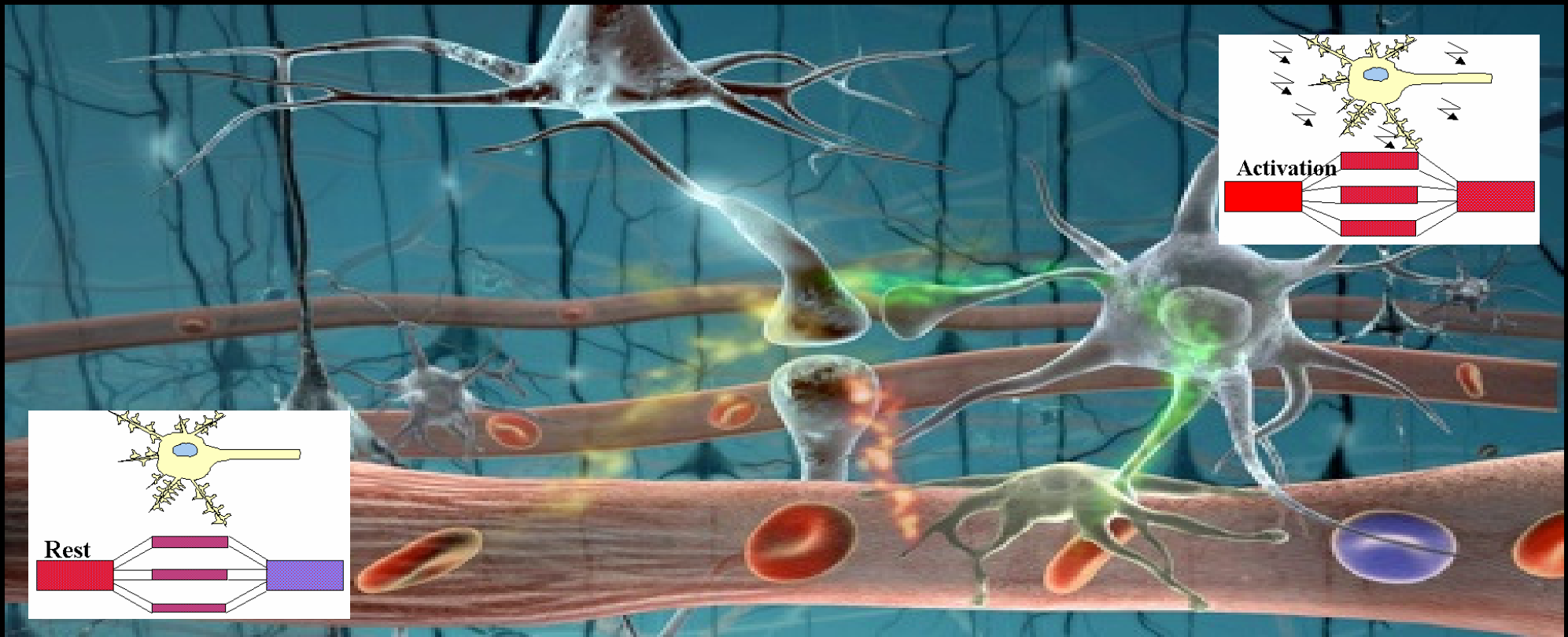
Magnetresonanztomographie (MRT)



Mehrkanal-Spulen, „Parallel Imaging“
Schnelle & hochauflösende Bildgebung

funktionelle Magnetresonanztomographie (fMRT)

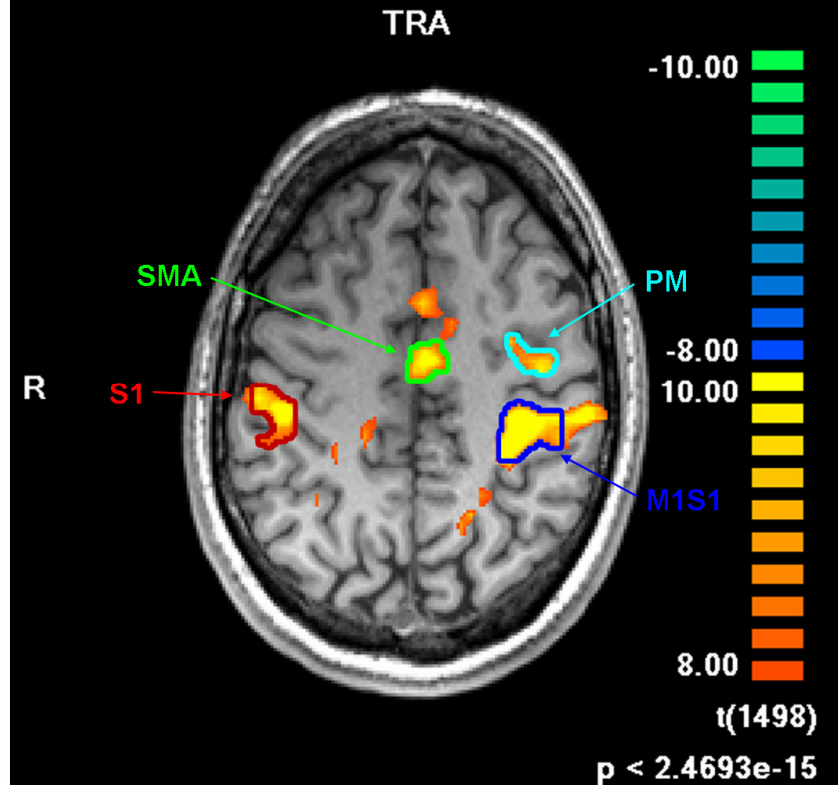
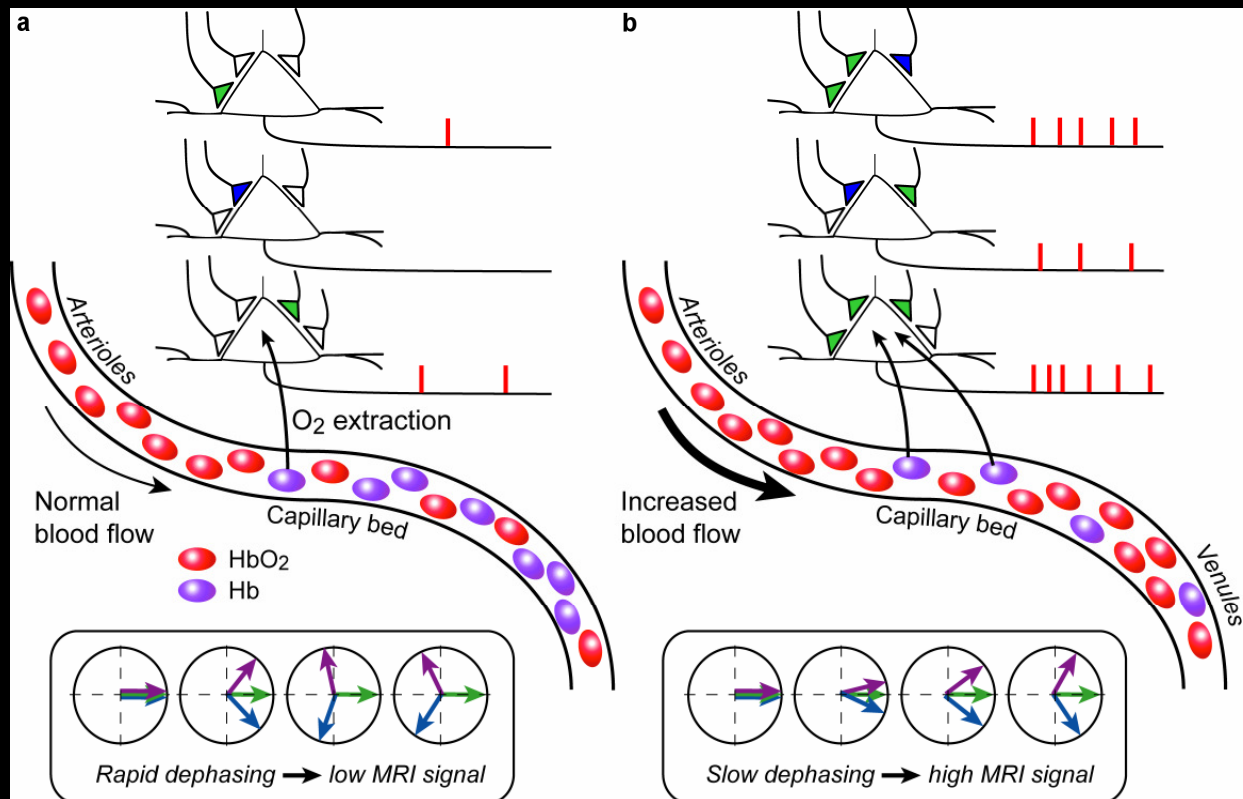
Morphologie & Funktion gemeinsam visualisieren !



Neurovaskuläre Kopplung

funktionelle Magnetresonanztomographie (fMRT)

BOLD-Effekt & Aktivierungskarte

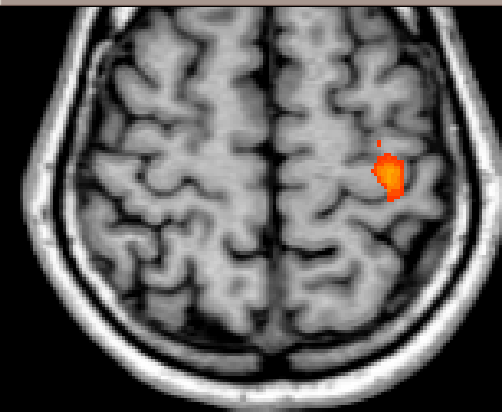
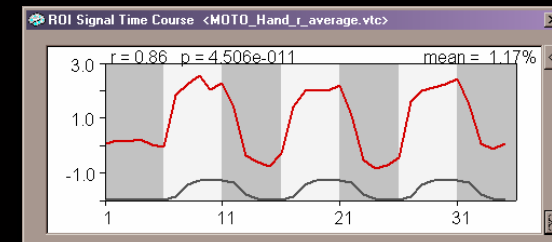
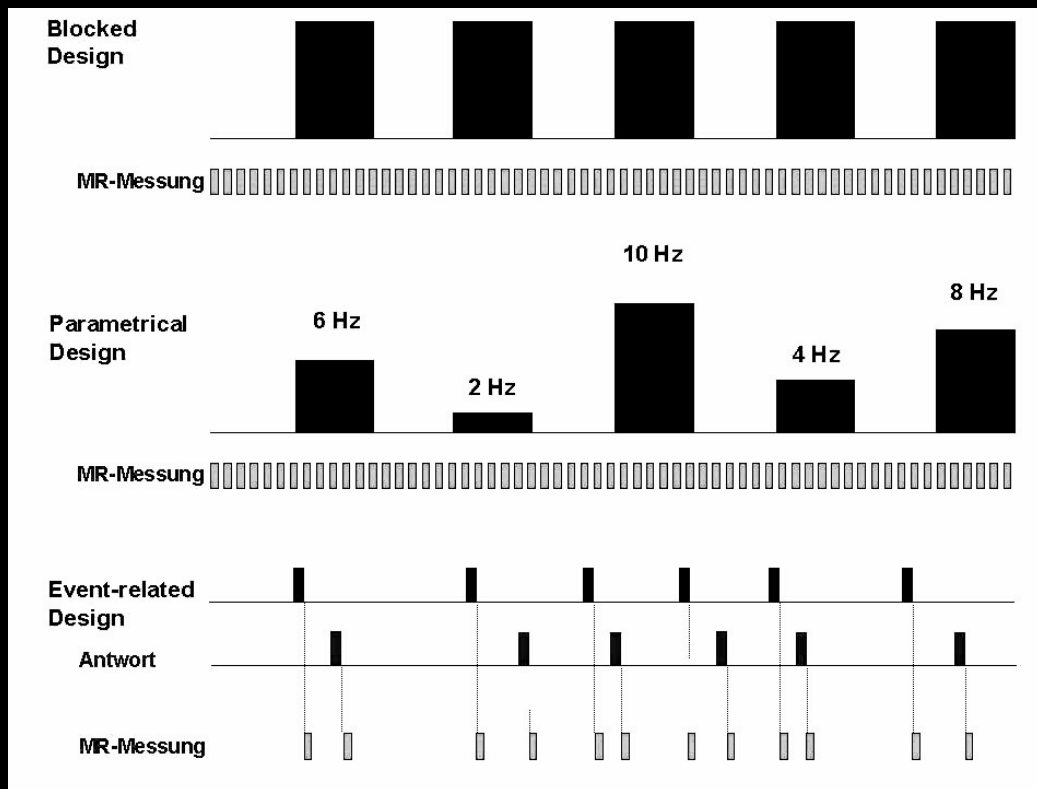


Blood Oxygen Level Dependent Kontrast

Kortikales motorisches Netzwerk

funktionelle Magnetresonanztomographie (fMRT)

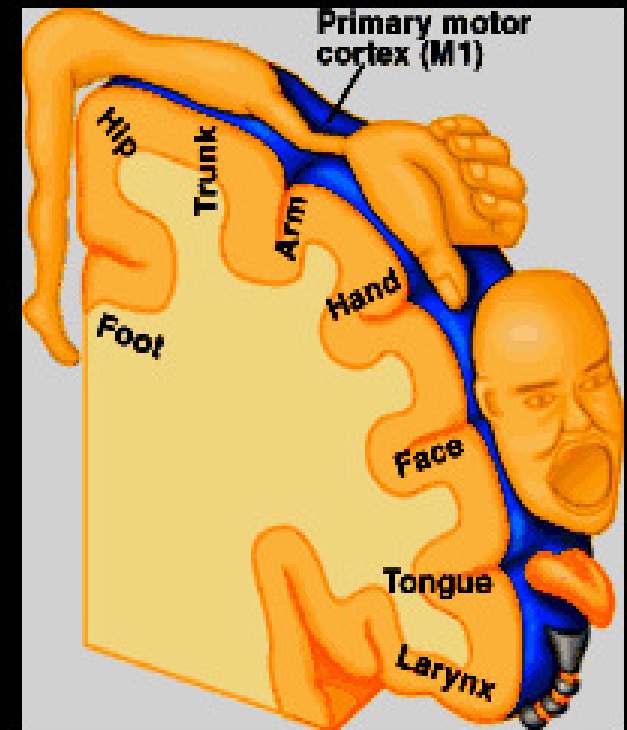
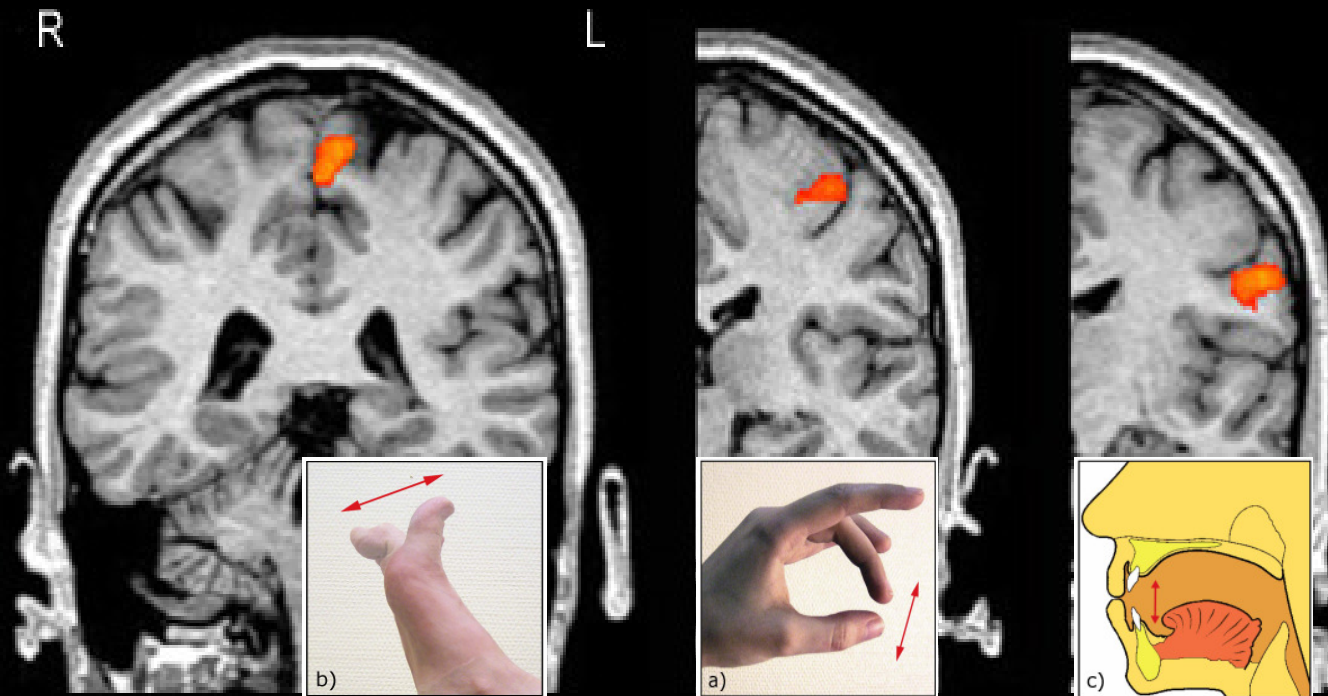
Stimulationsschemata



Typische fMRT-Untersuchungsschemata, klinisch relevant: **Block-Design**
Bewegung der rechten Hand, Intensitäts-Zeitverlauf des BOLD-Signals

FMRI of the Motor System

M1 Somatotopy

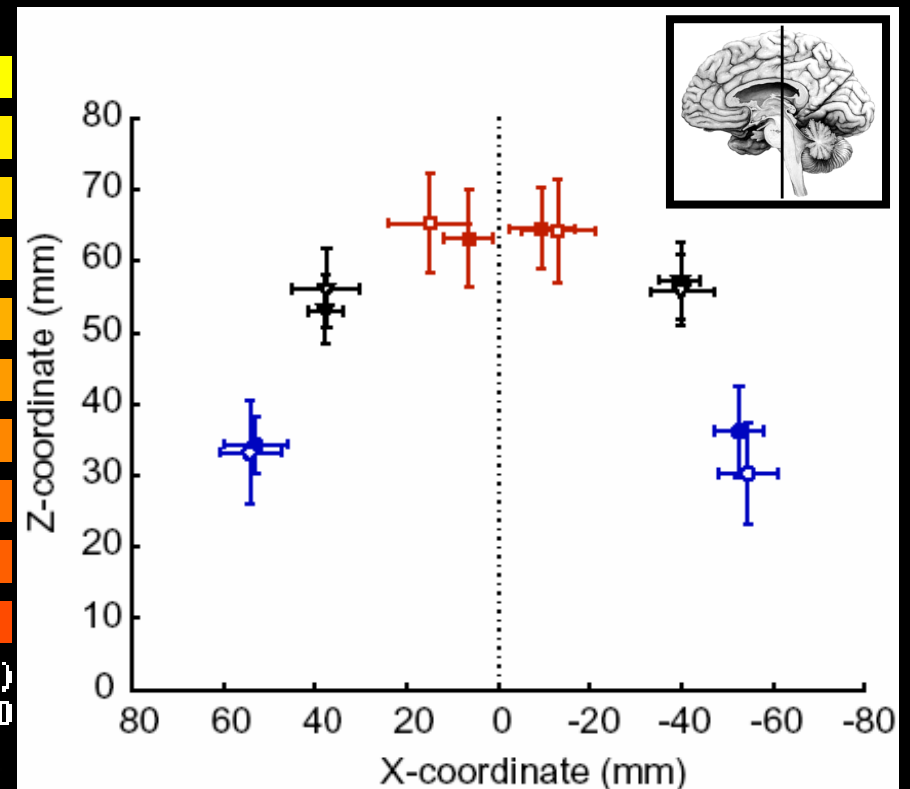
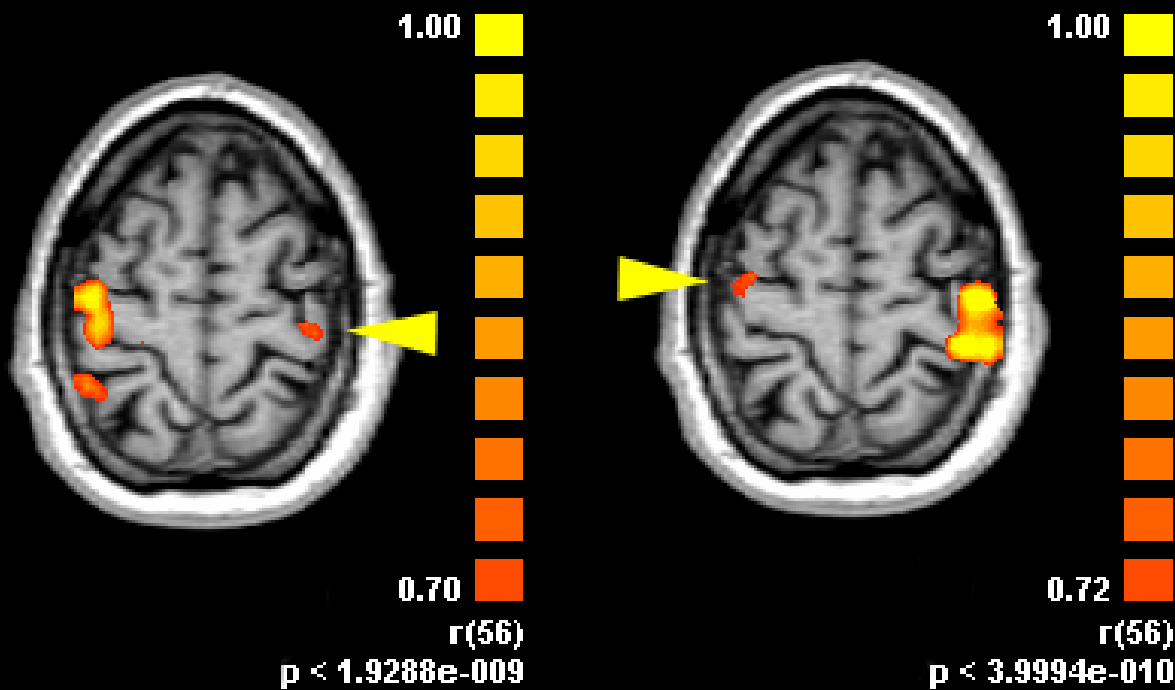


Motor Homunculus

Stippich C. et al., *RöFo* 2002

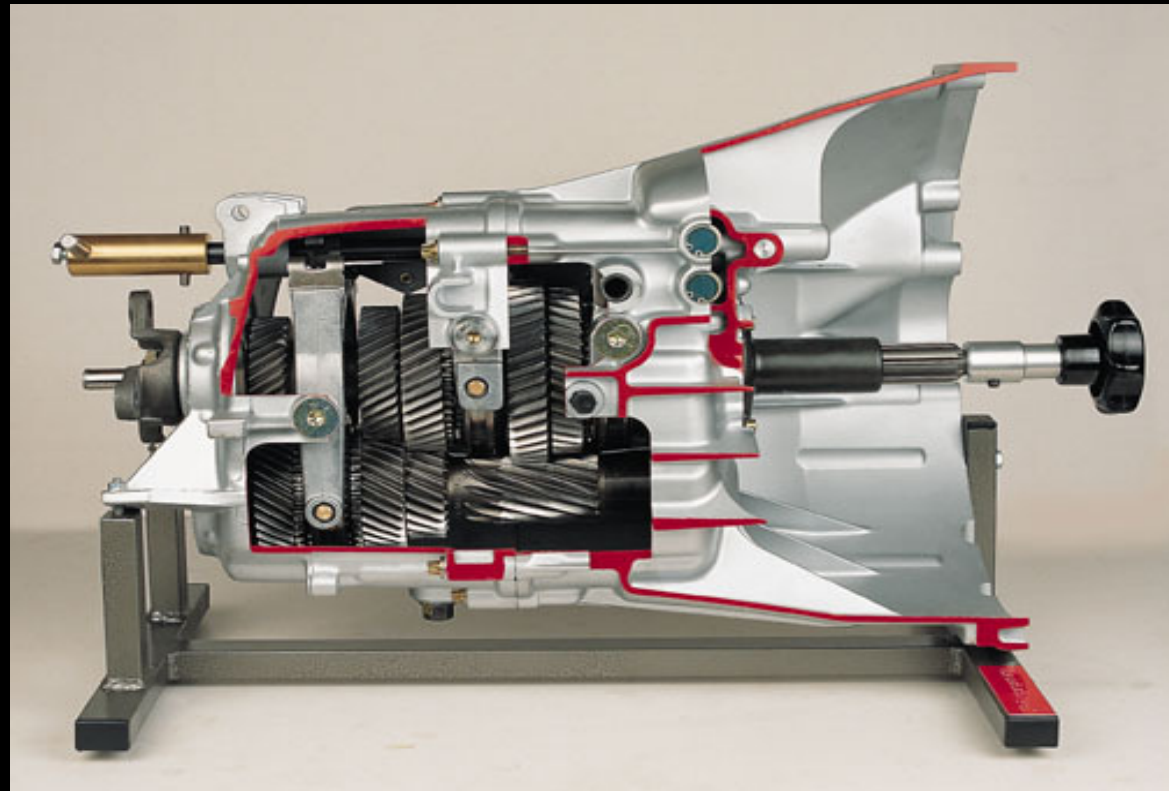
Funktionelle MRT des motorischen Systems

Konnektivität des primären Motorkortex (M1)



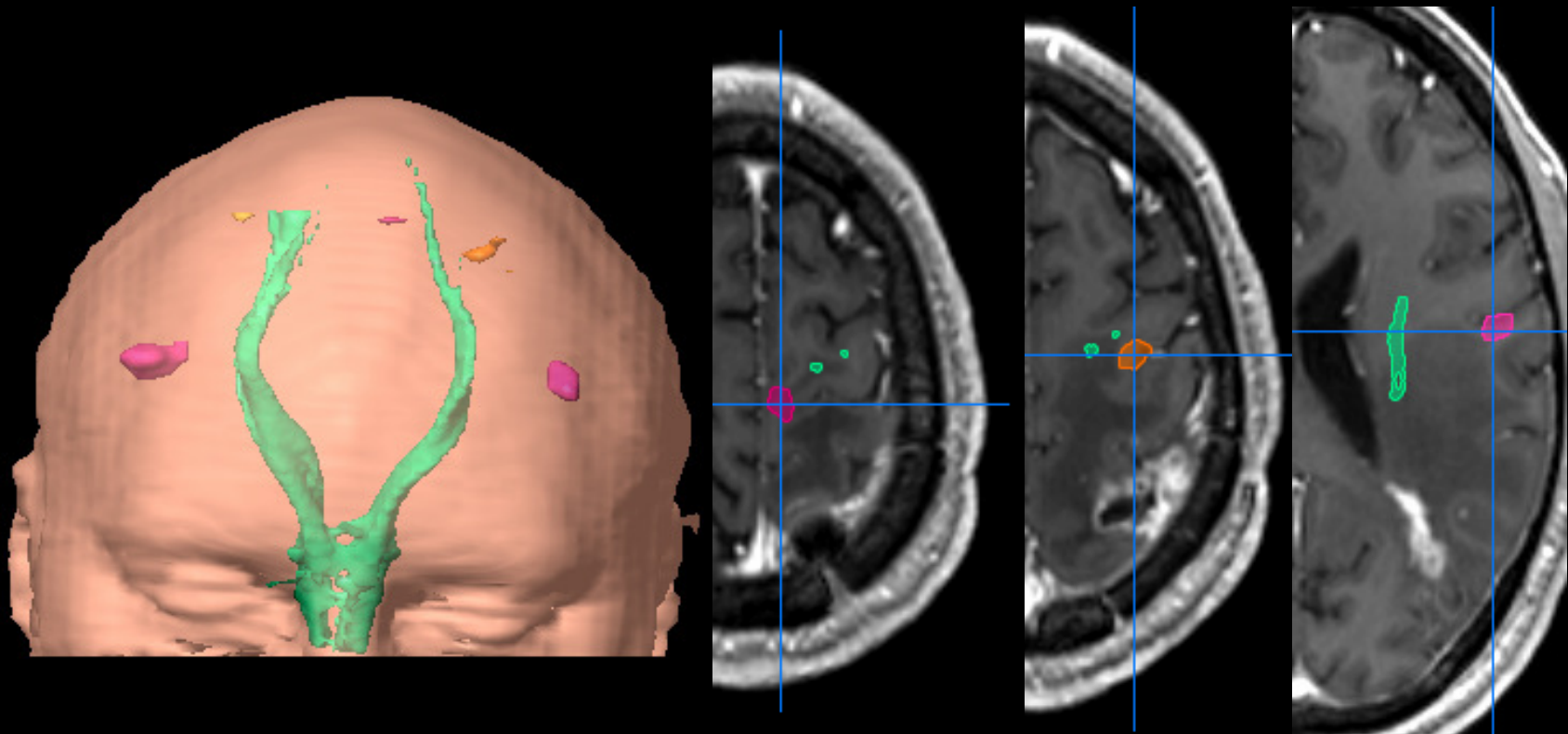
Funktionelle MRT des motorischen Systems

Synchrongetriebe



Präoperative fMRT bei rolandischen Hirntumoren

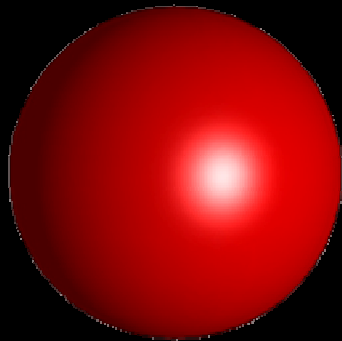
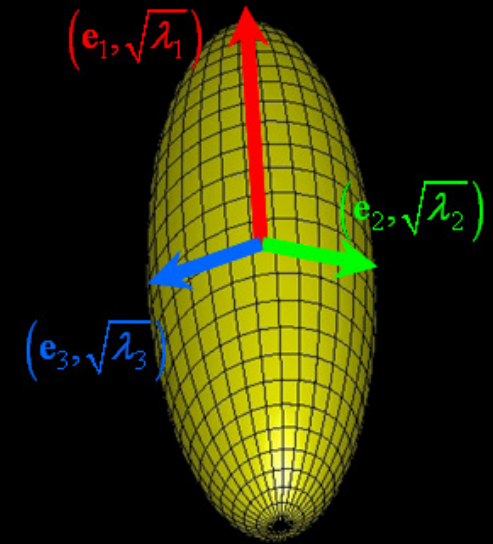
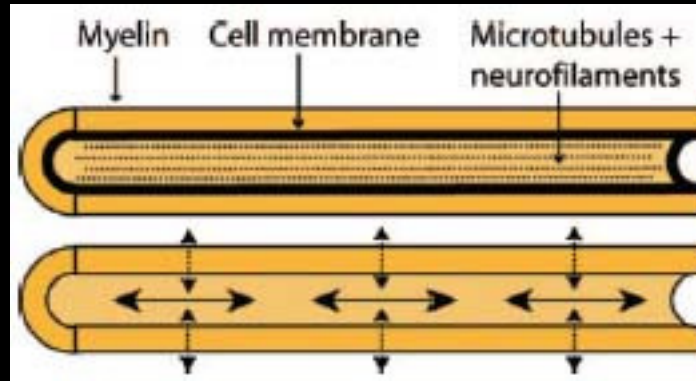
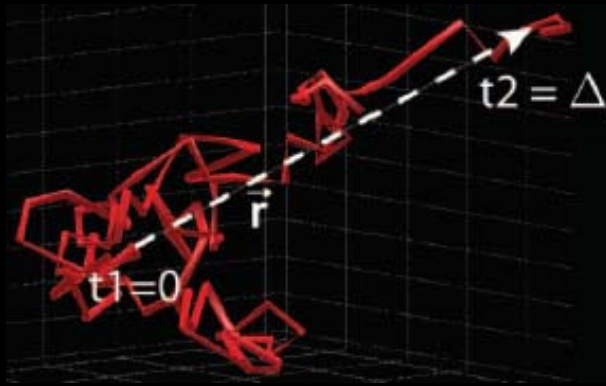
fMRT & DTI-Traktographie



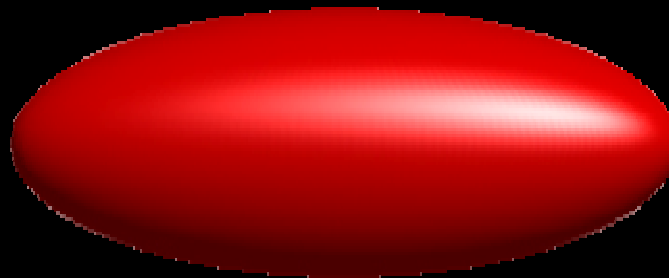
Motorische Somatotopie & Pyramidenbahn

Diffusion-Tensor-Imaging (DTI)

Diffusion & Tensor



Isotrope Diffusion



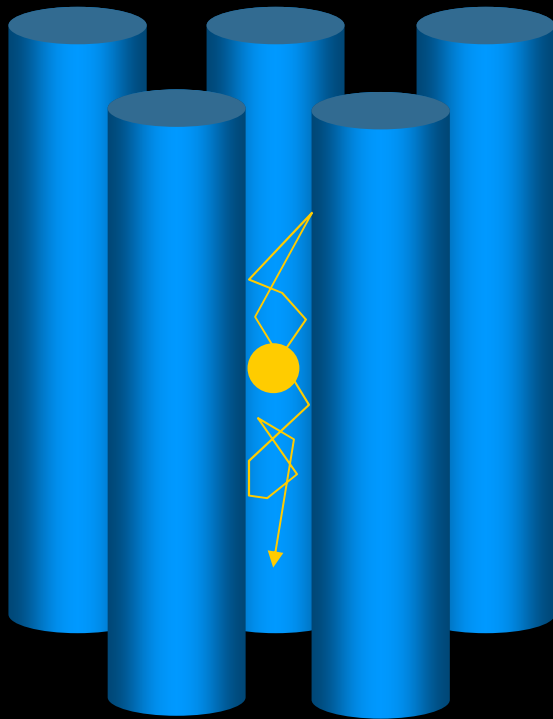
Anisotropie Diffusion

$$\mathbf{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{xy} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{bmatrix}$$

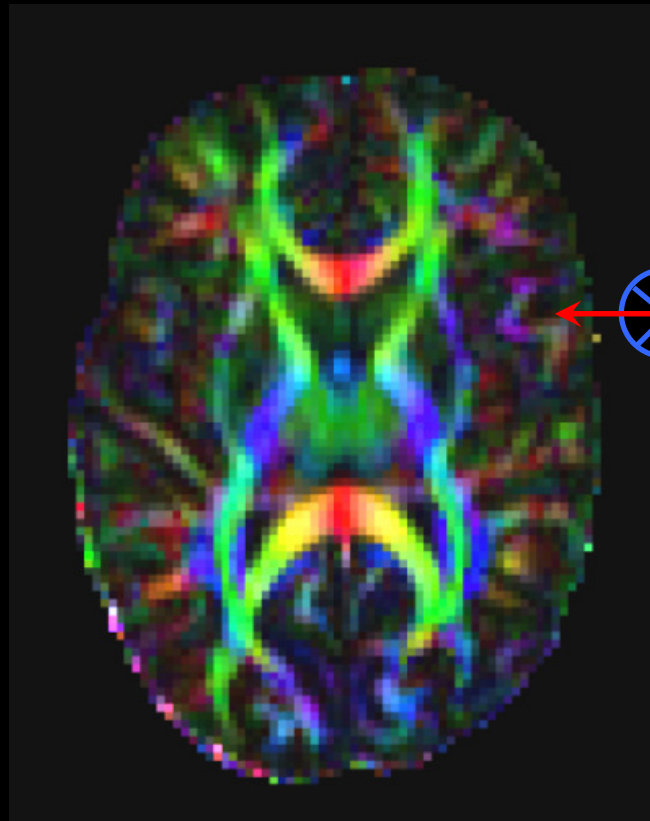
Diffusions-Tensor

Diffusion-Tensor-Imaging (DTI)

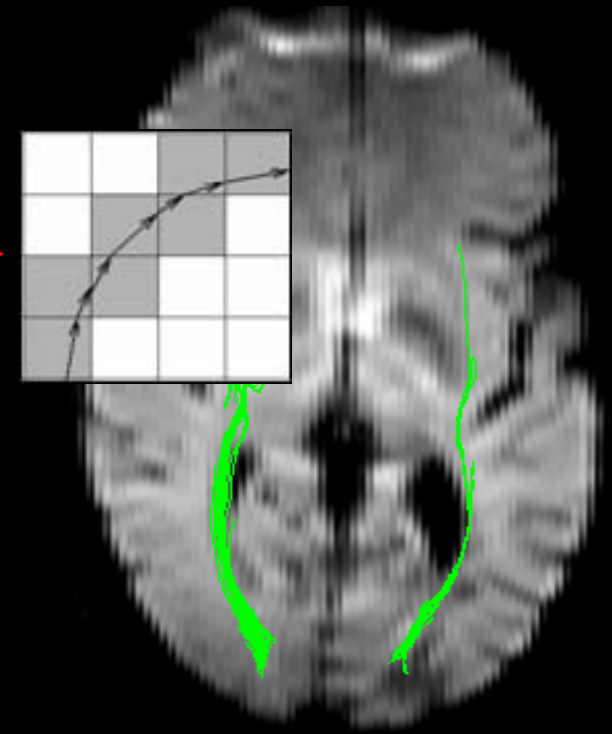
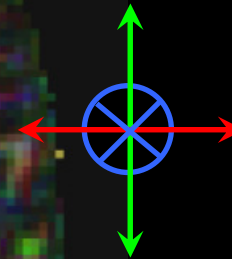
Fraktionale Anisotropie (FA) & Traktografie



Anisotropie Diffusion



FA -Farkarte



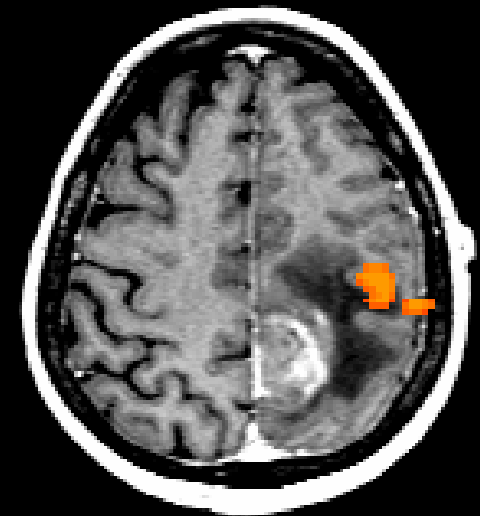
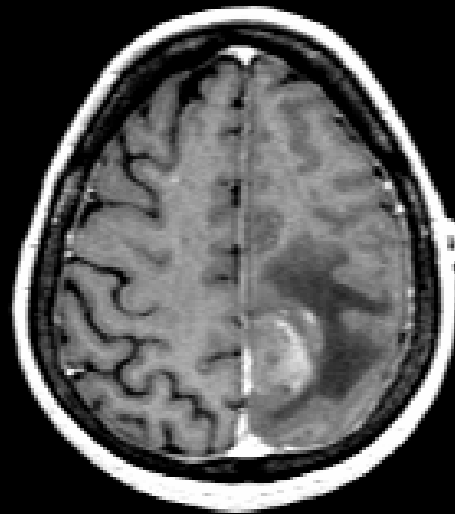
Traktografie

fMRT bei Patienten mit rolandischen Hirntumoren

Standardprotokoll, kontralat. Fingeropposition



anatomische MR-Bildgebung

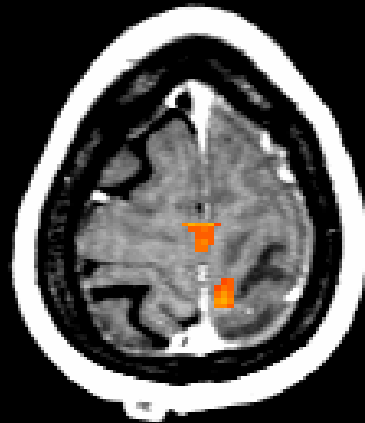


fMRT rechte Hand

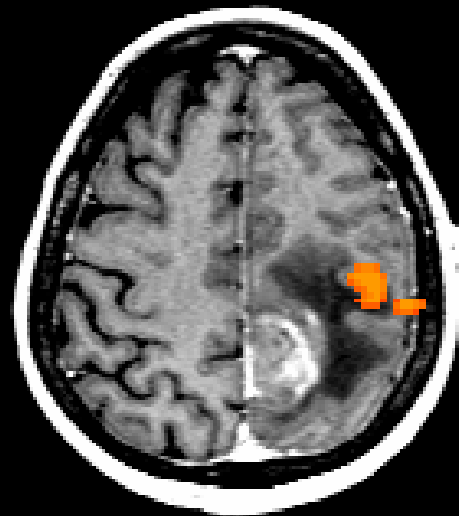
60 jährige Patientin, links-parietales Glioblastom (WHO IV), kontralaterale Parese Kraftgrad 3/5

fMRT bei Patienten mit rolandischen Hirntumoren

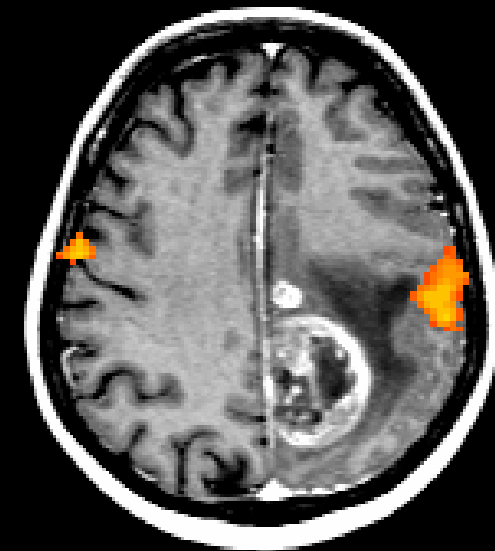
Somatotopie des primären Motorkortex



Rechter Fuss



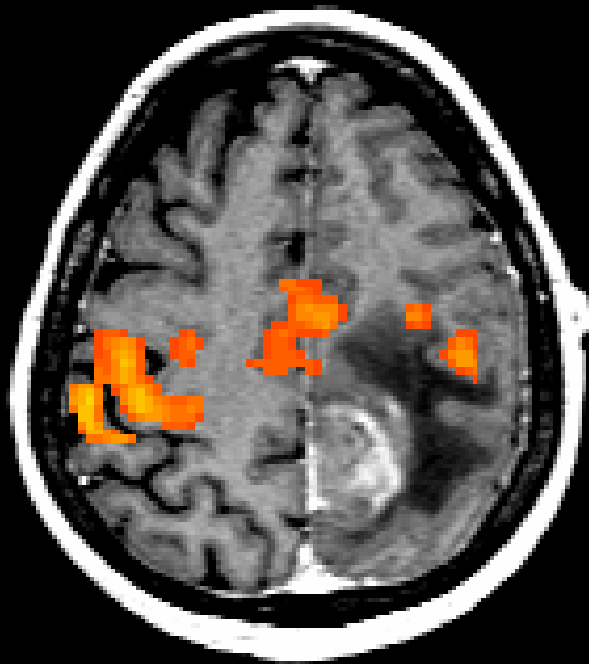
rechte Hand



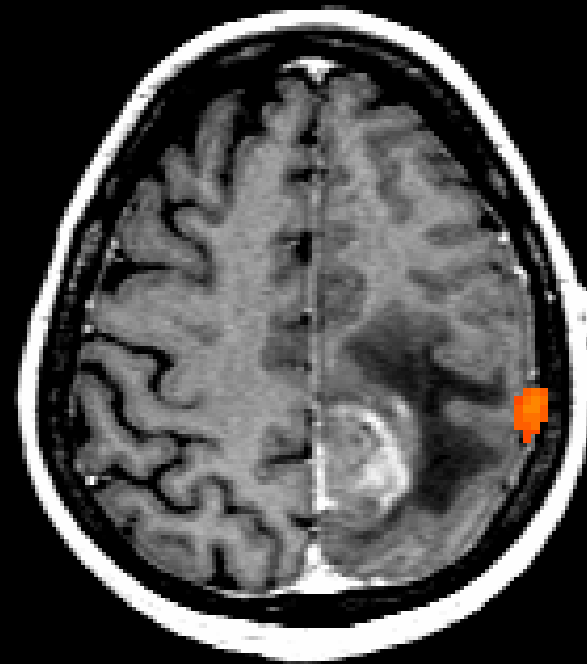
Zunge

fMRT bei Patienten mit rolandischen Hirntumoren

Paresen & Neuroplastizität



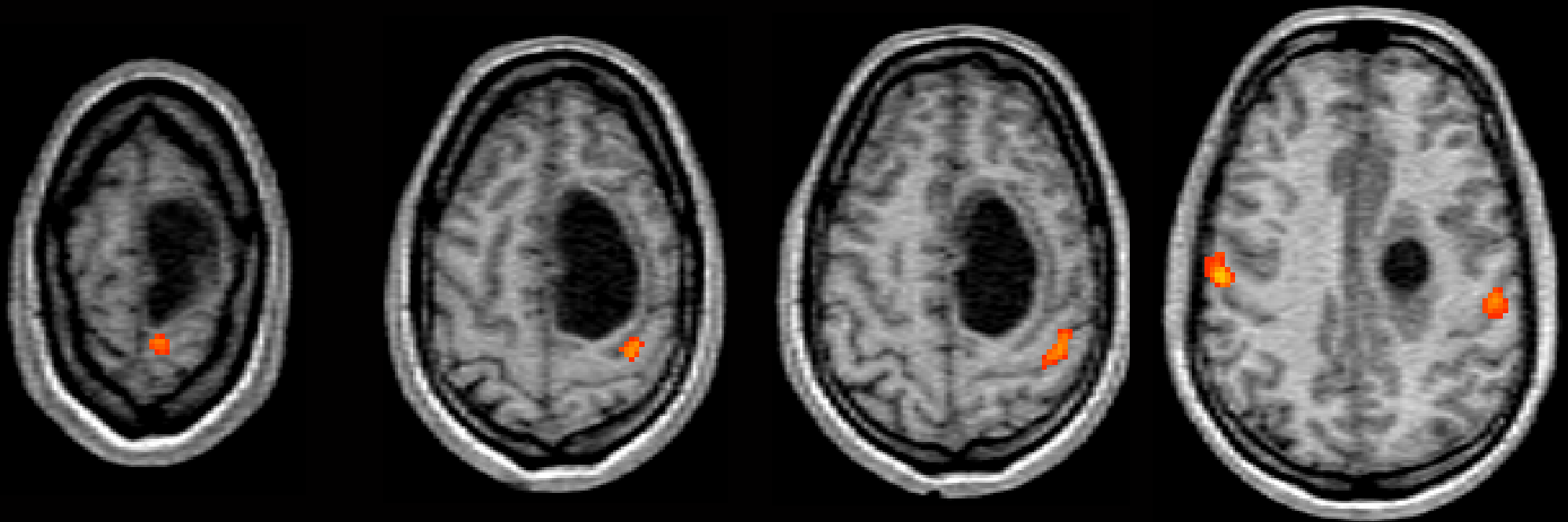
linke Hand



rechte Hand, taktil

Preoperative fMRI in Patients with Rolandic Brain Tumors

Primary Motor Coactivation (Paretic leg)



Right foot (M1S1)

M1CoA

Right hand (M1S1)

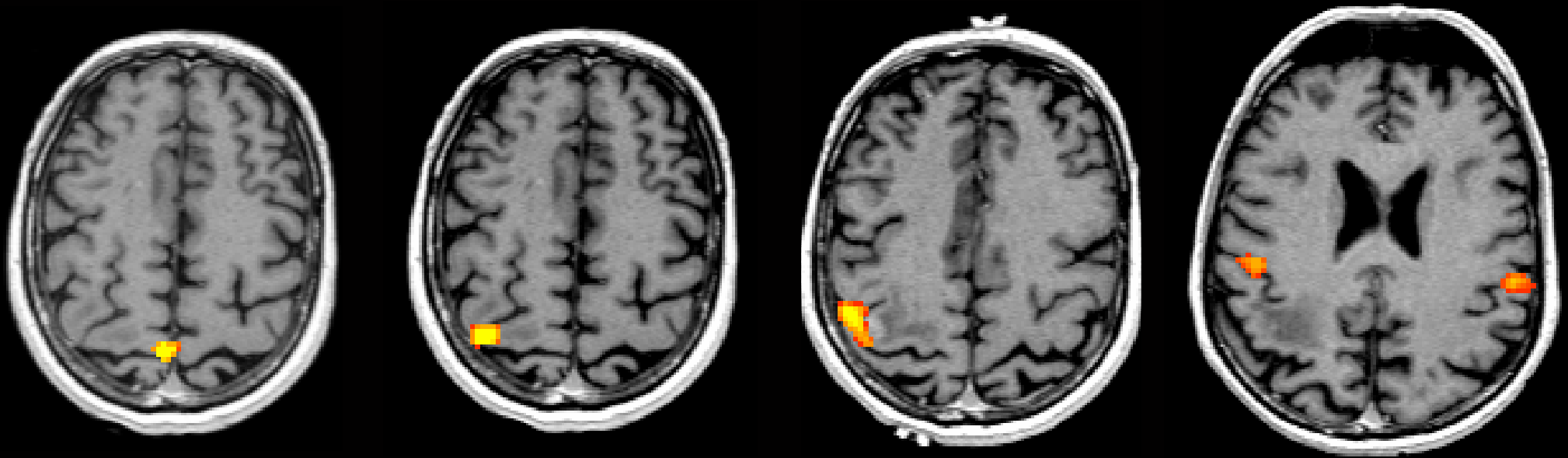
Tongue (M1S1)

Toe movements: M1-coactivation between precentral hand- and foot representations

21 year old male with a left frontal cystic glioma, paretic right leg

Preoperative fMRI in Patients with Rolandic Brain Tumors

Primary Motor Coactivation (Paretic arm)



Left foot (M1S1)

M1CoA

Left hand (M1S1)

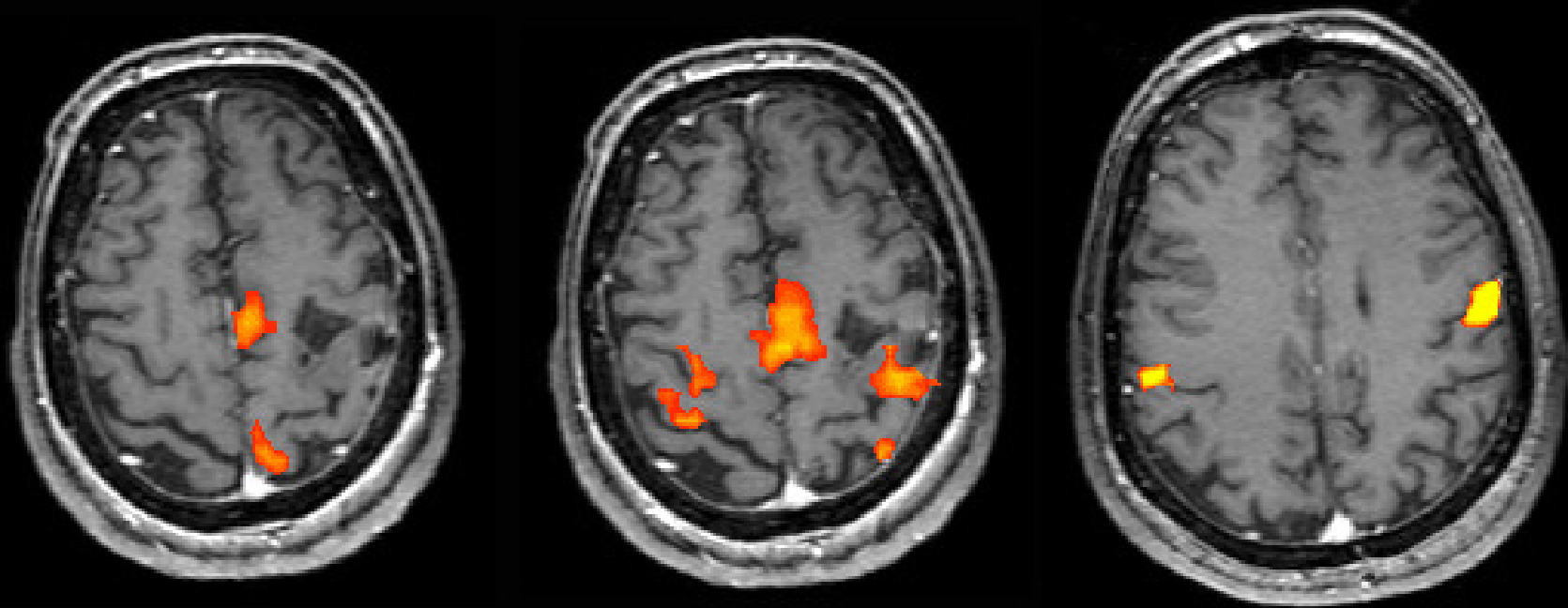
Tongue (M1S1)

Toe movements: M1-coactivation between precentral hand- and foot representations

53 year old male with a right central metastasis, paretic left arm (3/5)

fMRT bei Patienten mit rolandischen Hirntumoren

Starke sekundär-motorische Aktivierung



rechter Fuss

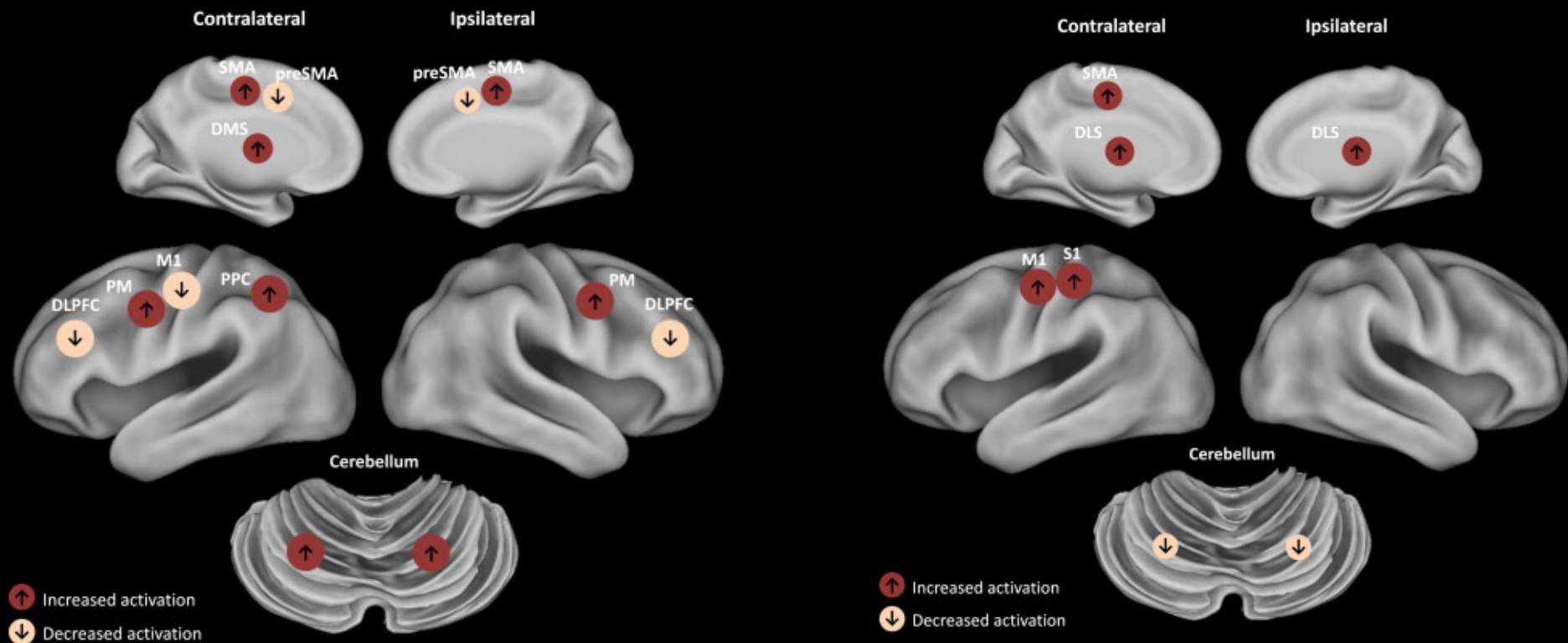
rechte Hand

Zunge

Atypisch starke Aktivierung sekundär-motorischer Areale, SMA (Fuß), SMA, PMi, M1S1i (Hand)
44 jähriger Patient mit 3/5 Armparese, leichte Beinschwäche bei Rezidiv eines Oligodendroglioms

Motorisches Lernen: fMRT & PET

Kortikale Aktivitätsänderung



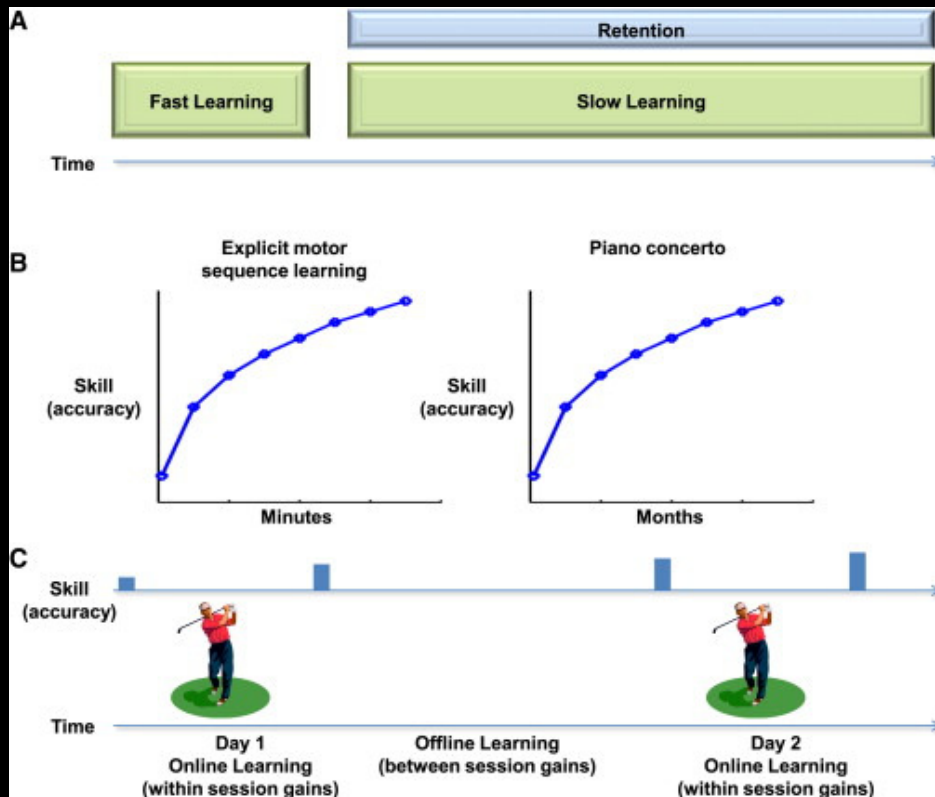
Kurzfristiges Lernen

Langfristiges Lernen

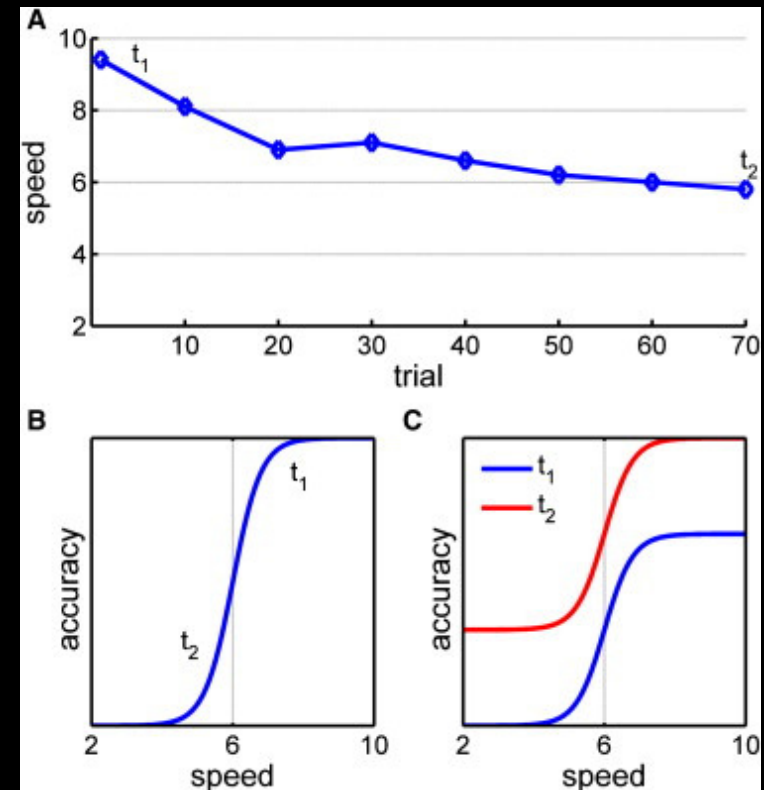
Dayan E. & Cohen LG., *Neuron* 2011

Motorisches Lernen: fMRT & PET

Motorisches Training



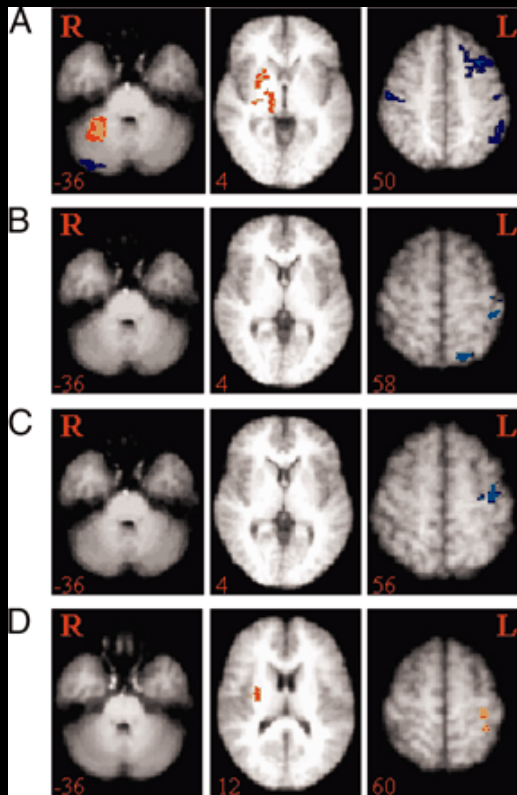
Kurzfristiges & langfristiges Lernen



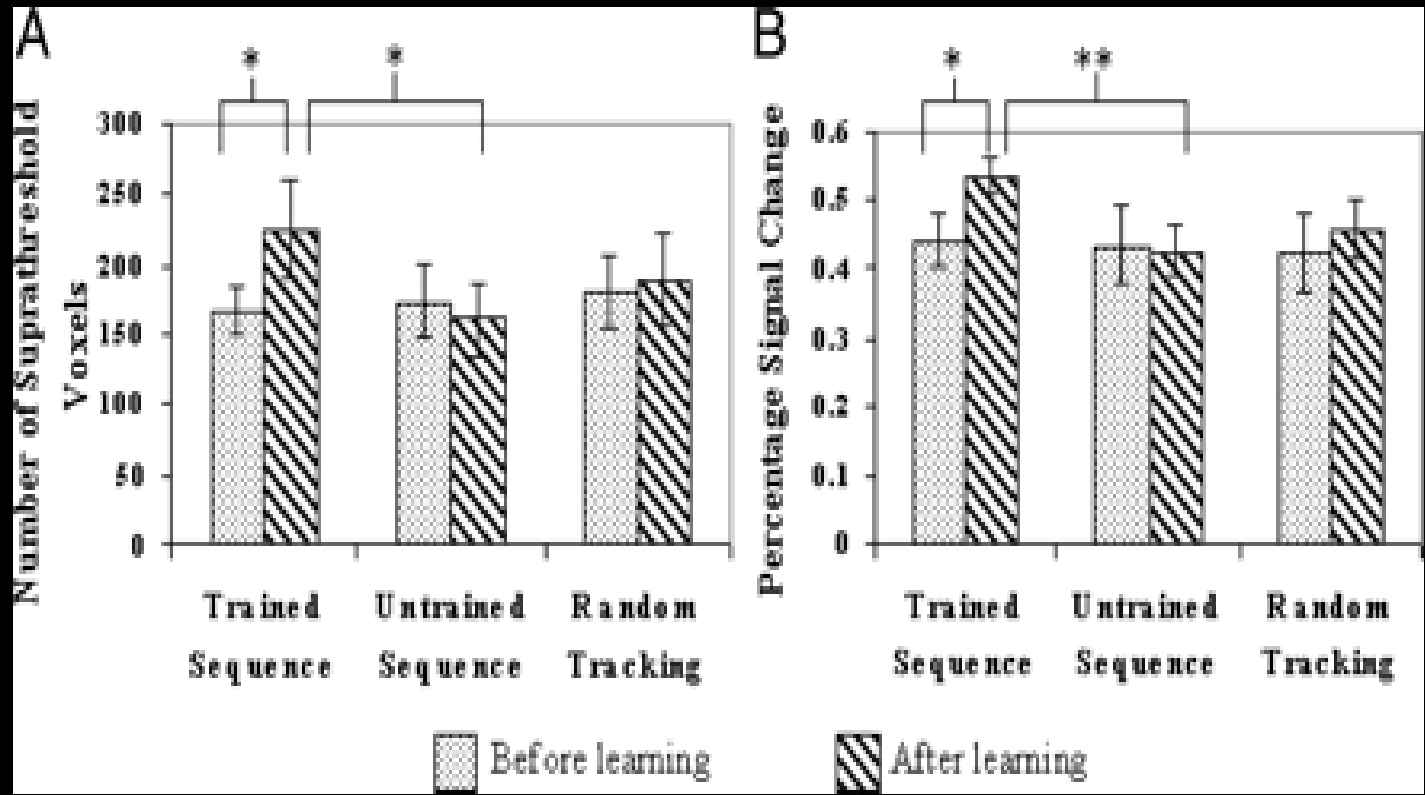
Geschwindigkeits-Genauigkeits Funktion

Funktionelle MRT des motorischen Systems

Differentielle Aktivierung unter Training



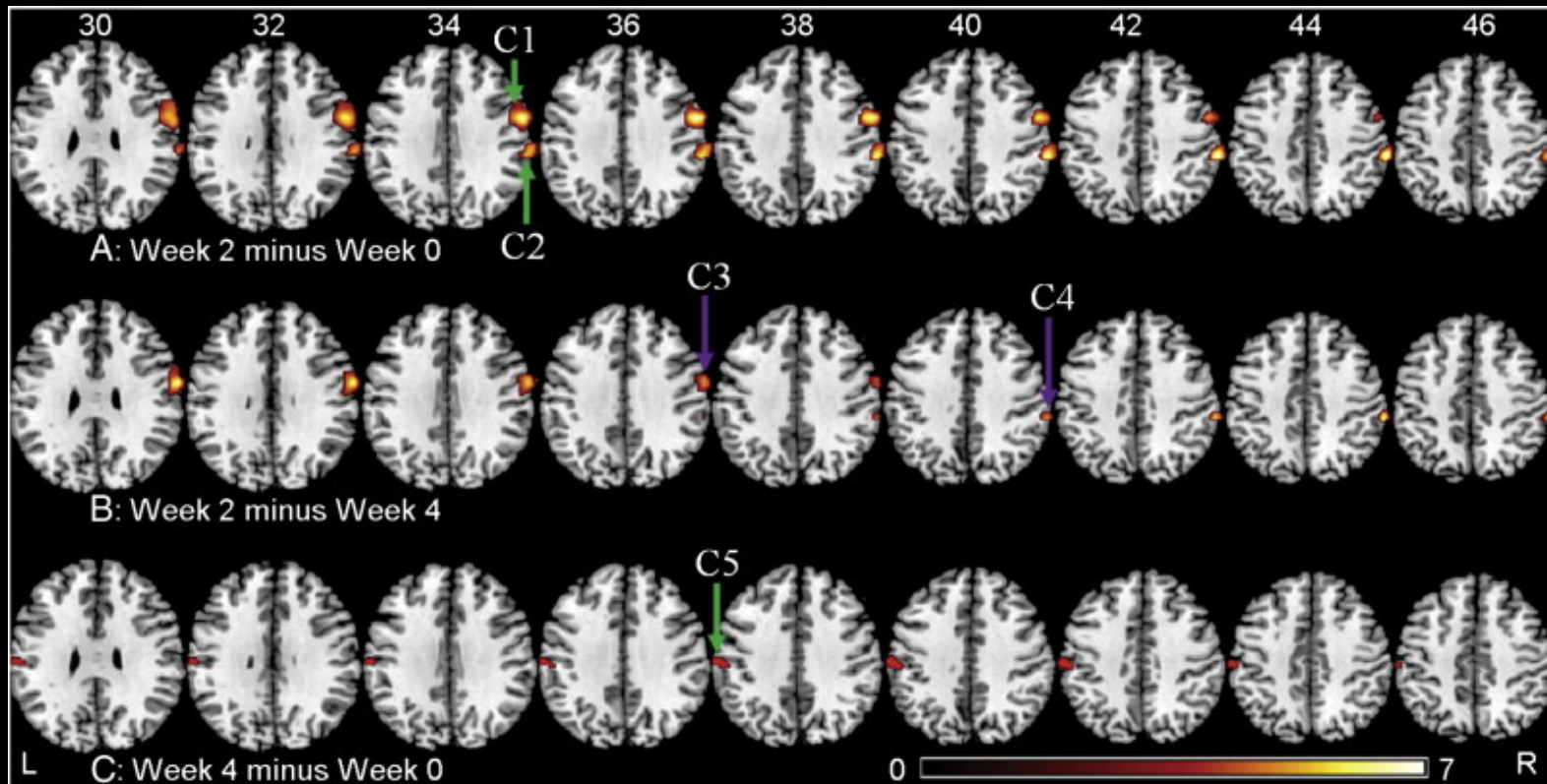
Rot +, blau -, zunehmende Trainingsdauer



BOLD-Signaländerung in M1

Resting-state fMRI

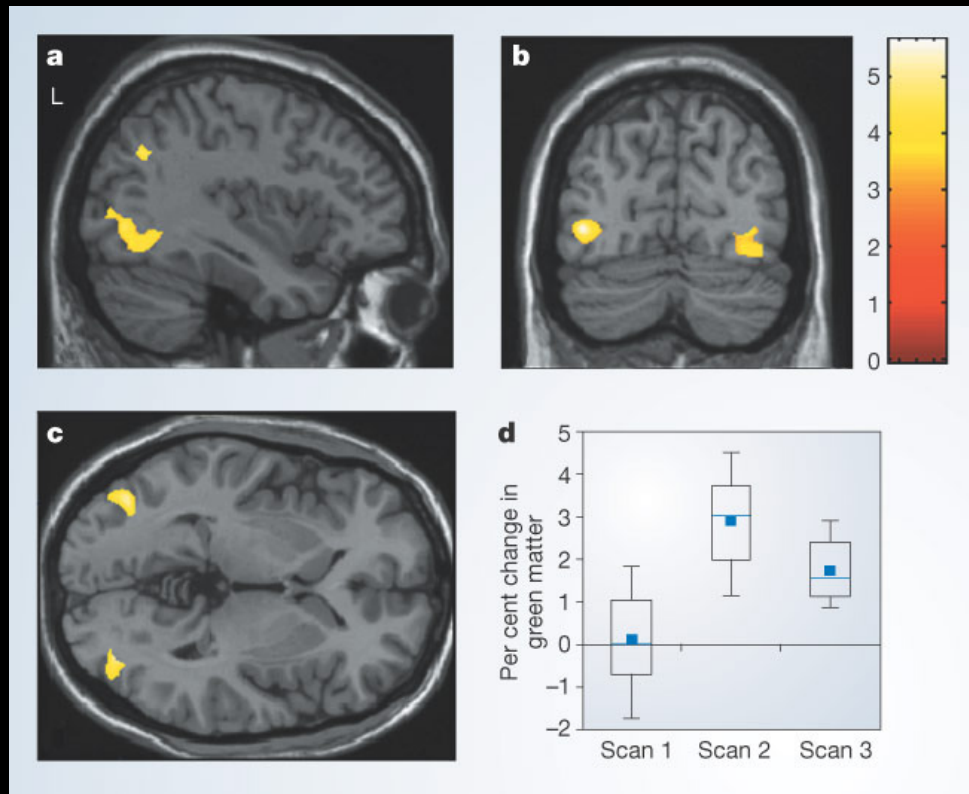
Veränderung motorischer Ruhenetzwerke



Gebiete mit signifikanter Aktivitätsänderung vor, während und nach Training

Voxel-basierte Morphometrie (VBM)

Zunahme grauer Substanz durch Training

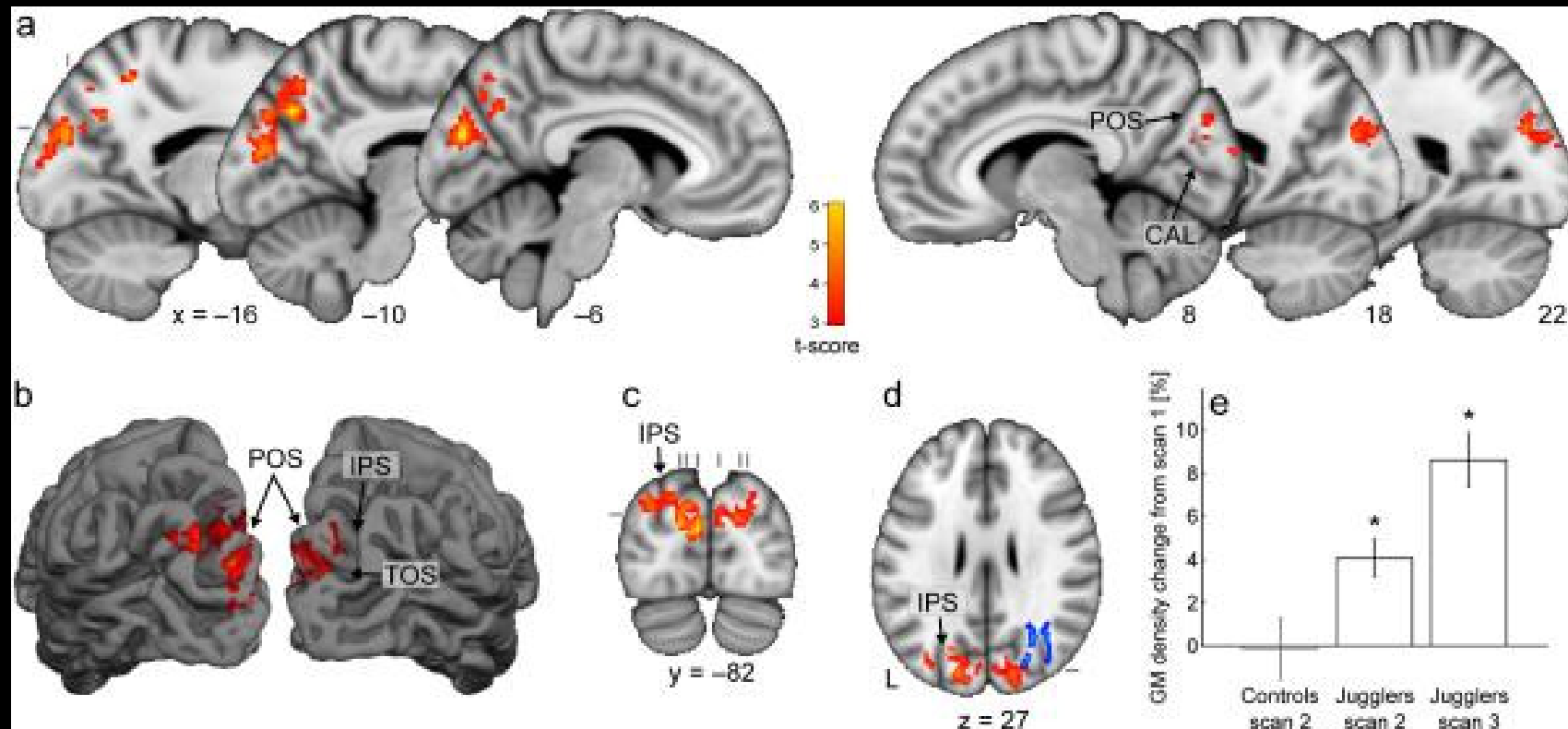


Gebiete mit signifikanter Volumen-Zunahme, Jonglage-Training

Dragannski B. et al., *Nature* 2004

Voxel-basierte Morphometrie (VBM)

Zunahme grauer Substanz durch Training

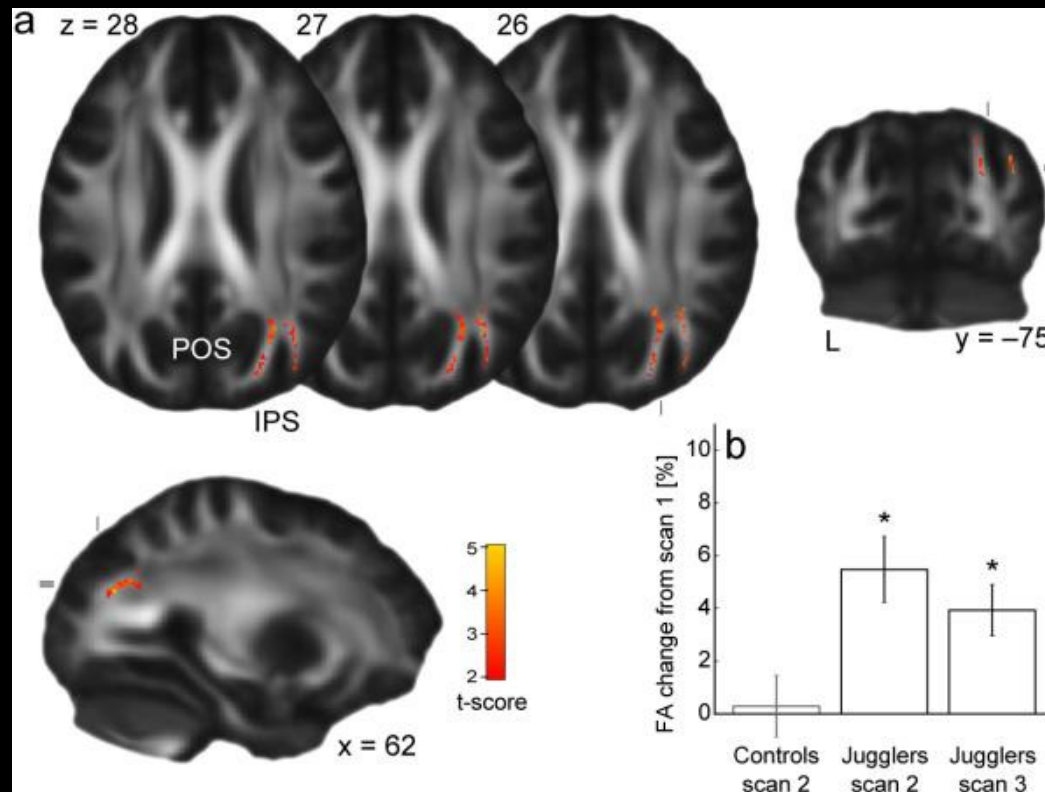


Gebiete mit signifikanter Volumen-Zunahme

Scholz J. et al., *Nature Neurosci* 2009

Diffusions-Tensor-Imaging (DTI)

Veränderung weisser Substanz durch Training

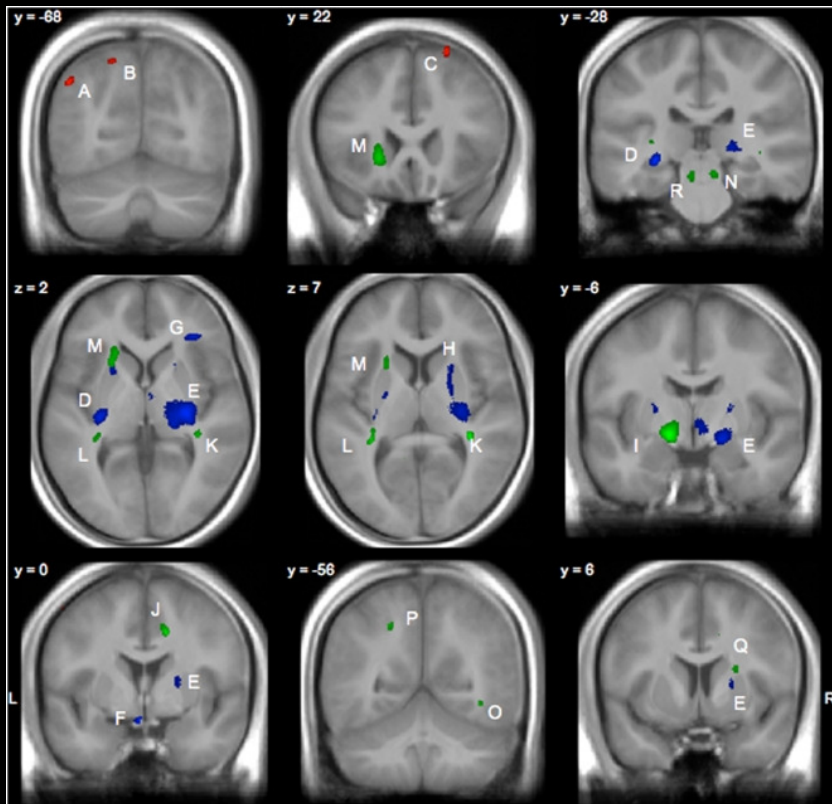


Gebiete mit signifikanter FA-Zunahme

Scholz J. et al., *Nature Neurosci* 2009

VBM & FA

Profi vs. Amateur

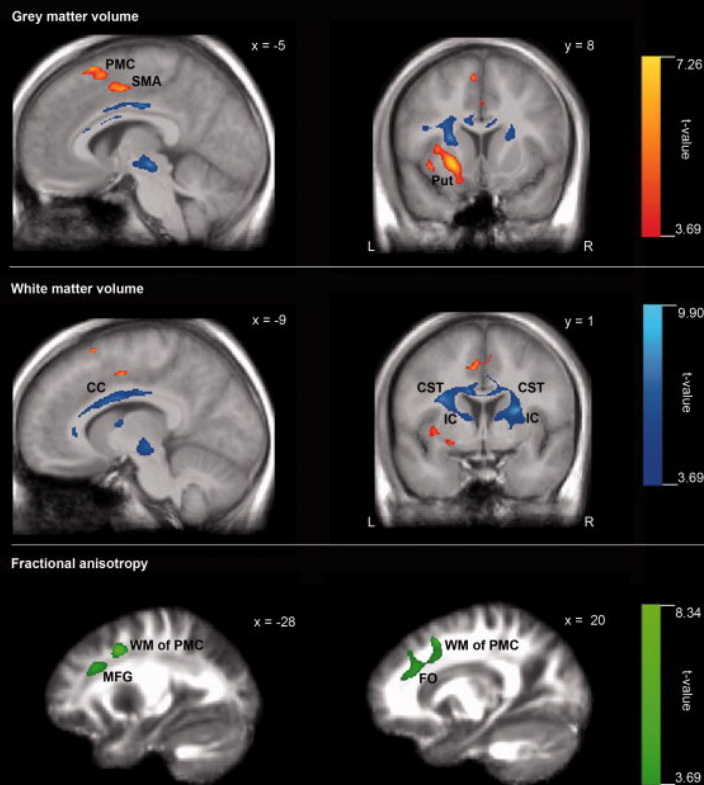


Rot: GM +, blau: WM -, grün: FA -

Jäncke L. et al., *PLoS ONE* 2009

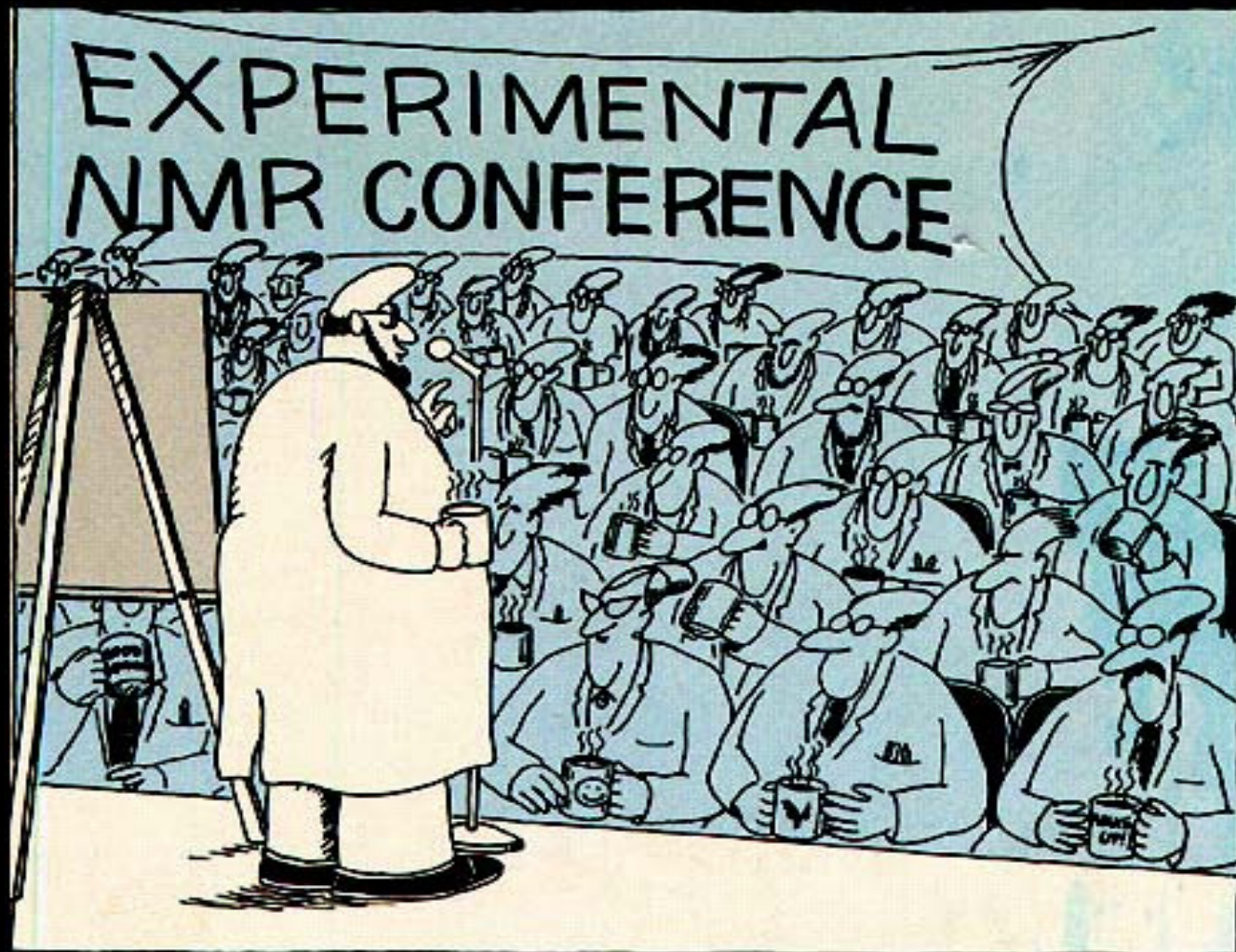
VBM & FA

Profi vs. Amateur



Rot: GM -, blau: WM -, grün: FA -

Hänggi J. et al., *HBM* 2010

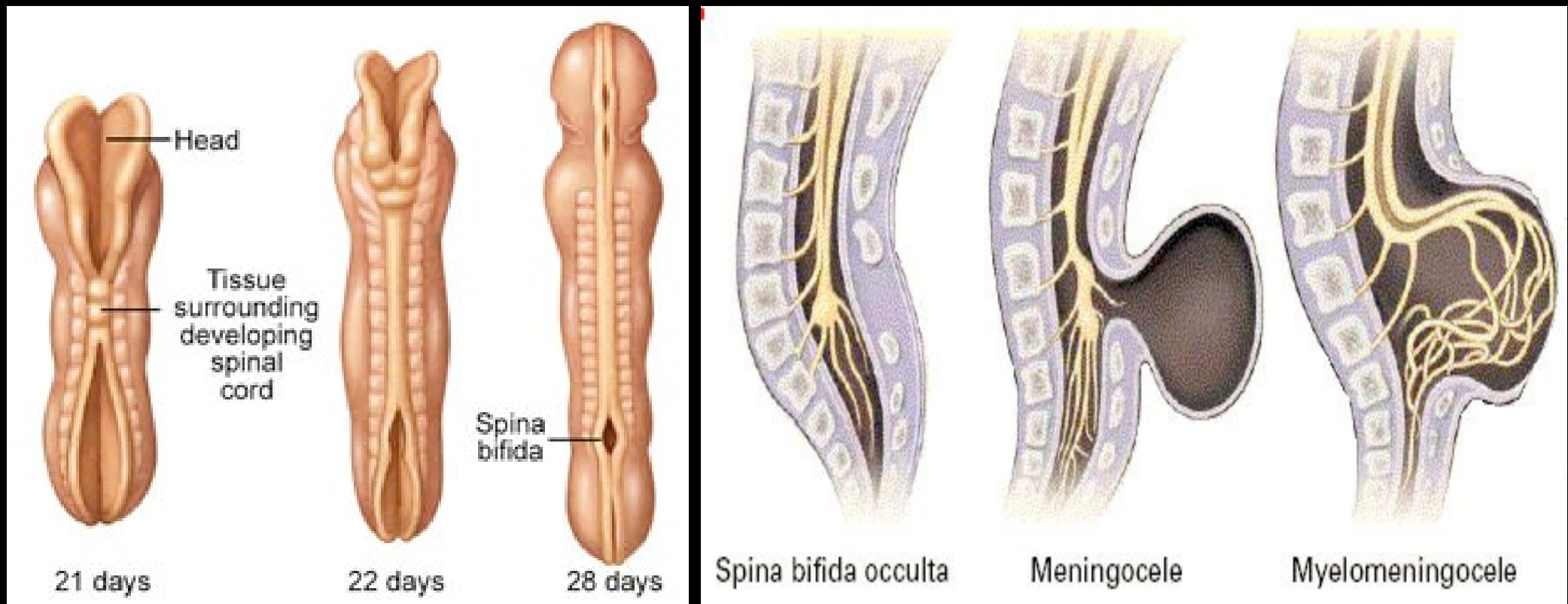


"Therefore, we can draw the conclusion that long-term exposure to high magnetic fields has no known harmful physical effect."

THX for your ATTN!

Motorisches System

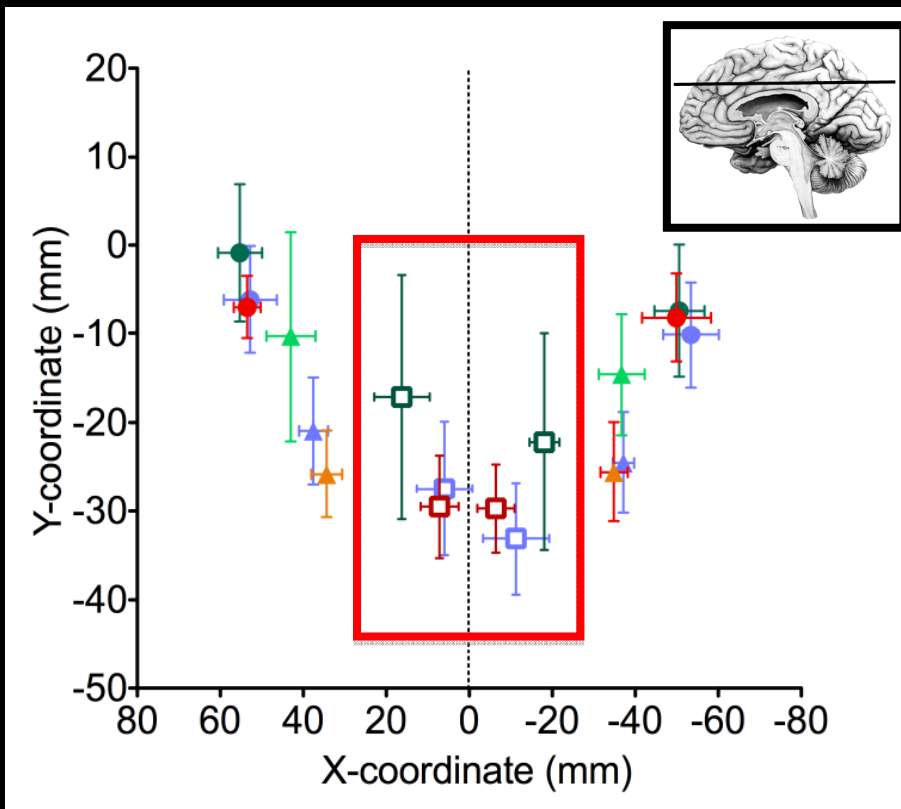
Rückenmark: Embryologie & MMC



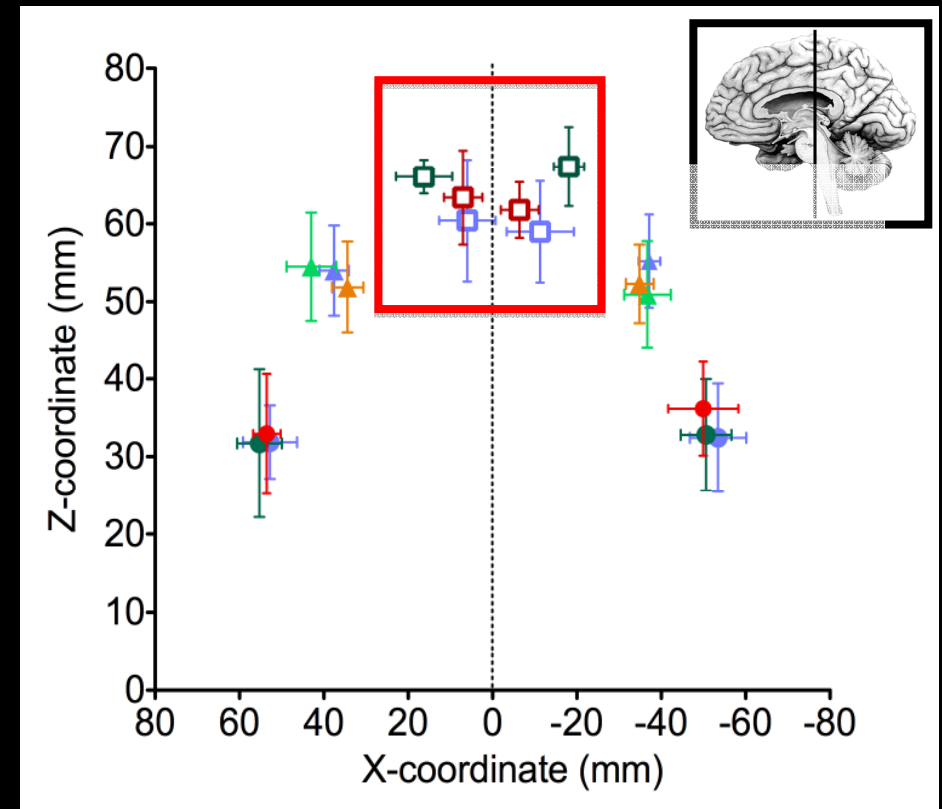
Schemazeichnung Transversalschnitt

M1 Somatotopie

VP, MMC & SCI



transversal



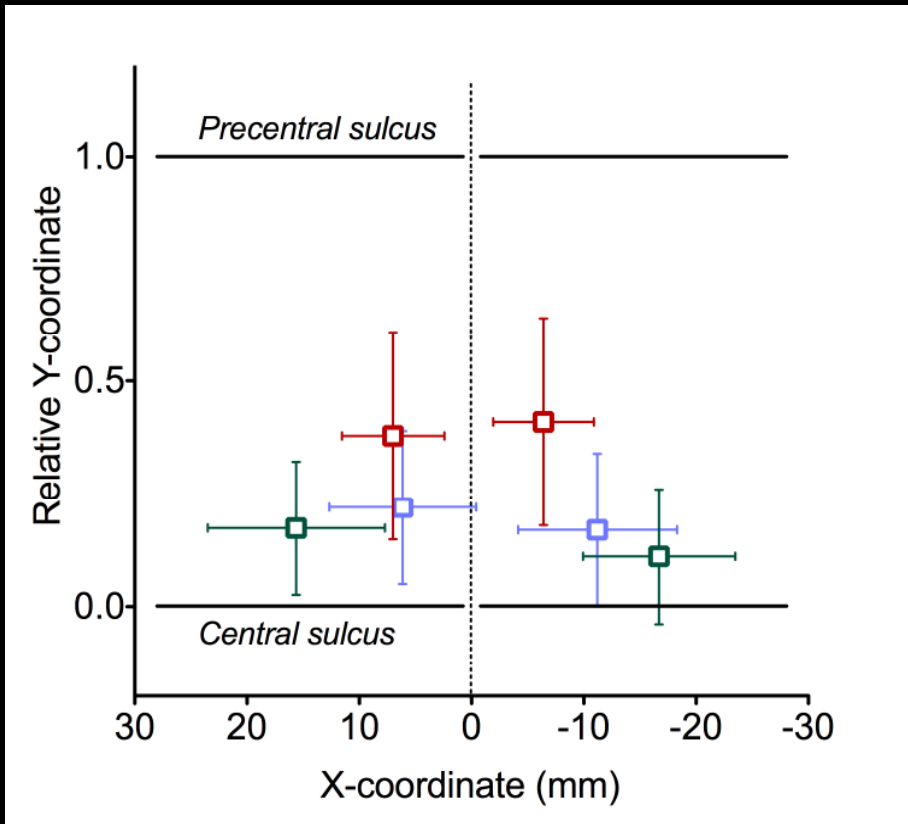
Mittelwerte

koronar

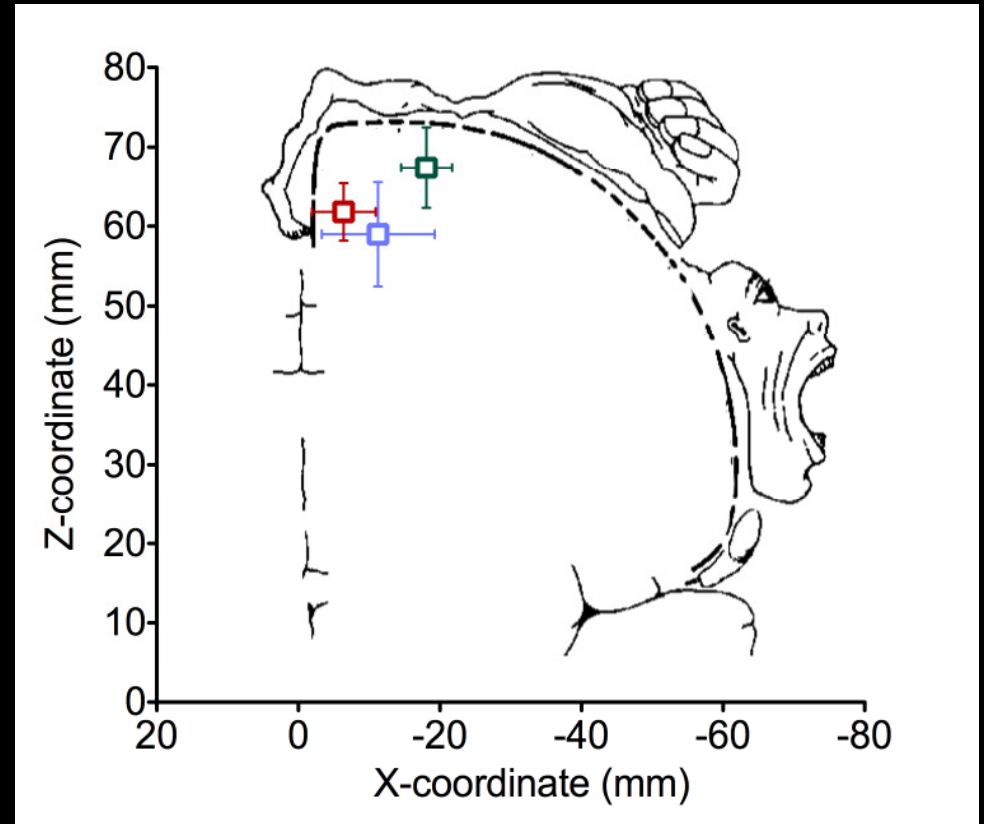
VP: Blau, MMC: Grün, SCI: Rot

M1 Fussrepräsentation

VP, MMC & SCI



transversal



koronar

Mittelwerte

VP: Blau, MMC: Grün, SCI: Rot