

Bioingegneria per le Neuroscienze

Fabio Baselice

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

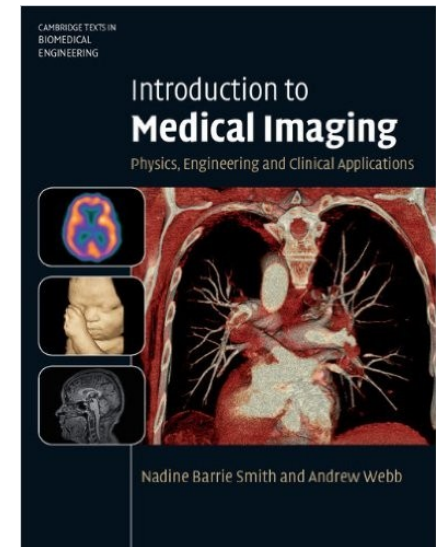
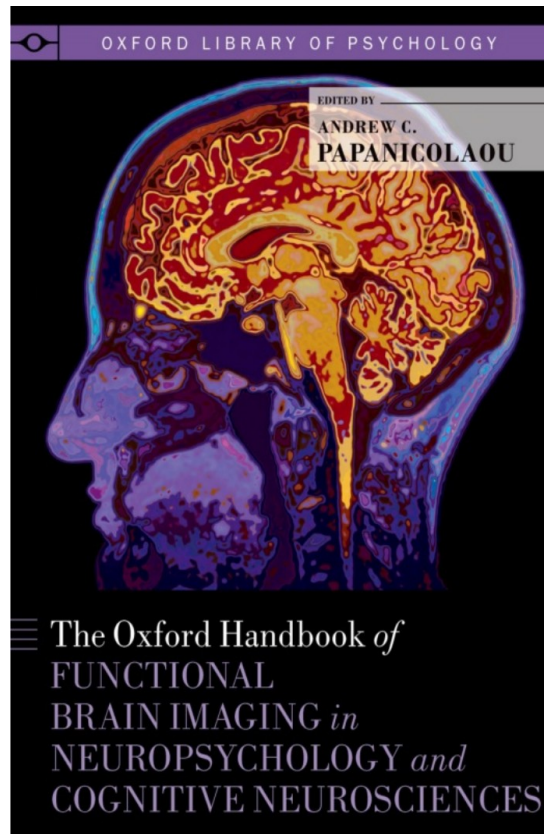
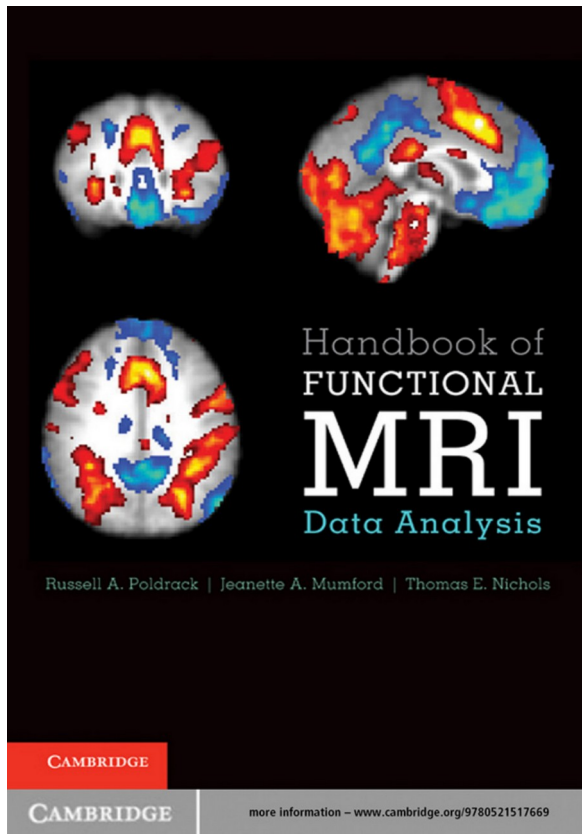


Argomenti

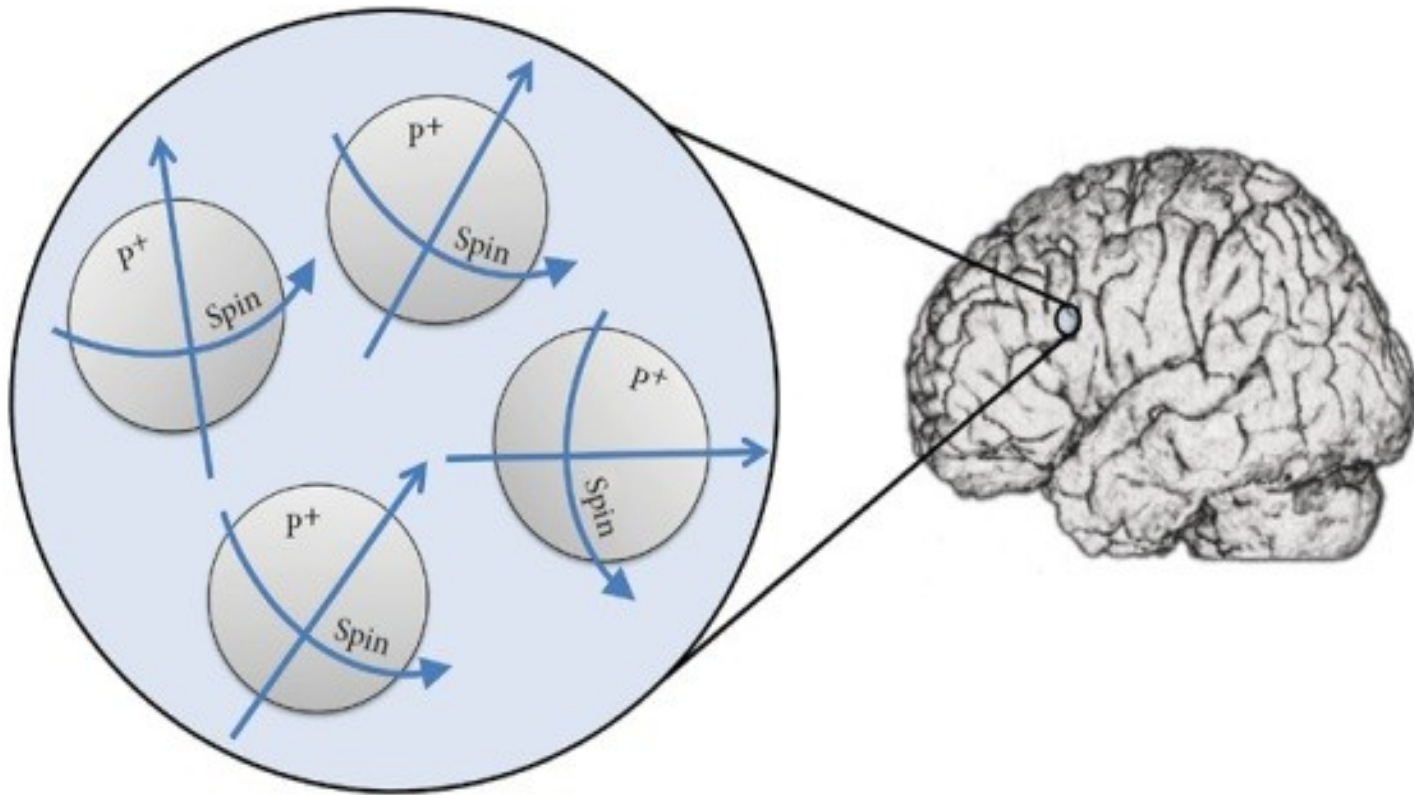
- Richiami MRI
- Gradient-echo echoplanar imaging (EPI)
- fMRI
- Preprocessing
 - Distorsion correction
 - Slice-timing correction
 - Motion correction
 - Spatial normalization



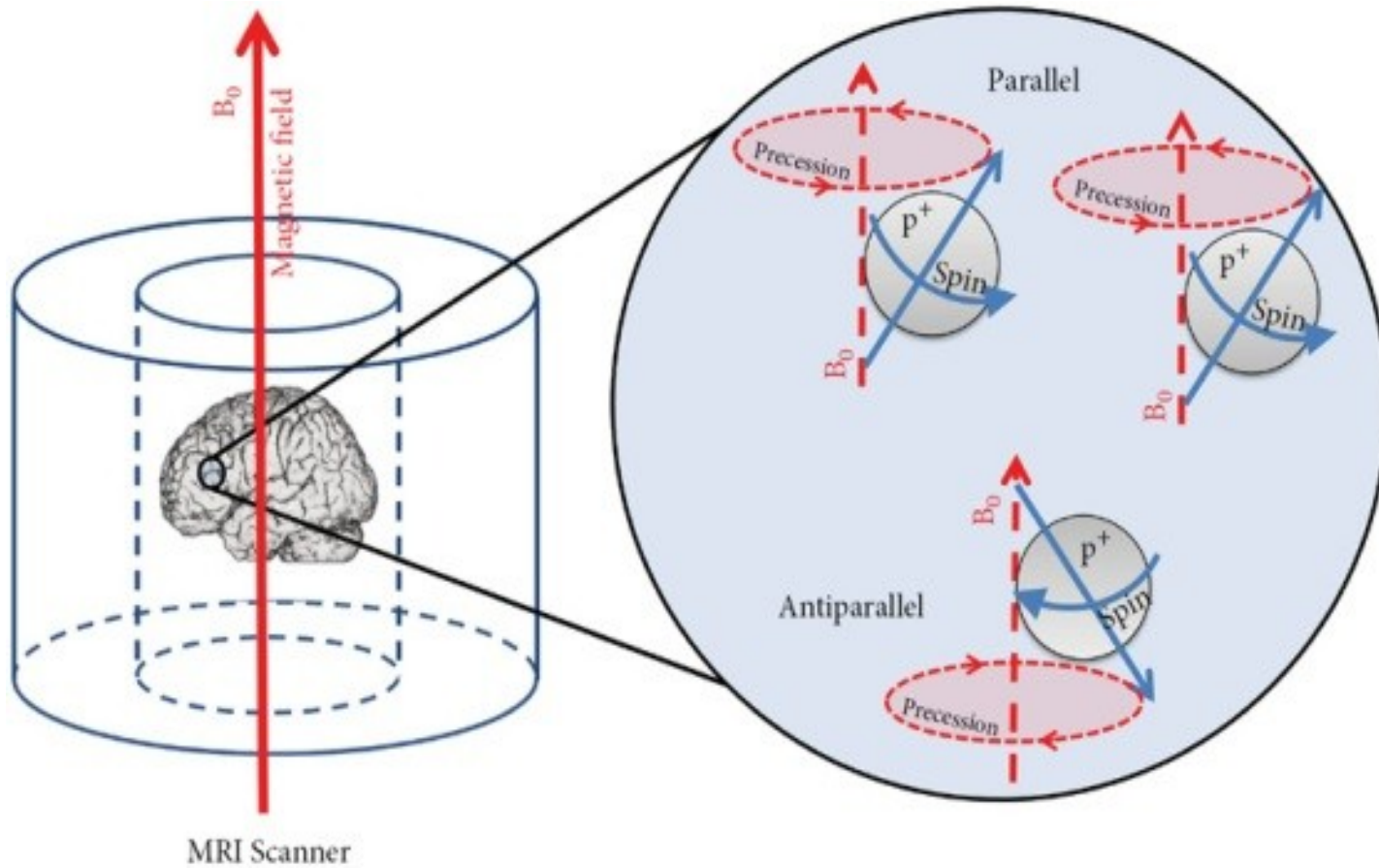
Riferimenti



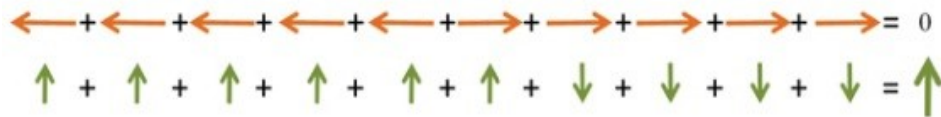
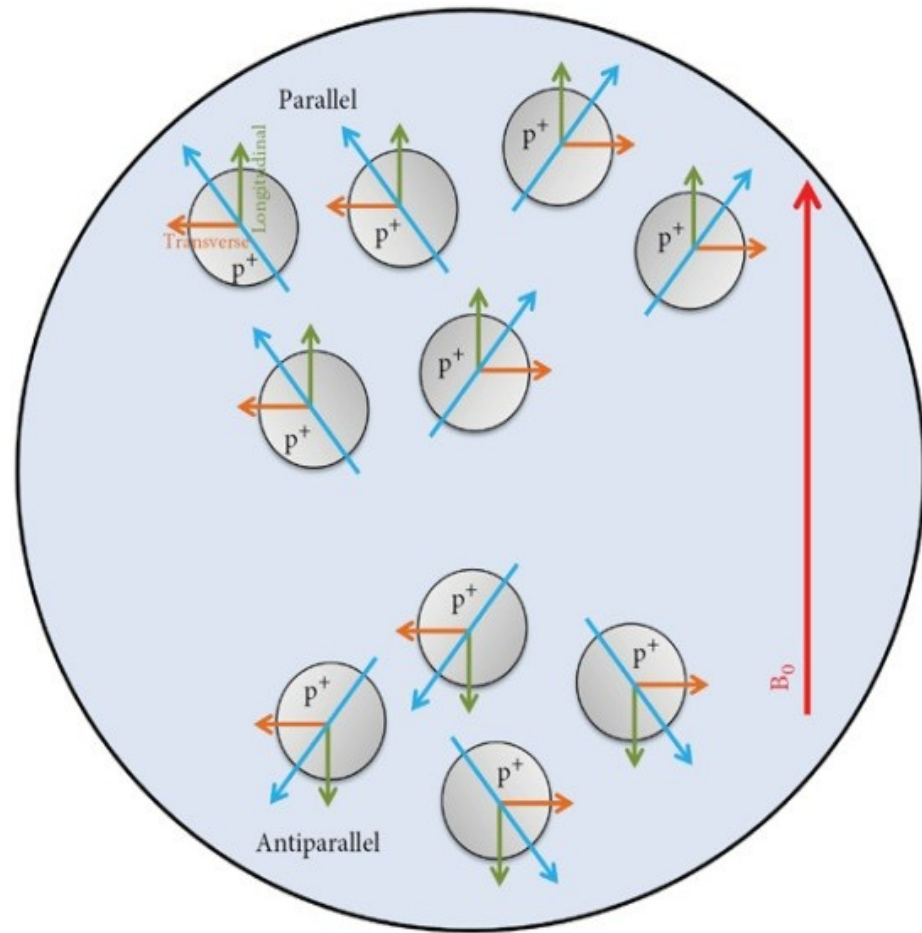
Richiami MRI



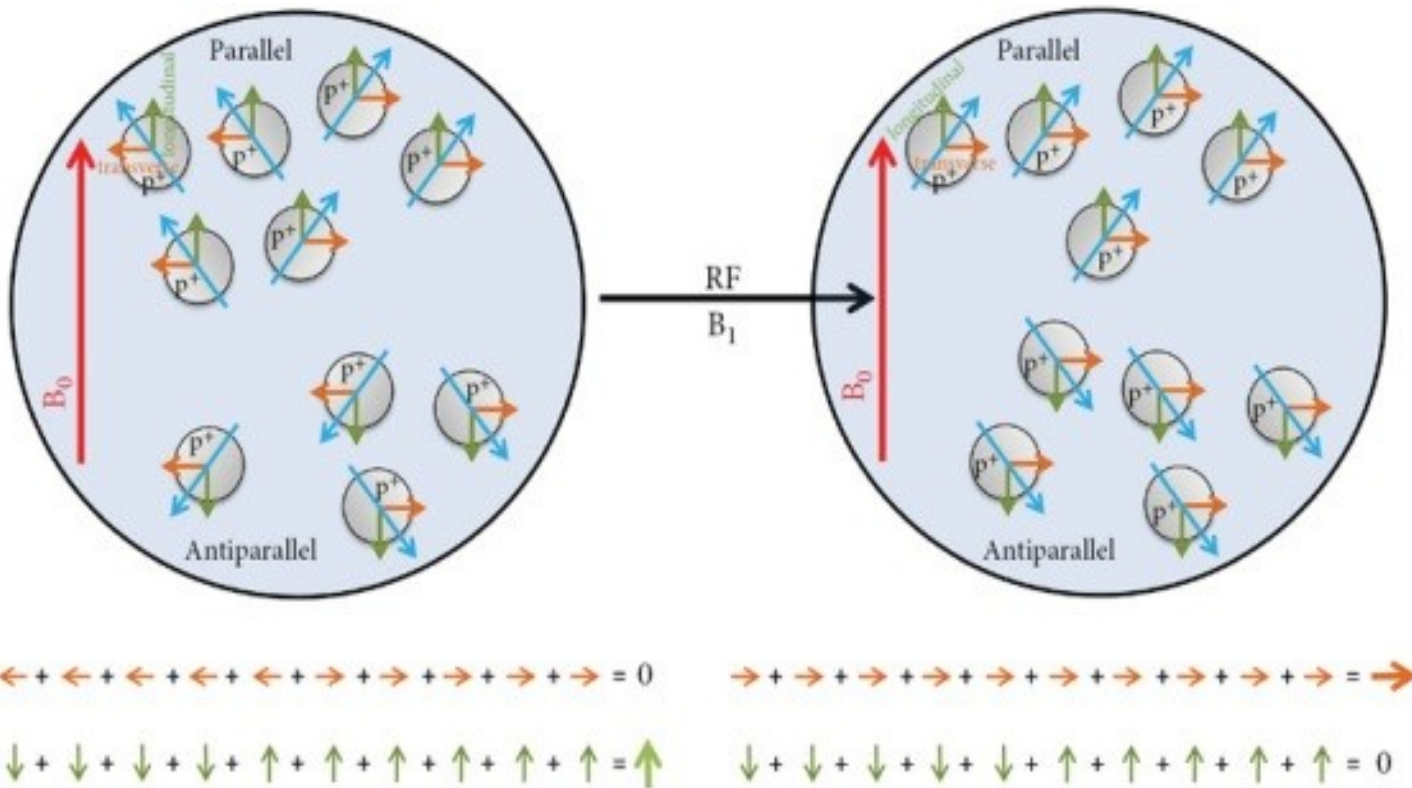
Richiami MRI



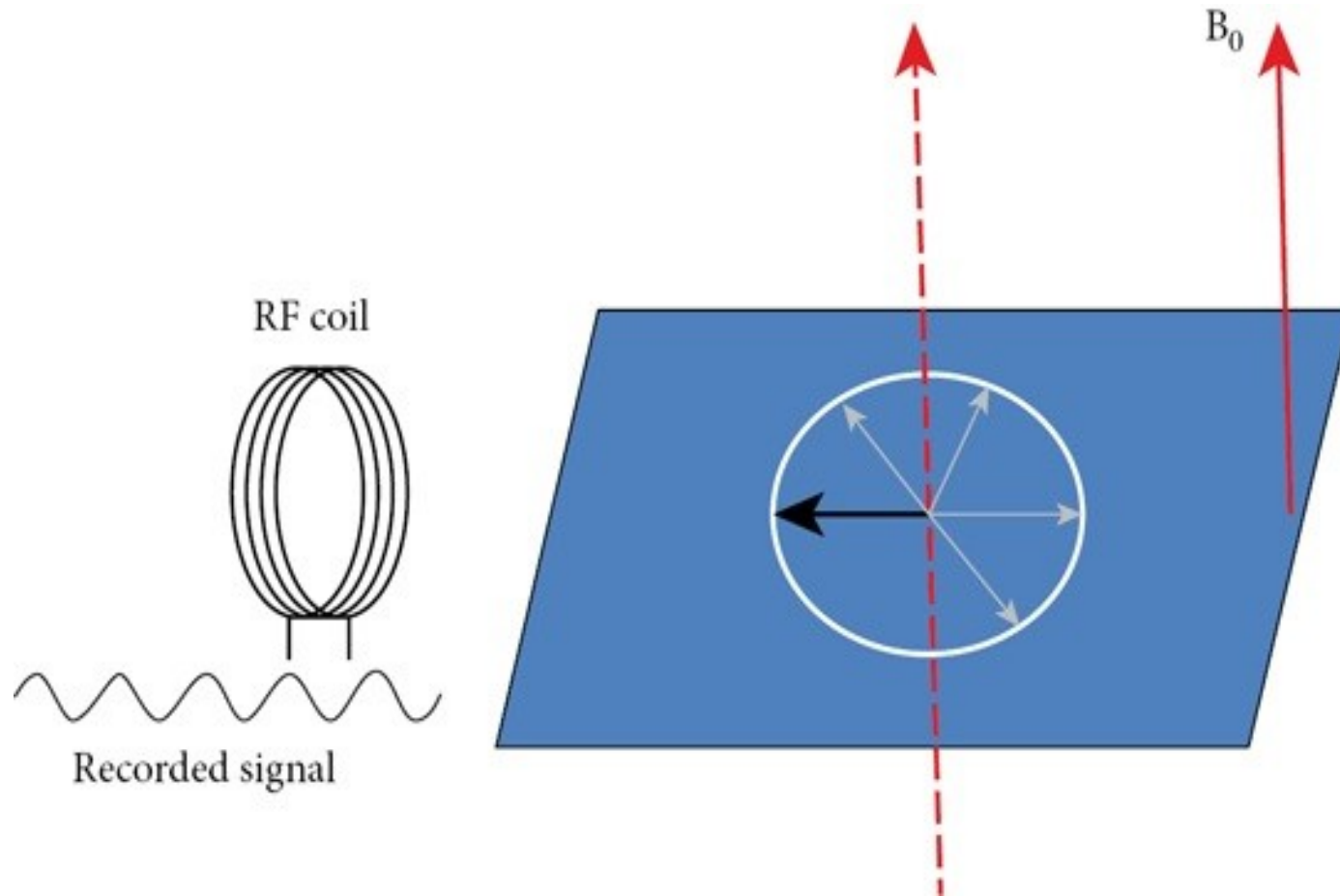
Richiami MRI



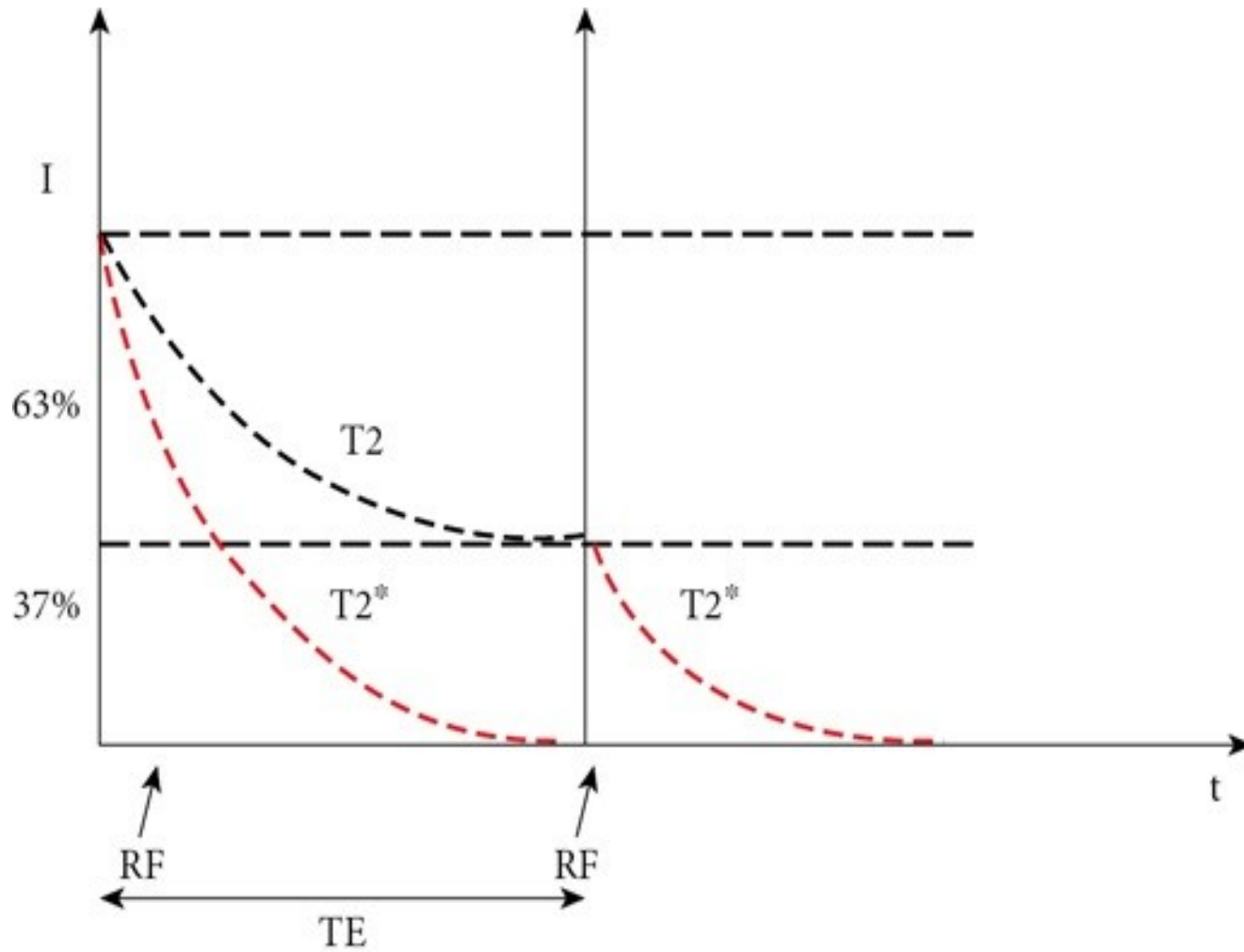
Richiami MRI – impulsi RF



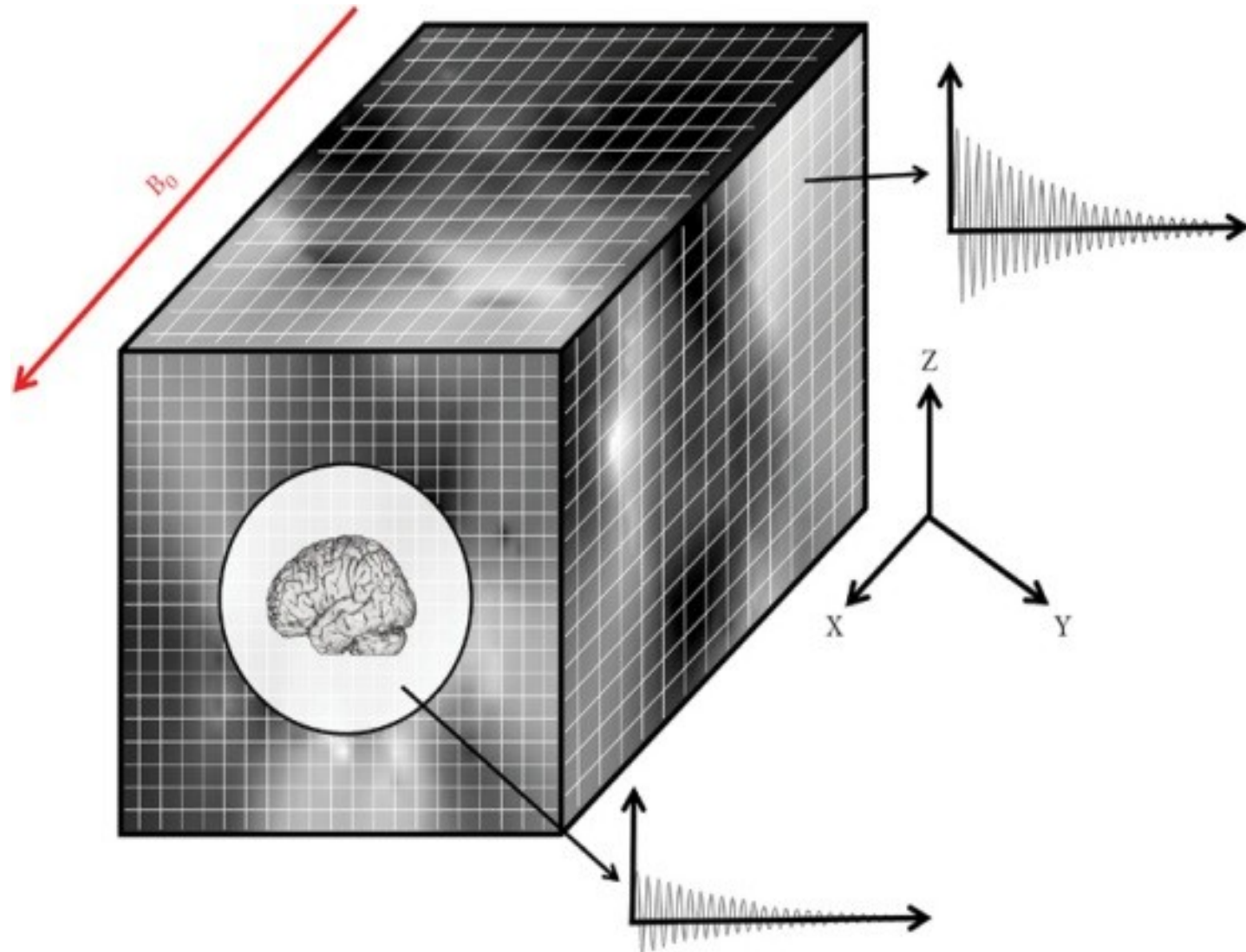
Richiami MRI – impulsi RF



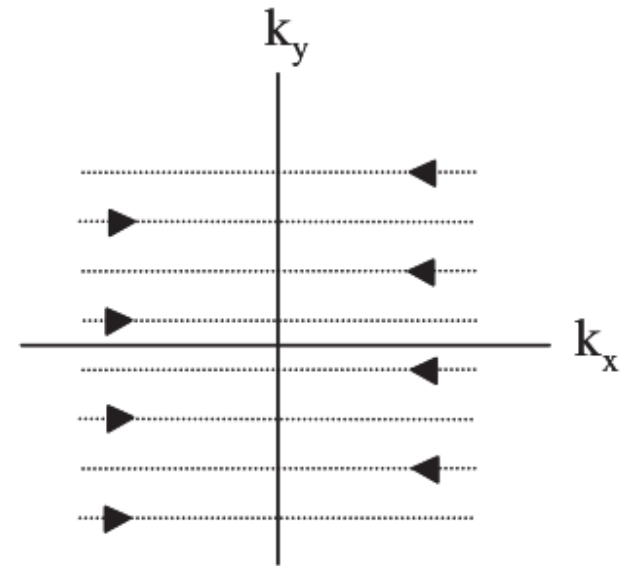
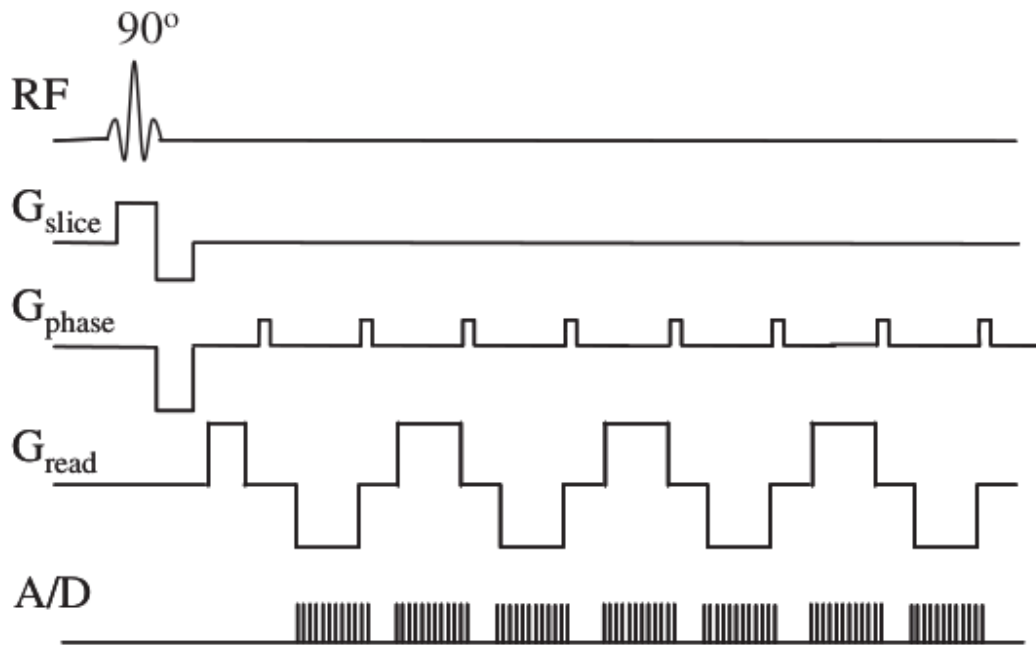
Richiami MRI - rilassamento



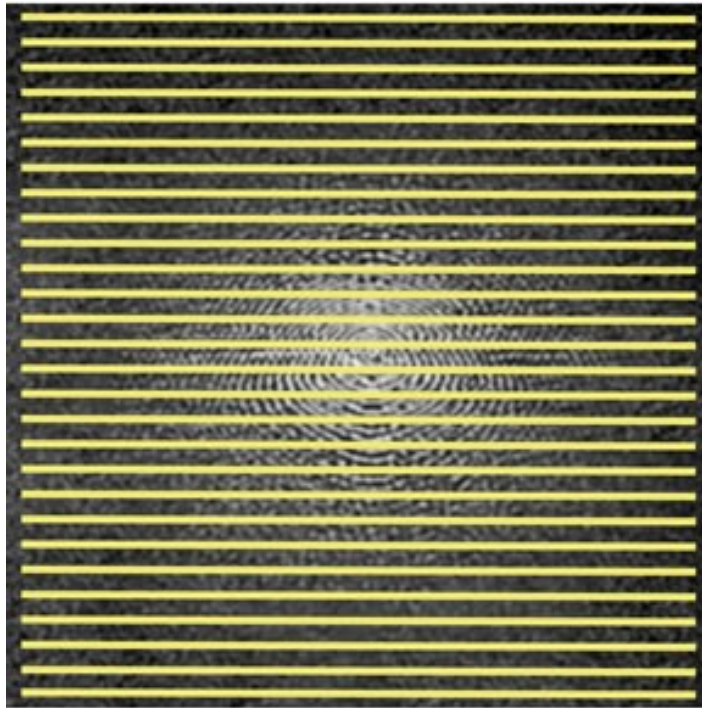
Richiami MRI - gradienti



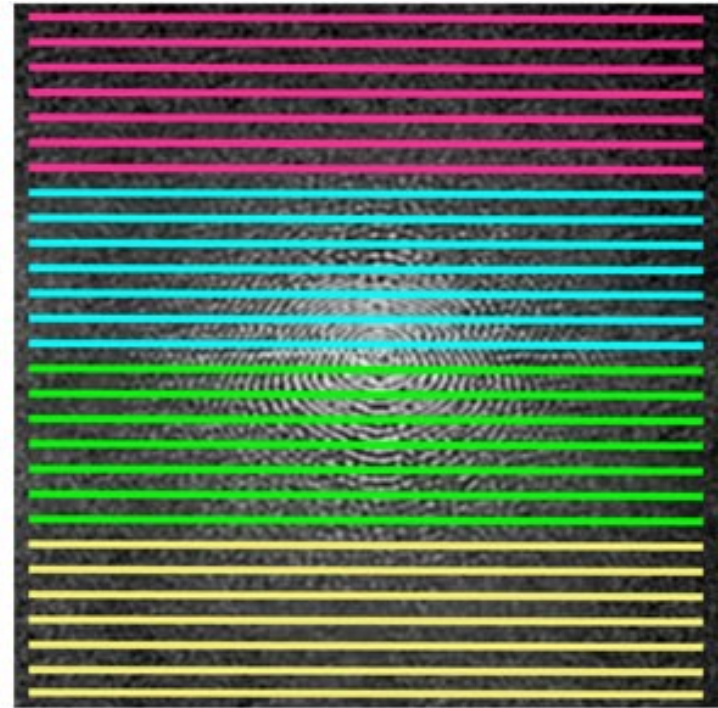
Echo Planar Imaging (EPI)



EPI

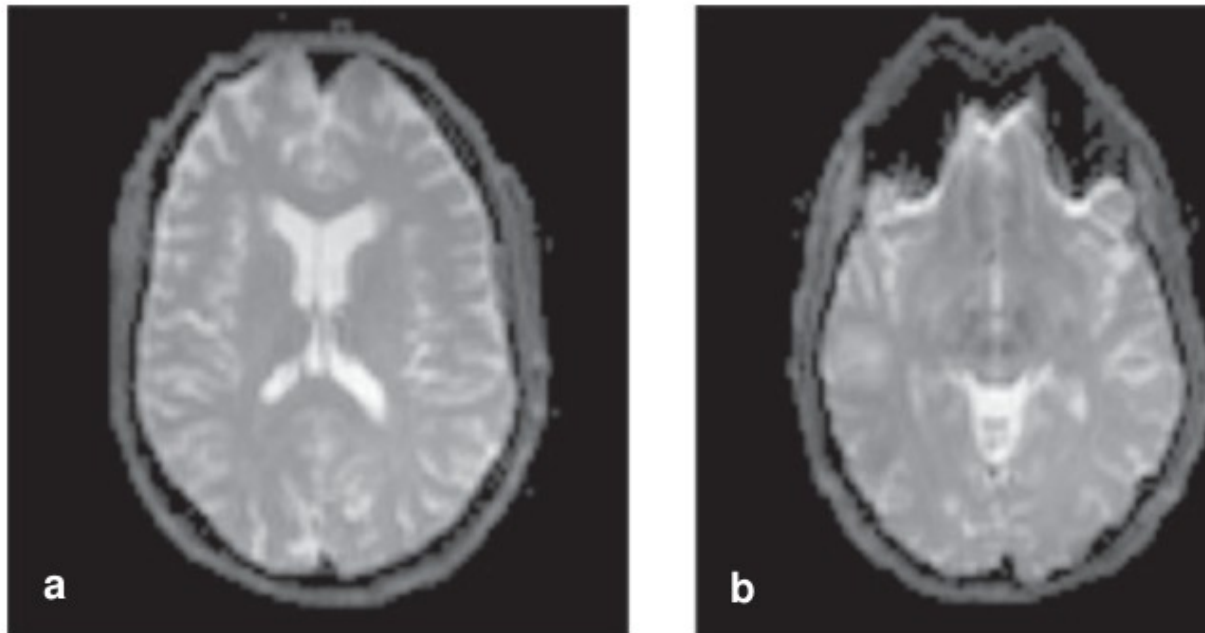


Single Shot



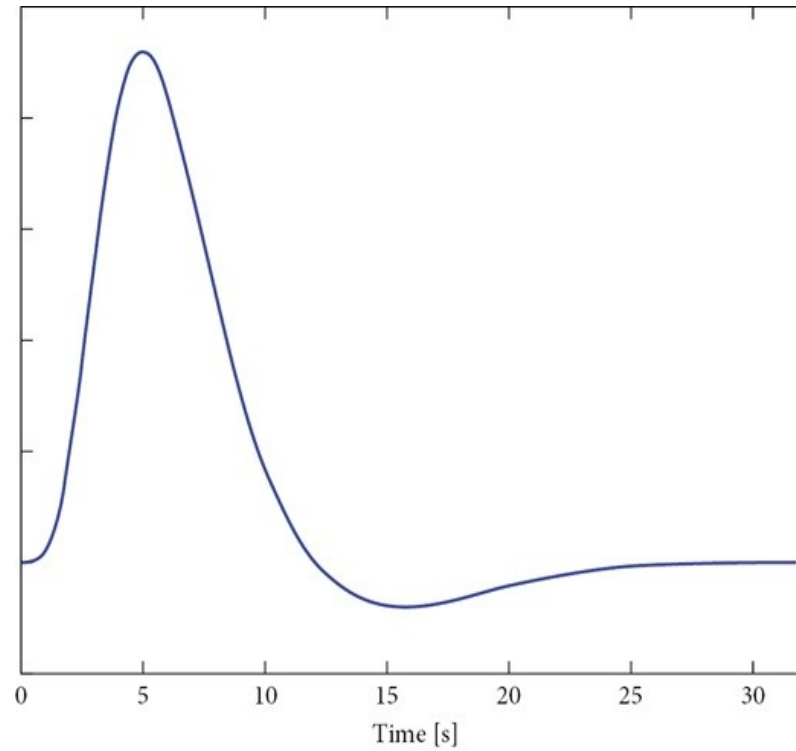
Multi-Shot

EPI



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

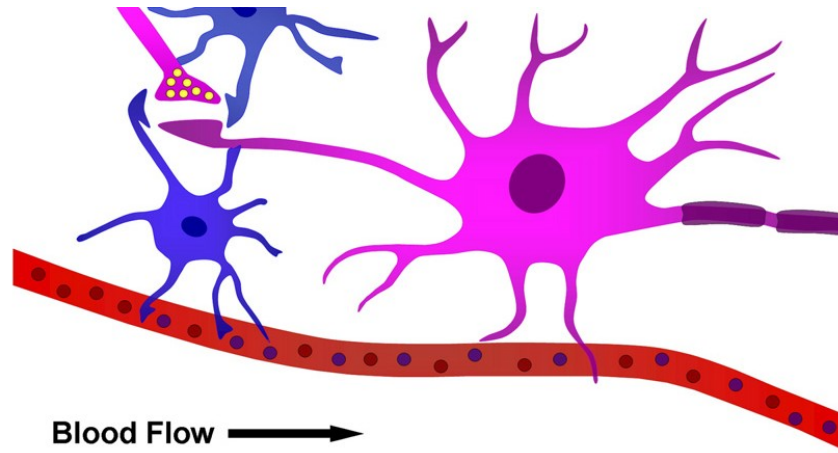
Segnale BOLD



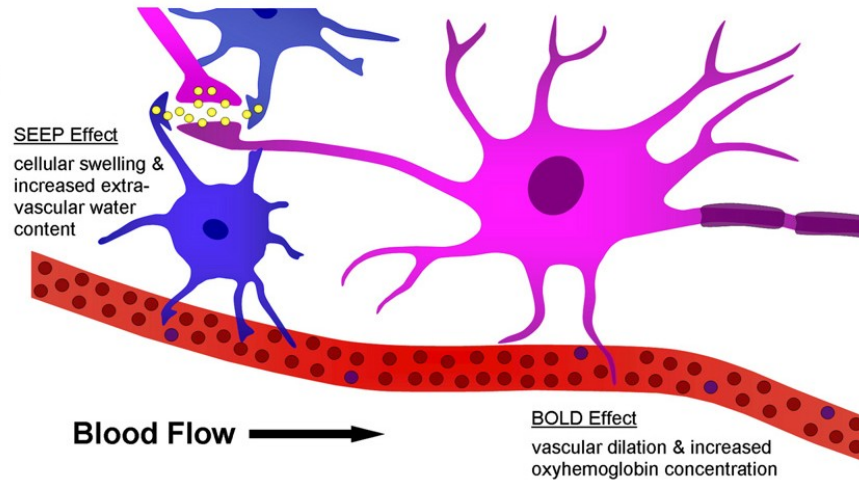
Risposta emodinamica.

Segnale BOLD

Resting
Baseline



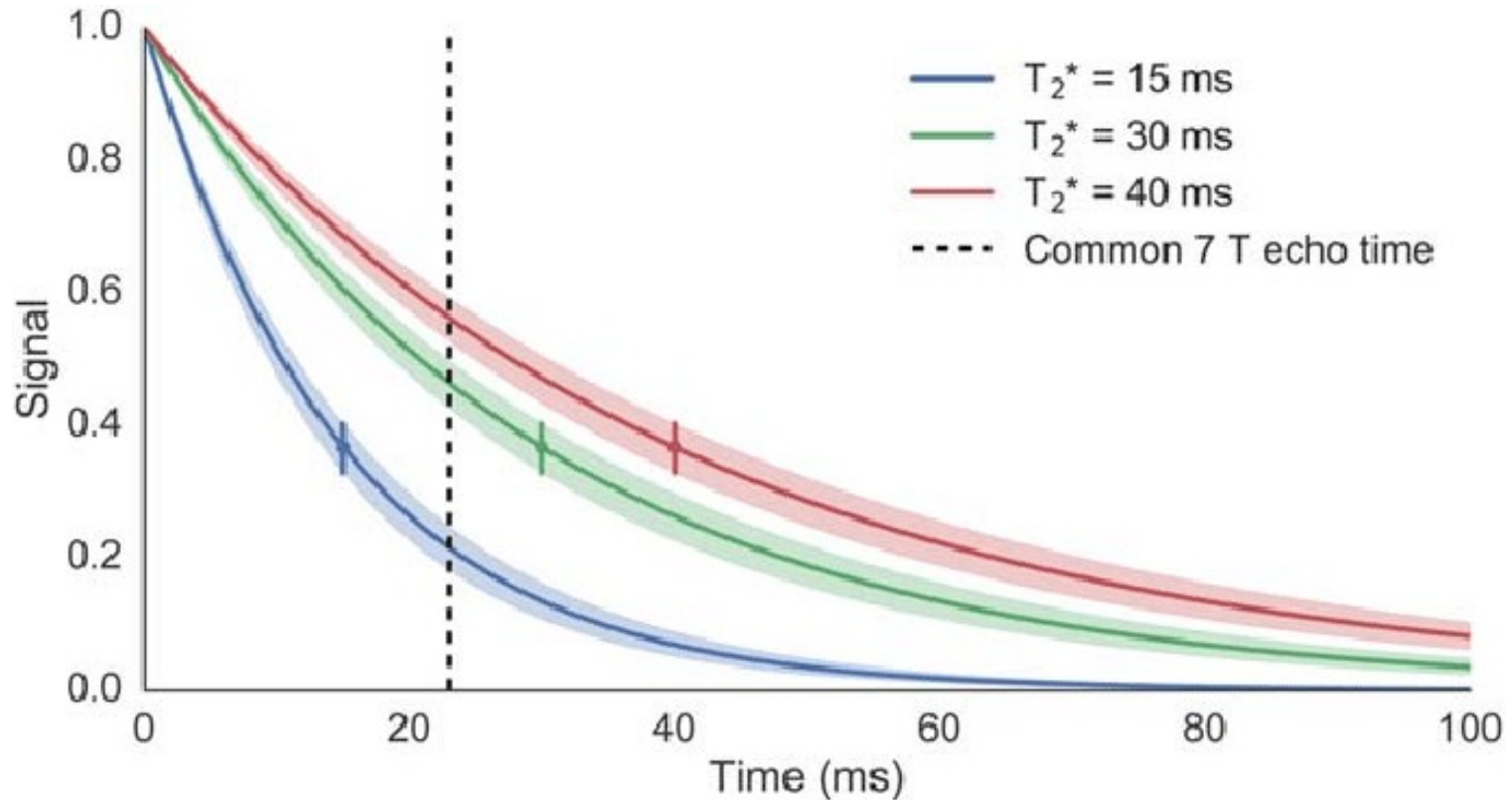
Neuronal
Activation



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

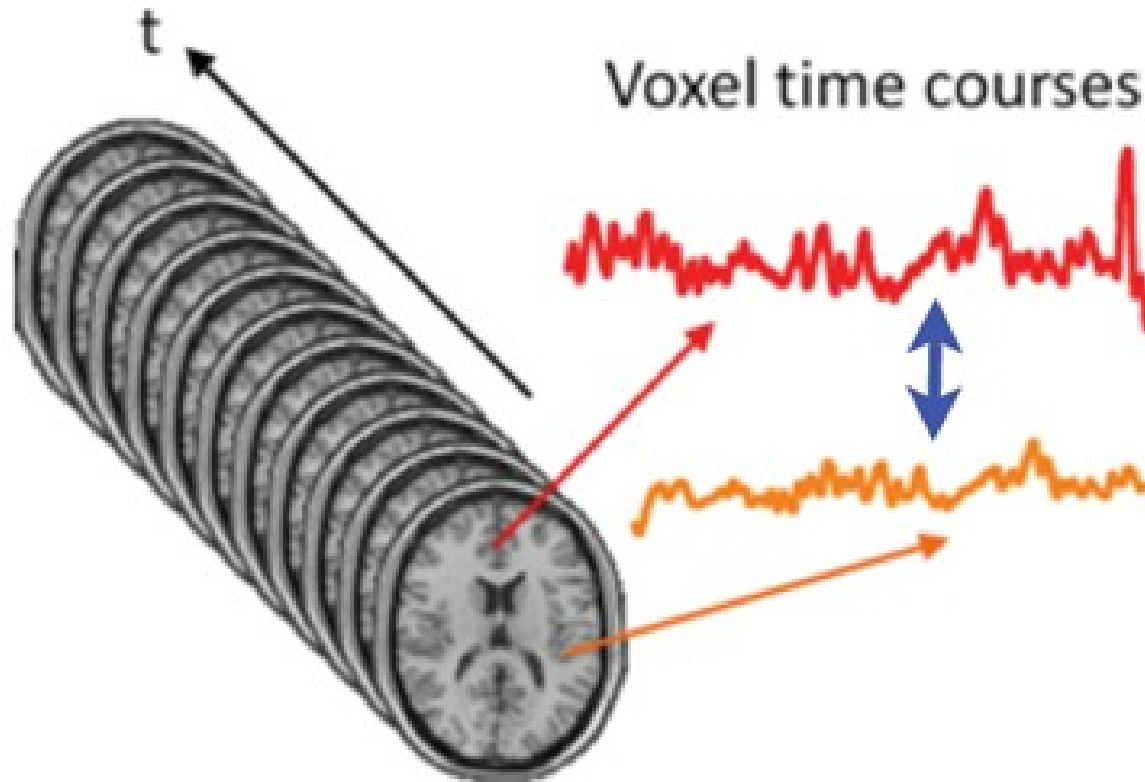


Segnale BOLD



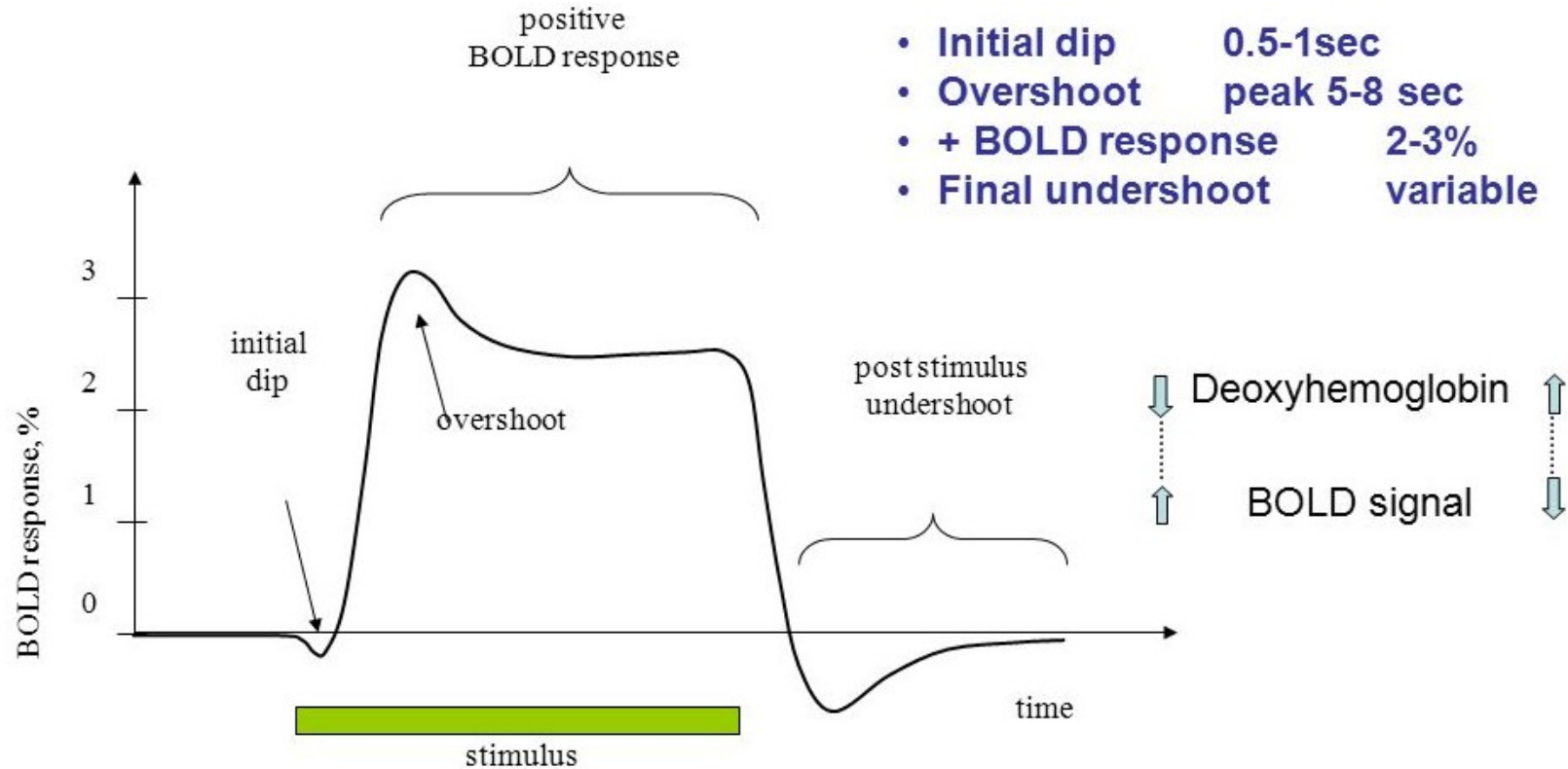
La concentrazione di emoglobina ossigenata fa variare il T_2^* .

Segnale BOLD

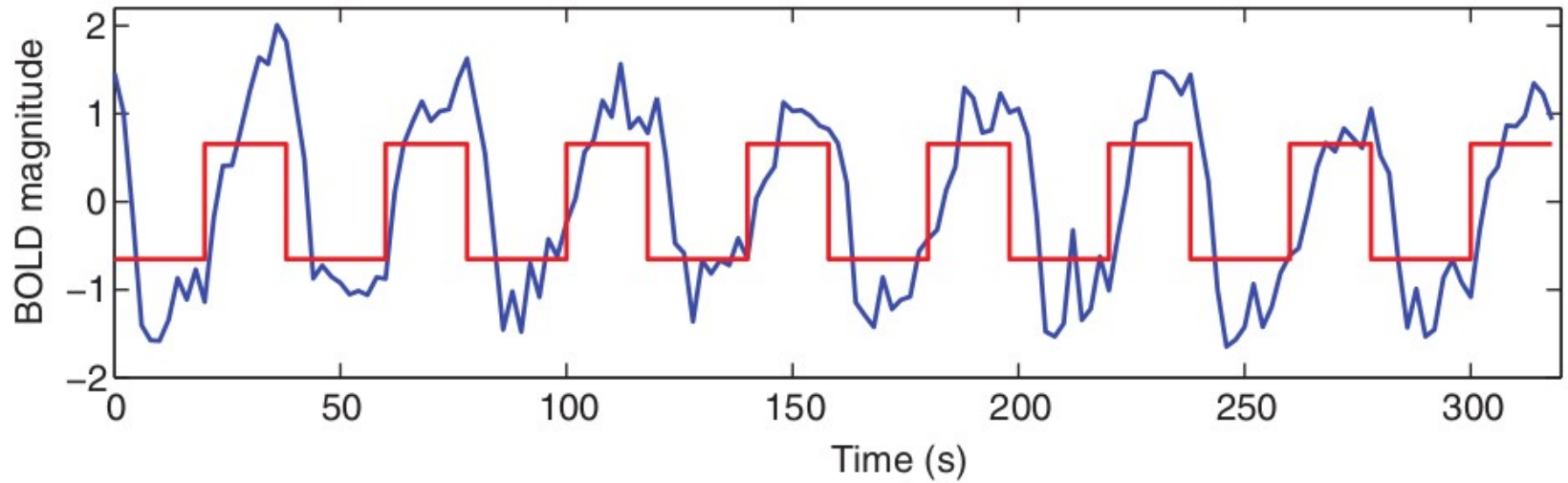


Misuriamo la variazione temporale dell'intensità del segnale per ciascun voxel.

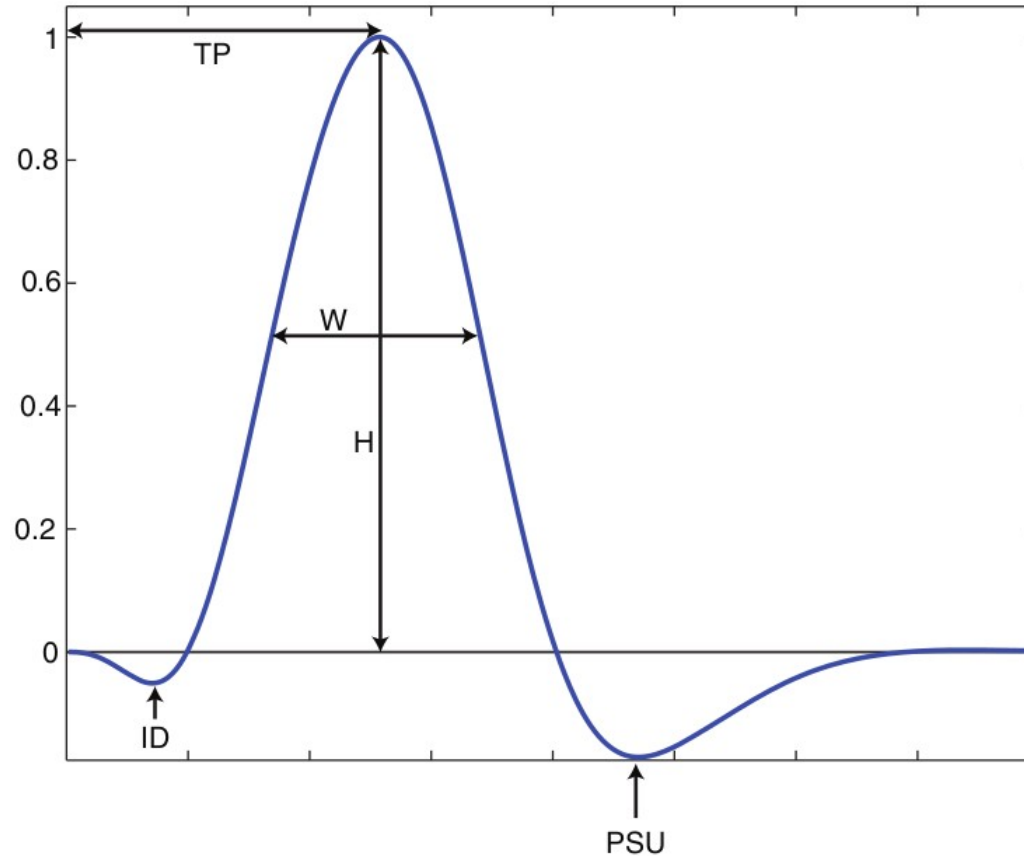
Segnale BOLD



Segnale BOLD

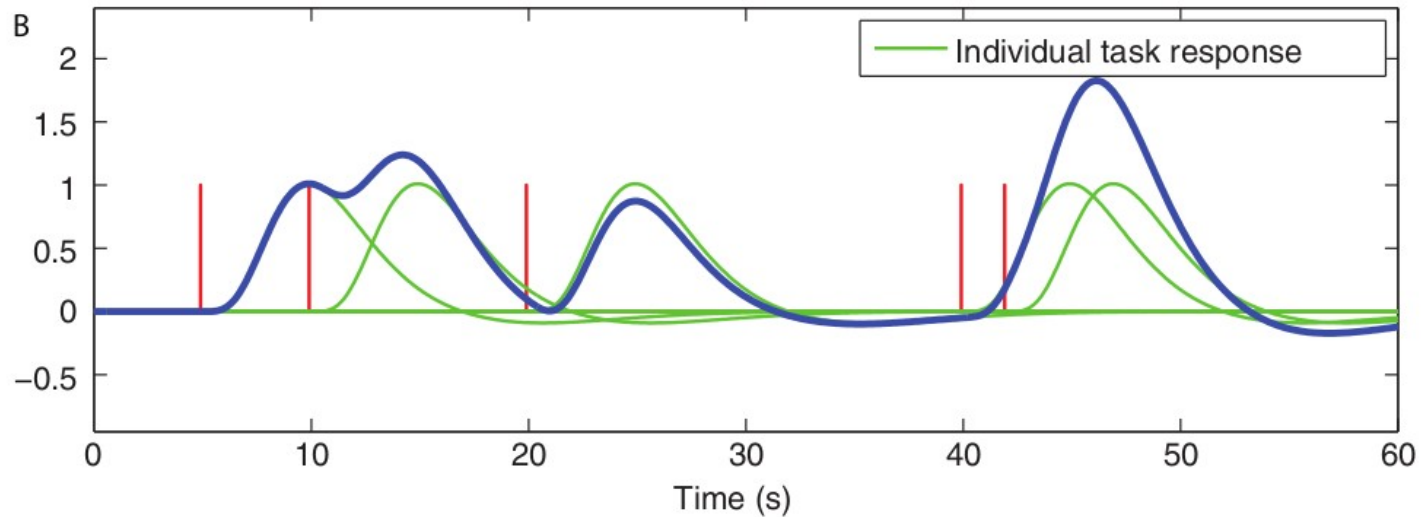
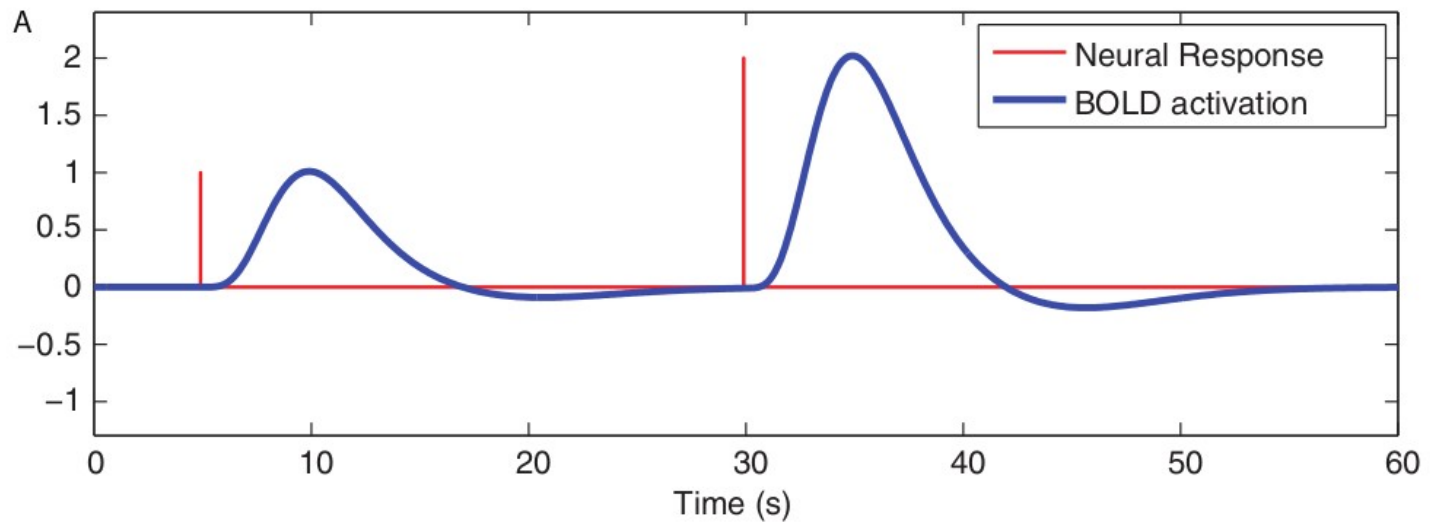


Segnale BOLD

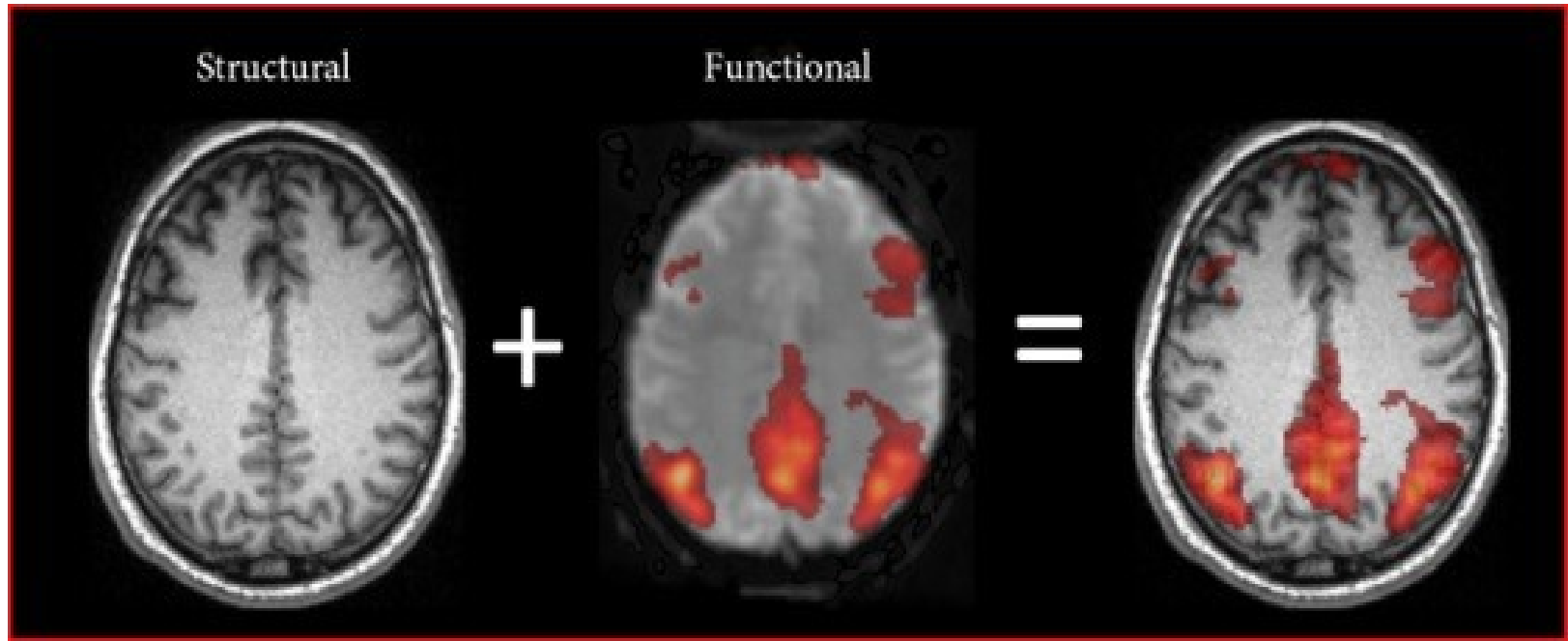


Initial dip (ID), time peak (TP), poststimulus undershoot (PSU).

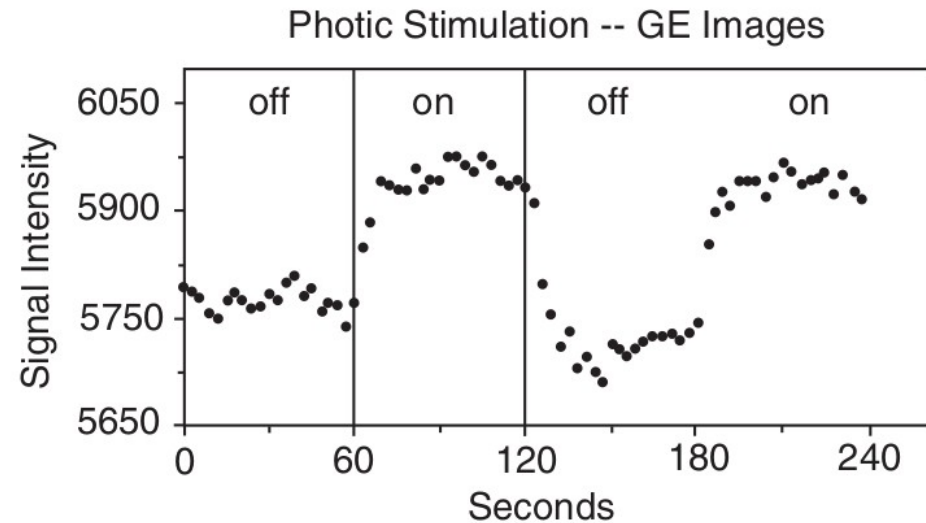
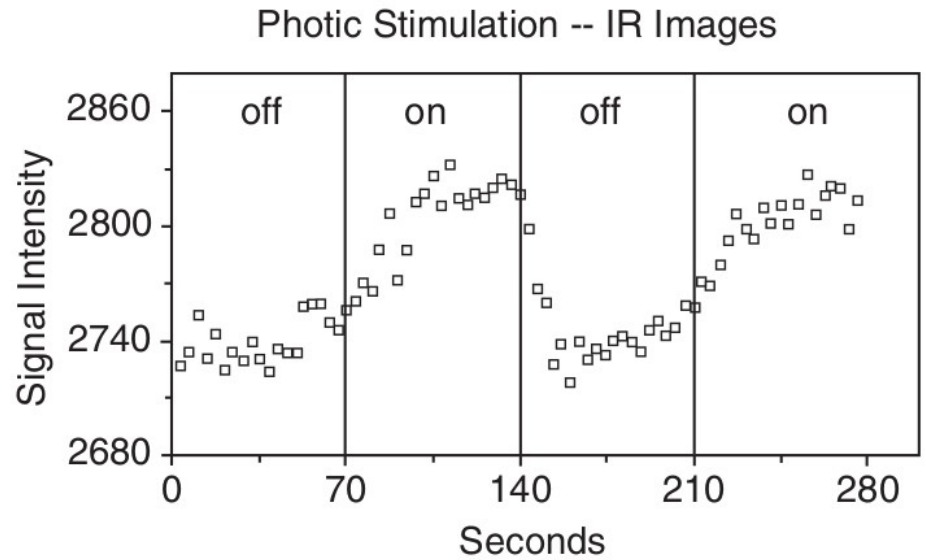
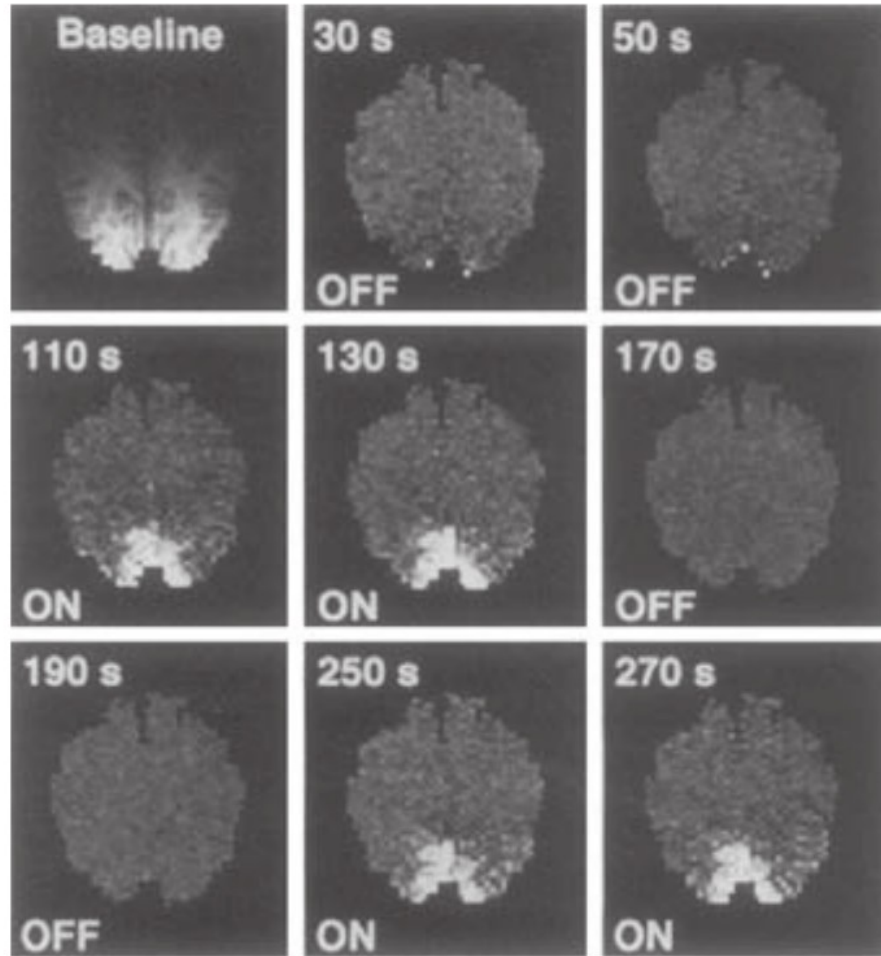
Segnale BOLD



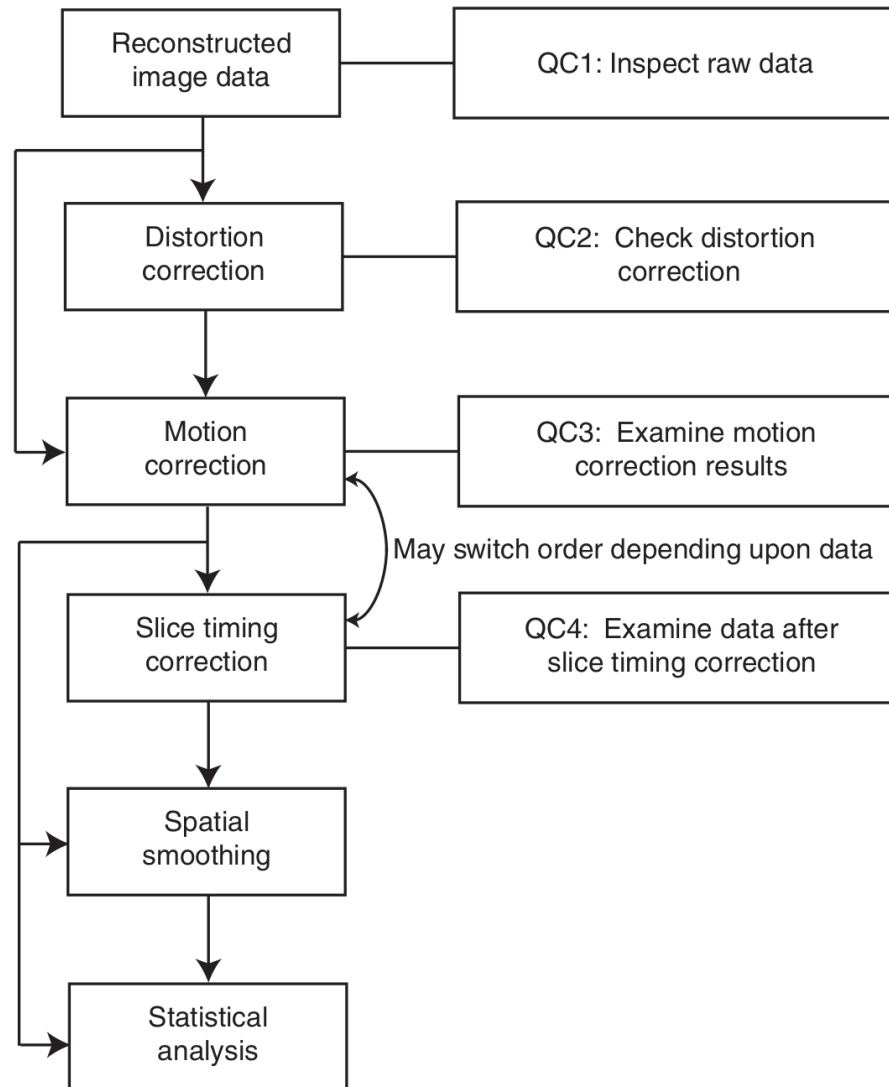
MRI funzionale



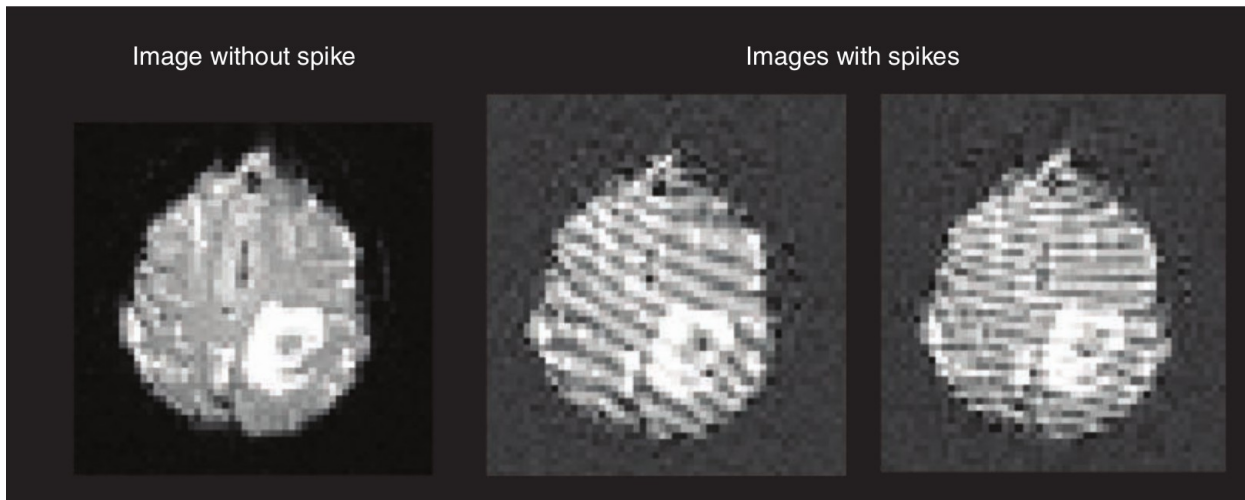
fMRI



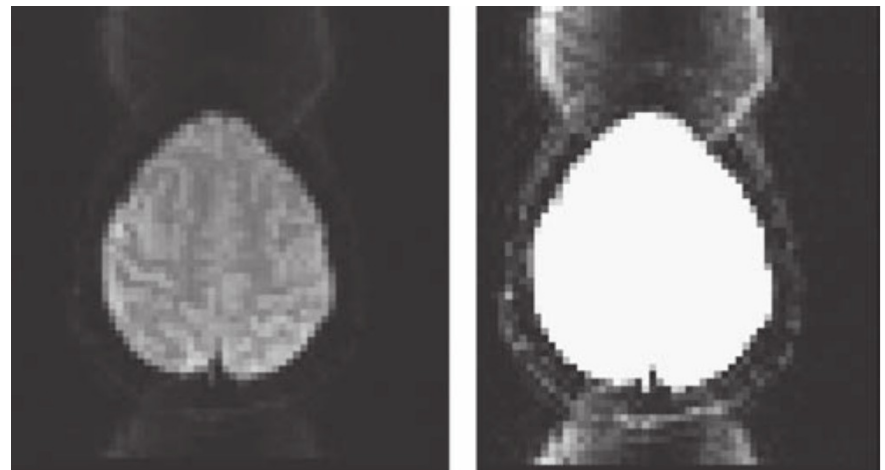
fMRI preprocessing



Artefatti



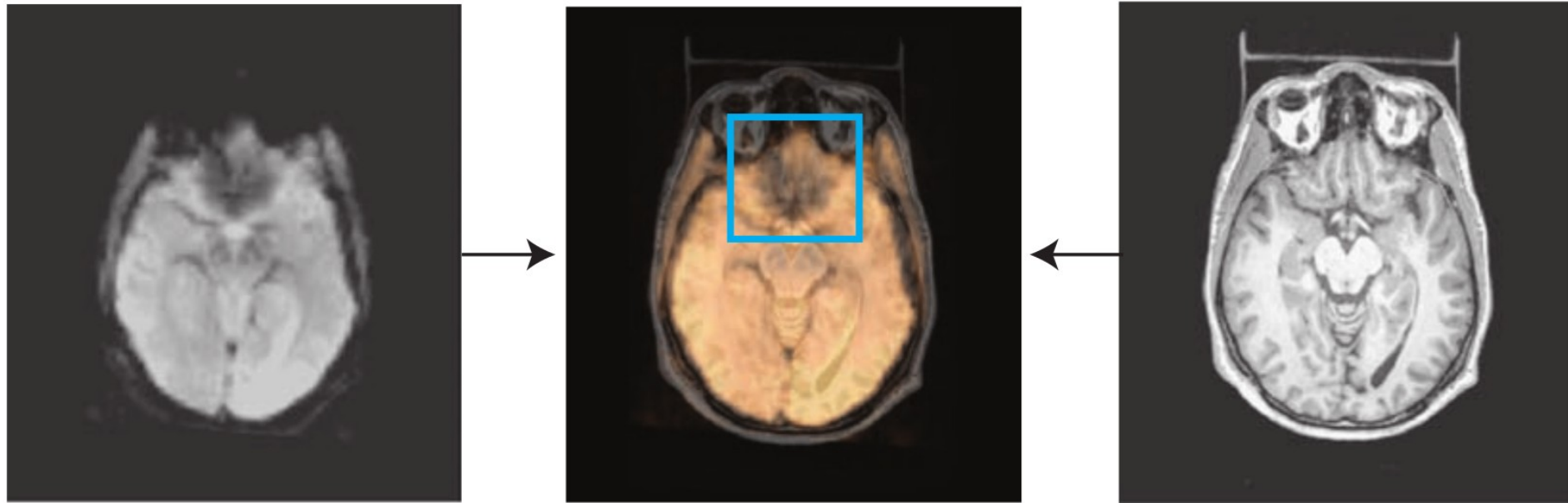
Ghosting



Distortion correction

EPI

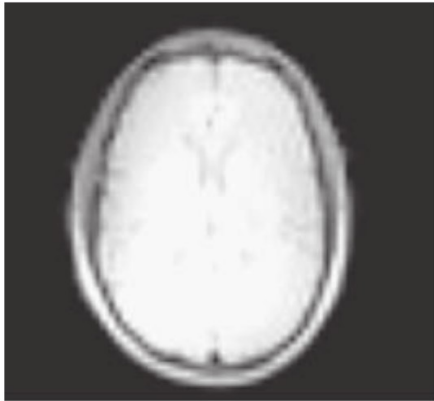
T1w



Dropout

Distortion correction

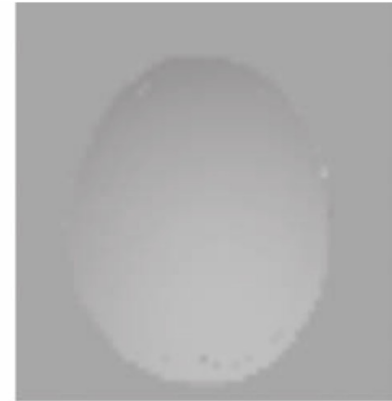
Field Map Images



Magnitude

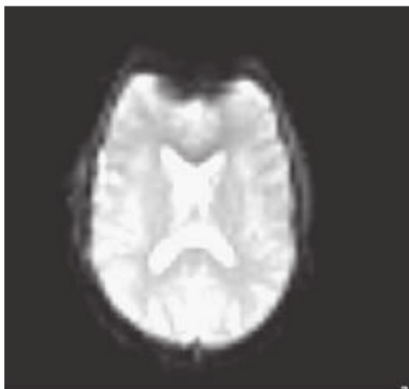


Phase (original)

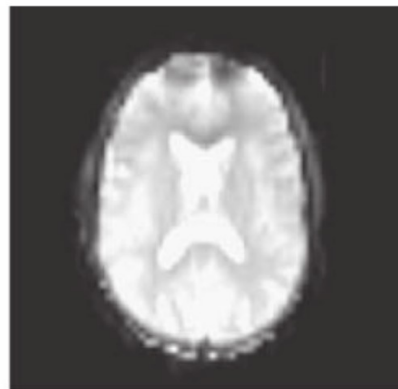


Phase (unwrapped)

Original EPI image



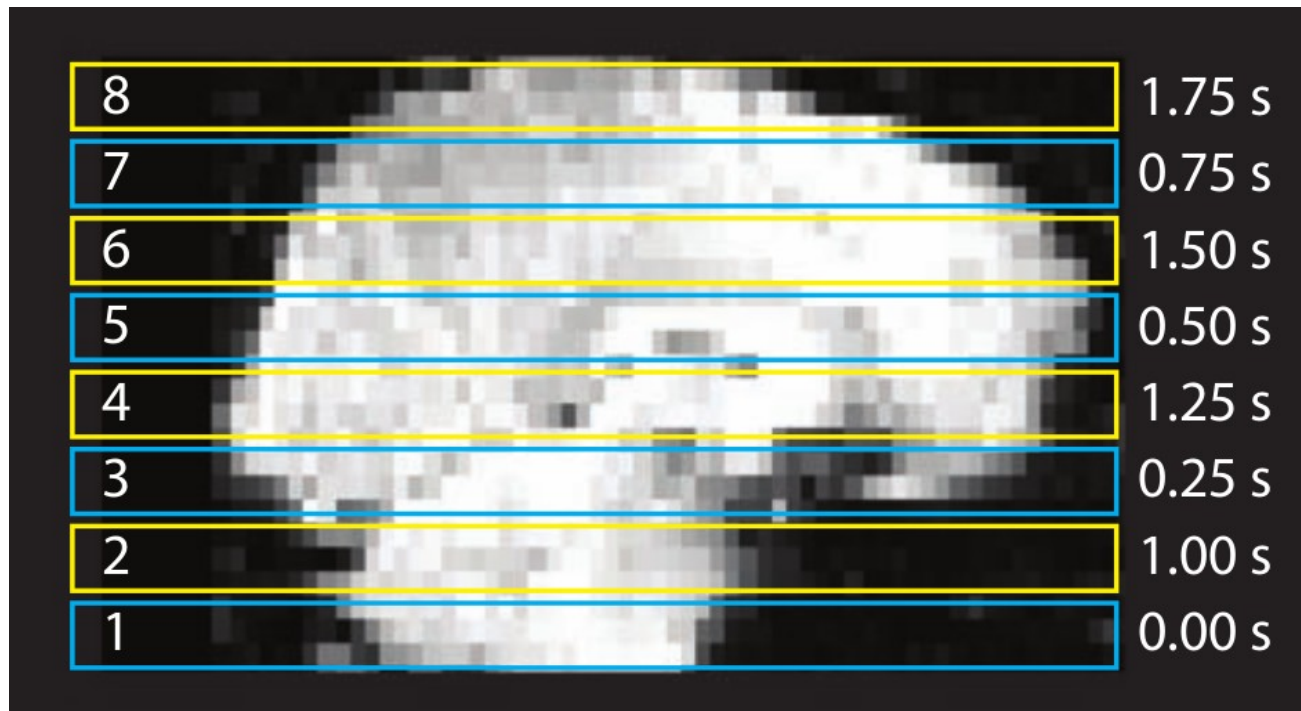
Unwarped EPI image



Difference image

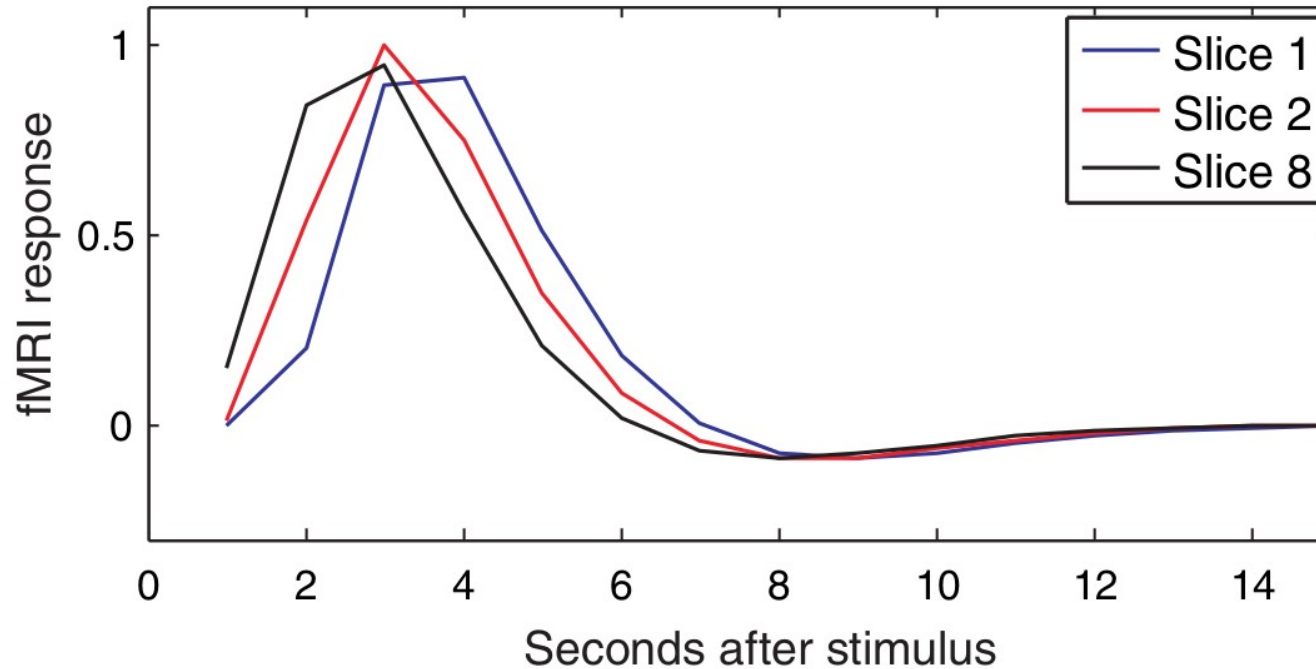


Slice timing correction



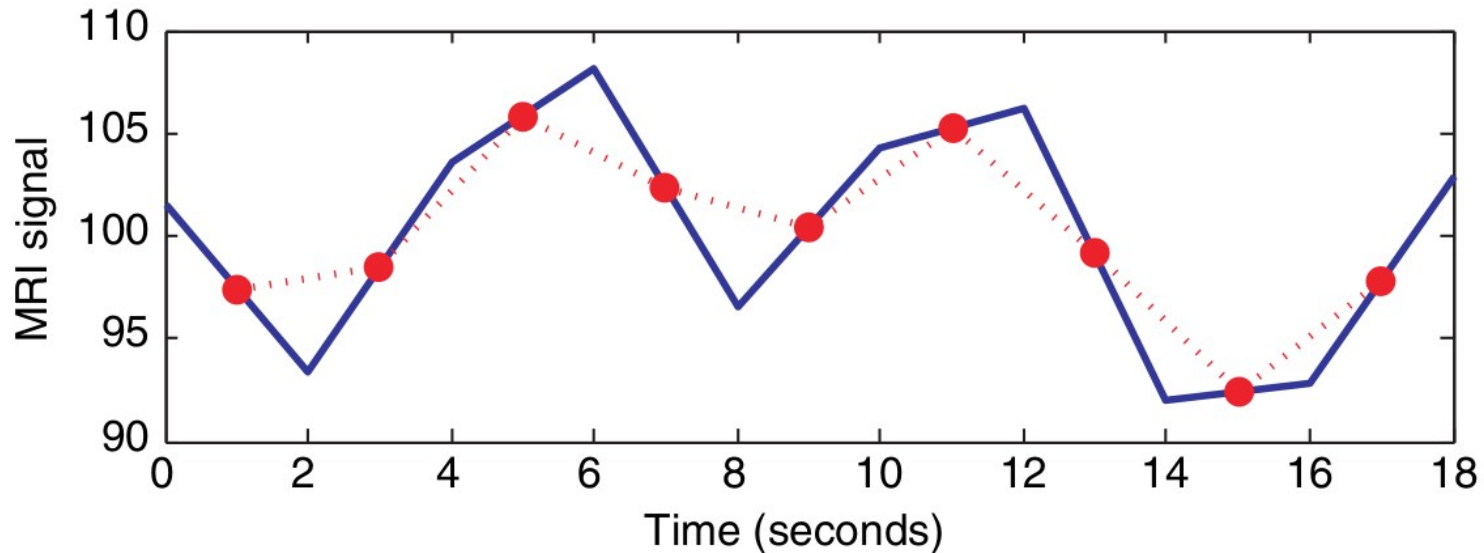
Acquisizione *interleaved* con TR=2 sec.

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.

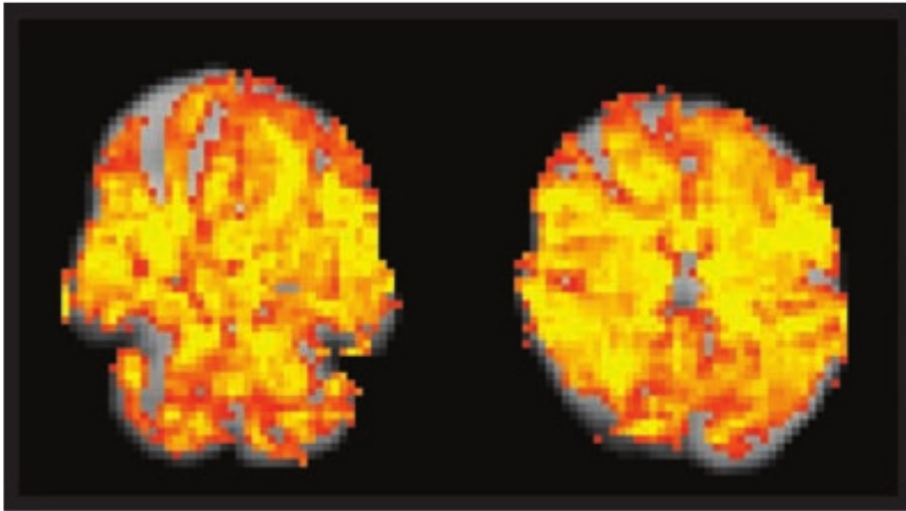
Relativamente agli ultimi, una possibile strategia consiste nel registrare il fenomeno (es. ECG, gli istanti di respirazione, etc.) e compensare il segnale registrato in post-processing.

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

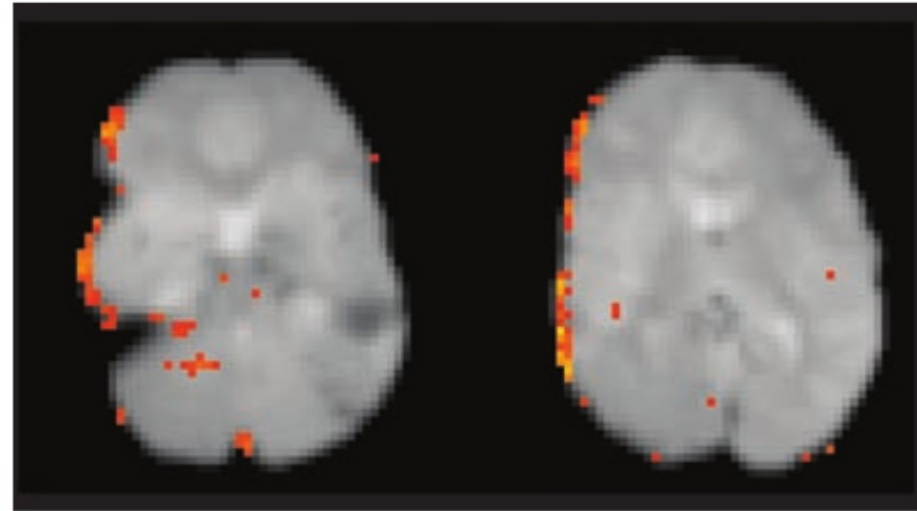


Motion correction

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



Artefatto “flaming brain”

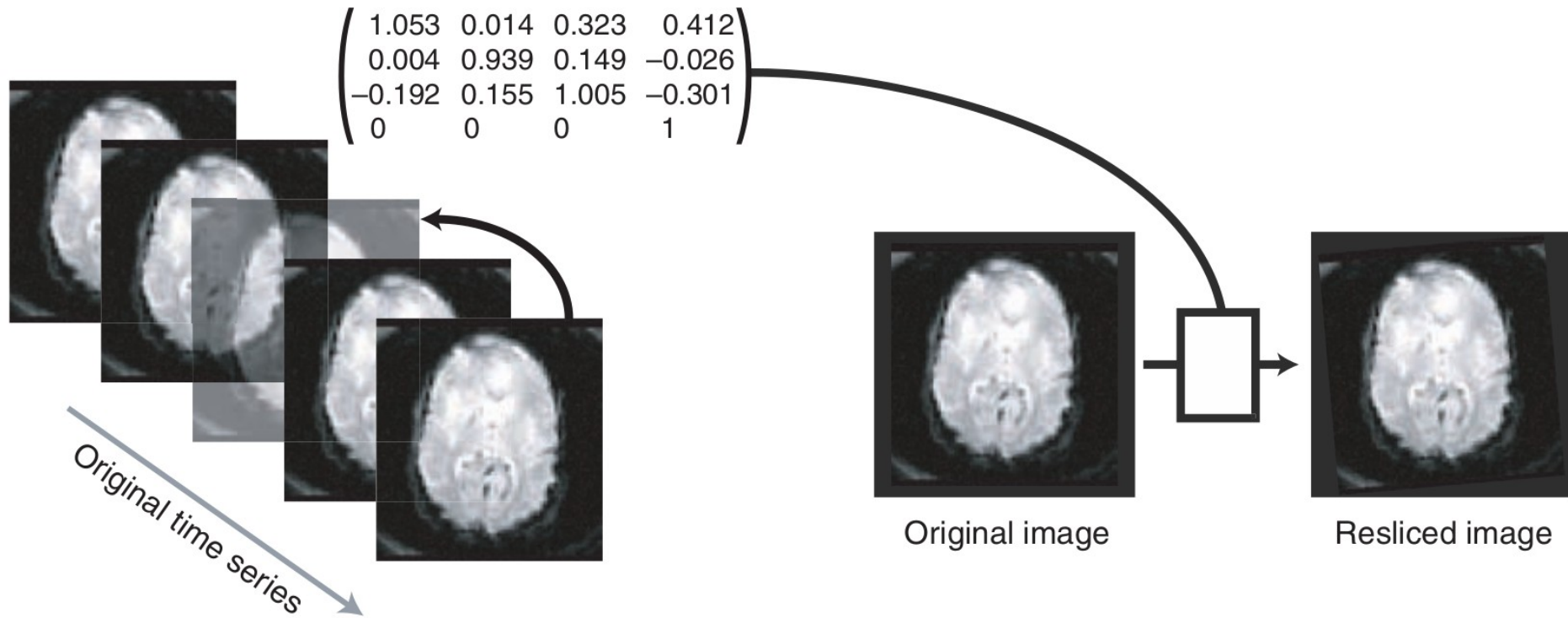


Classico artefatto motion

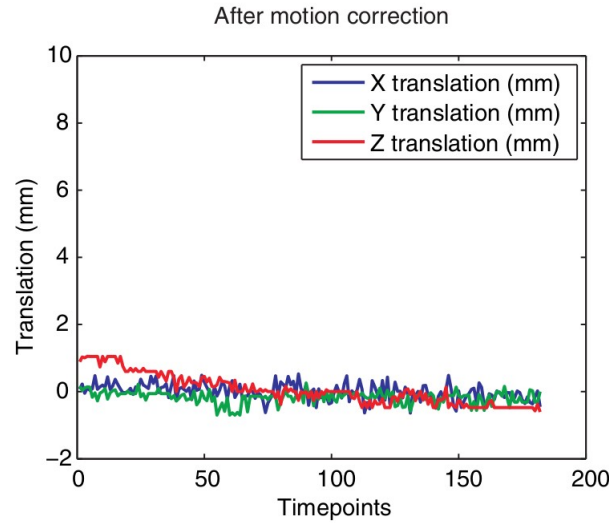
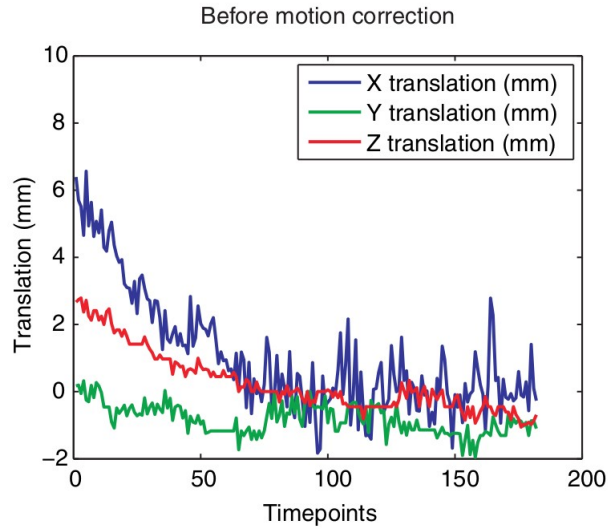
Motion correction

Step 1: Estimate parameters

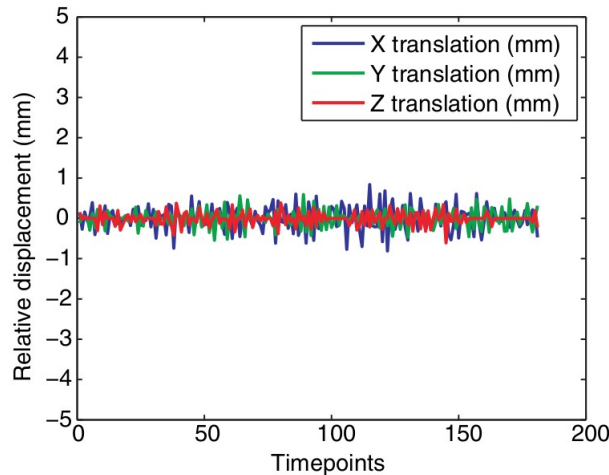
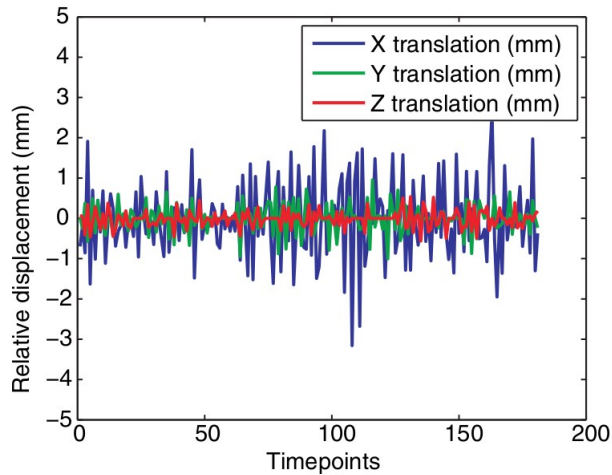
Step 2: Reslice images



Motion correction



Rispetto al
reference



Rispetto
all'istante
precedente



Spatial smoothing

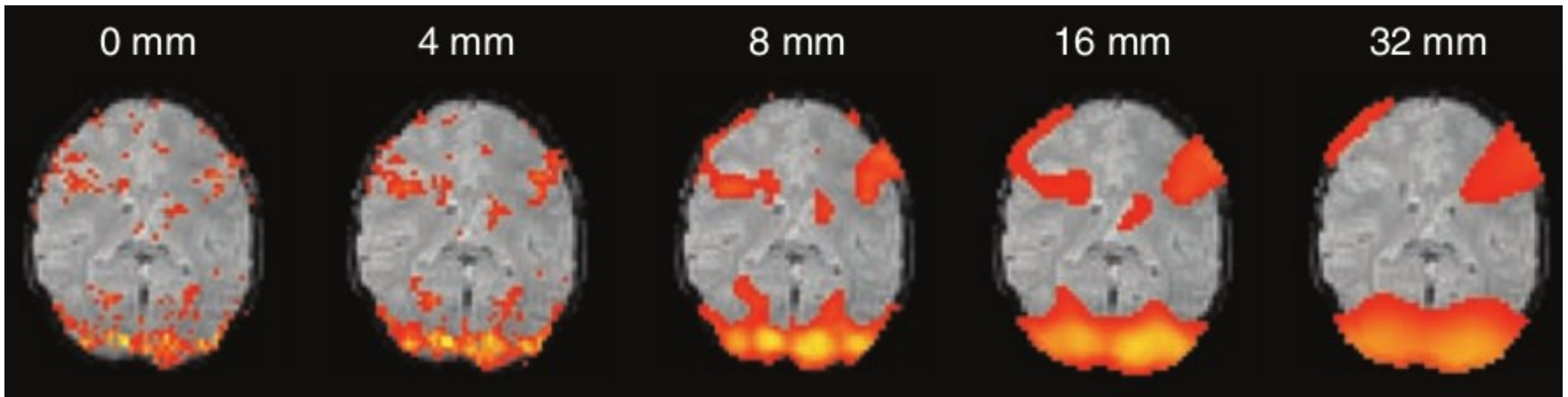
Riduce la risoluzione dell'immagine attraverso l'applicazione di un filtro passa-basso.

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

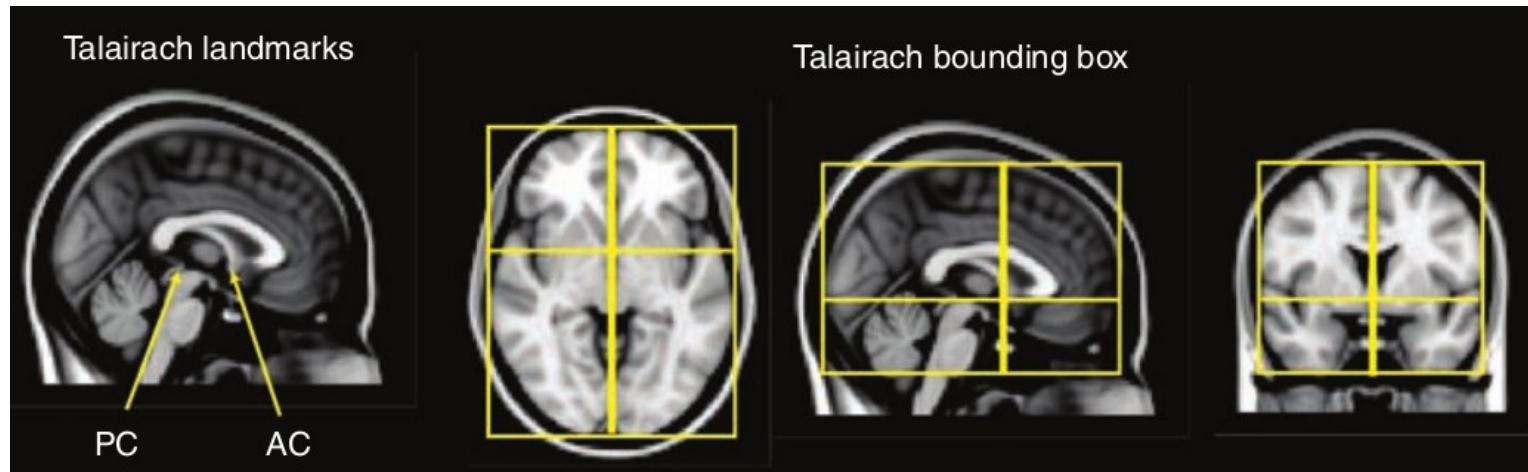


Attivazioni ottenute utilizzando diversi filtri di smoothing. Scompaiono le attivazioni di piccoli clusters, ma quelle di regioni grandi sono rilevate con maggiore efficacia.

Spatial normalization

La normalizzazione spaziale, anche detta registrazione inter-soggetto, consiste nel trasformare i segnali acquisiti proiettandoli in un sistema di riferimento comune.

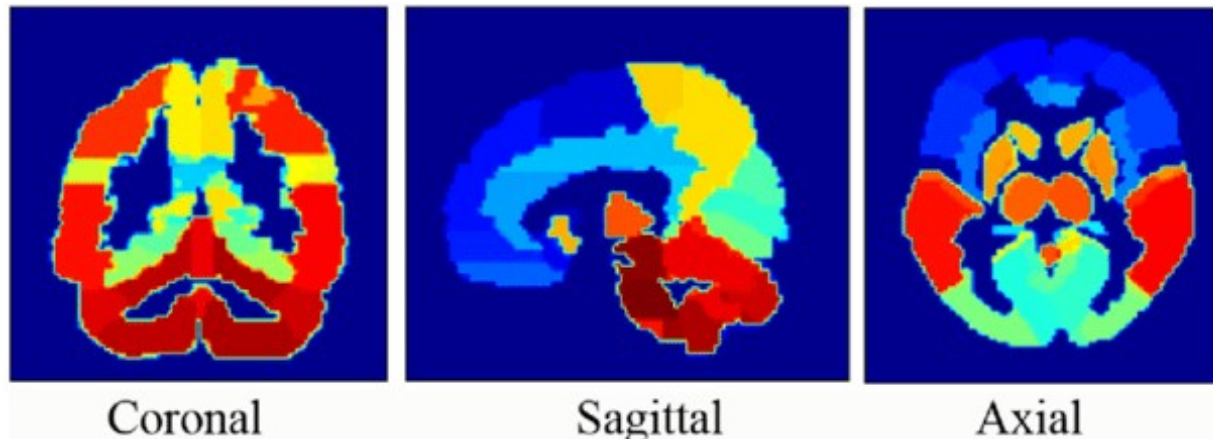
Per prima cosa è necessario definire dei riferimenti anatomici (*landmarks*) ed un relativo sistema di riferimento.



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 da un sistema di riferimento relativo.

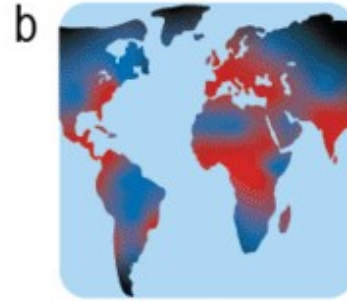


Atlanti e template

Clarifying Terminologies



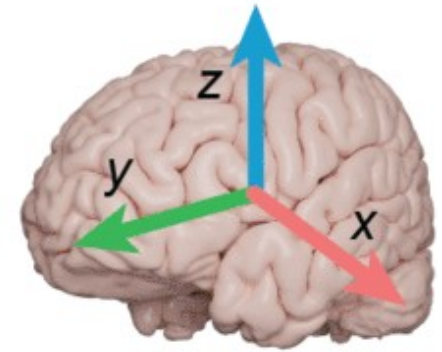
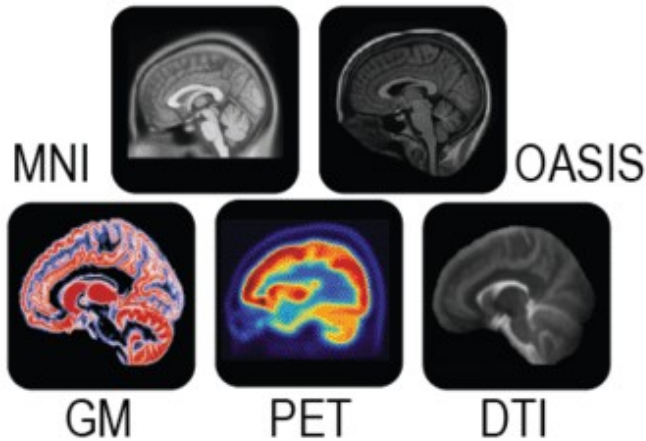
Atlas



Template



Coordinate System




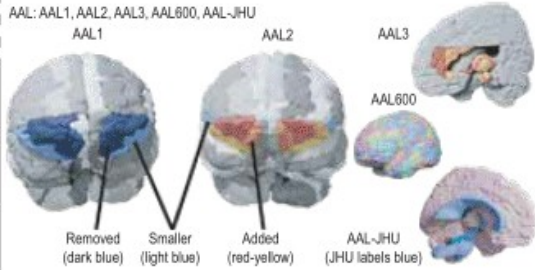





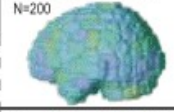
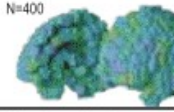







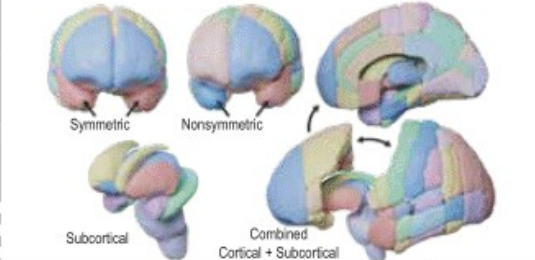

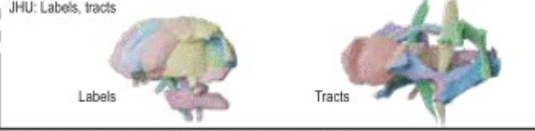








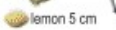
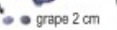
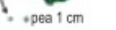







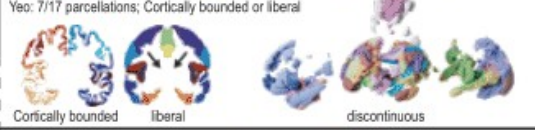



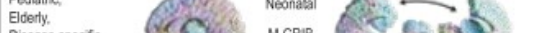
Atlanti e template

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

Sono state allianate 305 immagini MRI all'atlante Talairach (coregstrandoli 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*.

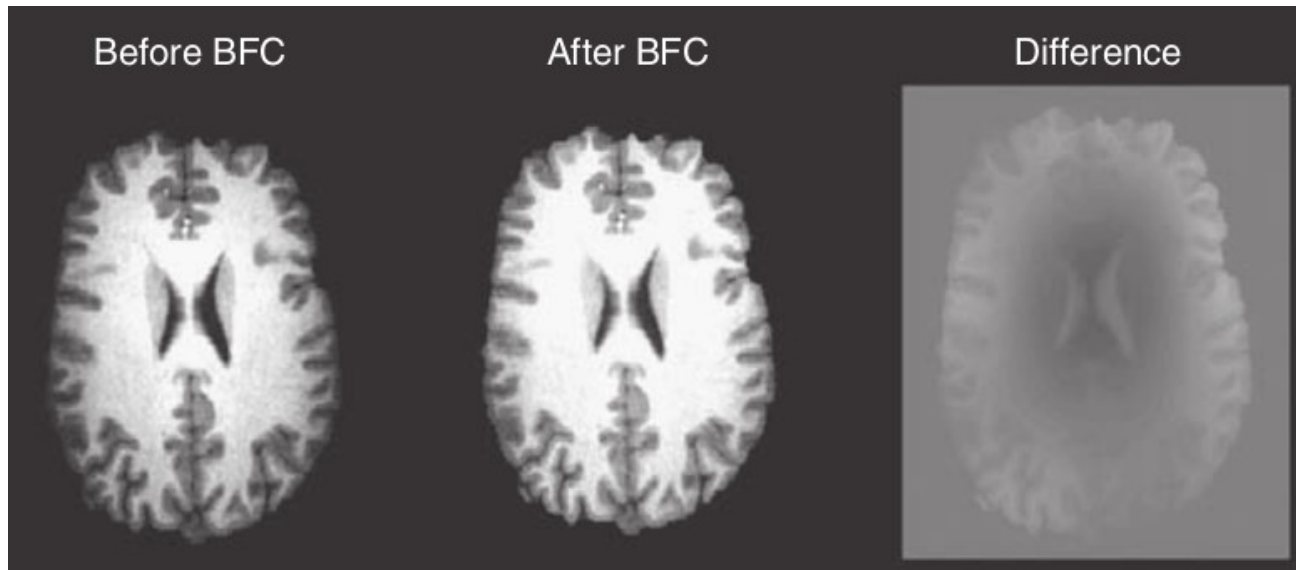


Atlas [regions]	Sources	3D Render	Description	Variations
AAL [116;120;166]	1-7 SPM		Structural atlas. Manual identification using a defined labeling protocol on single subject template (Collin-27). Three versions. Version 2: updated boundaries. Version 3: further parcellations. Successor to Talairach.	AAL: AAL1, AAL2, AAL3, AAL600, AAL-JHU 
AICHA [384]	8		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		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		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		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		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 ³ resolution fMRI. Resliced.	Craddock: N parcellations N=200  N=400  1.7 cm  1.0 cm  pea 
DKT [111]	18-23 FreeSurfer		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		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		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		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		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		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		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		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		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 [100-1000]	42-43 GitHub		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.	Schaefer: 100 to 1,000 parcellations (by 100), named to Yeo 7 and 17 N=100  N=500  N=1,000 
Talairach [1105]	44-48 FSL		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]	49-50 FreeSurfer		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.	Yeo: 7/17 parcellations; Cortically bounded or liberal 
Region-specific	41-54 FSL		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		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. 



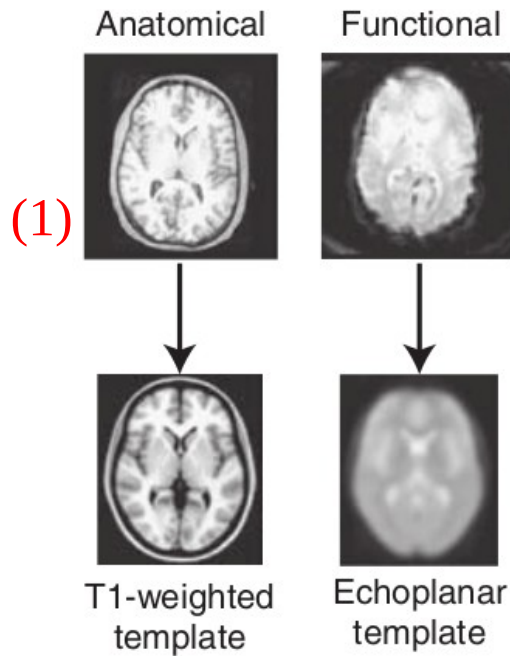
Spatial normalization

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

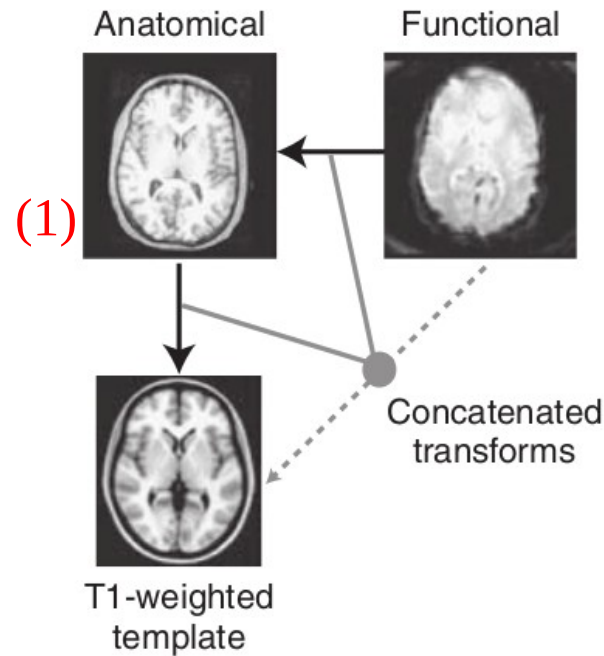


Spatial normalization

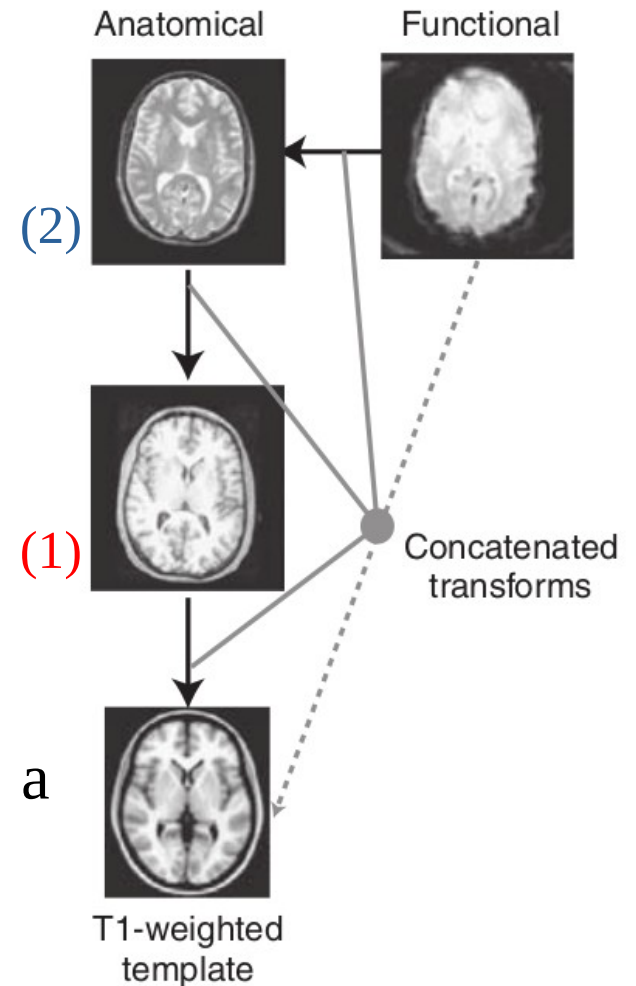
1-step normalization



2-step normalization



3-step normalization

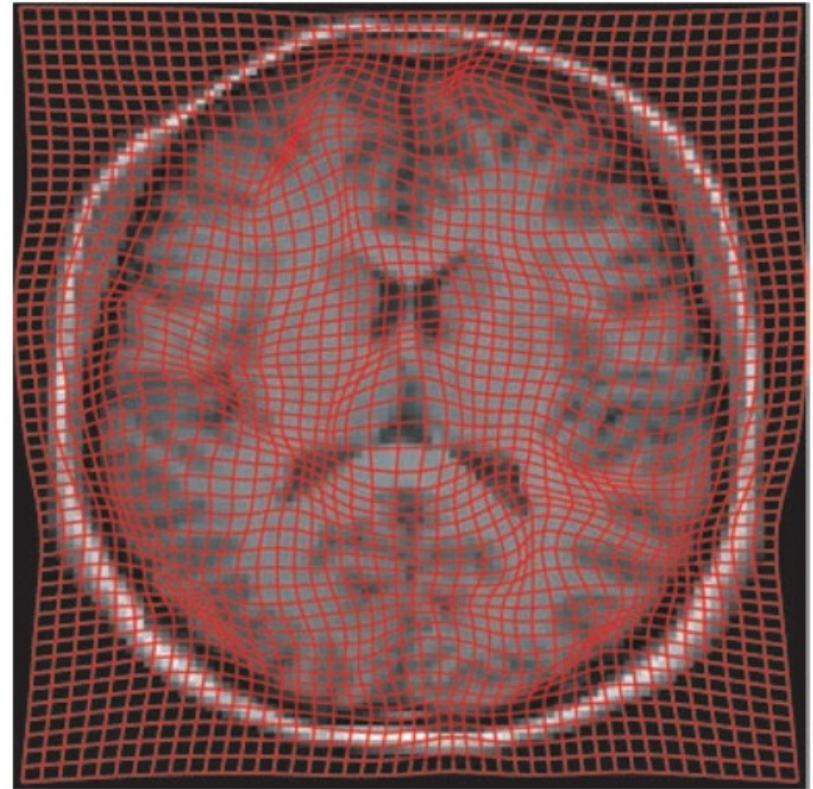
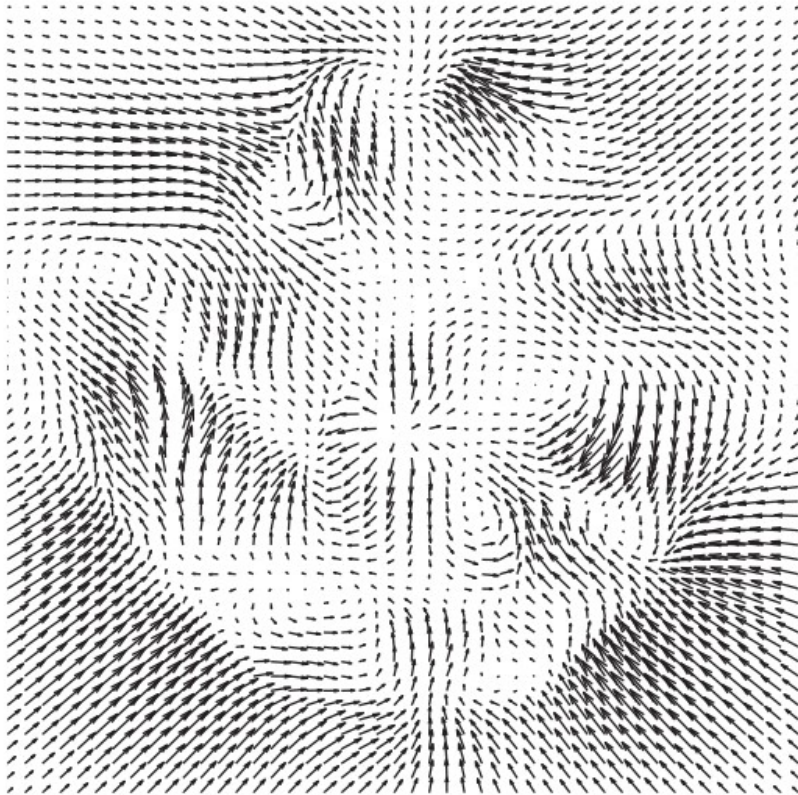


3 esempi di pre-elaborazioni da fare a monte della normalizzazione spaziale.

(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.

