

# Bioingegneria per le Neuroscienze

**Fabio Baselice**

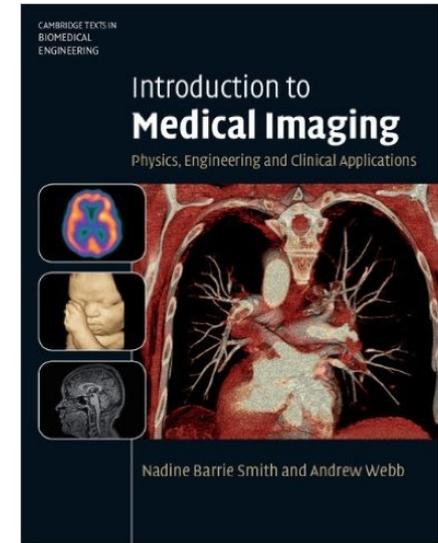
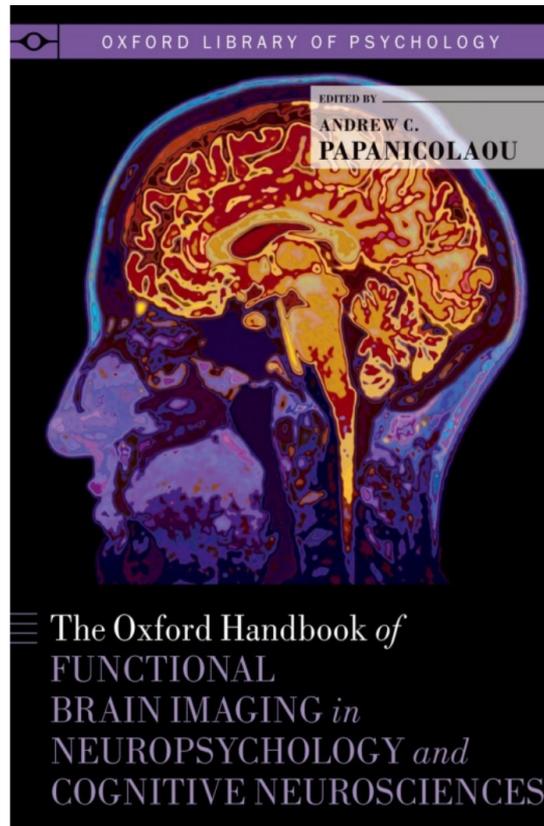
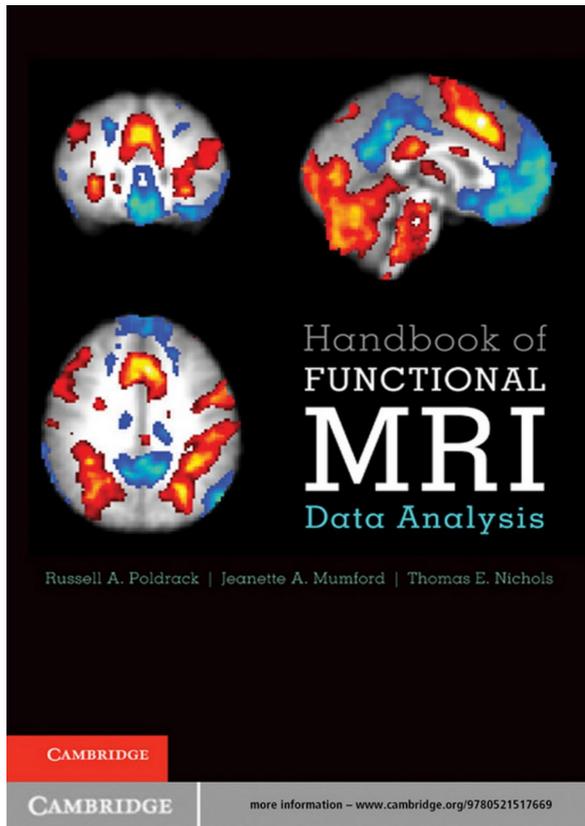
*Laurea in  
Ingegneria delle tecnologie dell'informazione  
per le comunicazioni e la salute*



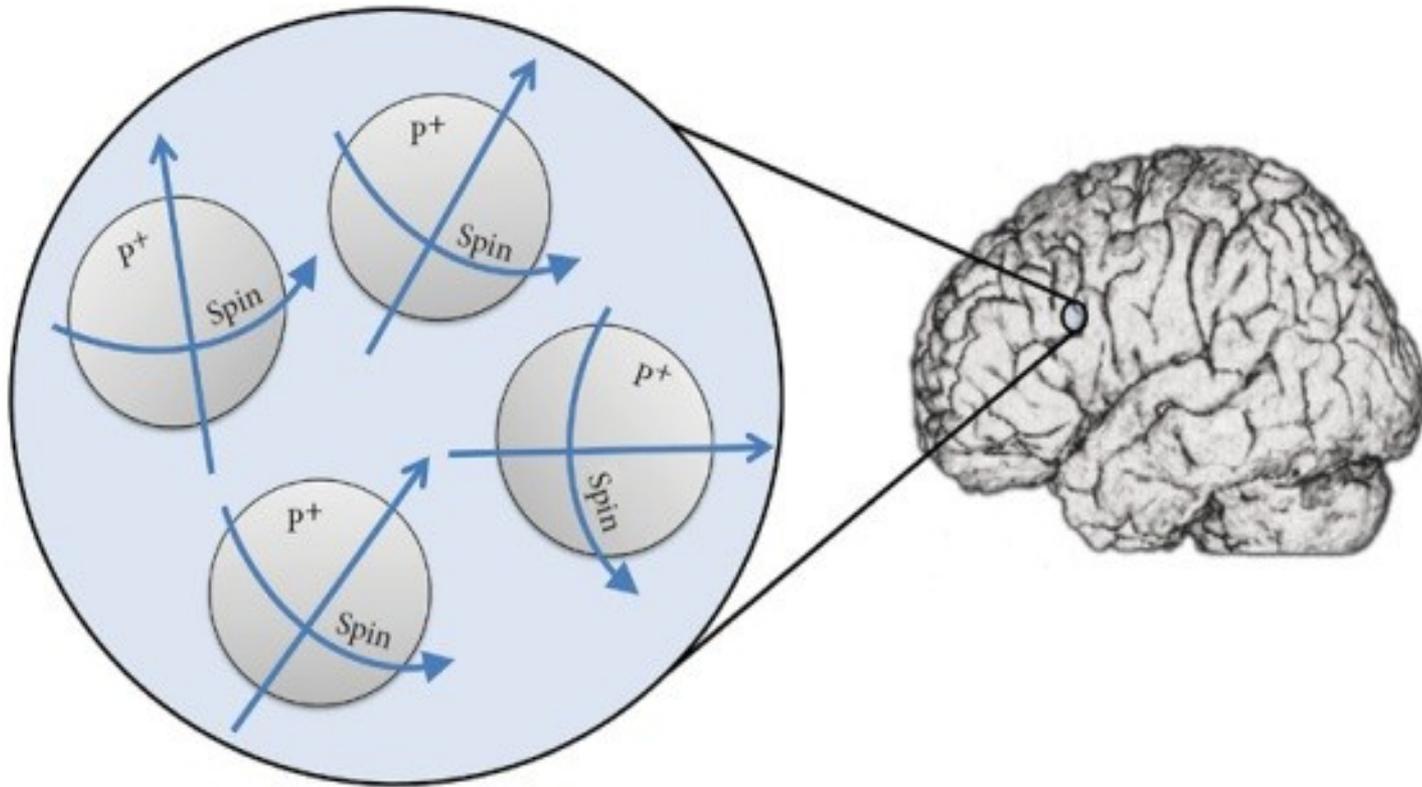
# Argomenti

- Richiami MRI
- Gradient-echo echoplanar imaging (EPI)
- fMRI
- Preprocessing
  - Distorsion correction
  - Slice-timing correction
  - Motion correction
  - Spatial normalization

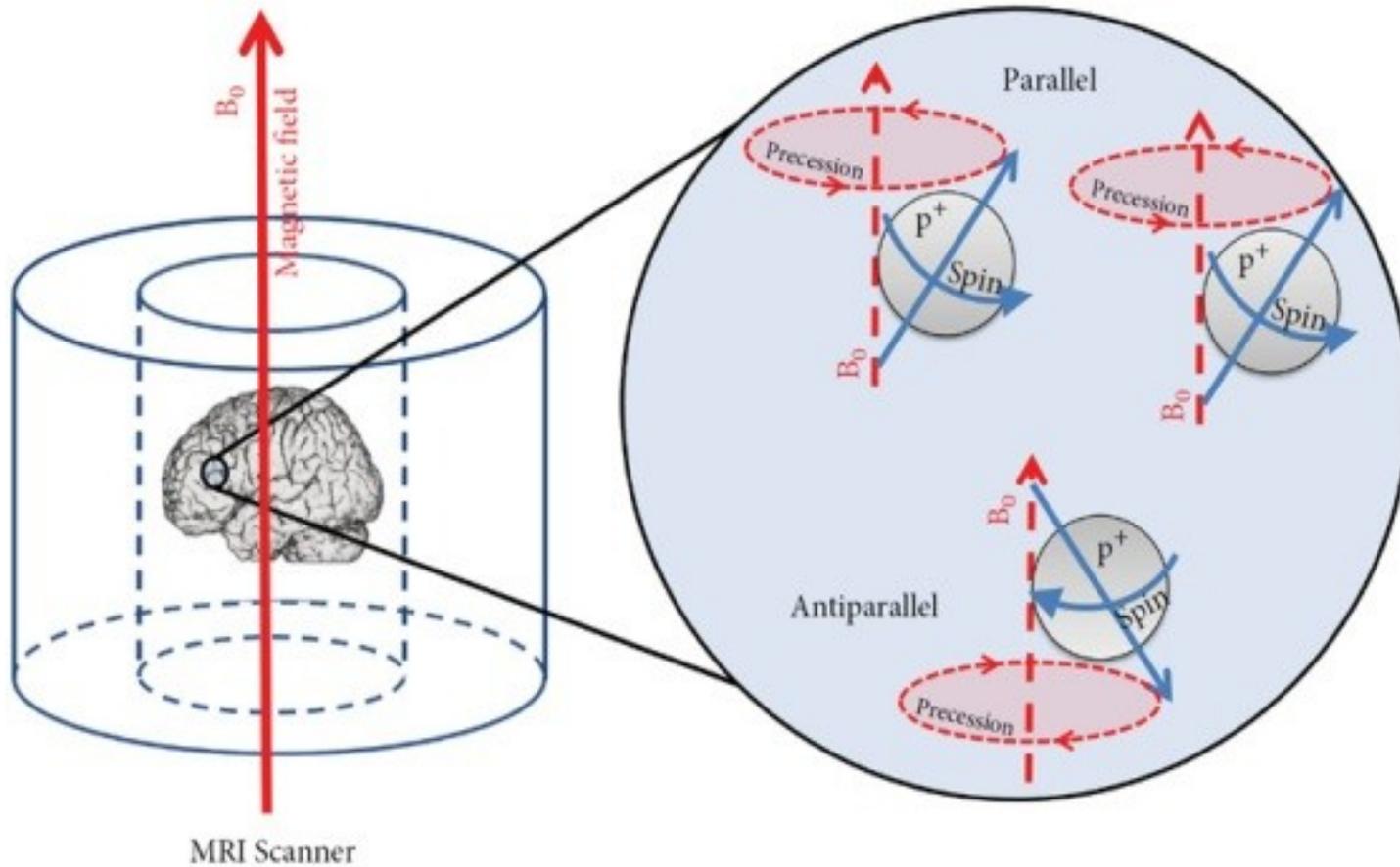
# Riferimenti



# Richiami MRI

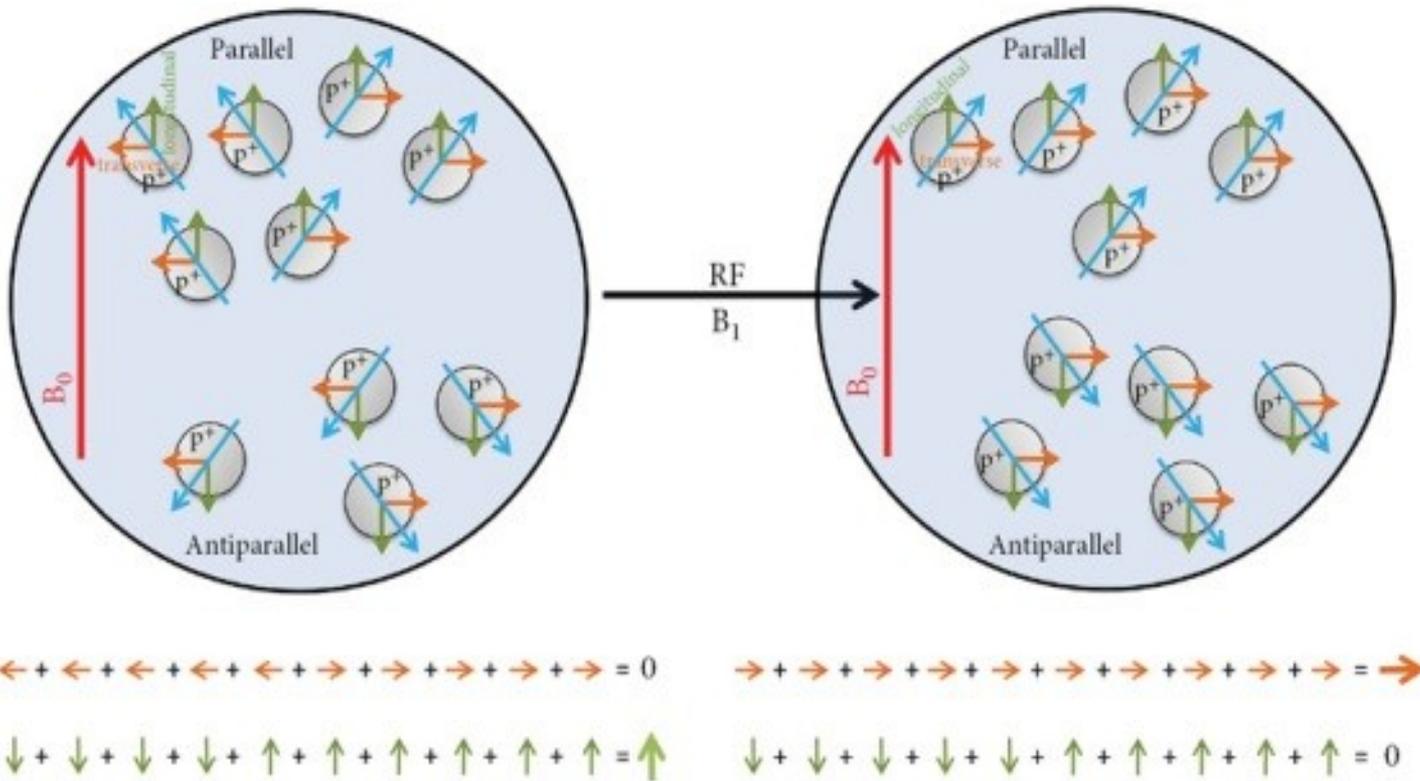


# Richiami MRI

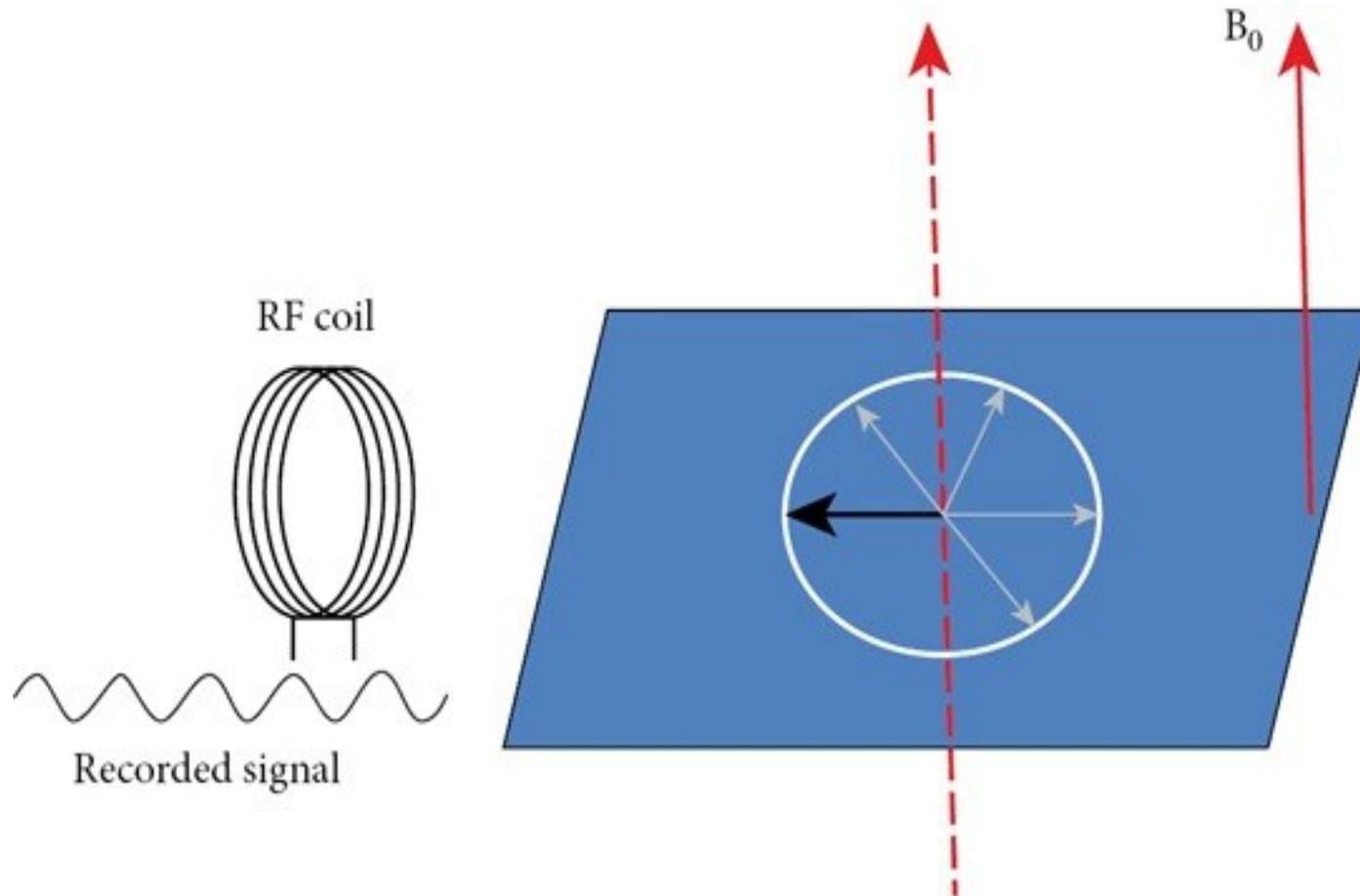




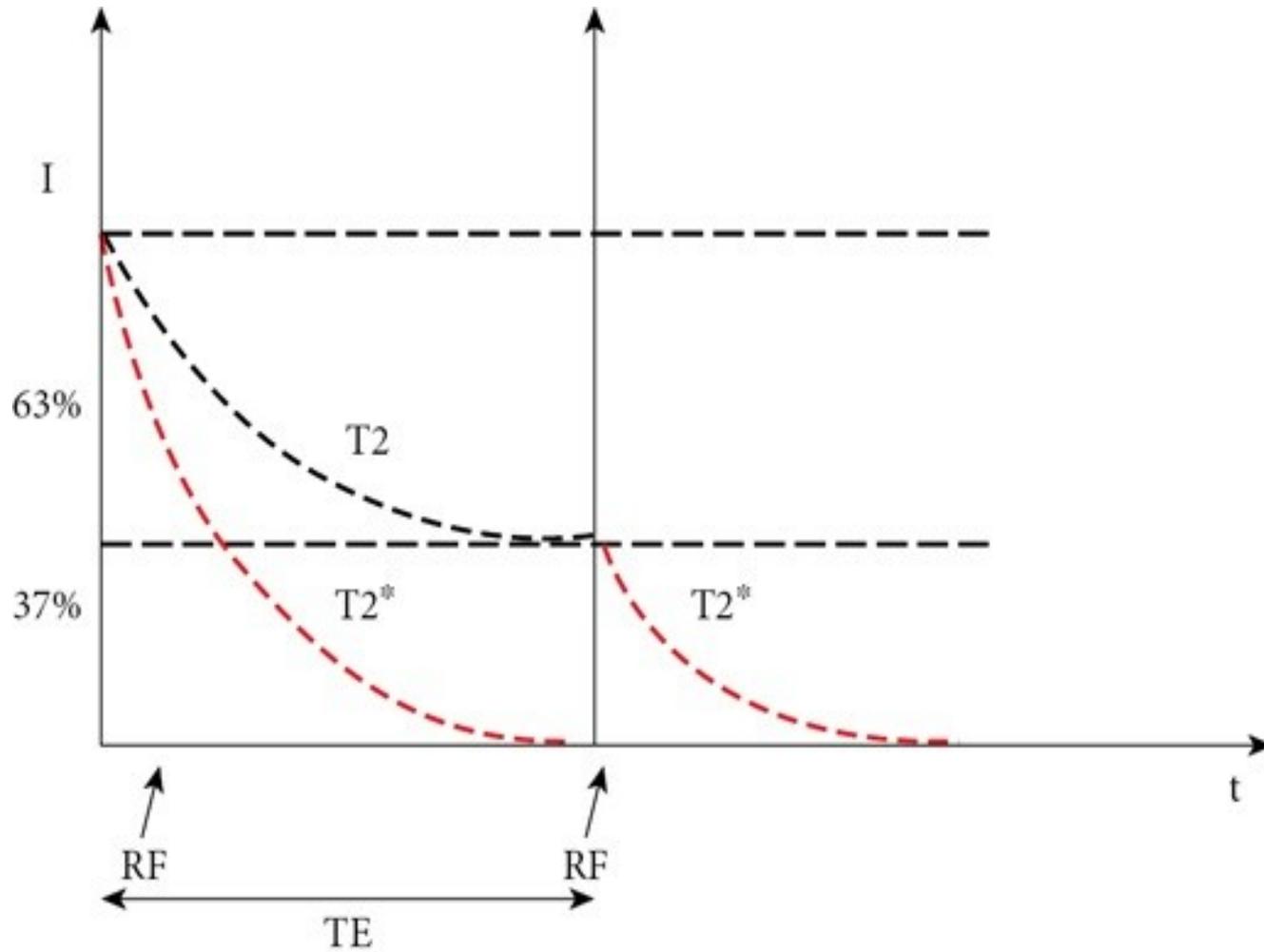
# Richiami MRI – impulsi RF



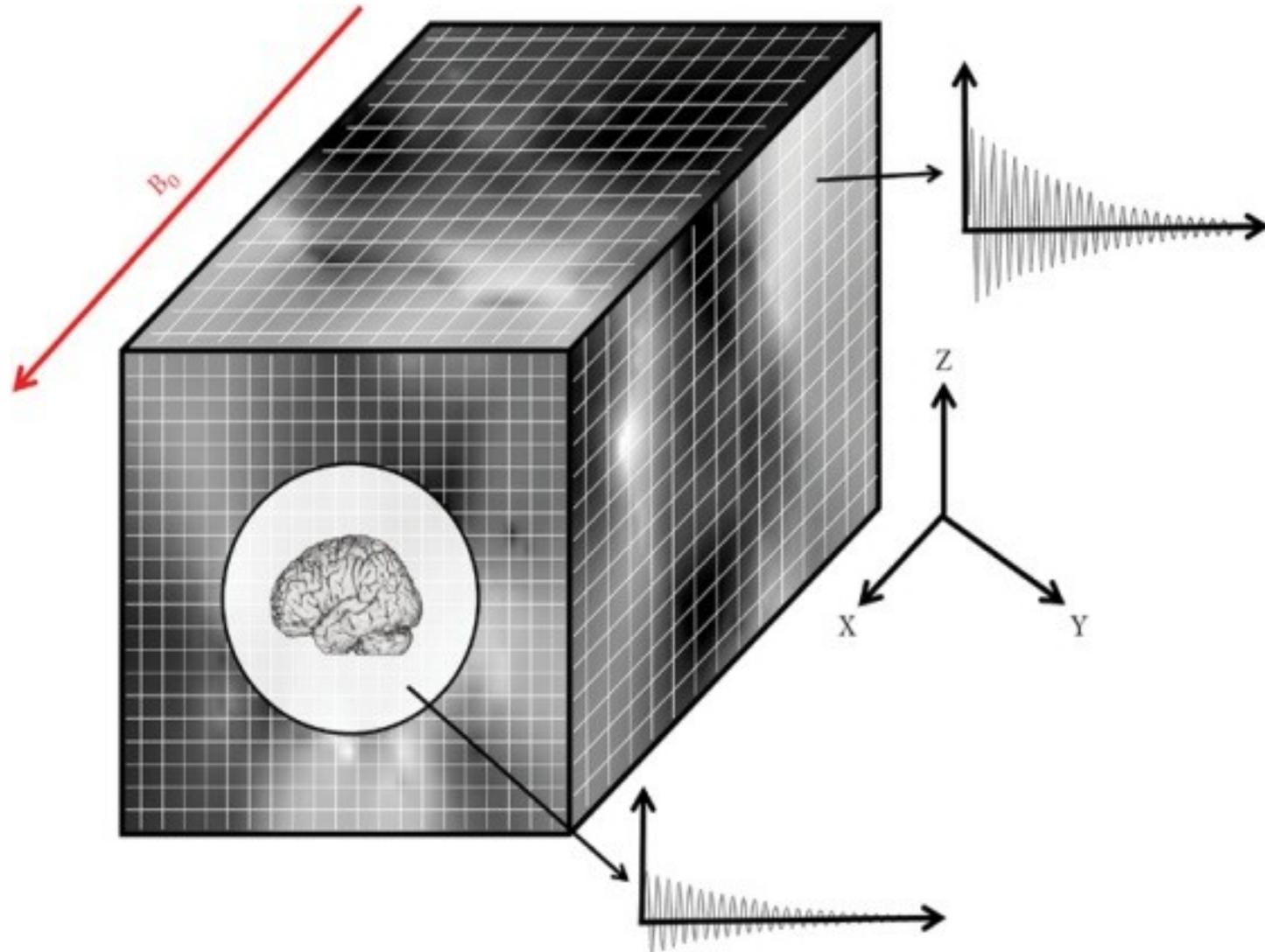
# Richiami MRI – impulsi RF



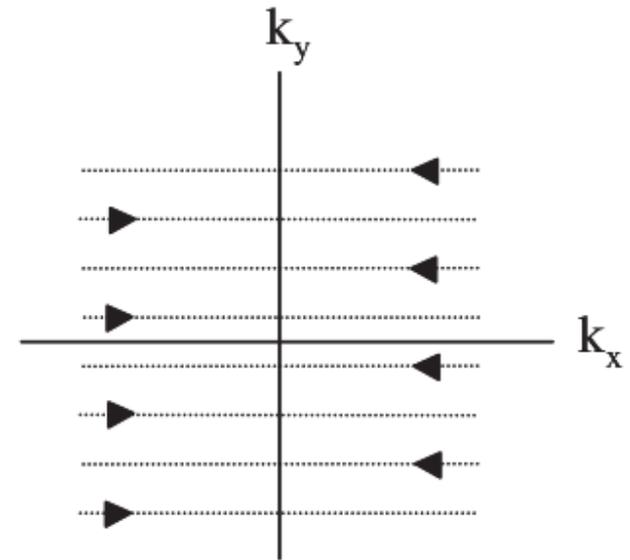
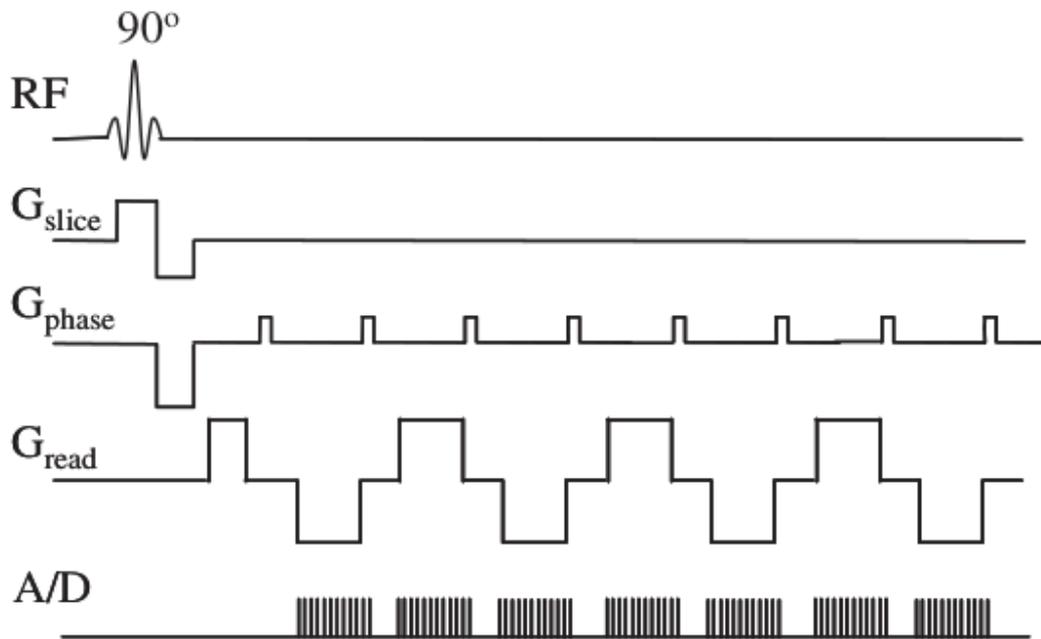
# Richiami MRI - rilassamento



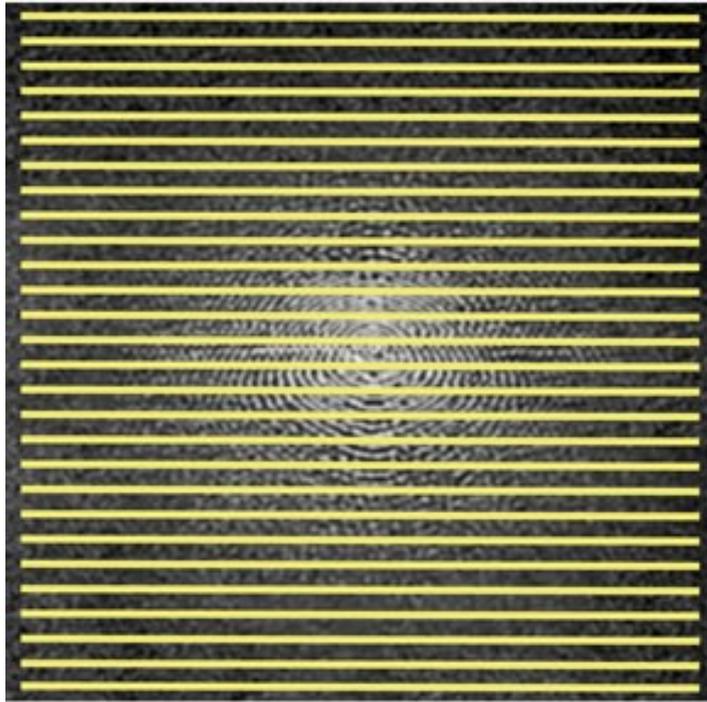
# Richiami MRI - gradienti



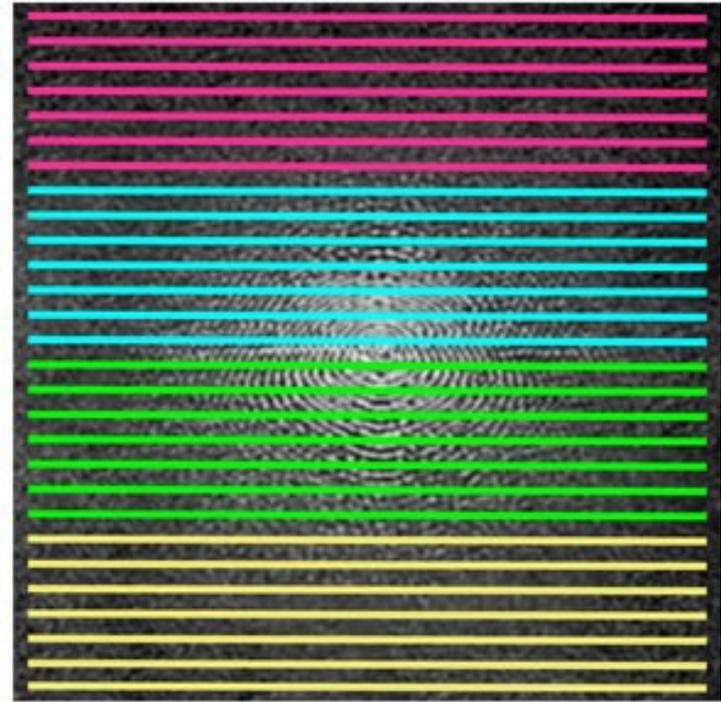
# Echo Planar Imaging (EPI)



# EPI

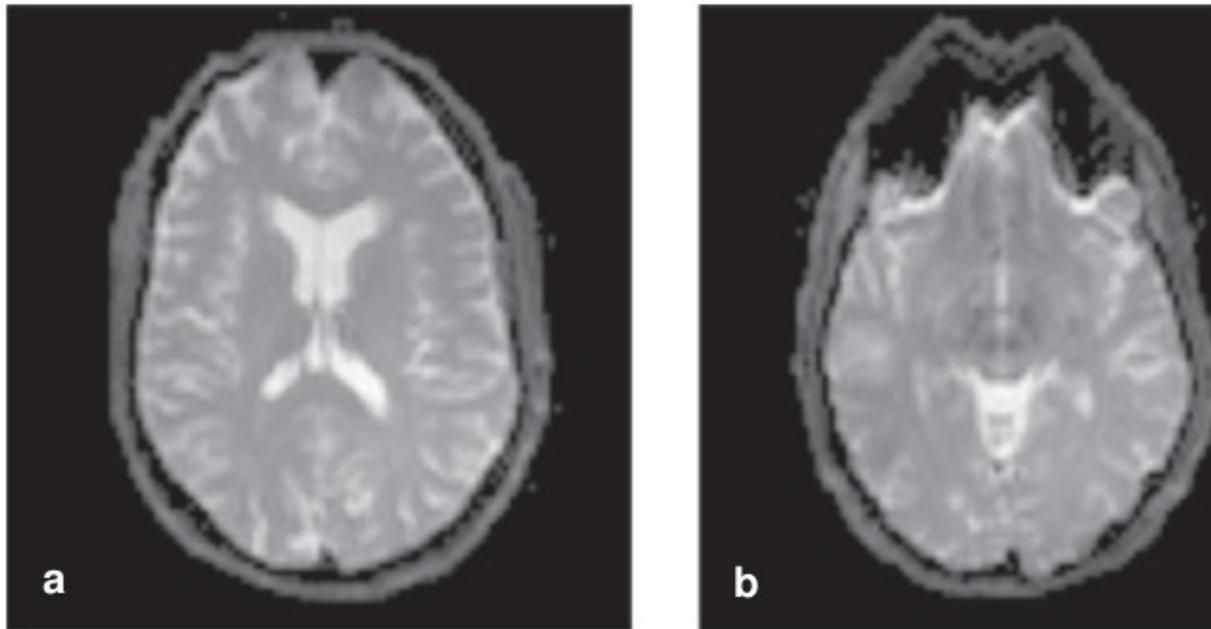


Single Shot



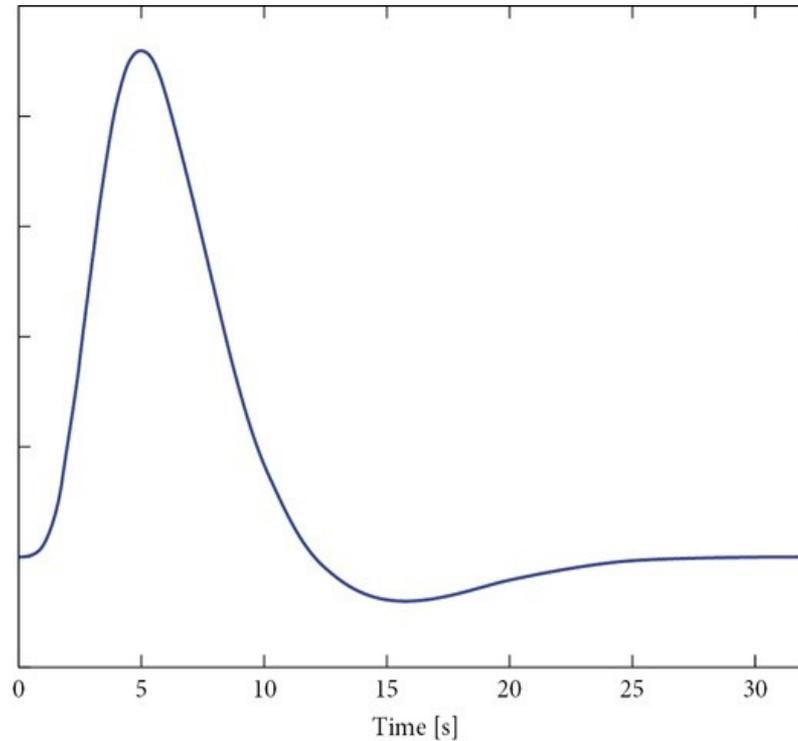
Multi-Shot

# EPI



Le cavità nasali (interfaccia aria/acqua) producono artefatti (b).

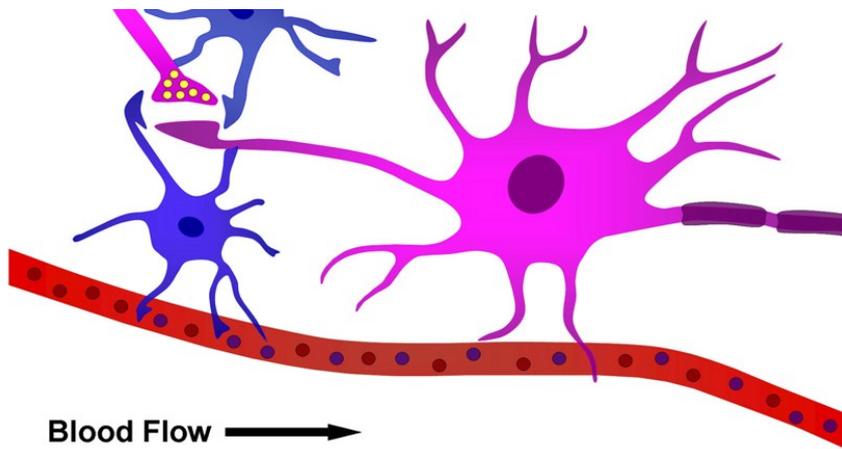
# Segnale BOLD



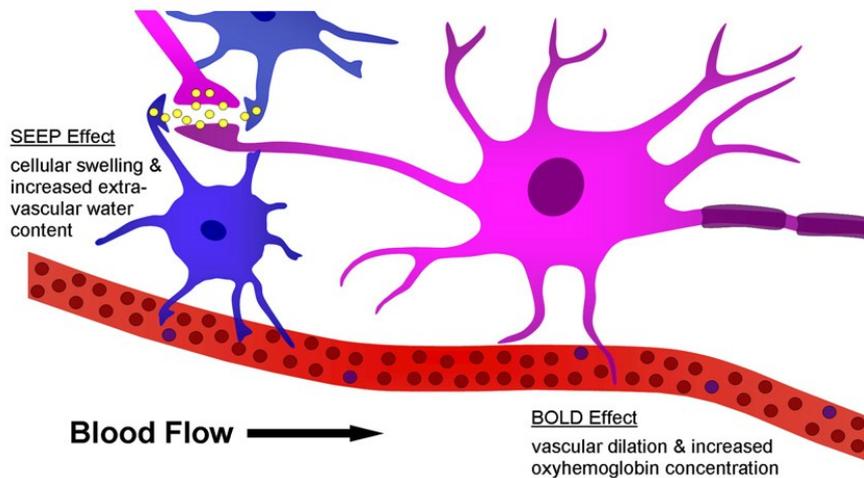
Risposta emodinamica.

# Segnale BOLD

Resting  
Baseline



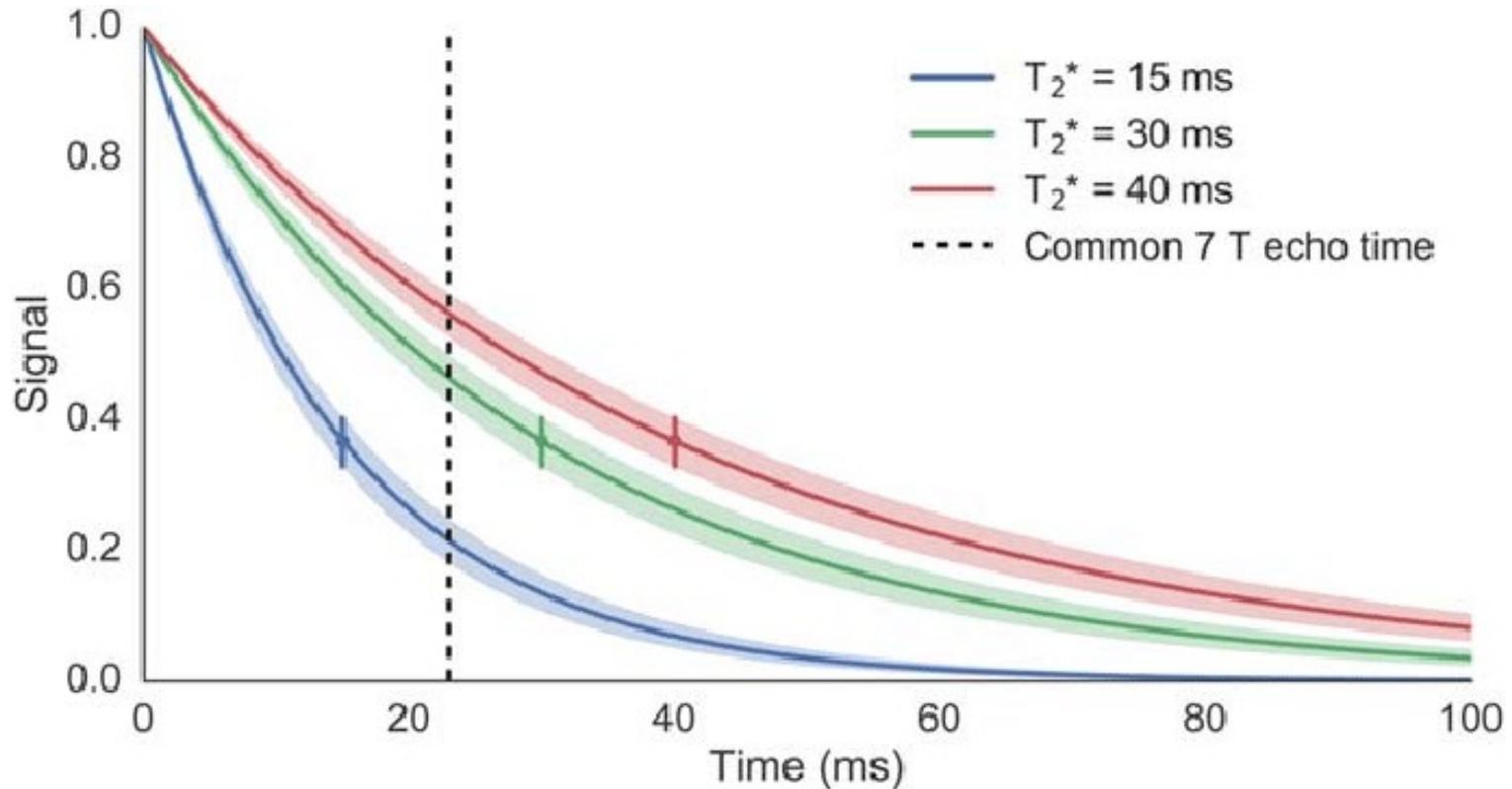
Neuronal  
Activation



- Neuron
- Astrocyte
- Capillary
- Neurotransmitter
- Deoxyhemoglobin
- Oxyhemoglobin



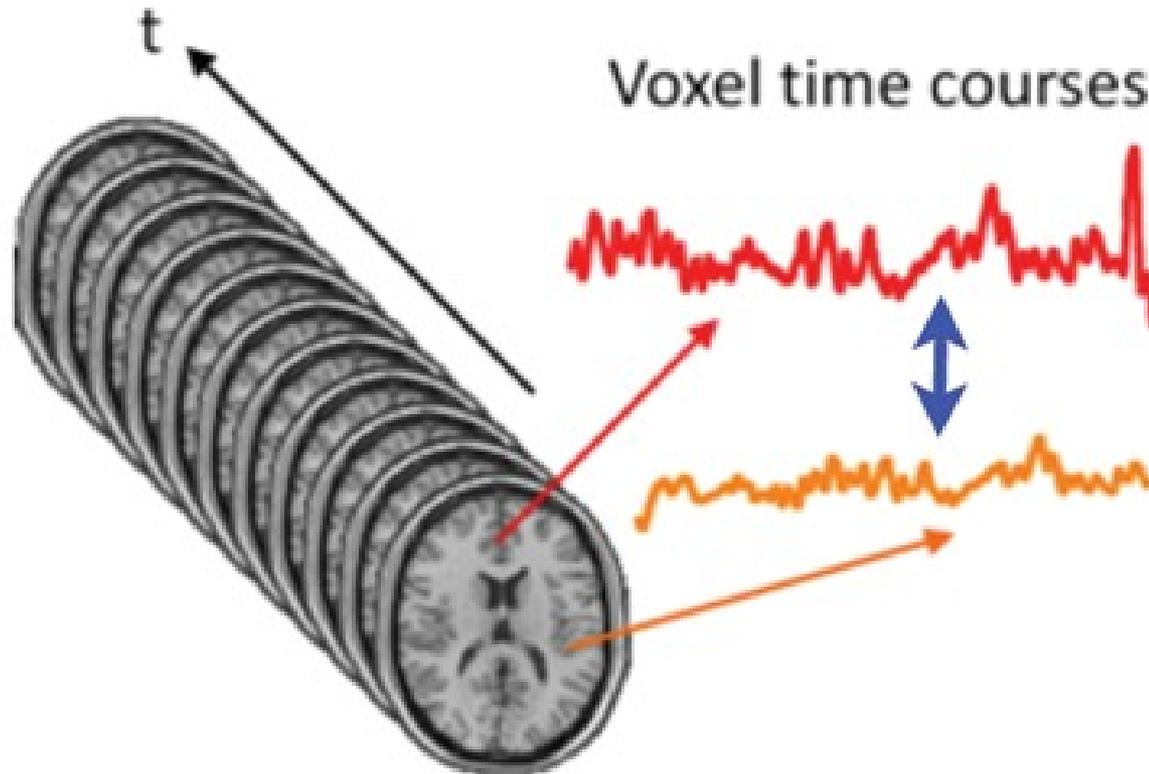
# Segnale BOLD



La concentrazione di emoglobina ossigenata fa variare il  $T_2^*$ .

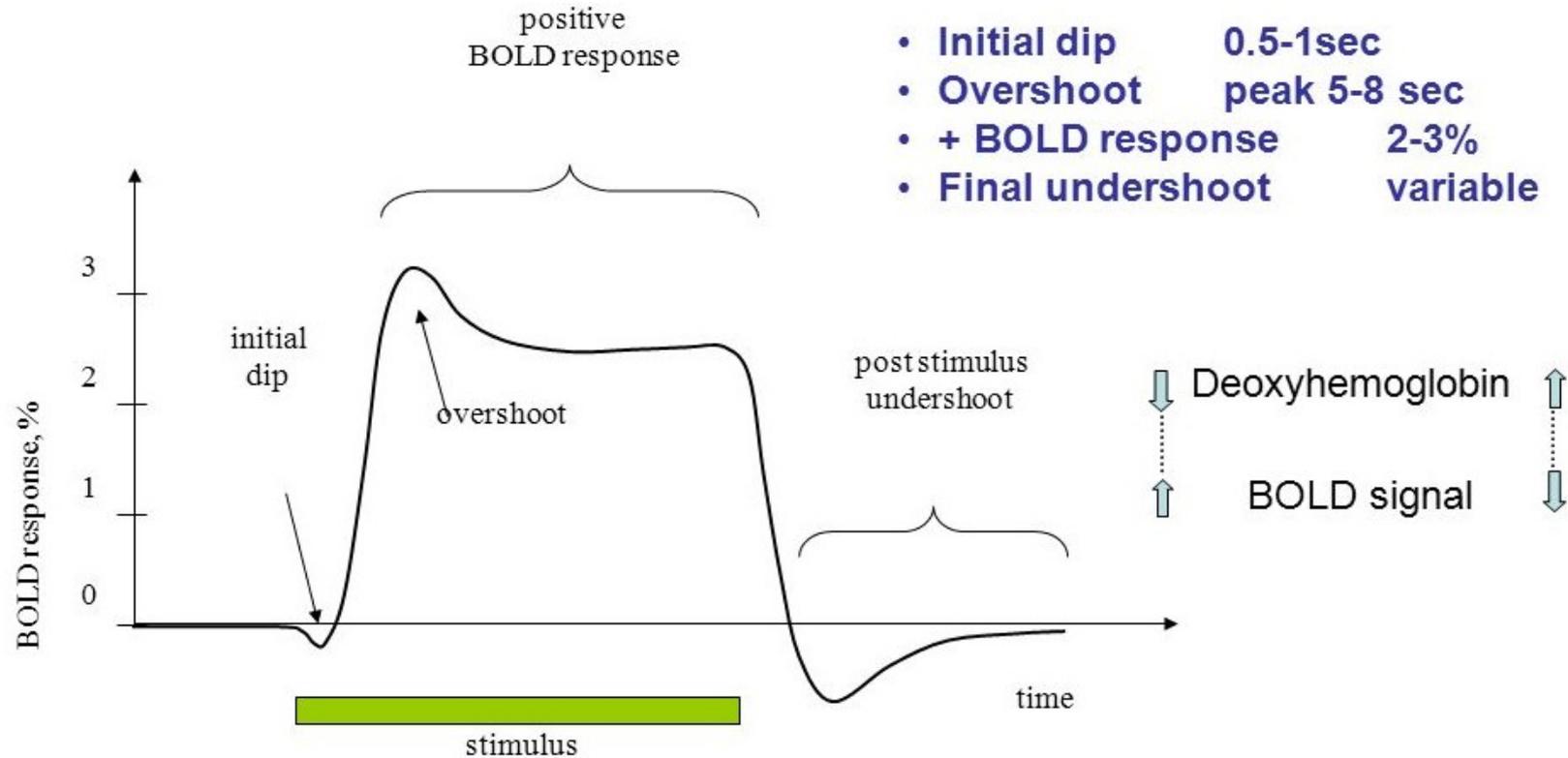


# Segnale BOLD

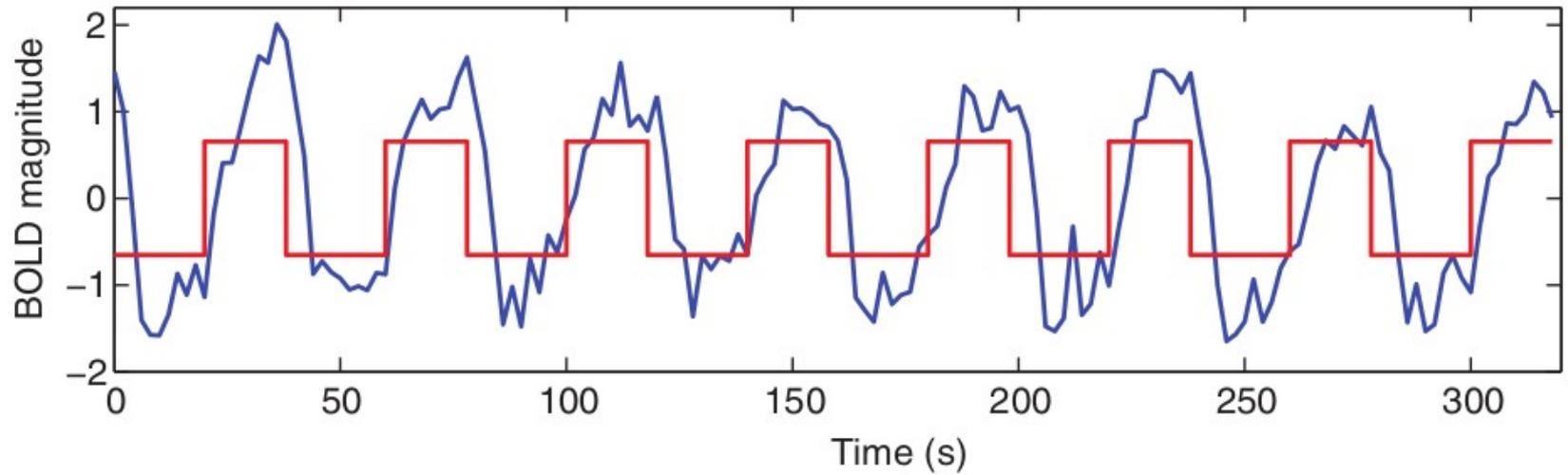


Misuriamo la variazione temporale dell'intensità del segnale per ciascun voxel.

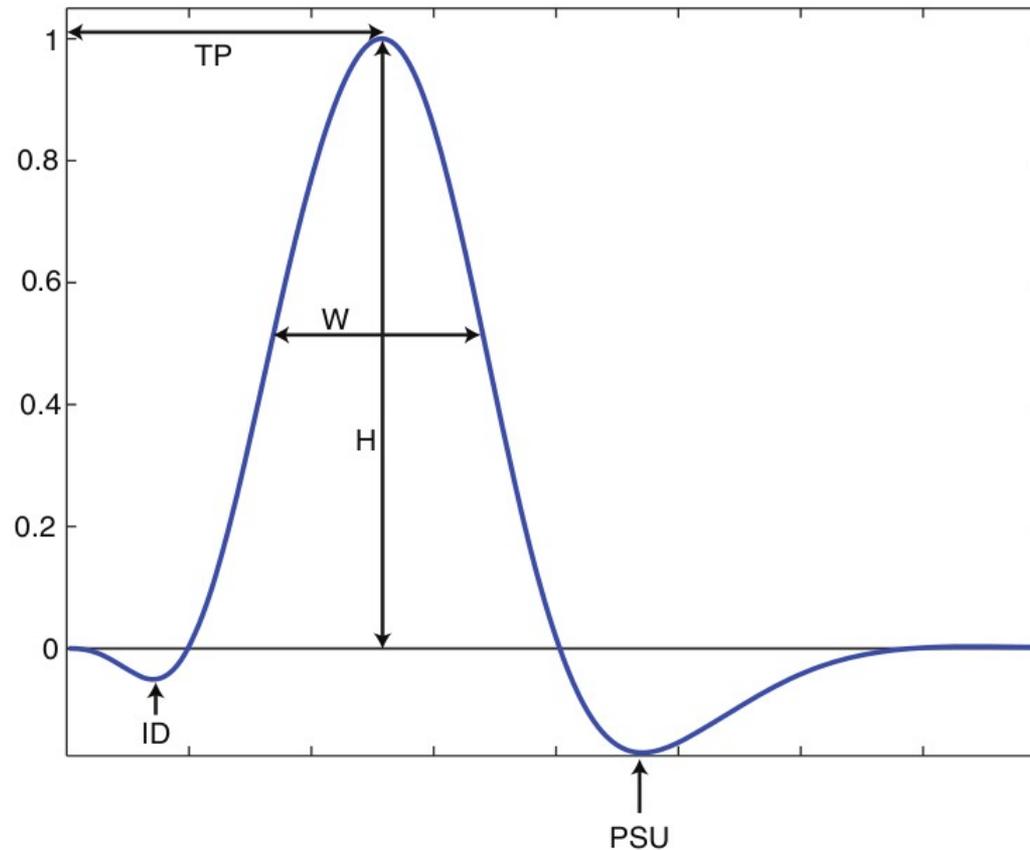
# Segnale BOLD



# Segnale BOLD

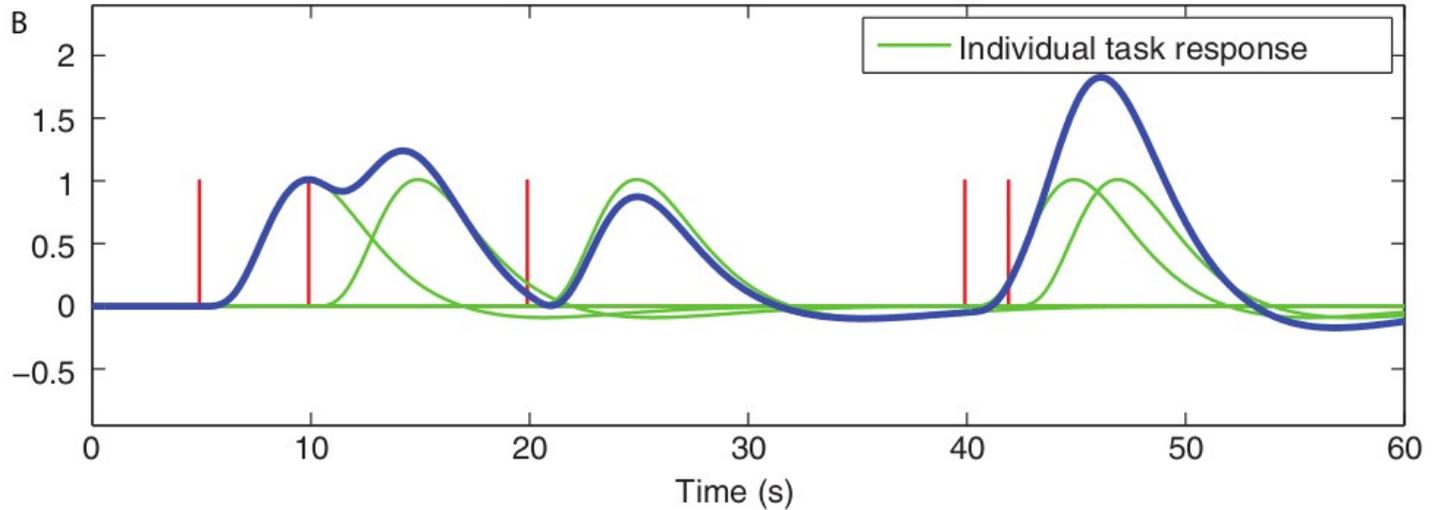
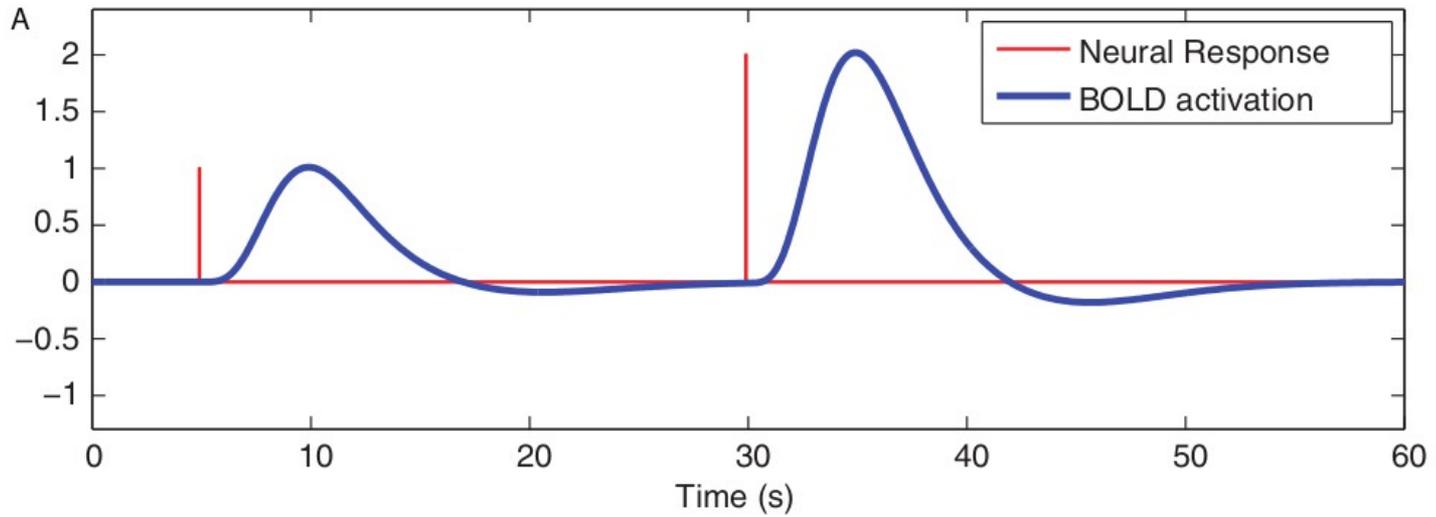


# Segnale BOLD

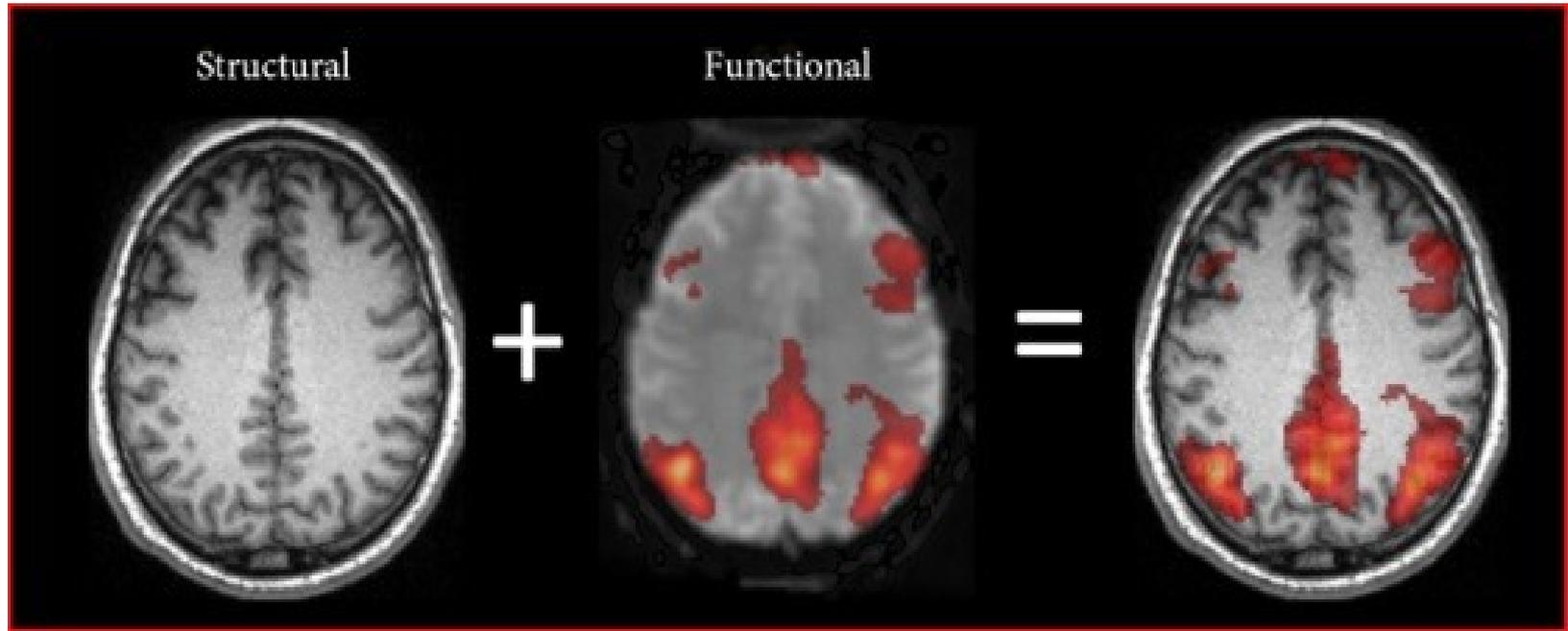


Initial dip (ID), time peak (TP), poststimulus undershoot (PSU).

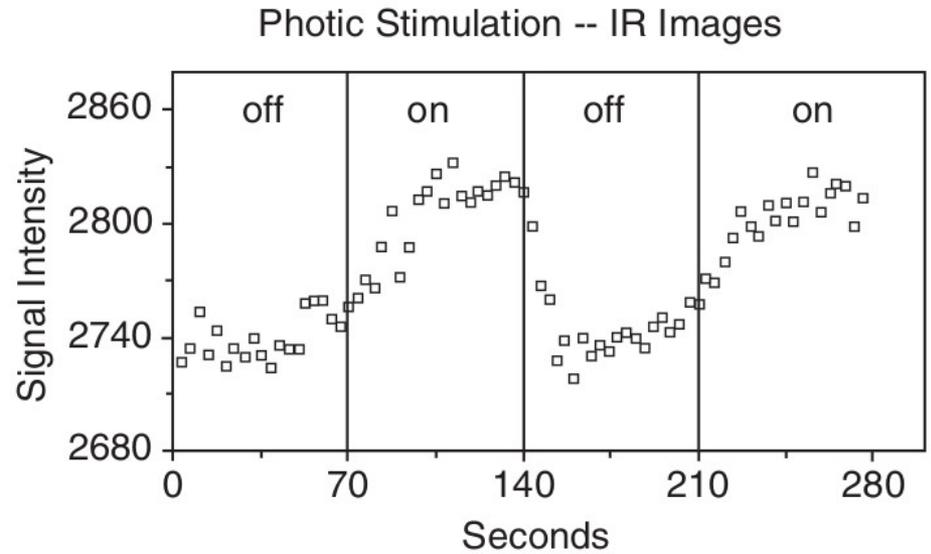
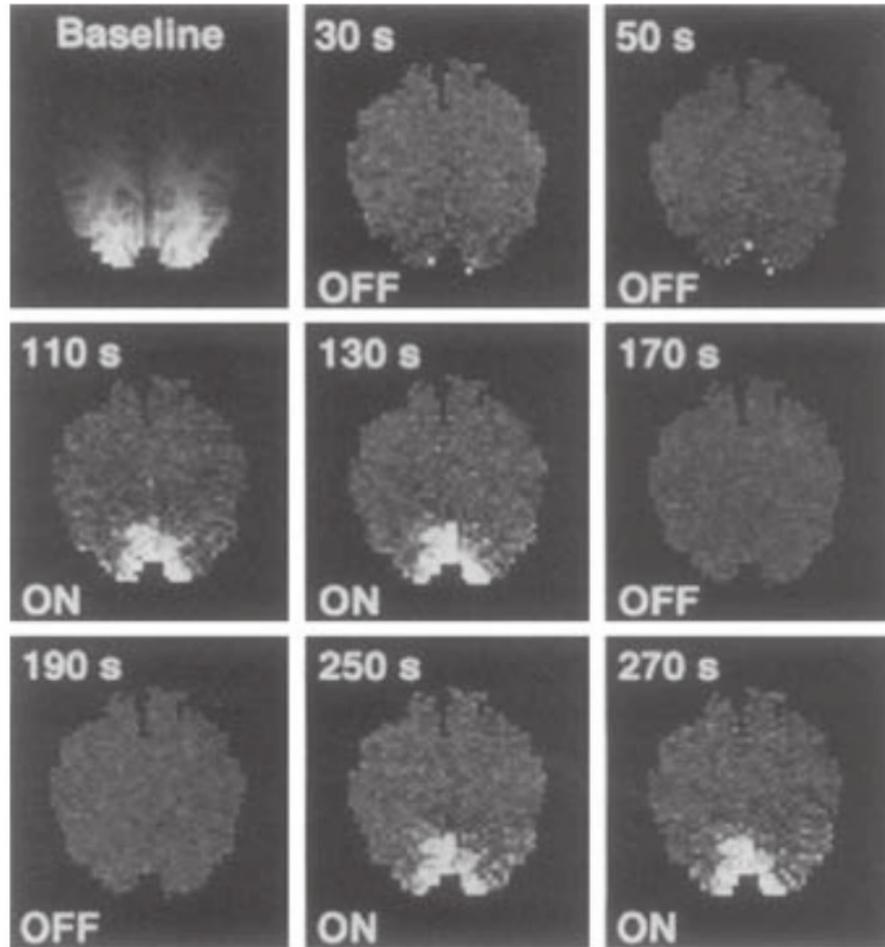
# Segnale BOLD



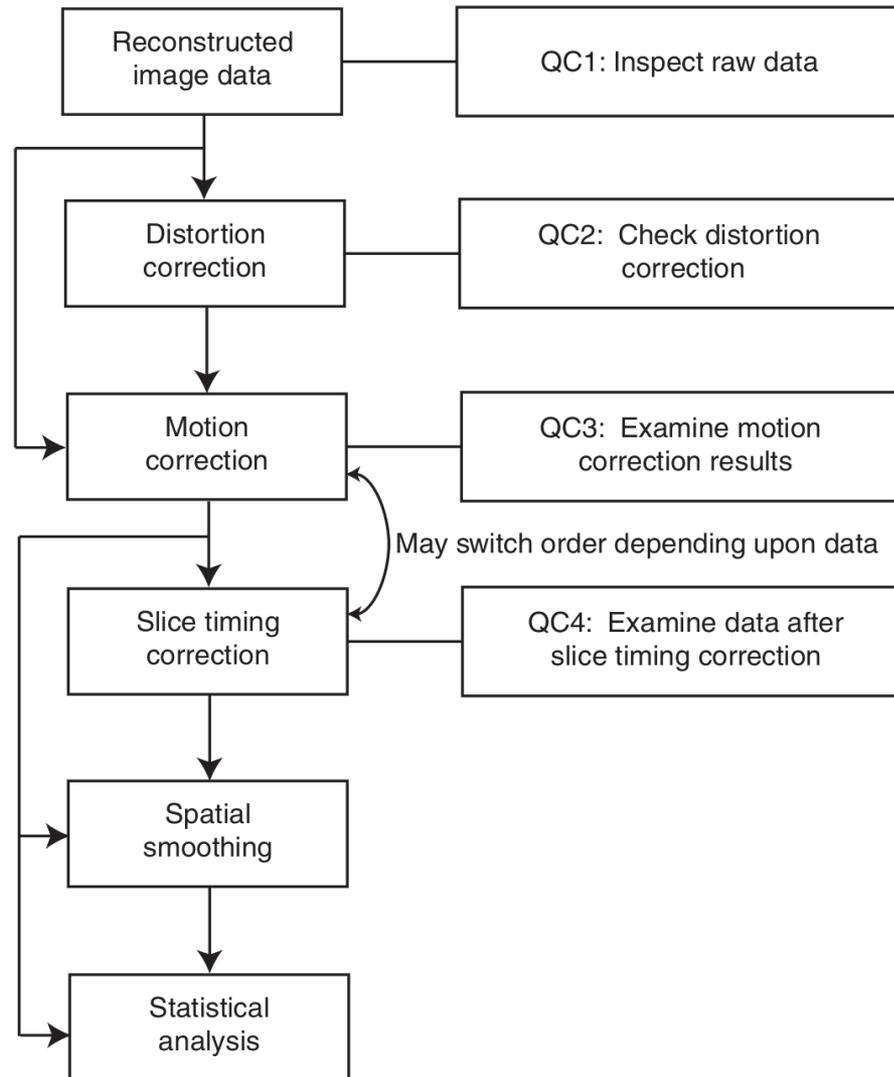
# MRI funzionale



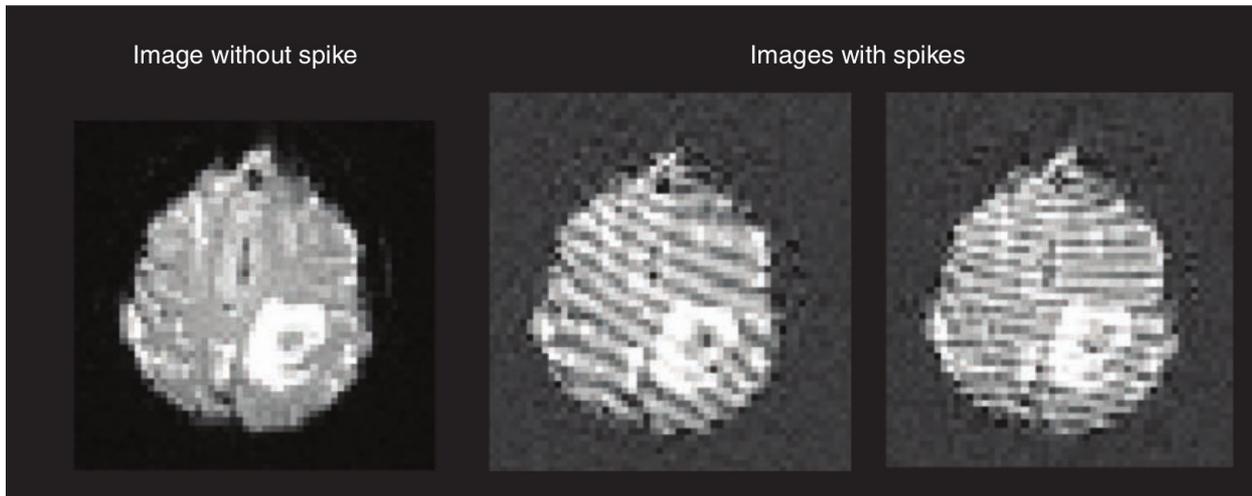
# fMRI



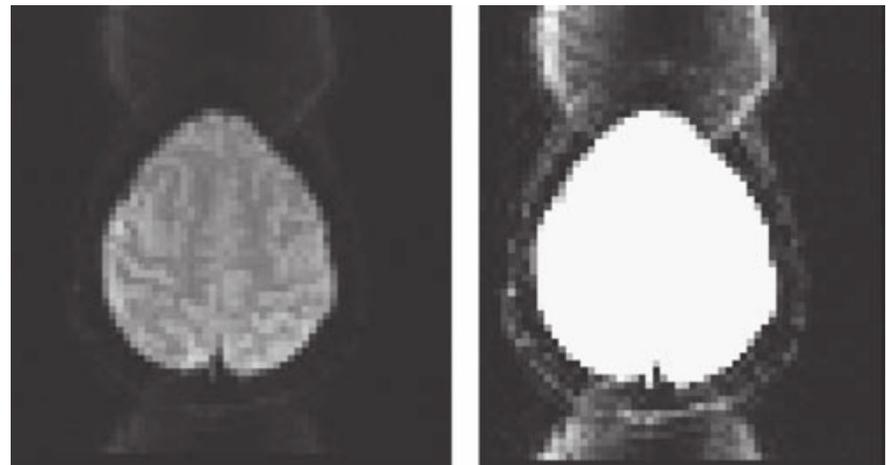
# fMRI preprocessing



# Artefatti



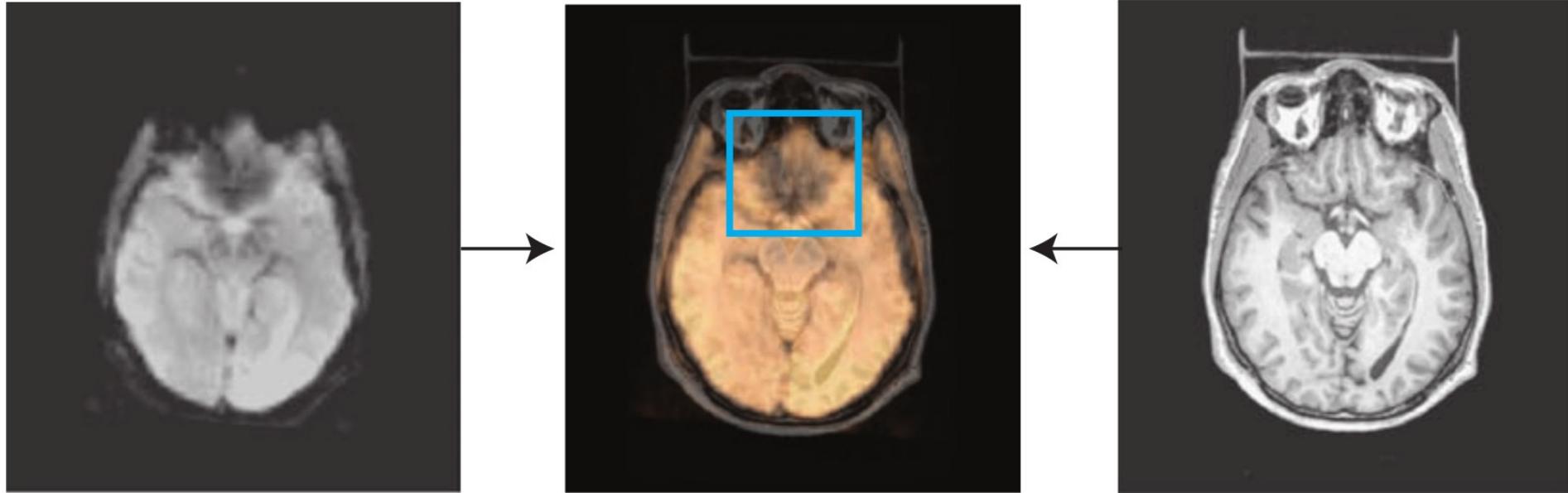
Ghosting



# Distortion correction

EPI

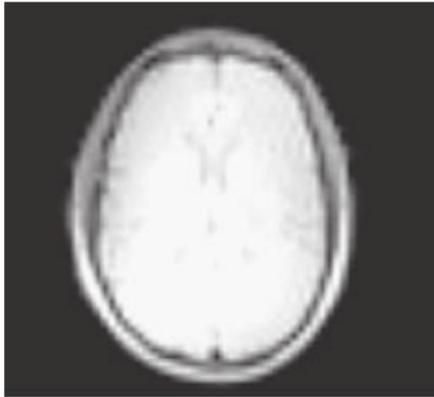
T1w



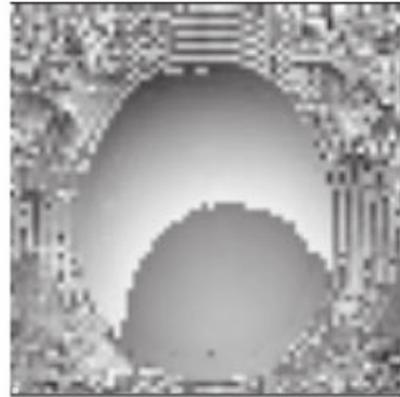
Dropout

# Distortion correction

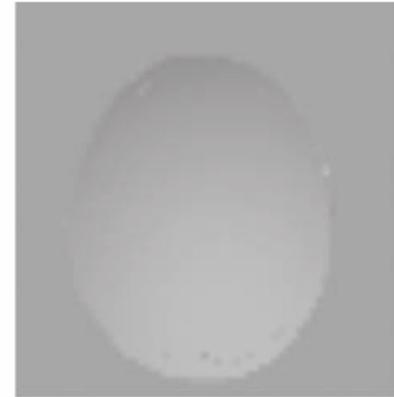
Field Map Images



Magnitude

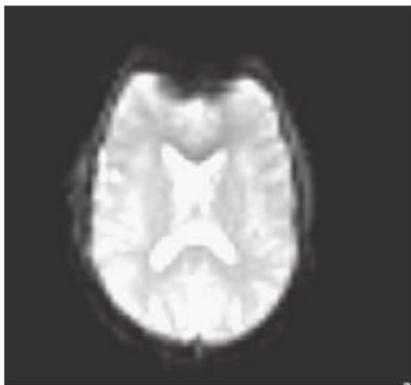


Phase (original)

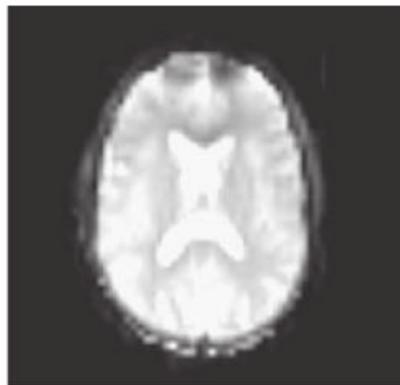


Phase (unwrapped)

Original EPI image



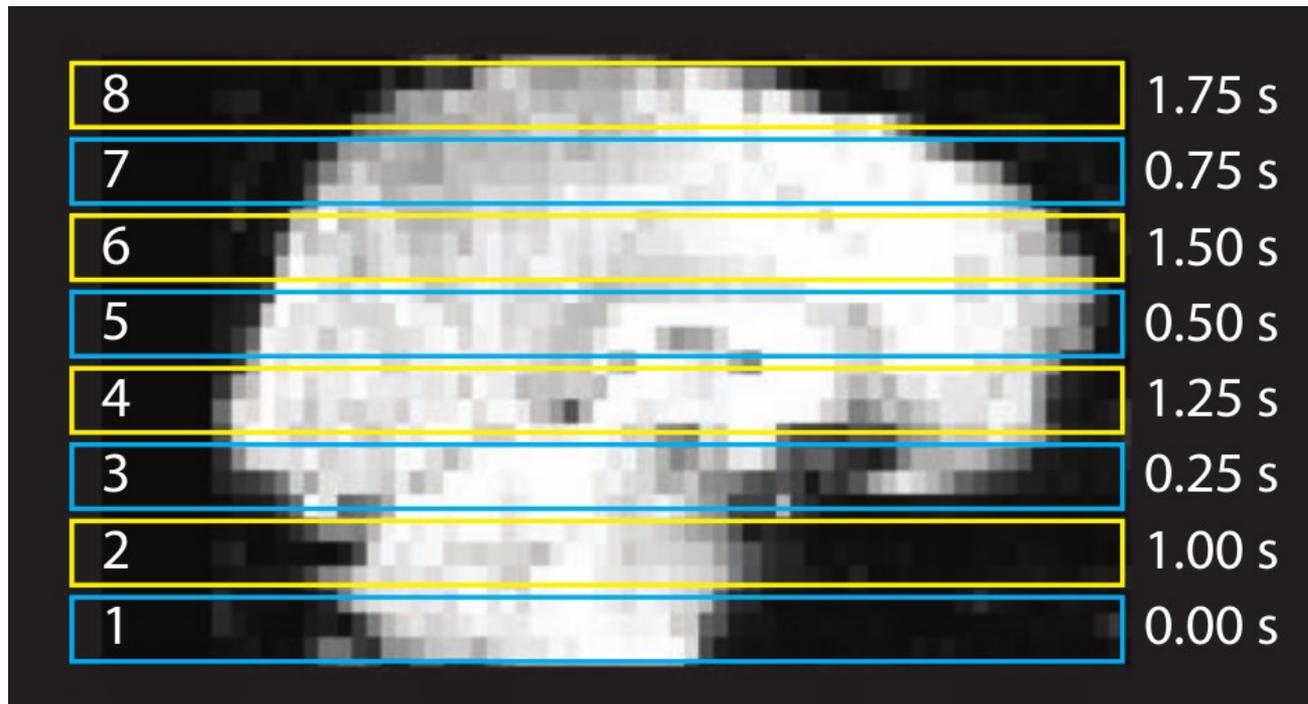
Unwarped EPI image



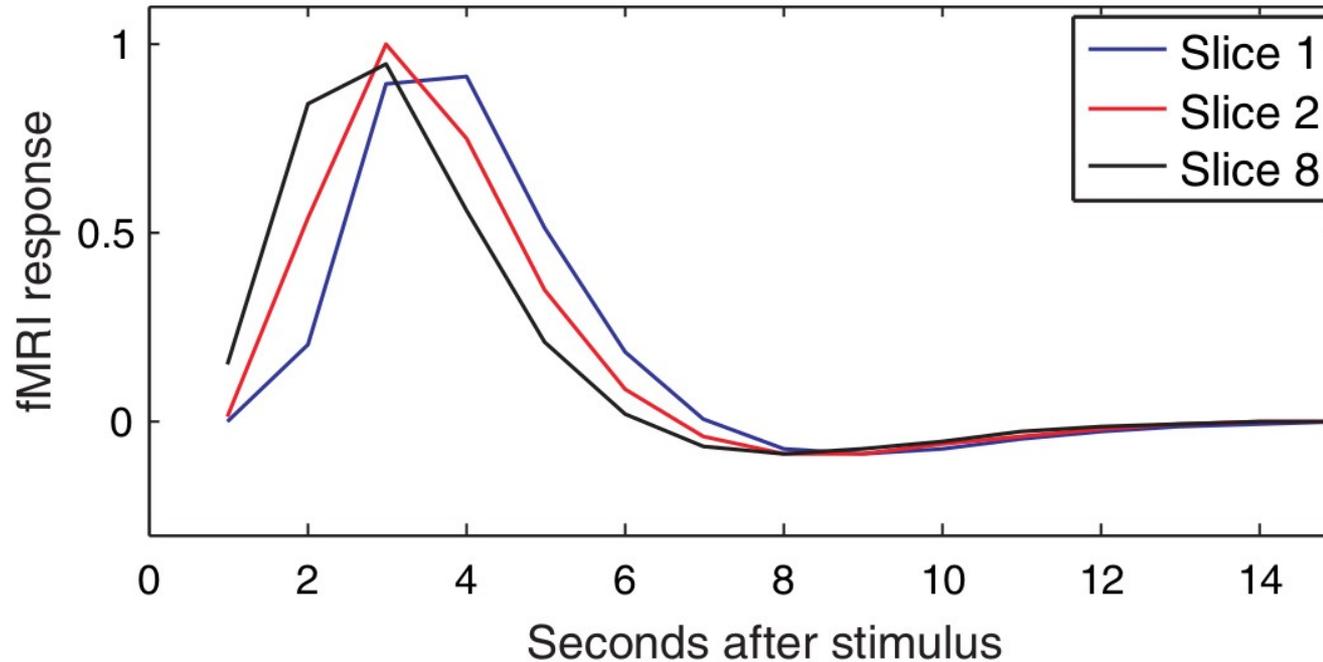
Difference image



# Slice timing correction

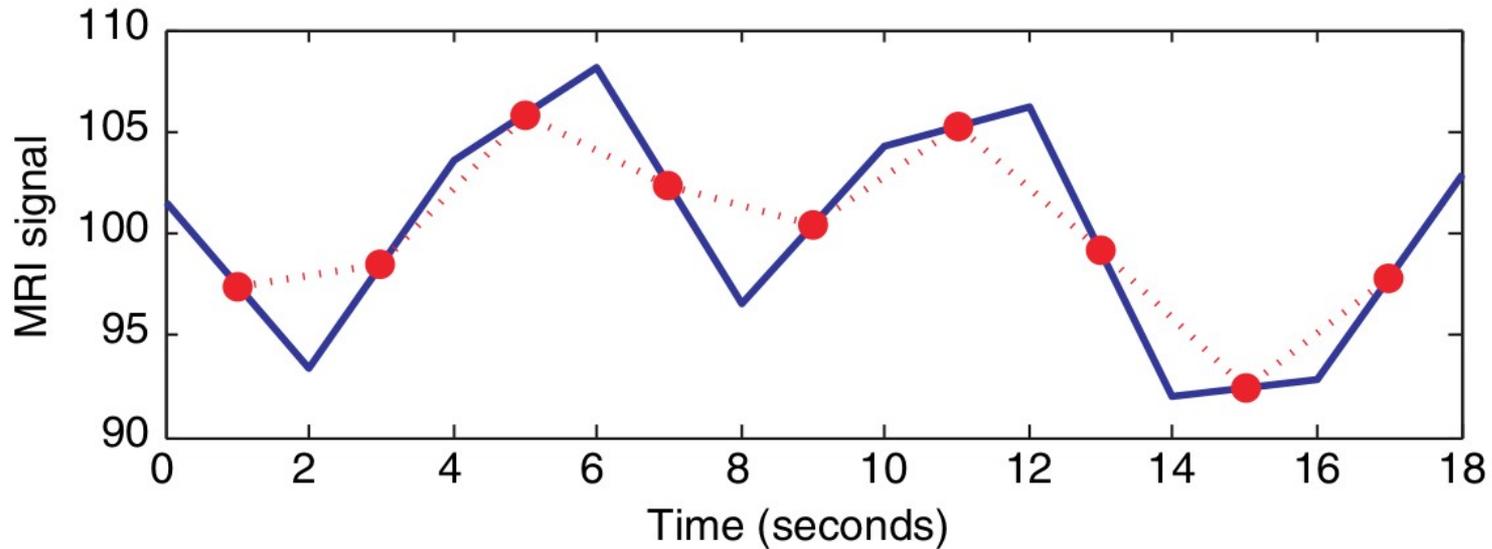


# Slice timing correction



Stessa risposta emodinamica. Le slices acquisite dopo mostrano un anticipo nella risposta allo stimolo (la risposta era già partita al momento dell'acquisizione).

# Slice timing correction



Correzione dello slice timing. In blu: serie temporale di un voxel in una slice acquisita per prima. In rosso: serie temporale interpolata per avere una corrispondenza con la slice centrale (a  $TR/2$ ).

# Motion correction

Possono esserci movimenti volontari e movimenti fisiologici, come ad esempio battito cardiaco e respirazione.

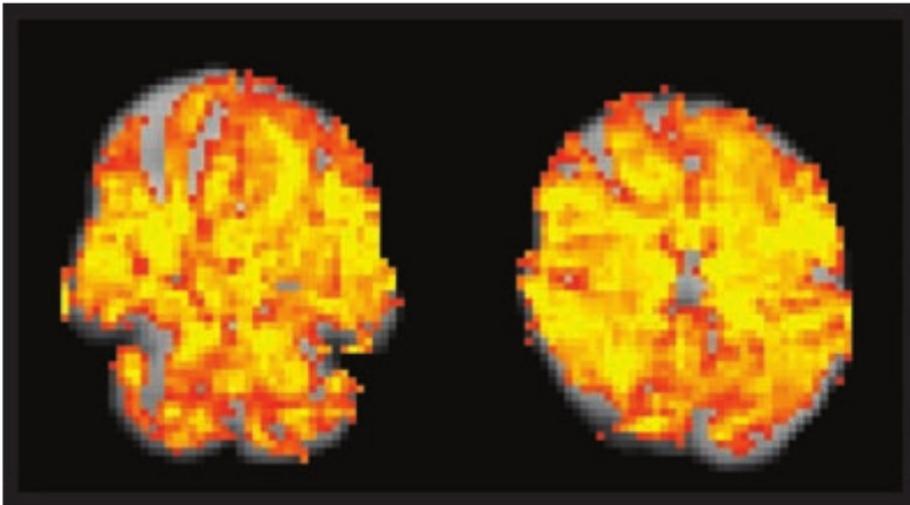
Relativamente agli ultimi, una possibile strategia consiste nel registrare il fenomeno (es. ECG, gli istanti di respirazione, etc.) e compensare il segnale registrato in post-processing.

Nel caso di alcuni movimenti, ad esempio per il battito cardiaco, è possibile acquisire le immagini in sincrono (gating cardiaco.)

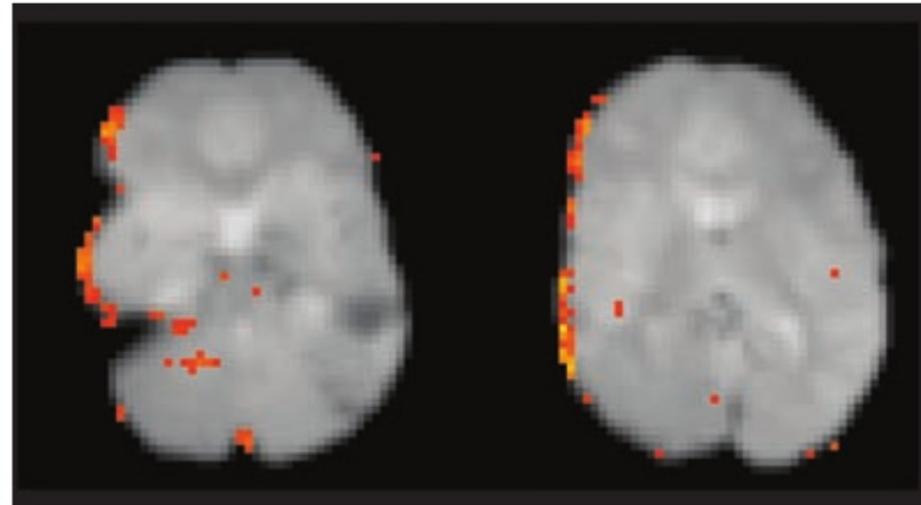


# Motion correction

Effetti del movimento del capo durante l'acquisizione. Attivazioni cerebrali per task motorio in raffronto con una baseline a riposo.



Artefatto “flaming brain”



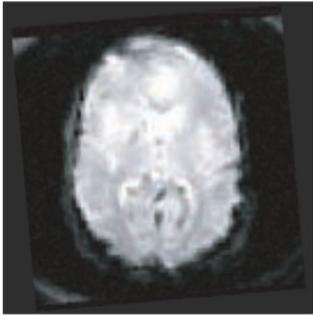
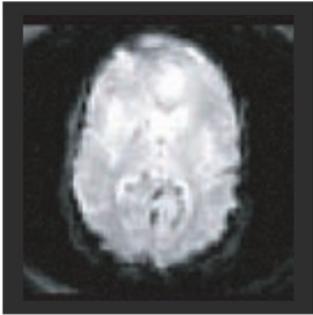
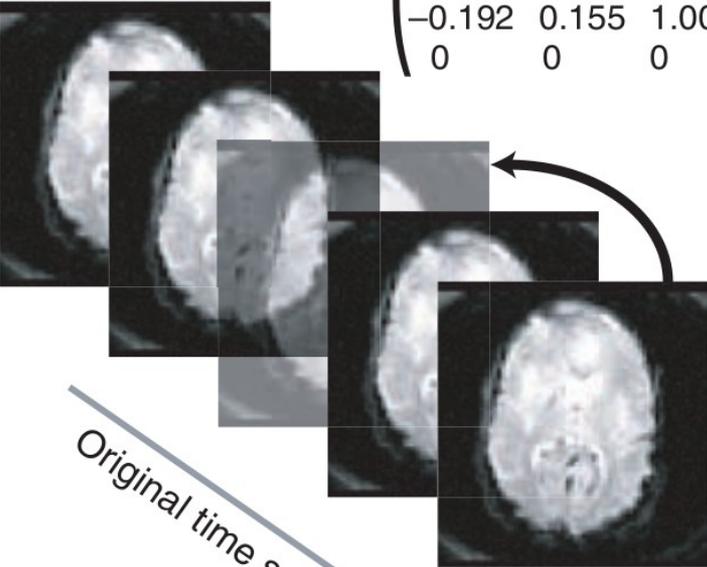
Classico artefatto motion

# Motion correction

Step 1: Estimate parameters

Step 2: Reslice images

$$\begin{pmatrix} 1.053 & 0.014 & 0.323 & 0.412 \\ 0.004 & 0.939 & 0.149 & -0.026 \\ -0.192 & 0.155 & 1.005 & -0.301 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

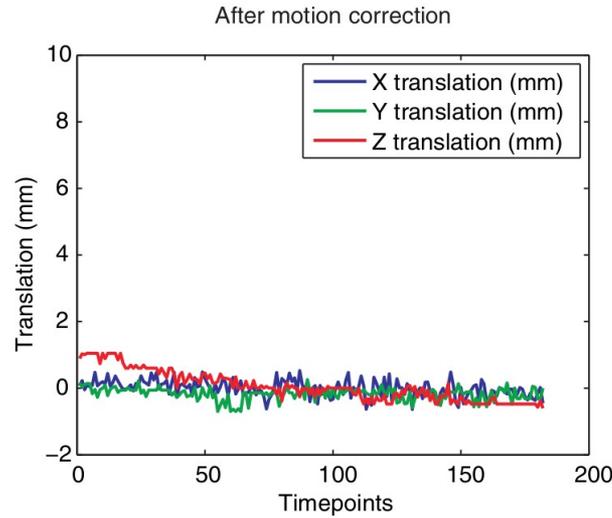
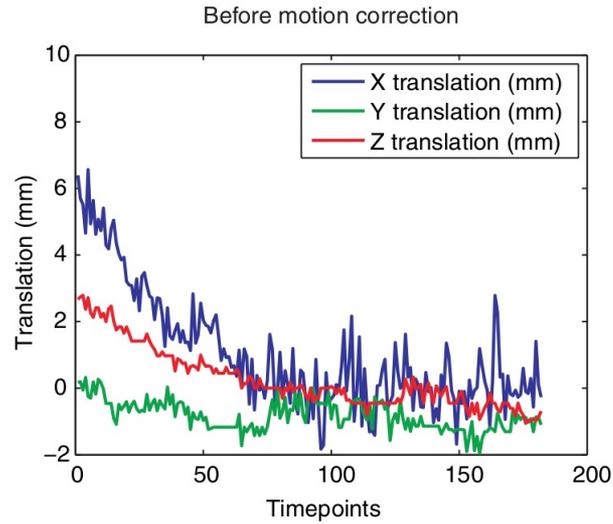


Original image

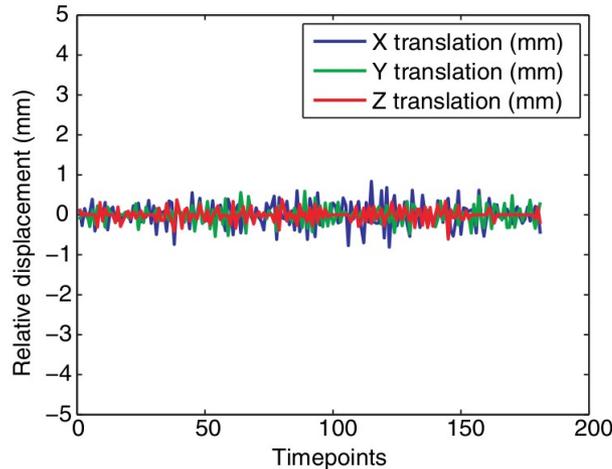
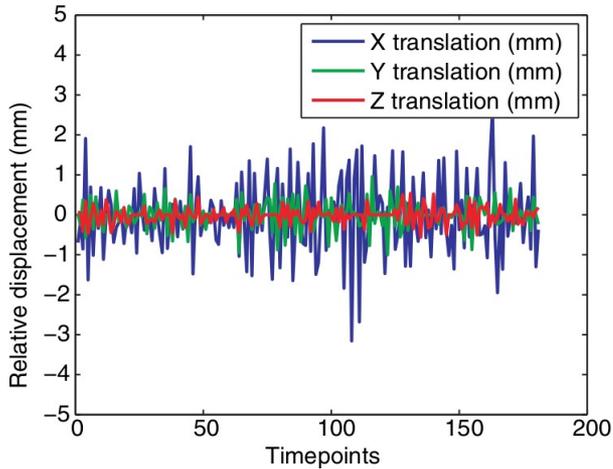
Resliced image



# Motion correction



Rispetto al  
reference



Rispetto  
all'istante  
precedente



# Spatial smoothing

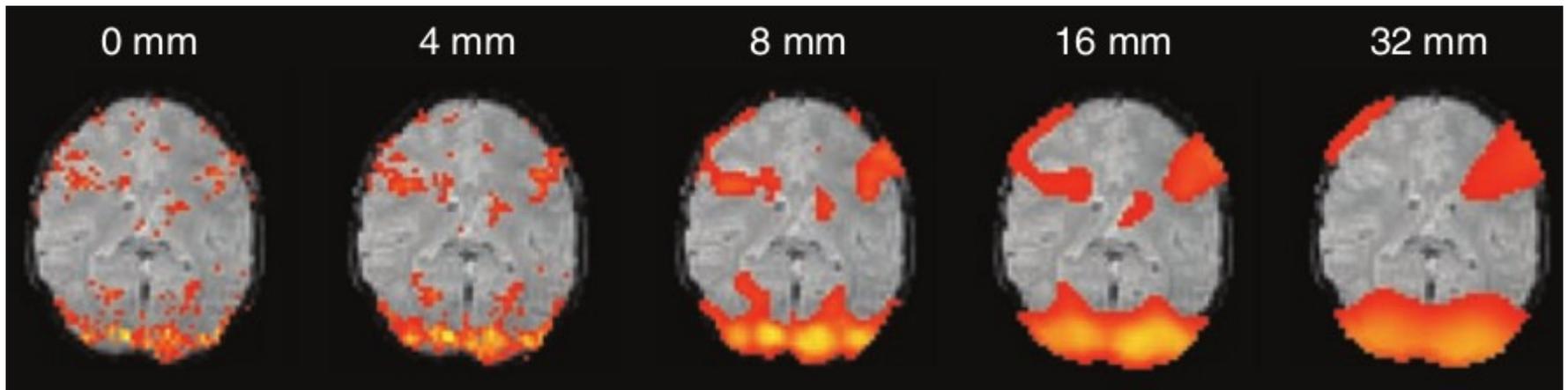
Riduce la risoluzione dell'immagine attraverso l'applicazione di un filtro passa-basso.

Ha diversi vantaggi:

- rimuove i cambiamenti su piccola scala (attivazioni di pochi voxel);
- migliora l'SNR dei cambiamenti su larga scala;
- riduce l'effetto del dropout;
- rende più semplice mediare i risultati fra più soggetti.



# Spatial smoothing

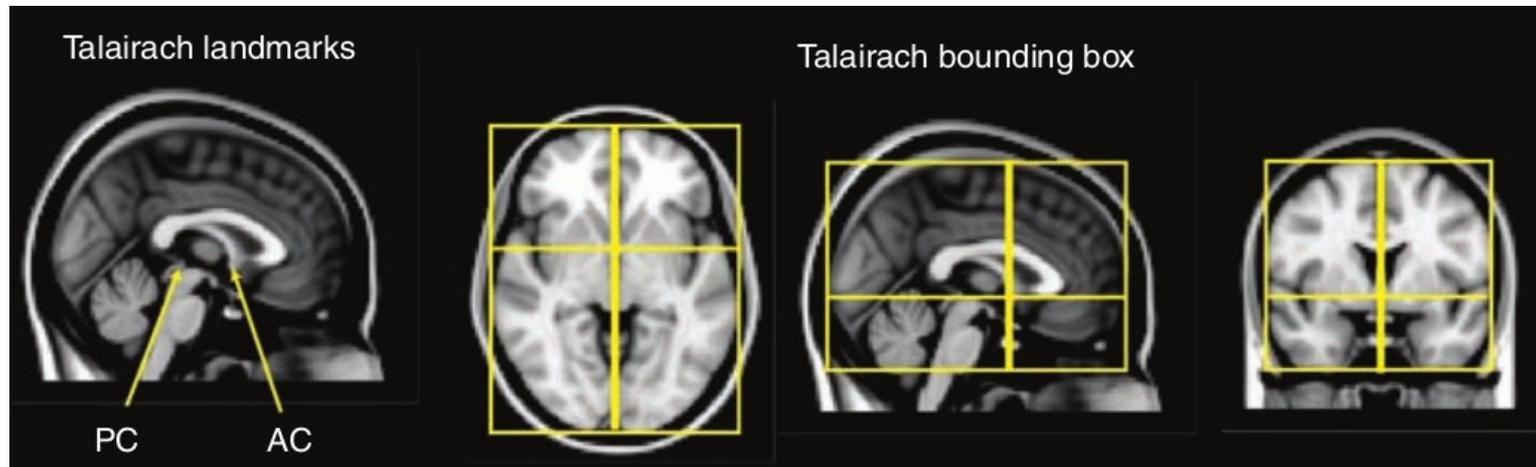


Attivazioni ottenute utilizzando diversi filtri di smoothing. Scompaiono le attivazioni di piccoli clusters, ma quelle di regioni grandi sono rilevate con maggiore efficacia.

# Spatial normalization

La normalizzazione spaziale, anche detta registrazione inter-soggetto, consiste nel trasformare i segnali acquisiti proiettandoli in uno spazio comune.

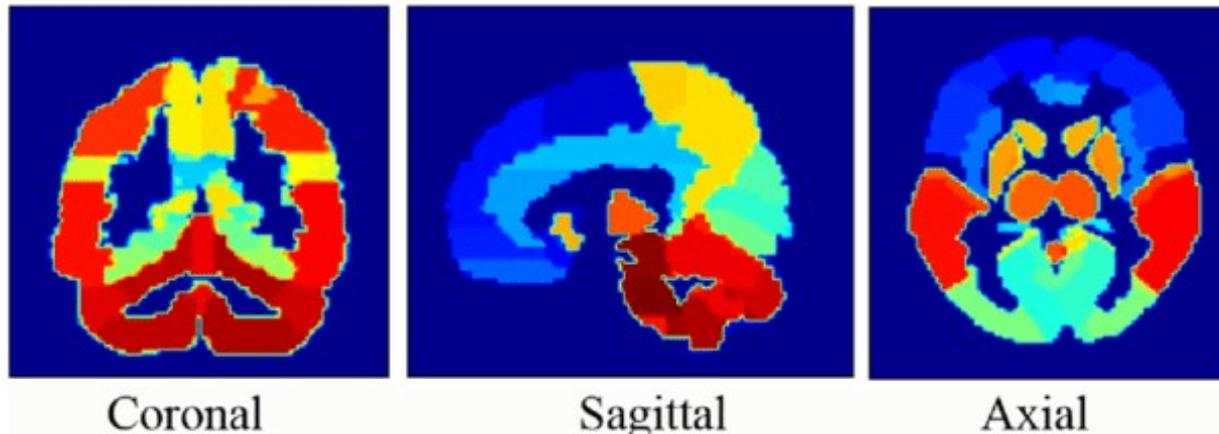
Per prima cosa è necessario definire dei riferimenti anatomici (*landmarks*) ed un relativo sistema di riferimento.



# Atlanti e template

Un atlante (*atlas*) fornisce una guida alla posizione di caratteristiche anatomiche in un certo sistema di riferimento.

Un *template* è una immagine (anche multi-dimensionale) che rappresenta l'atlante e fornisce il riferimento a cui allineare i dati acquisiti in un relativo sistema di riferimento.



# Atlanti e template

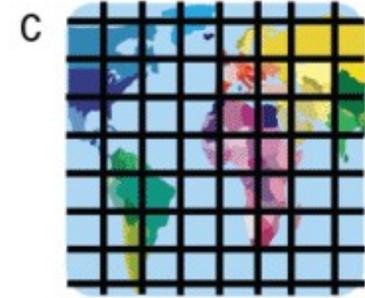
## Clarifying Terminologies



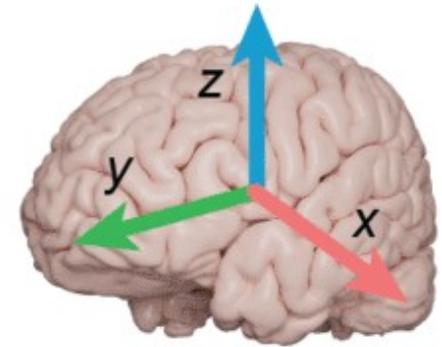
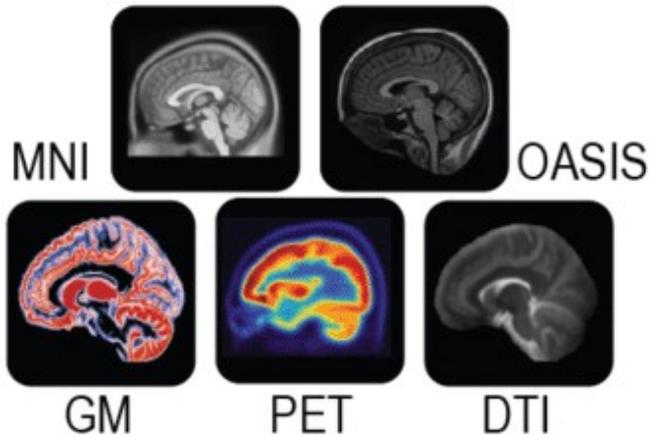
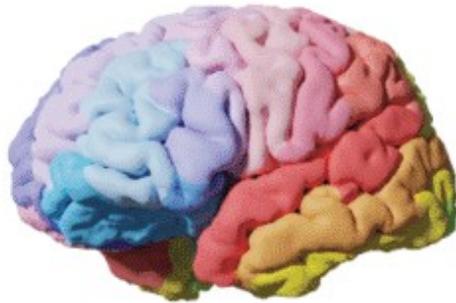
Atlas



Template



Coordinate System

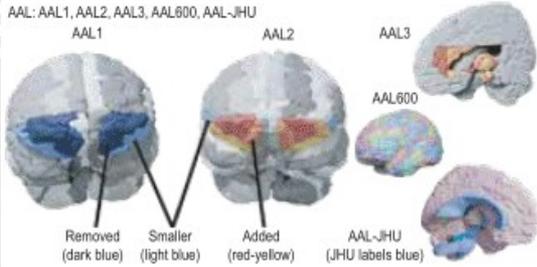
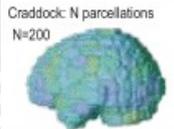
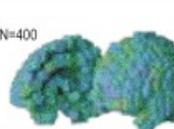
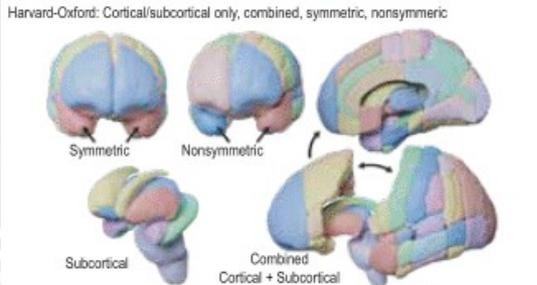
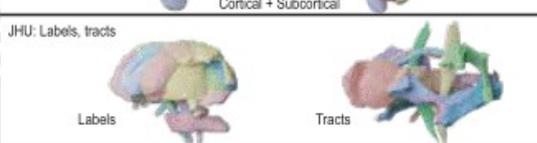
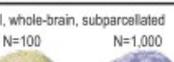
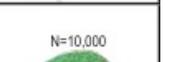
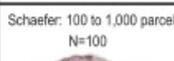
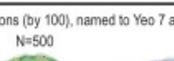
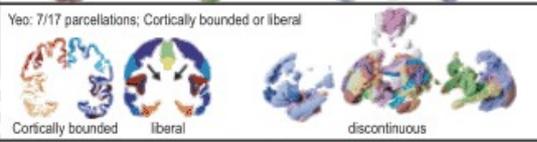


# Atlanti e template

Un template molto utilizzato è stato sviluppato dal Montreal Neurological Institute (MNI).

Sono state allianate 305 immagini MRI all'atlante Talairach (coregistrandoli usando landmarks anatomici) e poi mediate, ottenendo il template *MNI305*.

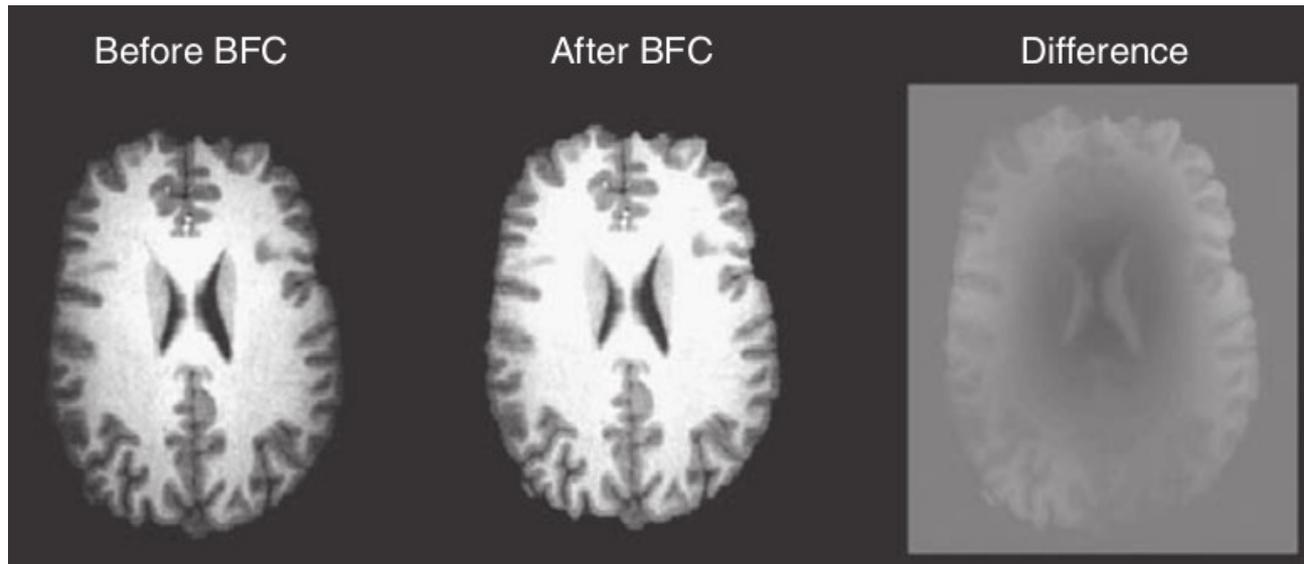
Successivamente sono state aggiunte altre immagini a risoluzione maggiore, ottenendo una versione diversa del template nota come *ICBM-152*.

Atlas [regions]	Sources	3D Render	Description	Variations
AAL [116;120;166]	1-7 SPM	S 	Structural atlas. Manual identification using a defined labeling protocol on single subject template (Collin-27). Three versions. Version 2: updated boundaries. Version 3: further parcellations. Successor to Talairach.	AAL: AAL1, AAL2, AAL3, AAL600, AAL-JHU 
AICHA [384]	8	F 	Functional atlas based on rsfMRI: 281 subjects. Each ROI has (1) homogeneity in its functional activity (2) a homotopic contralateral counterpart with which it has maximal connectivity.	
Brainnetome [246]	9-10 DSIstudio	S 	Connectivity-based parcellation. Based on idea that clustered regions of a brain region should share similar connectivity profiles; 40 subjects from HCP dataset. 210 cortical; 36 subcortical.	
Brodmann [48]	11-13 MRICron	S 	Developed by independent group at Washington University in St. Louis. Published with MRICron software. Warned by developer to be used with caution - not validated, nor based on multiple individuals.	
Cerebra [102]	14	S 	Structural atlas. Non-linear registration of cortical and subcortical labeling from MINDboggle-101 dataset (see DKT below) to the symmetric MNI-ICBM2009c template, followed by manual editing.	
Craddock [N]	15-17	F 	Functional atlas: rsfMRI; 41 subjects. ROIs are spatially clustered into regions of homogeneous functional connectivity. May be N regions. 200/400 regions publicly available. 4x4x4 mm <sup>3</sup> resolution fMRI. Resliced.	Craddock: N parcellations N=200  N=400  1.7 cm  1.0 cm  pea 
DKT [111]	18-23 FreeSurfer	S 	DKT is a labeling protocol. Used on MINDboggle-101 dataset (101 brains). Probabilistic atlas created using joint fusion algorithm. Surface version in FreeSurfer. Volumetric version uses 20 brain subset. Noncortical regions: Neuromorphometrics BrainCOLOR atlas.	
Gordon-Petersen [333]	24-25	F 	Identification of abrupt transitions in resting-state functional connectivity to identify parcellations. Based on rsfMRI. 108 subjects. Intended for surface-based analyses.	
Hammersmith [83]	26-28	S 	Manually identified 83 structures using defined labeling protocol; 30 subjects. Maximum probability map. First version in 2003 with 49 structures. Named after London hospital, Hammersmith. Hammers is author.	
Harvard-Oxford [48 + 21]	29-30 FSL	S 	Manual segmentation using defined labeling protocol; 37 subjects. Cortical and subcortical atlases provided separately. Left and right structures have same labels (symmetry). Must preprocess.	Harvard-Oxford: Cortical/subcortical only, combined, symmetric, nonsymmetric 
JHU [48; 20]	31-33 FSL	S 	White matter atlas. Two versions. (1) Labels: Hand segmentation average of diffusion MRI; 81 subjects. (2) Tracts: probabilistic identification from deterministic tractography; 28 subjects.	JHU: Labels, tracts 
Julich [121]	34-35 FSL	S 	Cytoarchitecture atlas. Successor to Brodmann. Average of 10-subject post-mortem cyto- and myelo-architectonic segmentations. Update to the Eickhoff SPM Anatomy Toolbox v1.5. Whole brain is not covered.	
MMP [380]	36-38 DSIstudio	M 	Multi-modal parcellation: (1) Architecture - T1w/T2w myelin maps + cortical thickness. (2) function - task-fMRI. (3) connectivity. (4) topography. 210 subjects. Cortical ONLY. Originally intended for surface analysis. Volumetric version independently created and used.	
Random [N]	39-40	V 	Brain is randomly parcellated into N regions. Variations used in studies include cortical and whole-brain. Other atlases (e.g. AAL) and their regions may be further randomly divided, or subparcellated.	Random: N parcellations, cortical, whole-brain, subparcellated N=10  N=100  N=1,000  N=10,000  N=30  lemon 5 cm  grape 2 cm  pea 1 cm 
MNI Structural [9]	41 FSL	S 	9 regions, including lobar and some subcortical regions. Hand segmented 50 subjects. Transformed into MNI152 space, averaged, probability maps produced. 25% max probability is shown.	Schaefer: 100 to 1,000 parcellations (by 100), named to Yeo 7 and 17 N=100  N=500  N=1,000 
Schaefer [100-1000]	42-43 GitHub	F 	Based on rsfMRI. Clusters found with gradient-weighted Markov Random Field model. 1489 subjects. Cortical only. Spatial resolutions provided: 100 - 1000 parcellations (by 100). Well documented.	
Talairach [1105]	44-48 FSL	S 	Conversion of original Talairach labeling. Digitized version of the original (coarsely sliced) Talairach atlas and registration to MNI 152 space. Atlas provided in FSL.	Yeo: 7/17 parcellations; Cortically bounded or liberal 
Yeo [7; 17]	49-50 FreeSurfer	F 	1000 subjects; rsfMRI. Clustered cortical regions by pattern of functional connectivity. Results in non-spatially continuous clusters. 7 and 17 clusters based on stability of clustering algorithm.	
Region-specific	41-54 FSL	V 	Atlases created for specific regions, usually high quality + high degree of accuracy (e.g. post-mortem histological verification). Examples: Thalamus nuclei, hippocampus, and other specific structures.	Thalamus, Hippocampus, Cerebellum 
Population-specific	55-56	V 	Atlases created from a specific population (e.g. elderly, pediatric, non-human). Disease-specific defines regions specific for disease (e.g. MS lesions, Alzheimer's).	Pediatric, Elderly, Disease-specific Neonatal, M.C.B.P. 

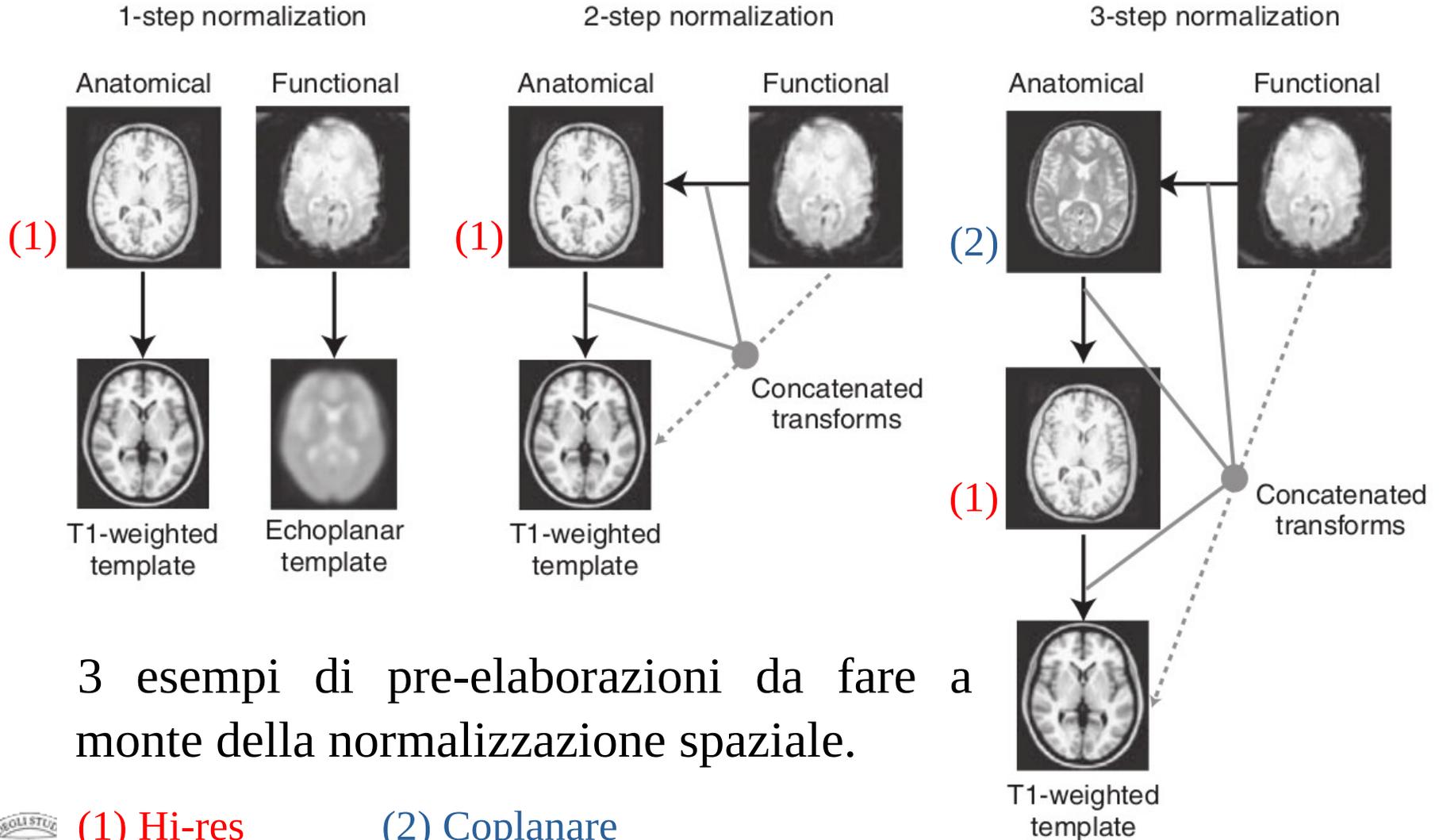


# Spatial normalization

Prima della normalizzazione spaziale, generalmente viene fatta la Bias Field Correction (BFC) e la segmentazione del cervello.



# Spatial normalization



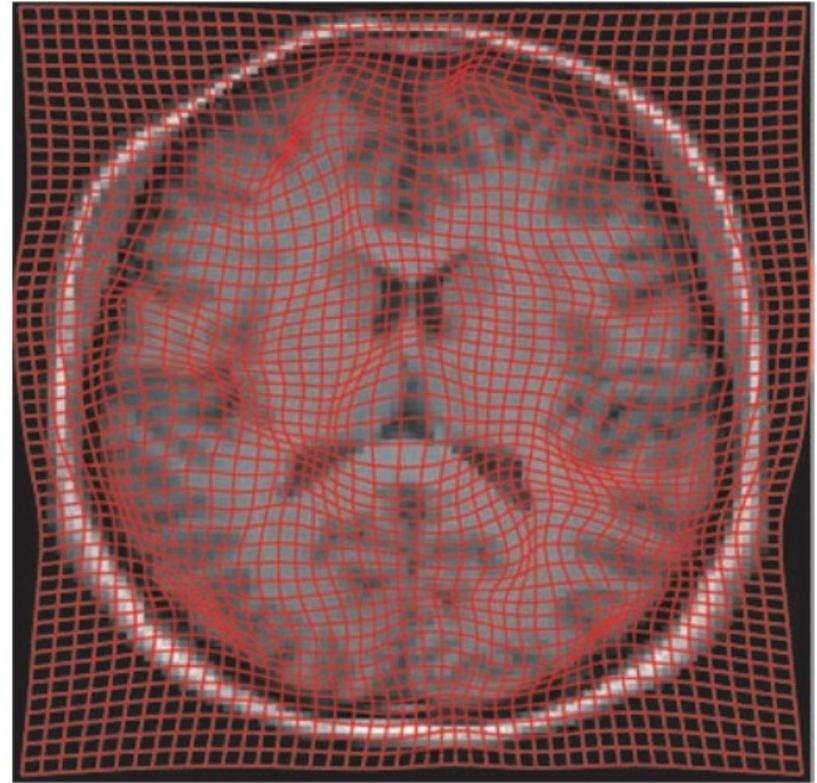
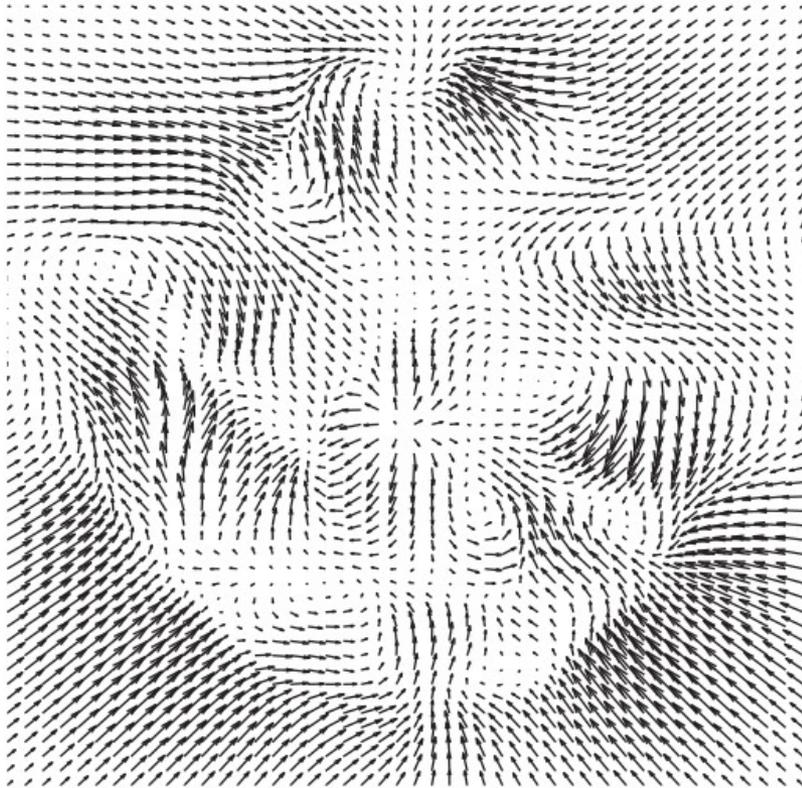
3 esempi di pre-elaborazioni da fare a monte della normalizzazione spaziale.

(1) Hi-res

(2) Coplanare



# Spatial normalization



Approccio *computational anatomy* (deformazioni elastiche).

# Spatial normalization

Un altro approccio consiste nell'estrazione e nel successivo allineamento della superficie corticale.

