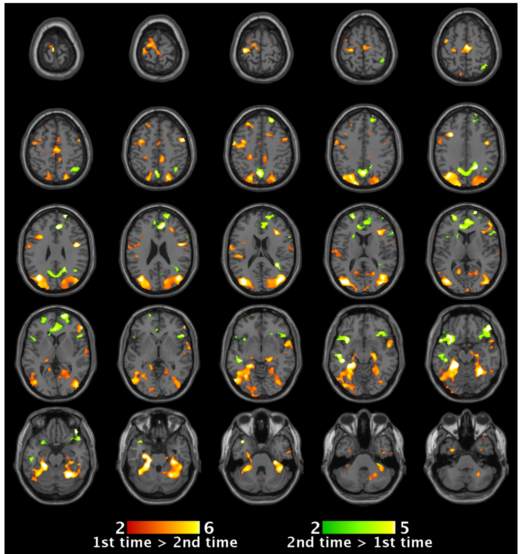

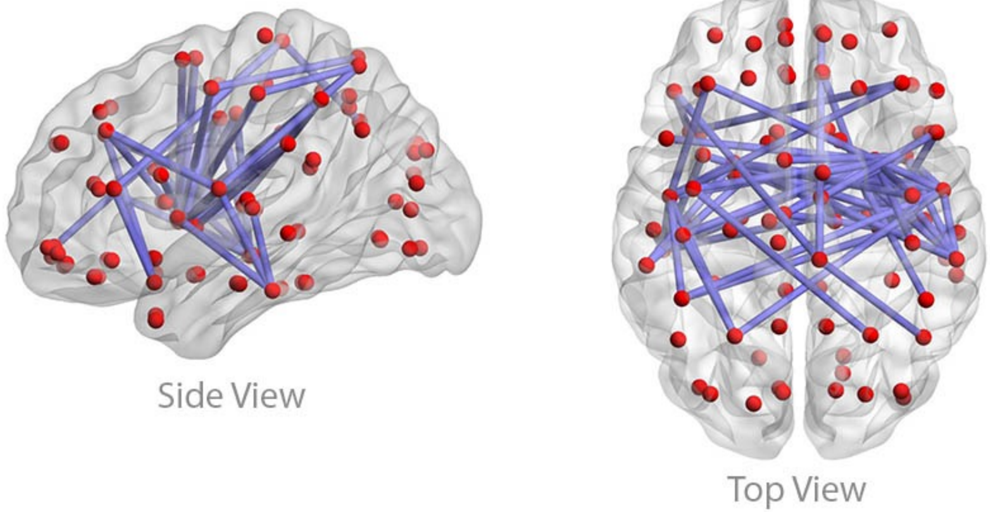

Functional MRI

Dr. Peter Van Schuerbeek

Universitair
Ziekenhuis
Brussel

VUB

Introduction

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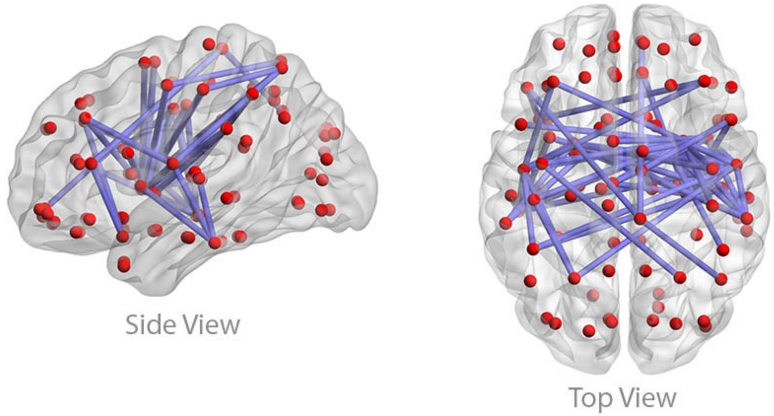
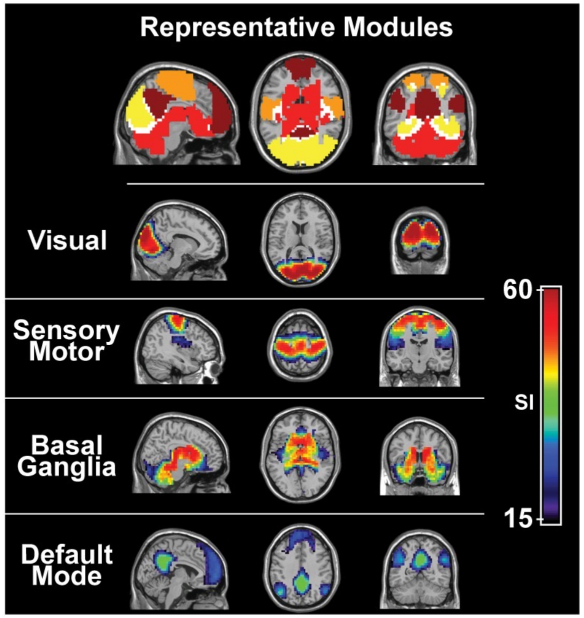
Brussel

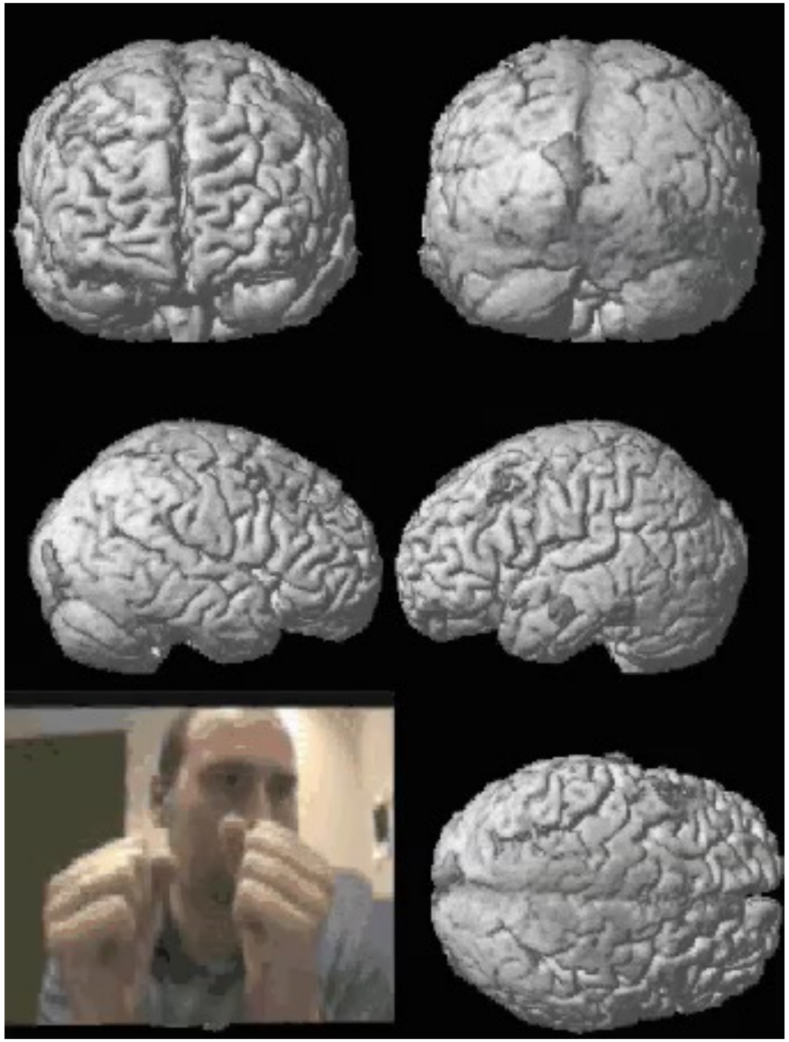
Functional connectivity





Resting state fMRI

Task based fMRI



Short introduction to MRI

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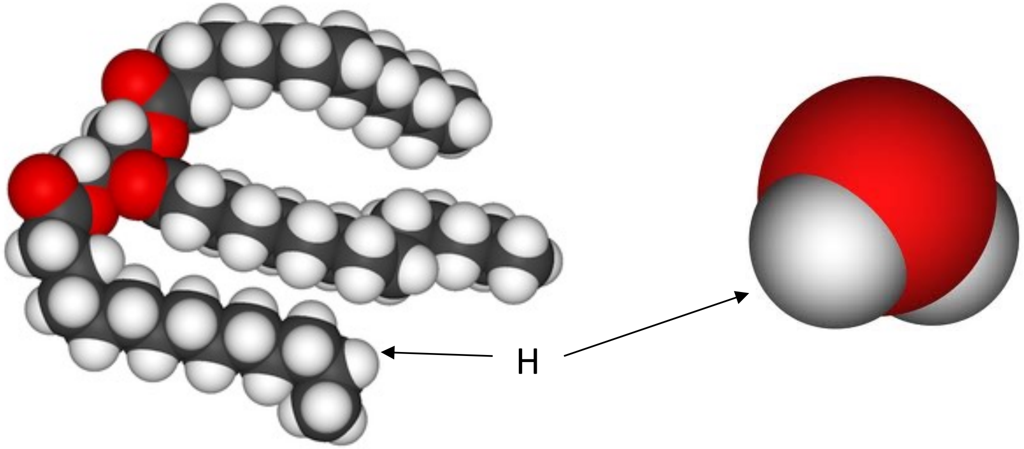
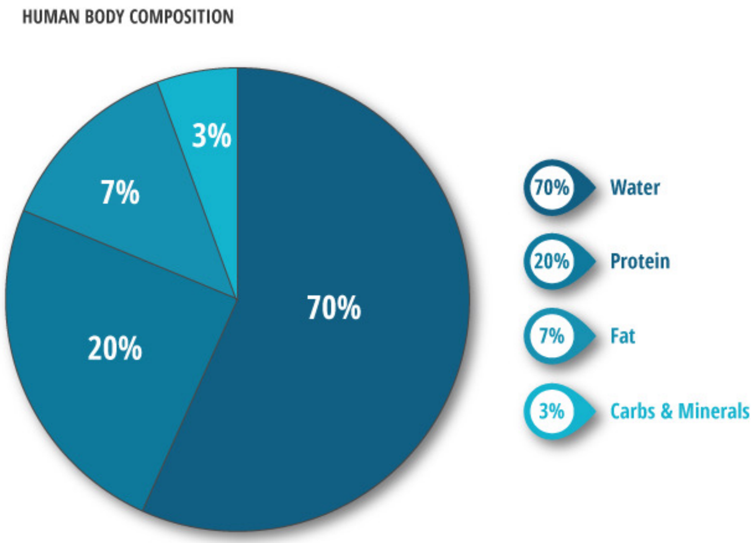
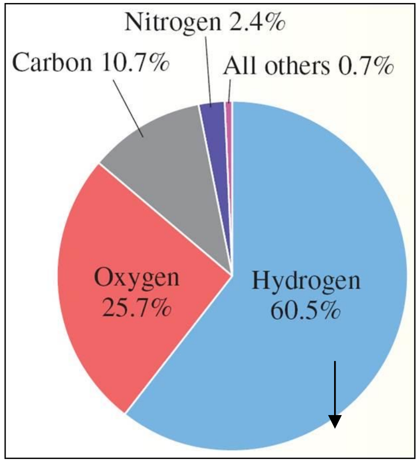
Interesting sides about the physics of MRI:

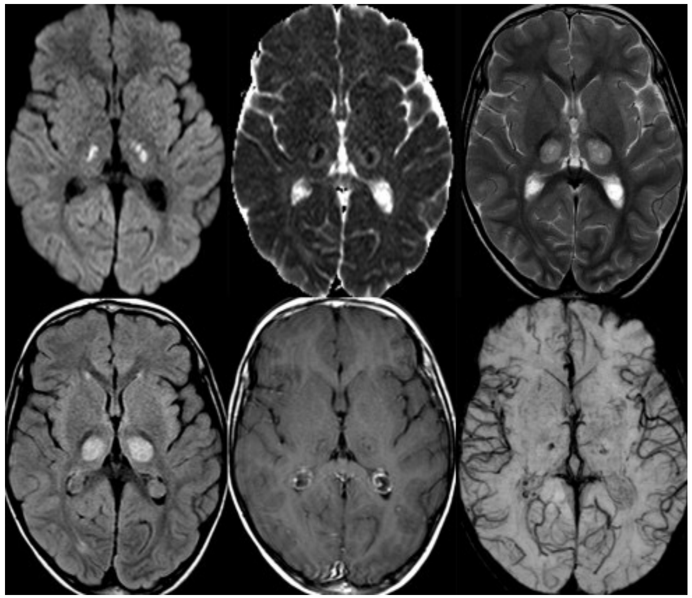
- mri-q.com
- mri-physics.net
- cis.rit.edu/htbooks/mri/
- www.mritutor.org
- revisemri.com
- https://radiopaedia.org
- https://www.imaios.com/en/e-Courses/e-MRI

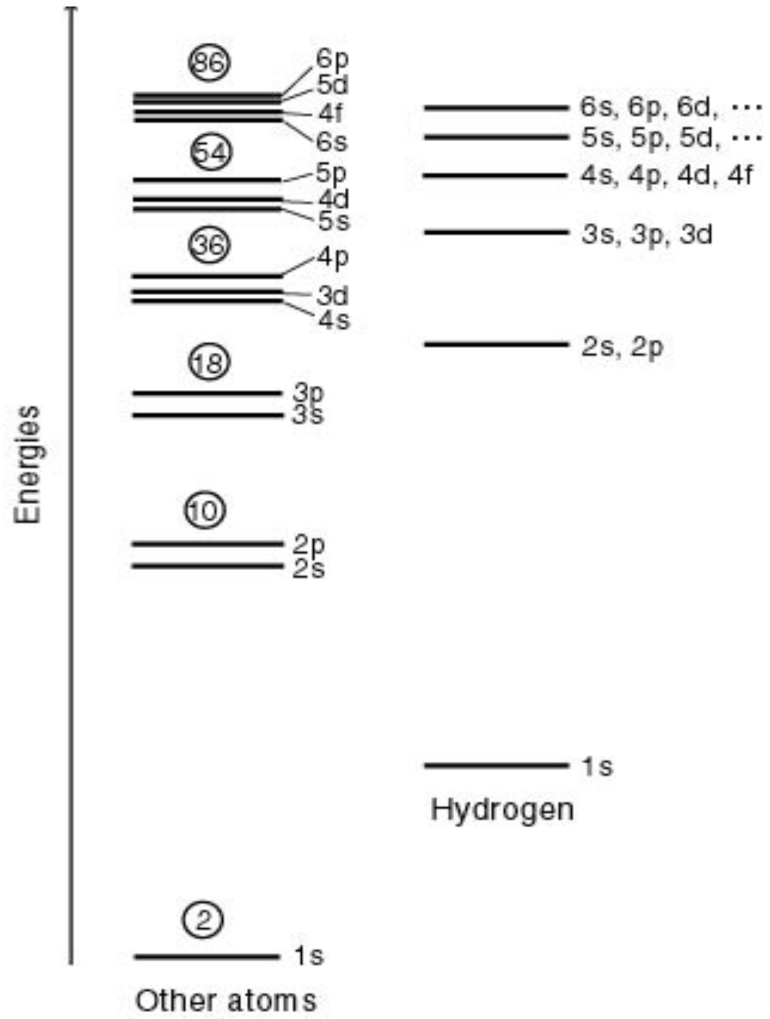


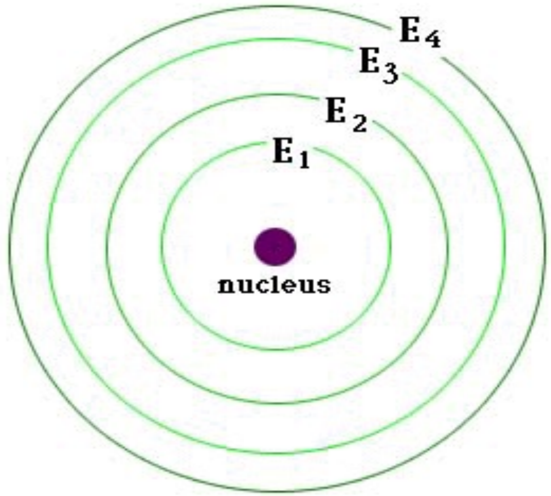
Soft tissues
Fluids
Fat
↓
Contains H_2O or $CH_3(CH_2)_n...CO_2H$



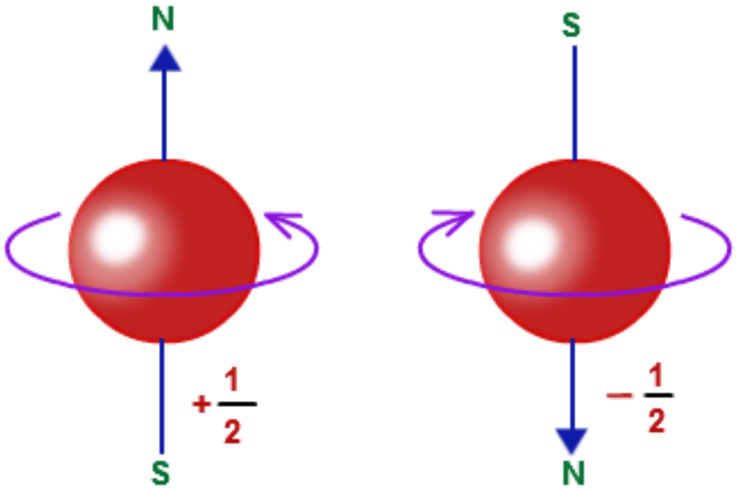








Principal quantum number	Azimutal (orbital) quantum number	Magnetic quantum number	Spin quantum number	Number of electrons
n	l	m_l	m_s	
1	0 (s)	0	–1/2 +1/2	2
2	0 (s) 1 (p)	0 -1 0 1	–1/2 +1/2 –1/2 +1/2	2 6
3	0 (s) 1 (p) 2 (d)	0 -1 0 1 -2 1 0 1 2	–1/2 +1/2 –1/2 +1/2 –1/2 +1/2	2 6 10
...	...	...	...	...

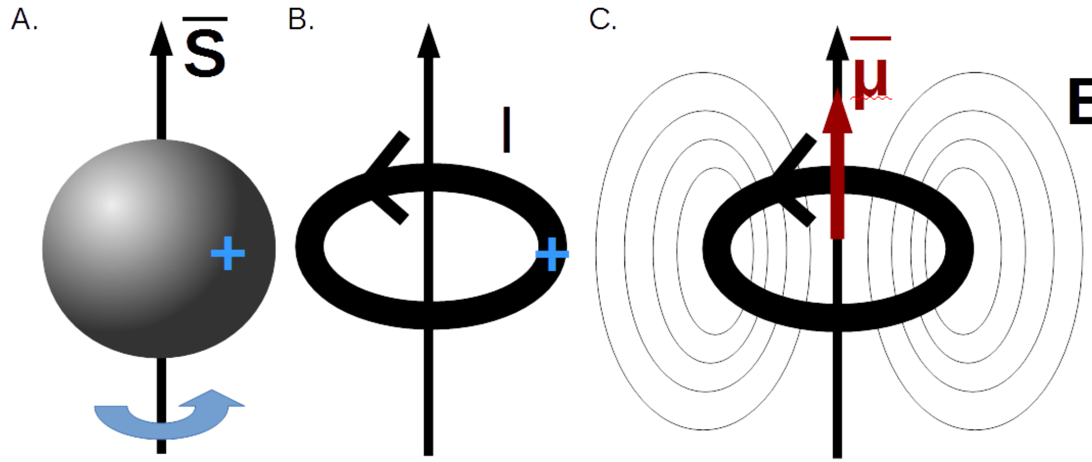


The spin angular moment

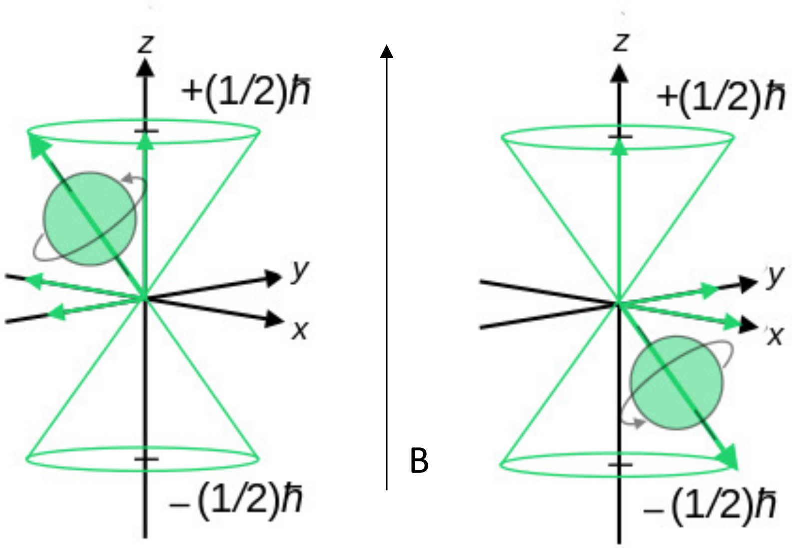
↓

The magnetic moment

$$\vec{\mu} = \gamma . \vec{S}$$



Spin angular momentum (spin-1/2 particles)

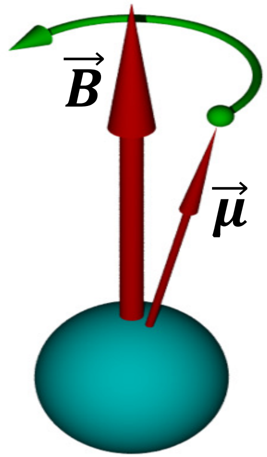


$|\uparrow\rangle \equiv \left|+\frac{1}{2}\right\rangle$

spin-up

$|\downarrow\rangle \equiv \left|-\frac{1}{2}\right\rangle$

spin-down



$$\vec{\Gamma} = \vec{\mu} \times \vec{B}$$

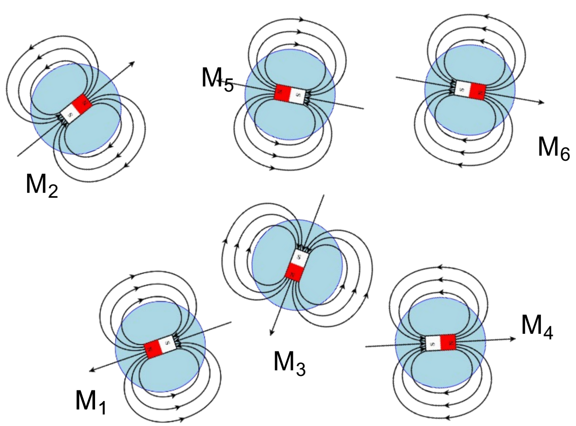
$$\tau = \frac{dS}{dt} = \mu . B . \sin\varphi$$

Precession of μ around B

The Larmor frequency: $\omega_L = \gamma . B$

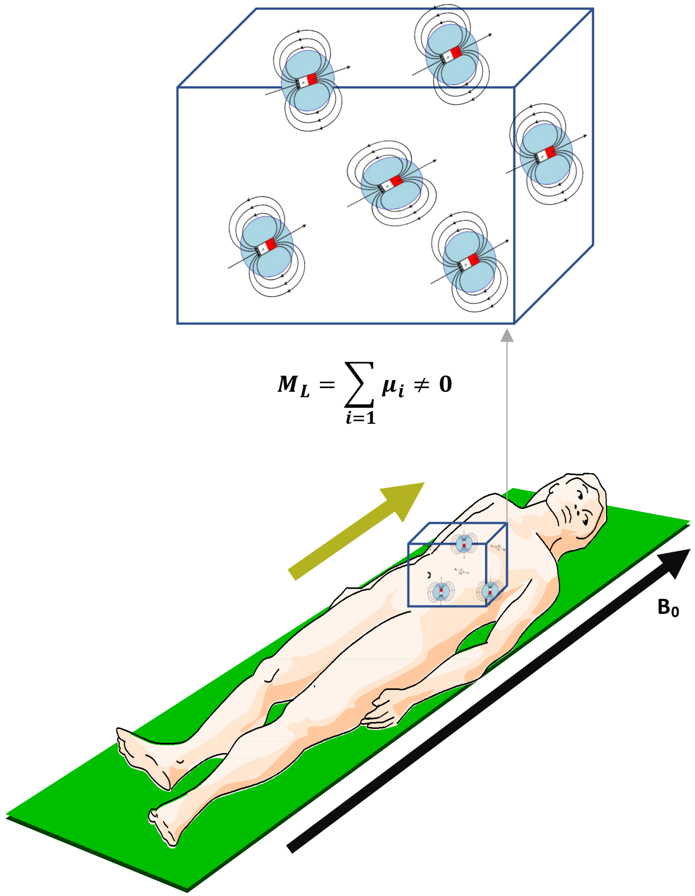
Generating a MRI signal step 1: the homogeneous magnetic field B_0

Without magnetic field:



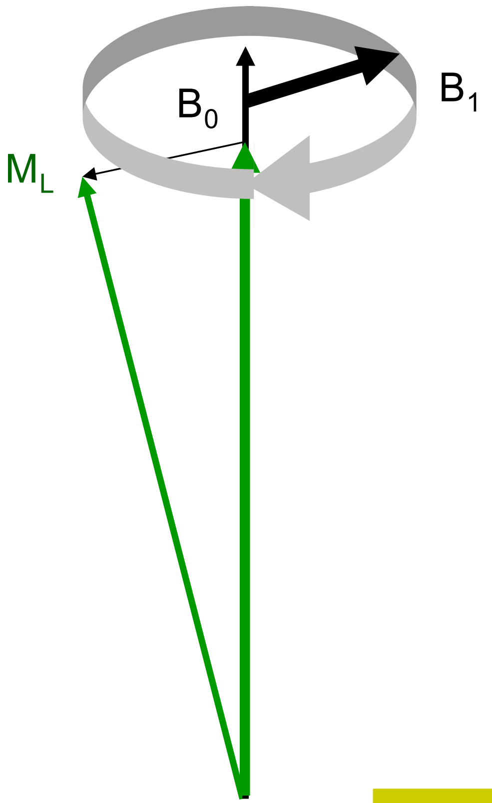
$$\Sigma\, M_i = 0$$

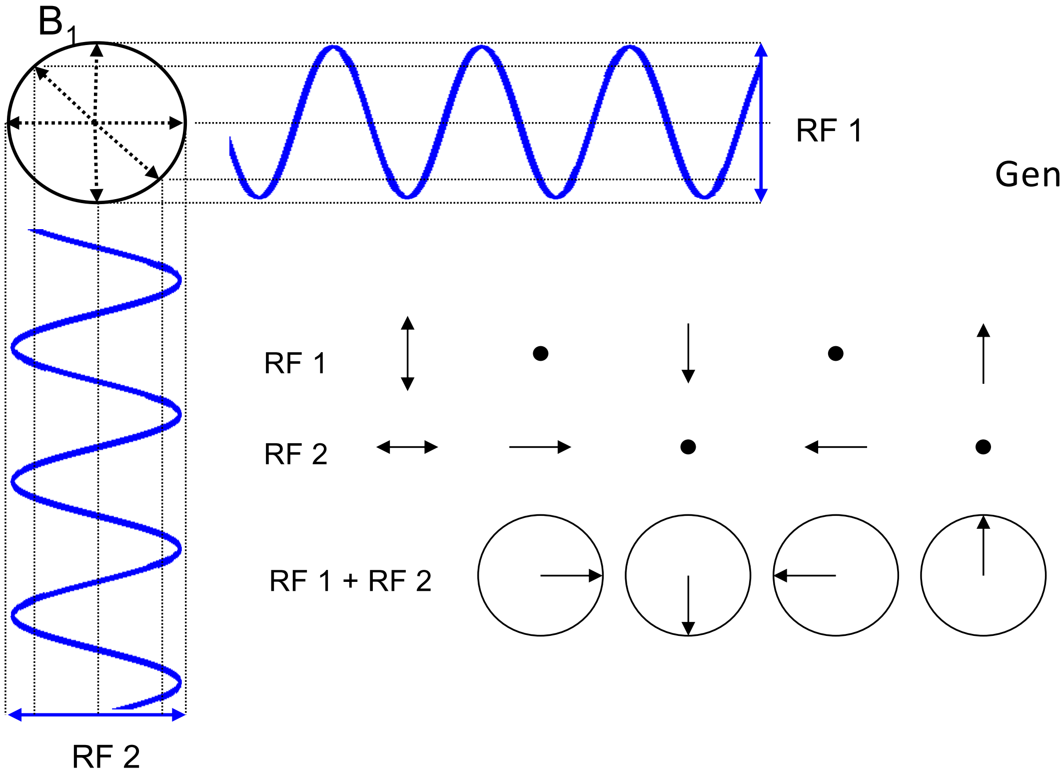
With magnetic field



Resulting net longitudinal magnetization (M_L) parallel to the field B_0

Generating a MRI signal step 2: applying a RF pulse





RF pulses

↓

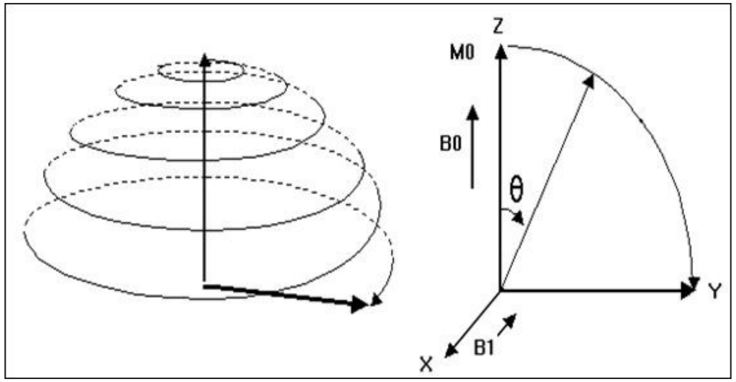
Generating a rotating B_1 field

Precession of M_L at the Larmor frequency

$$\boldsymbol{\omega = \gamma . B_0}$$

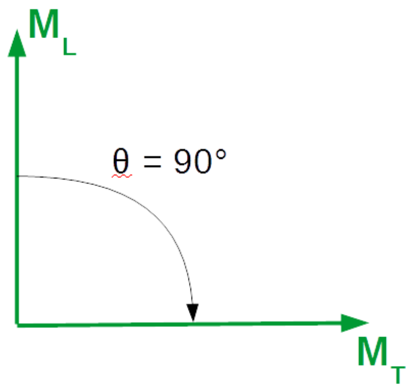
Generating a MRI signal step 2: applying a RF pulse

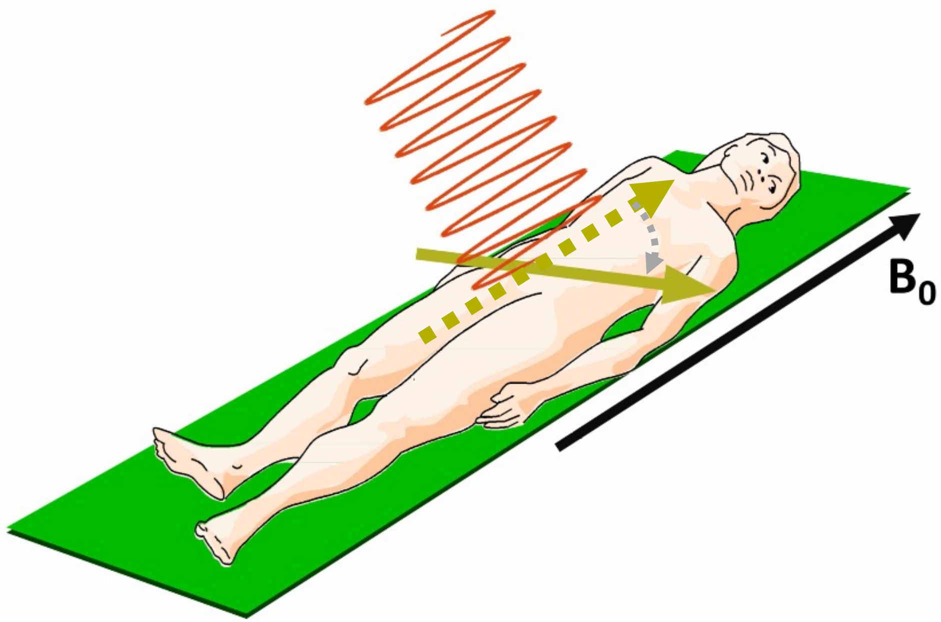
If $\omega_{RF} = \omega_L$ (resonance condition)



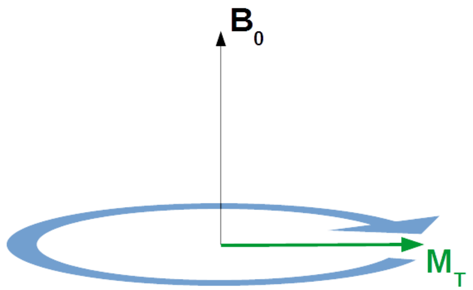
Longitudinal magnetization (M_L) flipped into transversal magnetization (M_T)

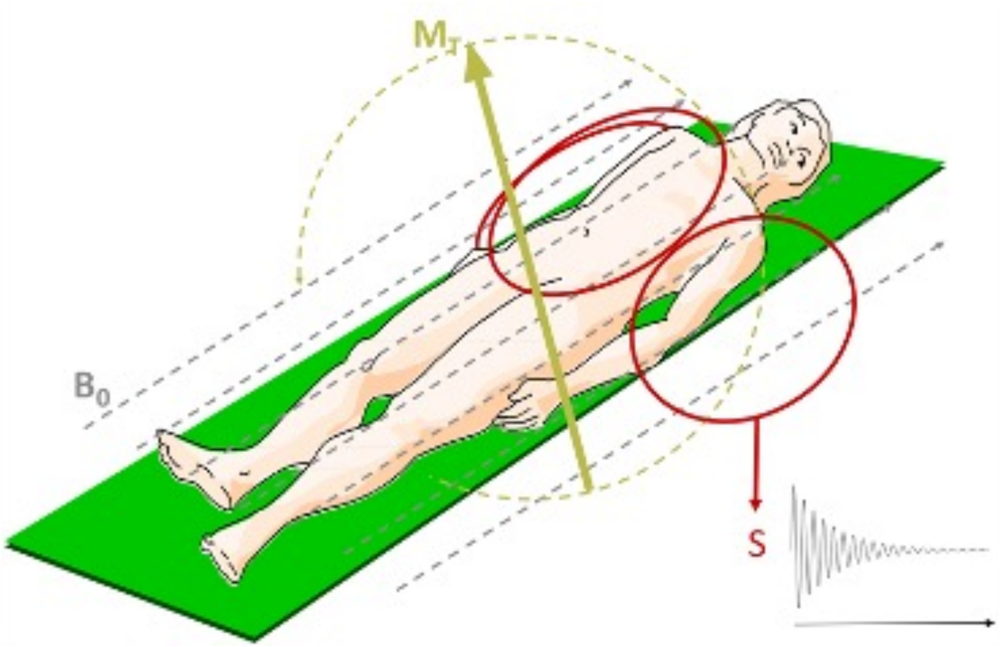
$$\omega_L = \gamma . B_0$$

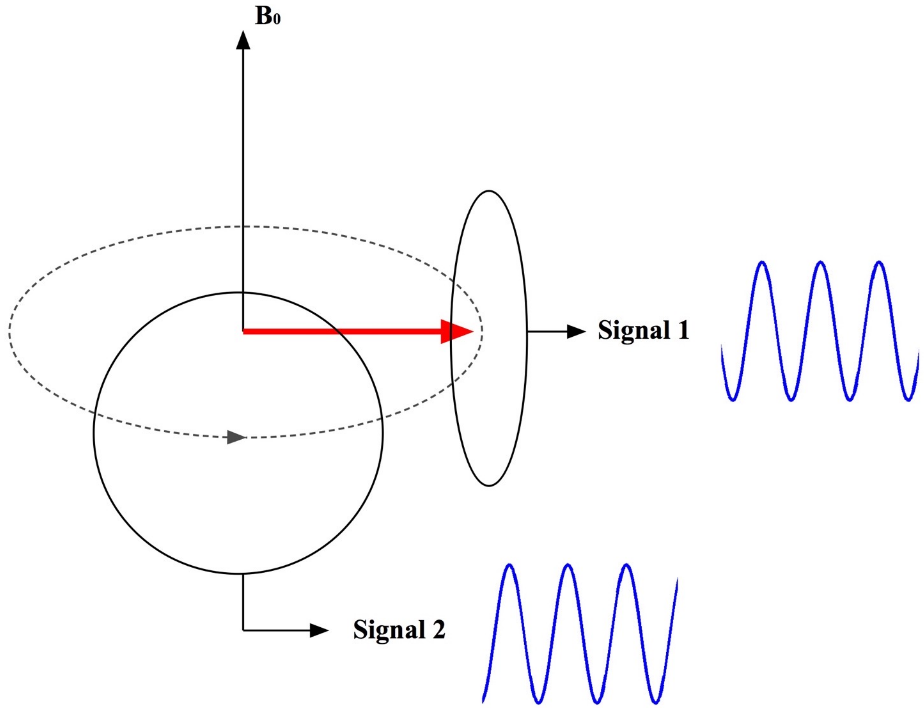




Generating a MRI signal step 3: induction of an MRI signal



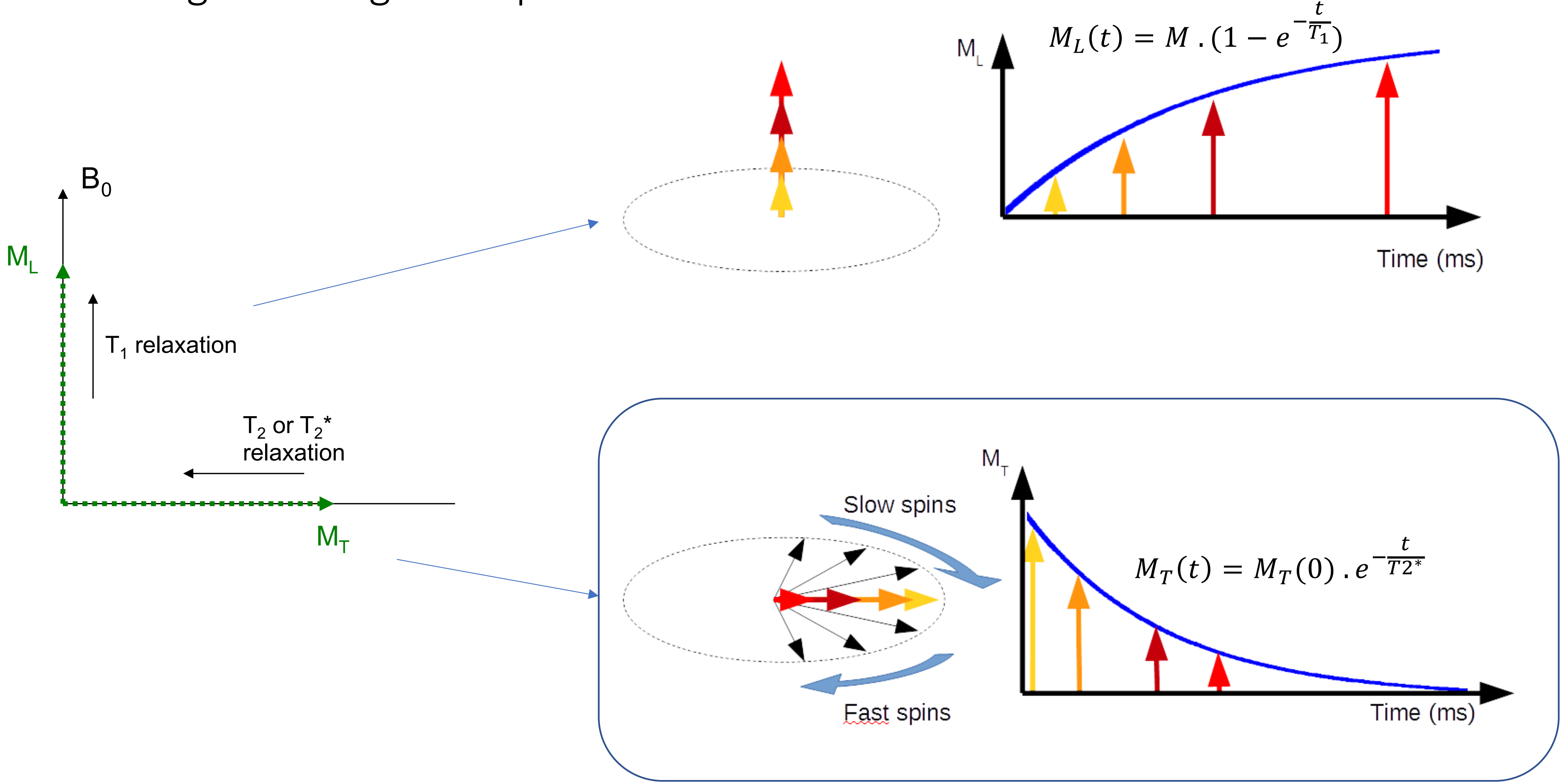




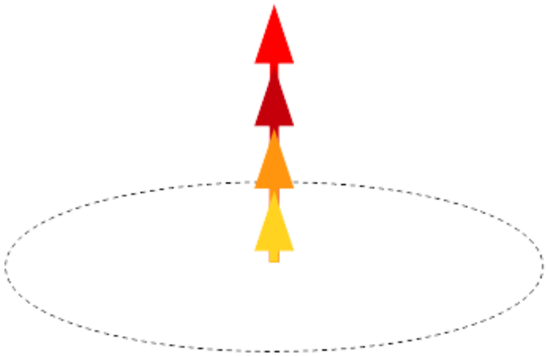
Rotating transversal magnetization (M_T)

induces a signal in the detection coil

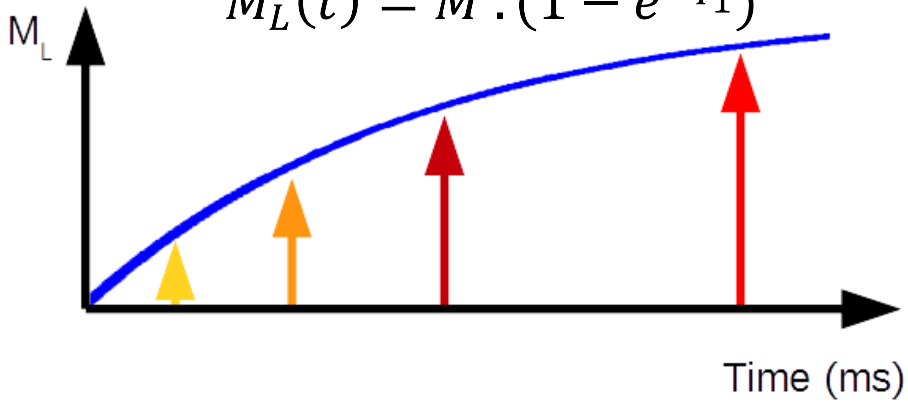
Generating a MRI signal step 4: relaxation

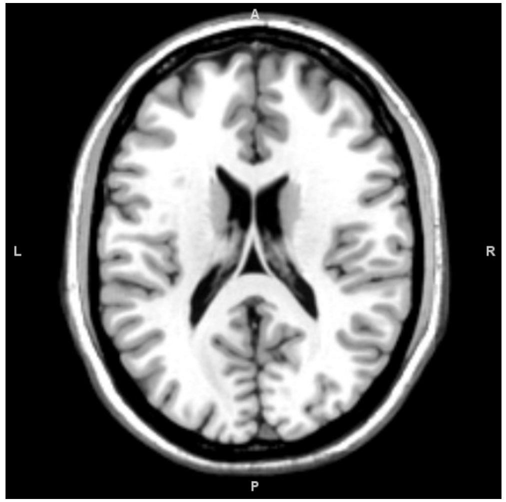


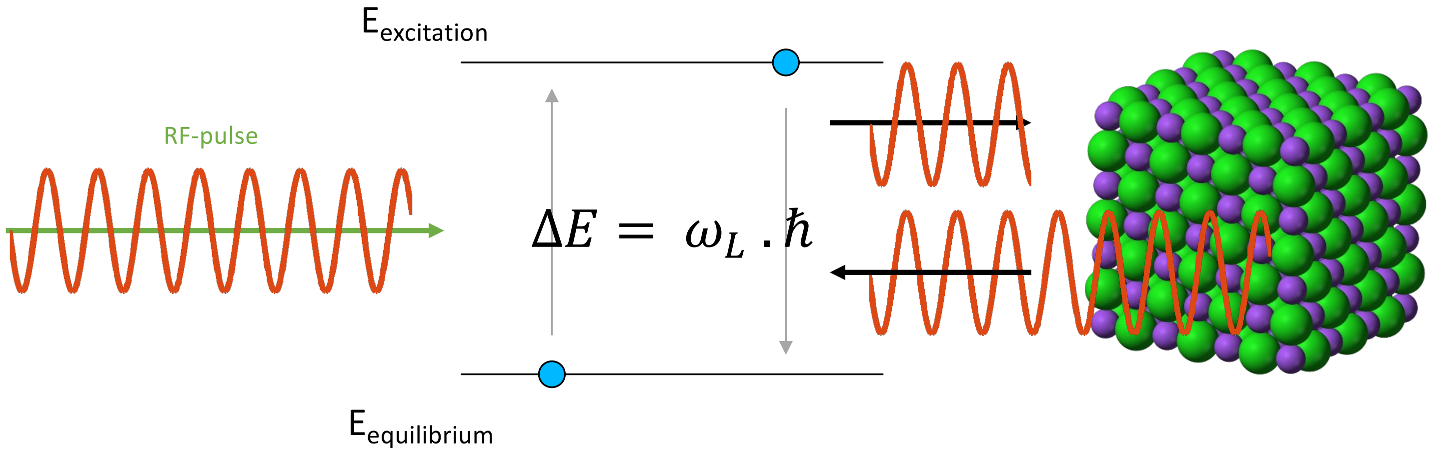
T1 relaxation



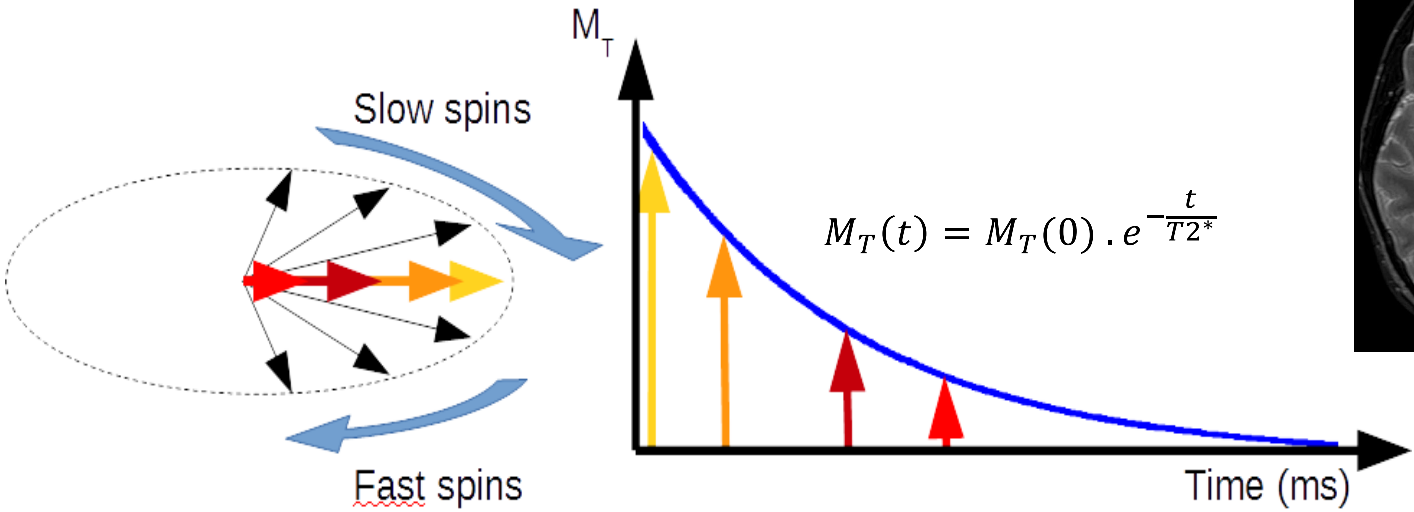
$$M_L(t) = M\,.\,(1 - e^{-\frac{t}{T_1}})$$



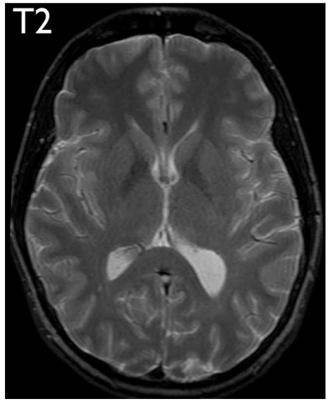


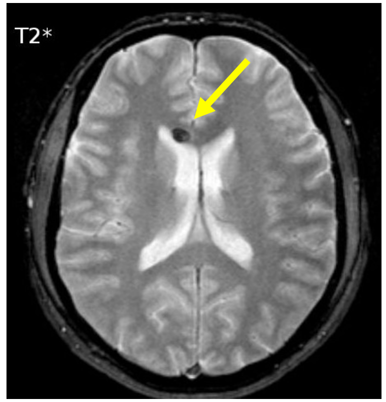


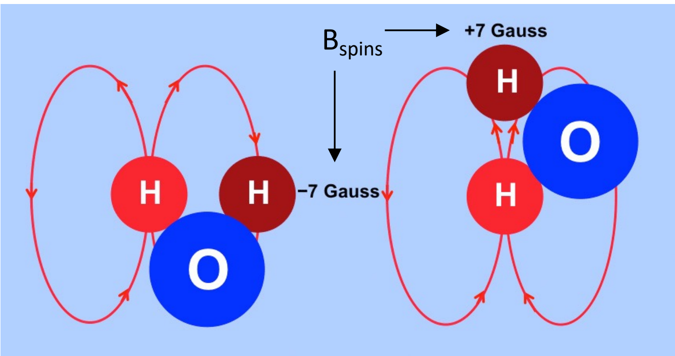
T2(*) relaxation



$$M_T(t) = M_T(0)\,.\,e^{-\frac{t}{T2^*}}$$

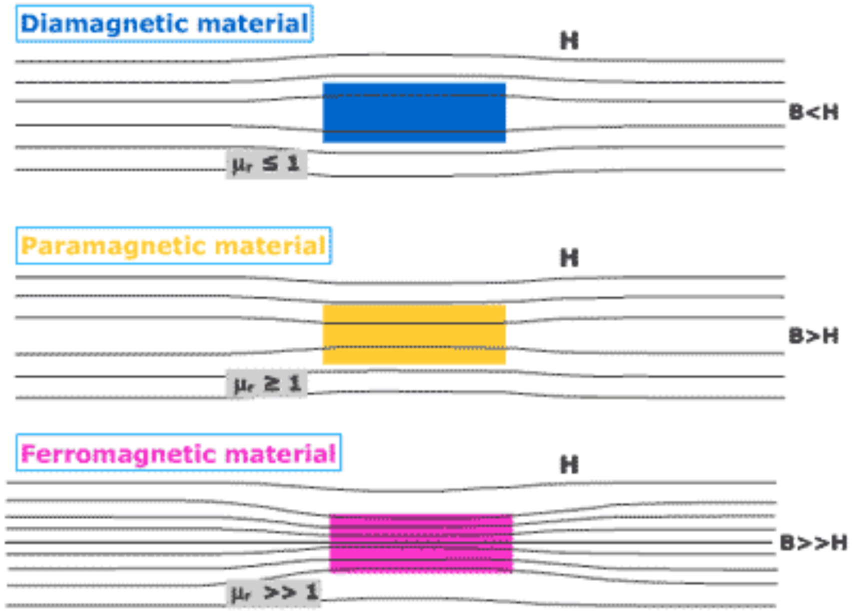






$$\omega_L = \gamma \cdot \left(B_0 + \underbrace{B_{spins}} + \Delta B\right)$$

$$\frac{1}{T2^*} = \frac{1}{T2} + \gamma . \Delta B$$



Example:

- diamagnetism: human tissues
- Paramagnetism: air
- Ferromagnetism: iron objects

Magnetic **susceptibility** (χ)= a measure of how much a material will become magnetized in an applied magnetic field.

Permeability ($\mu_r = (1 + \chi)$) = the measure of magnetization that a material obtains in response to an applied magnetic field.
(μ_r the relative permeability of a tissue, μ_0 the permeability of free space)

The magnetic induction (B) is linked to the magnetic field strength (H) by
$B = \mu_r . H = \mu_0(1 + \chi)H$

In diamagnetic and paramagnetic materials: $\mu_r \approx 1$

$\downarrow$

No distortion of the magnetic field -> $\Delta B = 0$ -> $T_2^* = T_2$

In ferromagnetic materials: $\mu_r \gg 1$

$\downarrow$

Strong distortion of the magnetic field -> $\Delta B > 0$ -> $T_2^* < T_2$

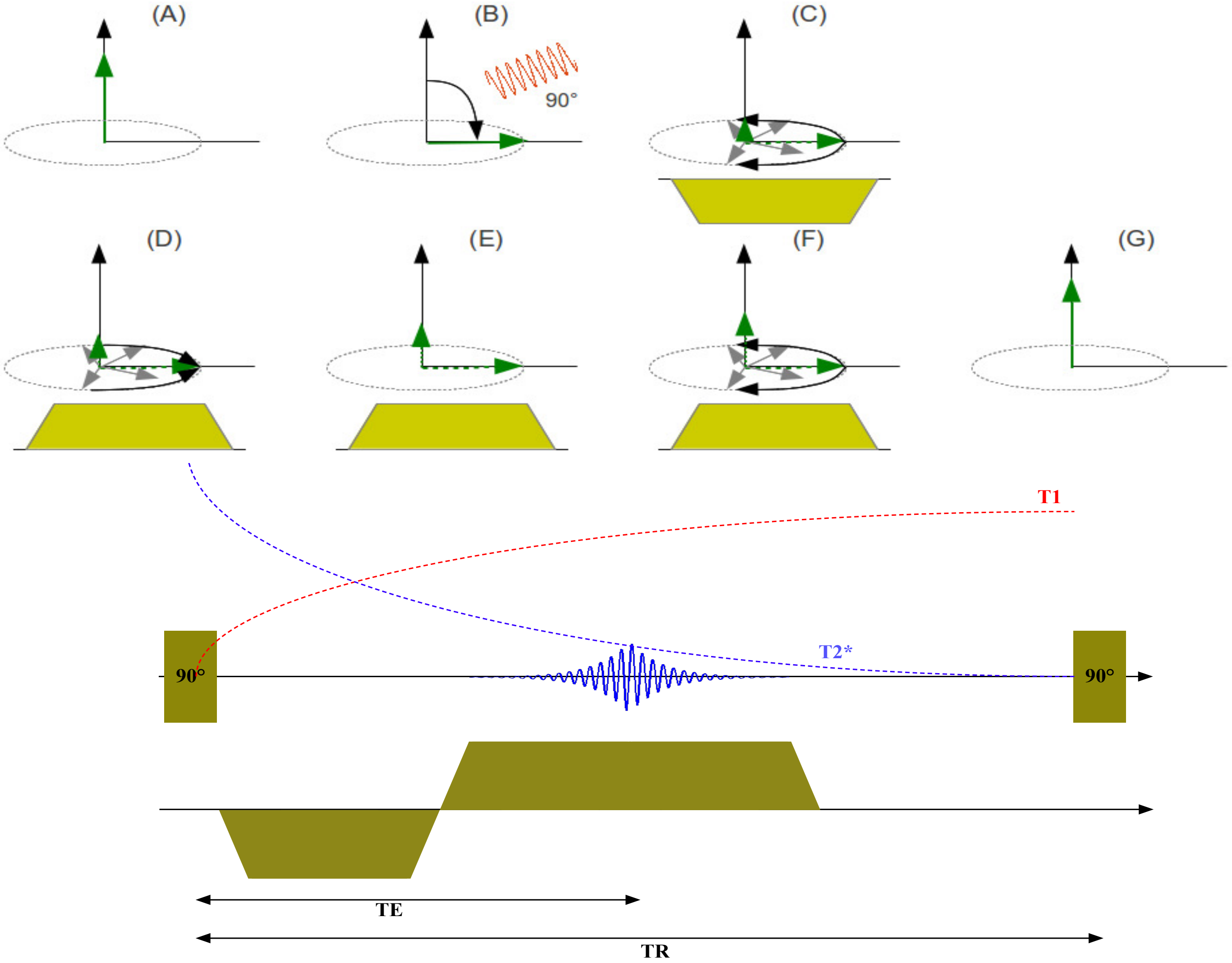
If the local field inhomogeneity increases

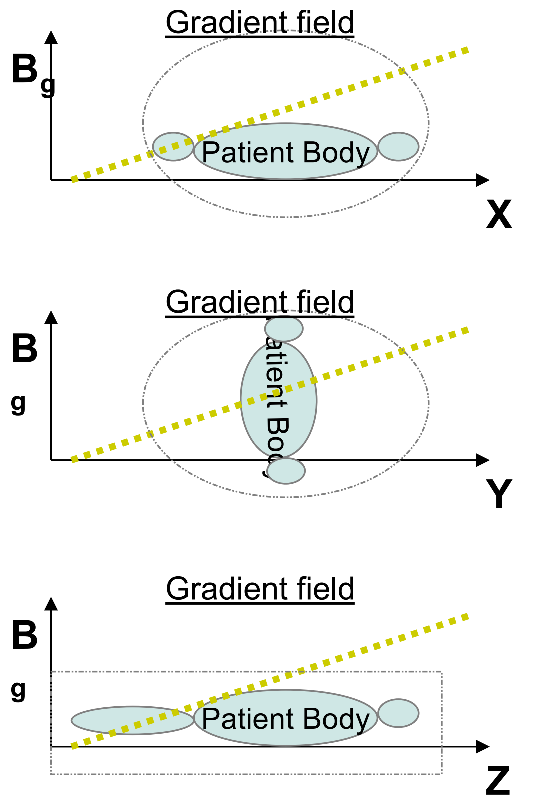
a. T2* will increase
b. T2* will decrease
c. T2* will not be affected

Gradient echo

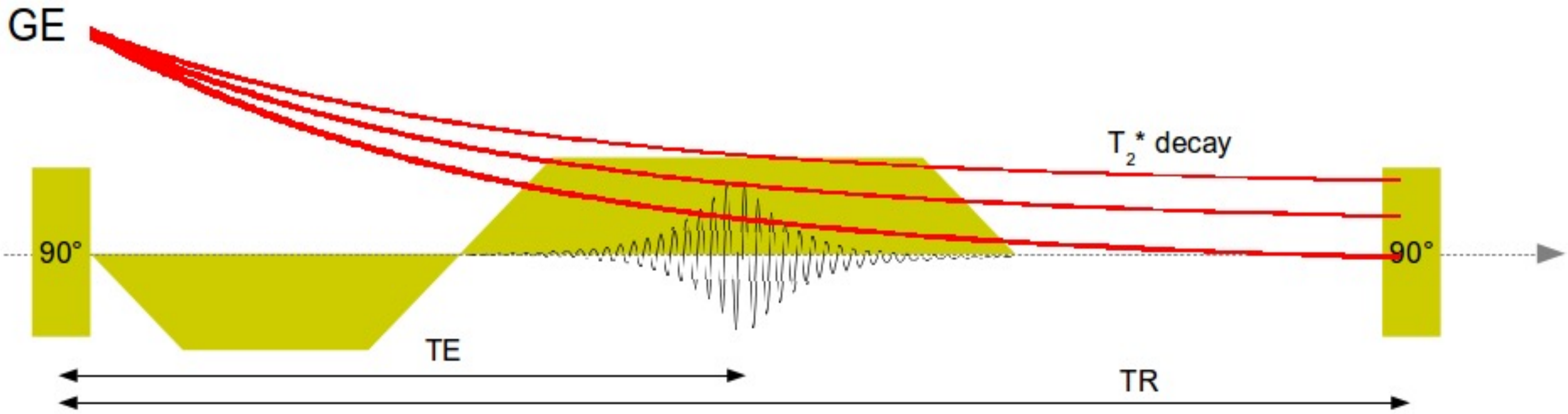
Off: $B(x,y,z,t) = B_0$

On: $B(x,y,z,t) = B_0 + B_G(x,y,z,t)$





T2* contrast



Longer T2* relaxation -> Larger signals -> Brighter image contrast

Shorter T2* relaxation -> smaller signals -> Darker image contrast

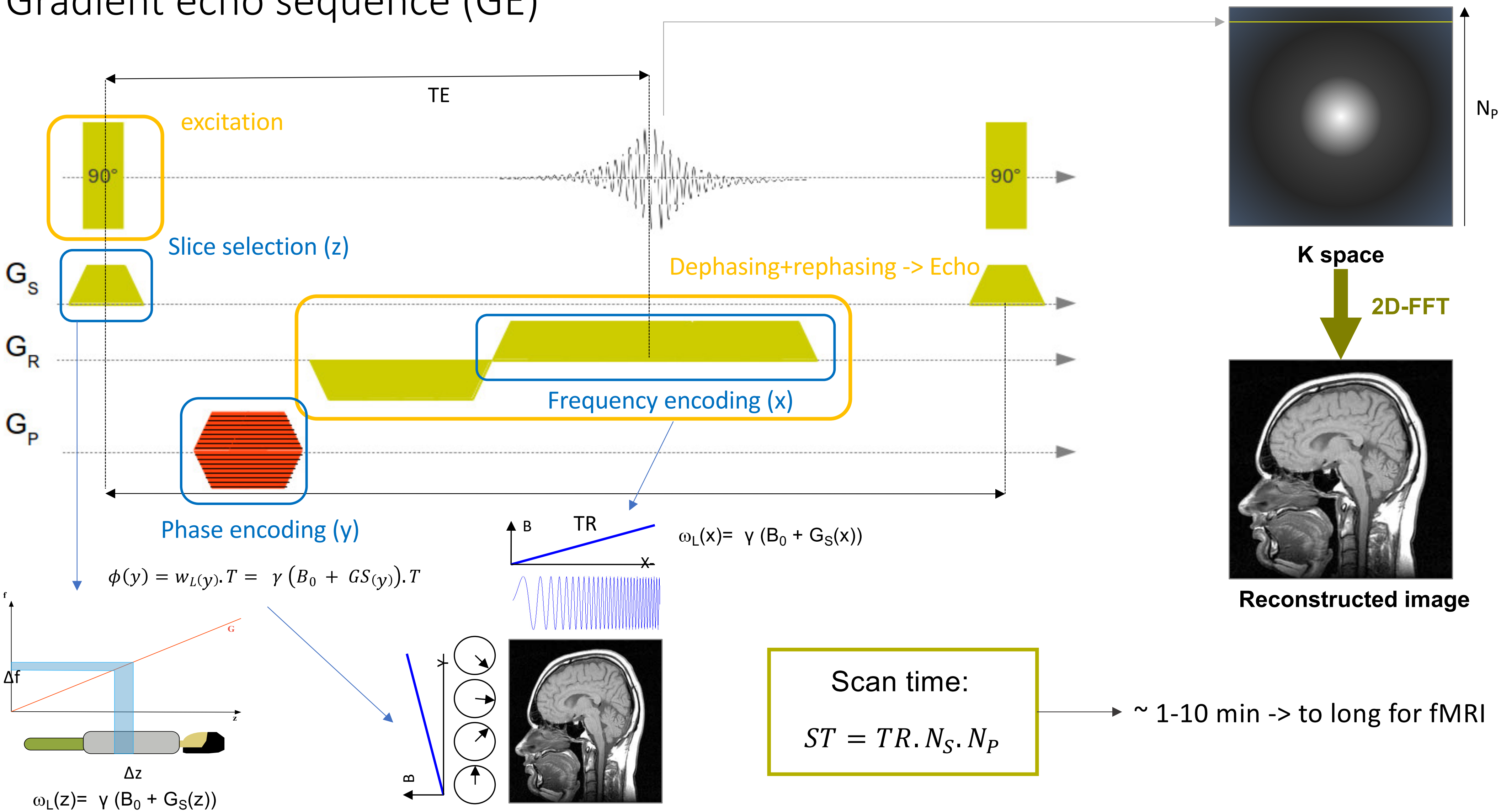
An increase in T2* will result in a loss of image contrast

Ferromagnetic screw
↓
susceptibility effect

If the local field inhomogeneity increases

a. The image contrast will increase
b. The image contrast will decrease
c. The image will not be affected

Gradient echo sequence (GE)

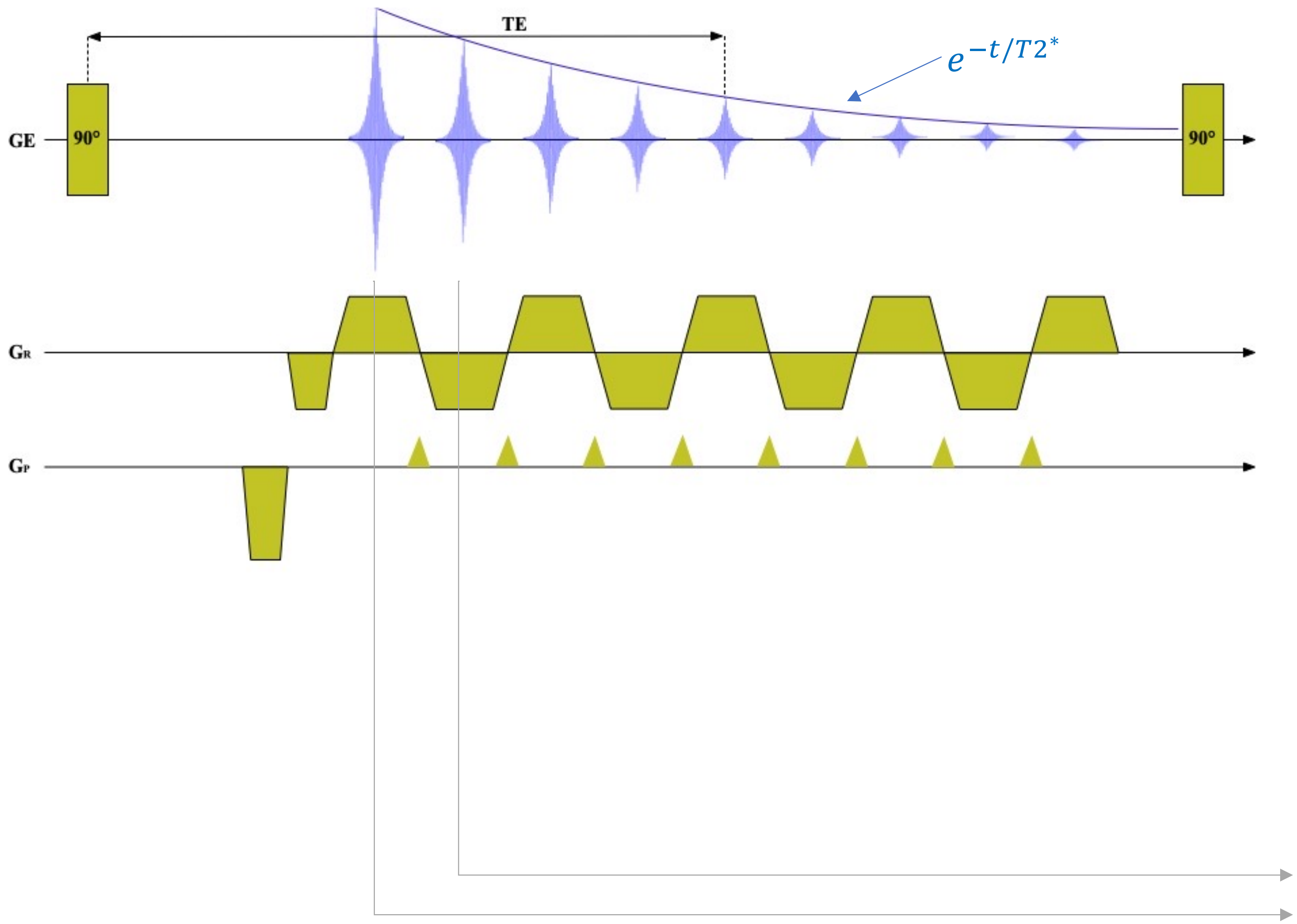


Scan time:

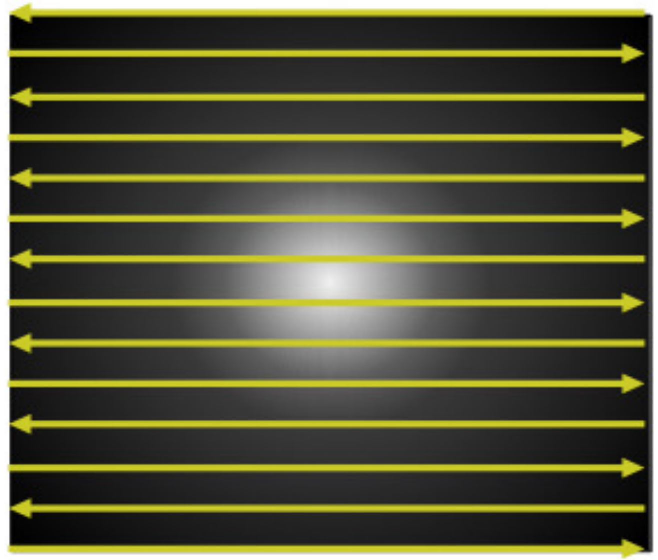
$$ST = TR.N_S.N_P$$

~ 1-10 min -> to long for fMRI

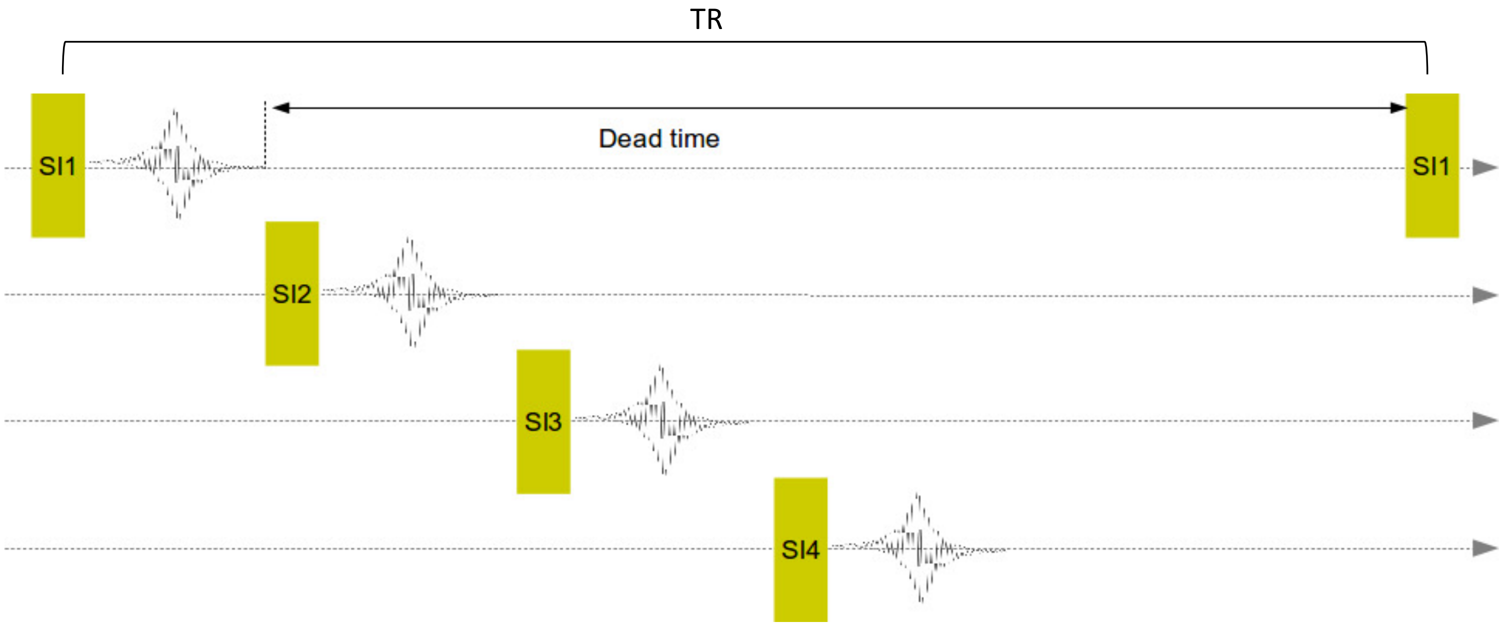
GE-EPI: Echo Planar Imaging



$$ST = TR.NS$$



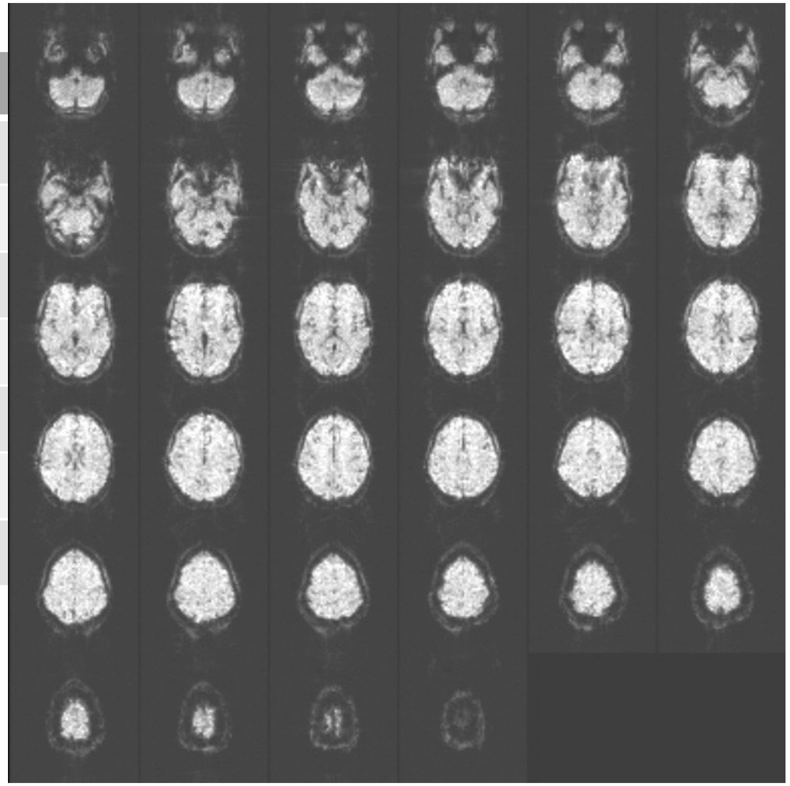
Multi slice imaging



$$\boxed{ST = TR} \rightarrow \sim 1500 - 3000 \text{ ms}$$

Example of fMRI GE-EPI settings

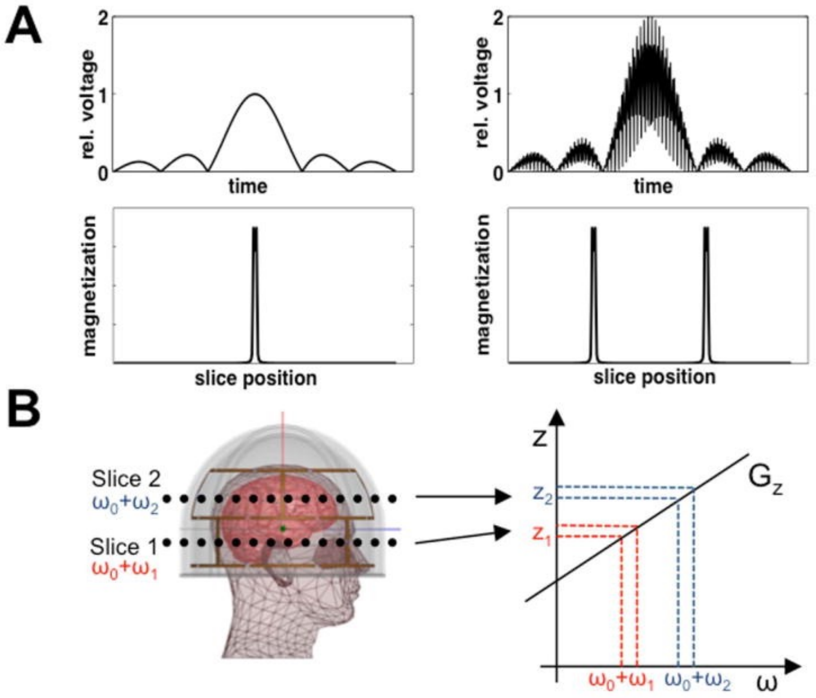
TR	2000 ms
TE	30 ms
Number of slices	36
Slice thickness	3 mm
Slice gap	0 mm
FOV	240 x 240 mm^2
Scan matrix	80 x 80
EPI factor	80

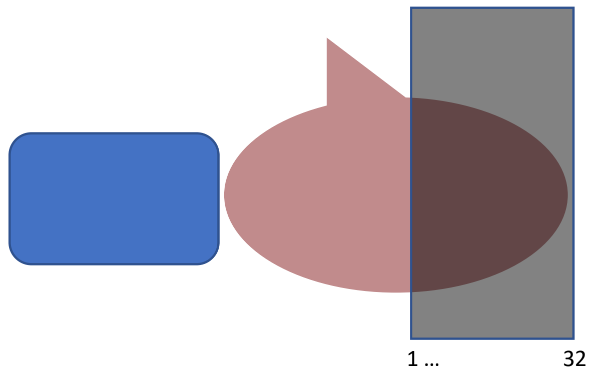


Scan time: 2s

Scan resolution: 3 x 3 x 3 mm^3

Simultaneous Multi-Slice (SMS) / MultiBand/ HyperBand





$$RF(t) = A(t).\sum_{N} e^{i.\omega_n.t+\varphi_n}$$

Without SMS: 1, 3, 5... 31, 2, 4, ... 32 (interleaved order)

↓

32 individual slices to measure

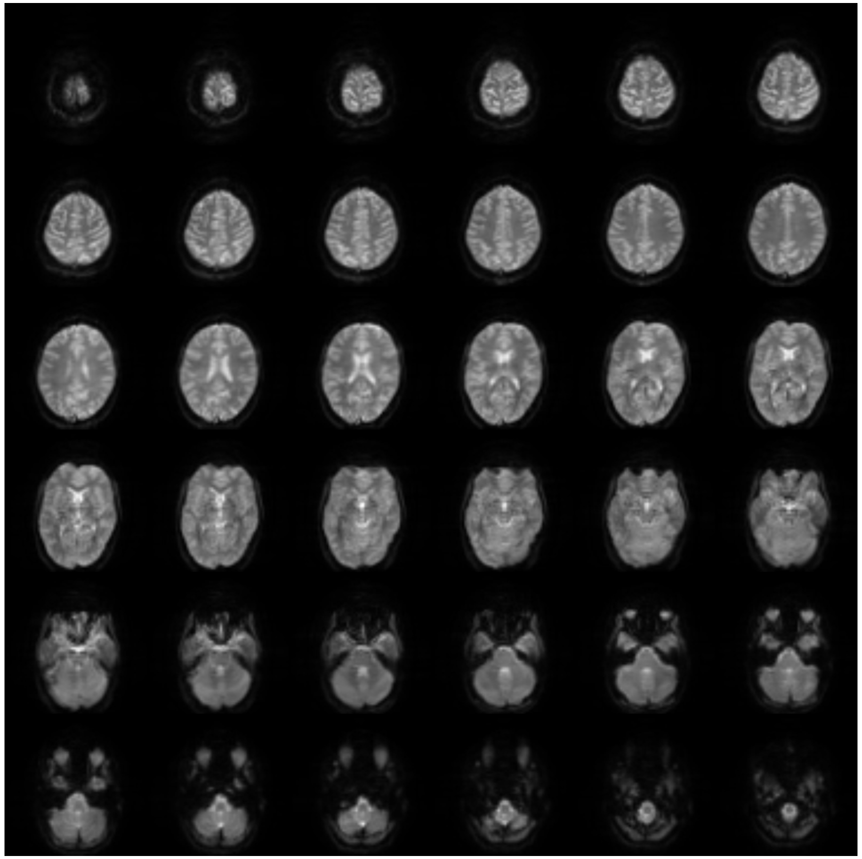
With SMS: (1, 5, 9, ... 29) , (3,7,11,...31), (2,6,10,...30), (4,8,12,...32)

↓

Only 4 slice packages with 8 slices each to measure

Current HCP fMRI scan protocol

TR	720 ms
TE	33 ms
Flip angle	52 deg
Number of slices	72
Slice thickness	2 mm
Slice gap	0 mm
FOV	208 x 180 mm^2
Scan matrix	104 x 90 (2x2 mm)
EPI factor	90
HyperBand factor	8



Temporal resolution = 720 ms

Spatial resolution is 2 mm isotroppic

The hemodynamic response

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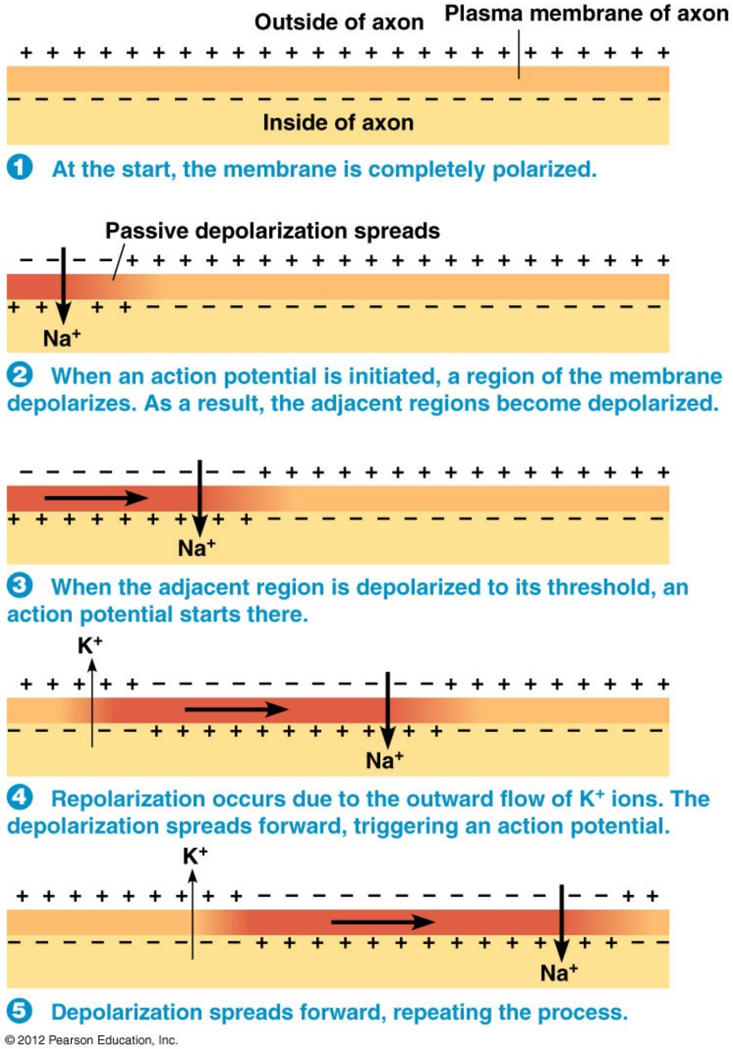
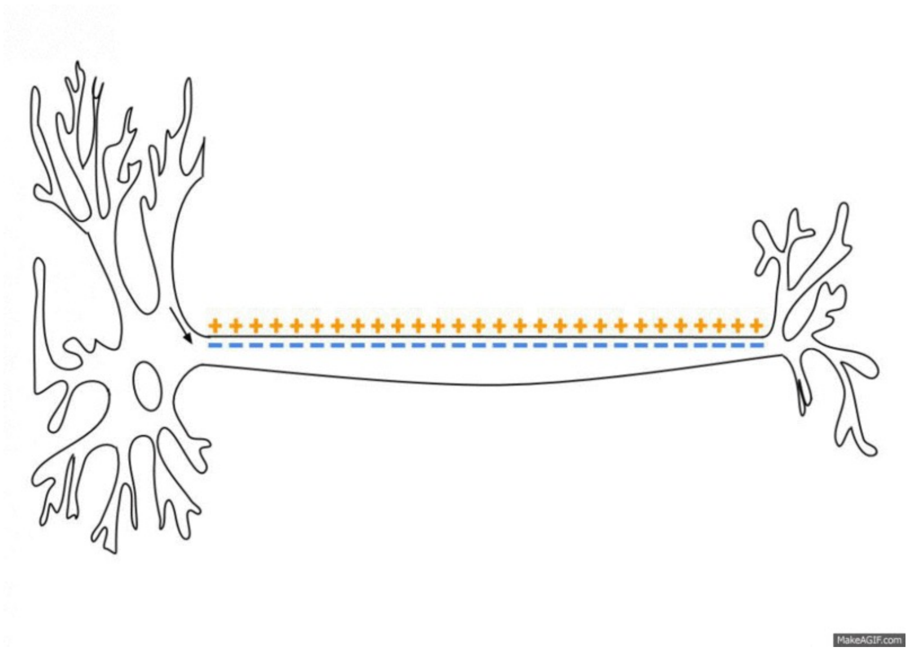
Equilibrium state:
(rest)

Disturbance of the
equilibrium state:
(activation)

Active repolarization:
(going back to rest)



Neural processing
||
processing and exchanging electric signals
between neurons



Neural activation -> chain of events from the neural to the vascular level (= neurovascular coupling)

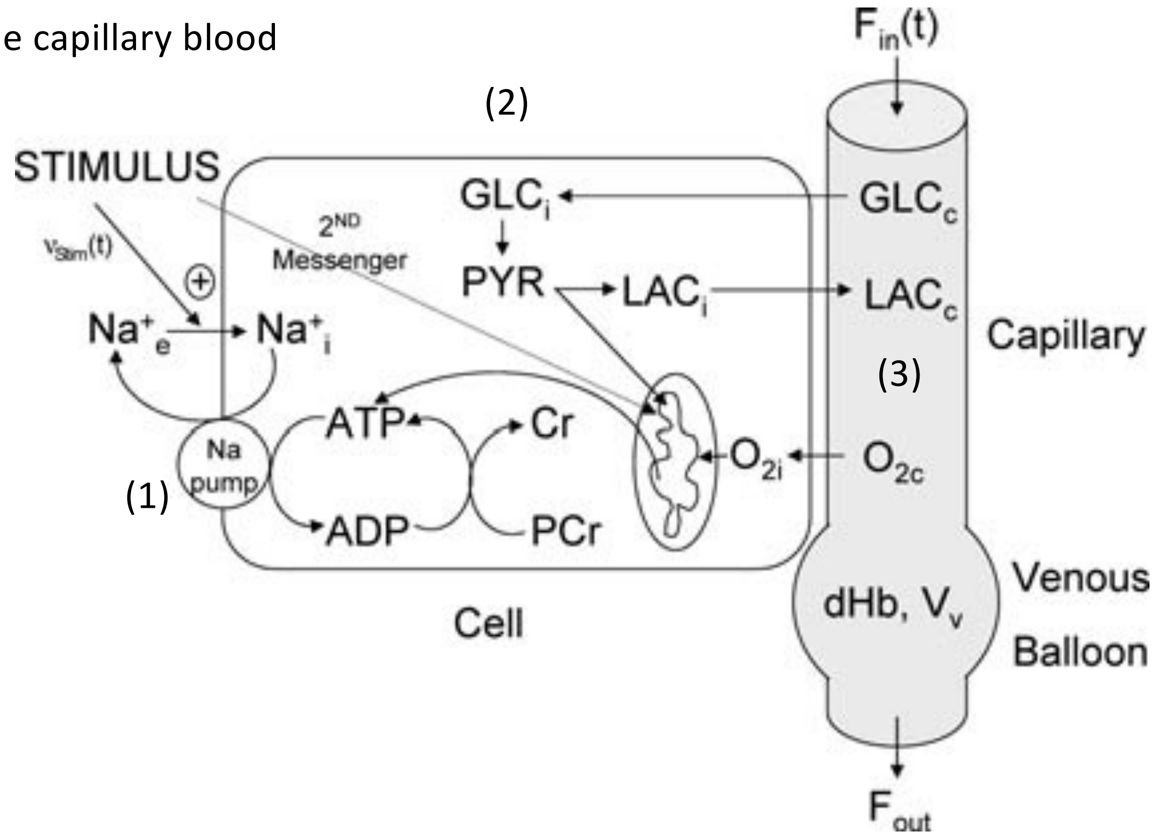
(1) Repolarization of the cell membrane requires energy

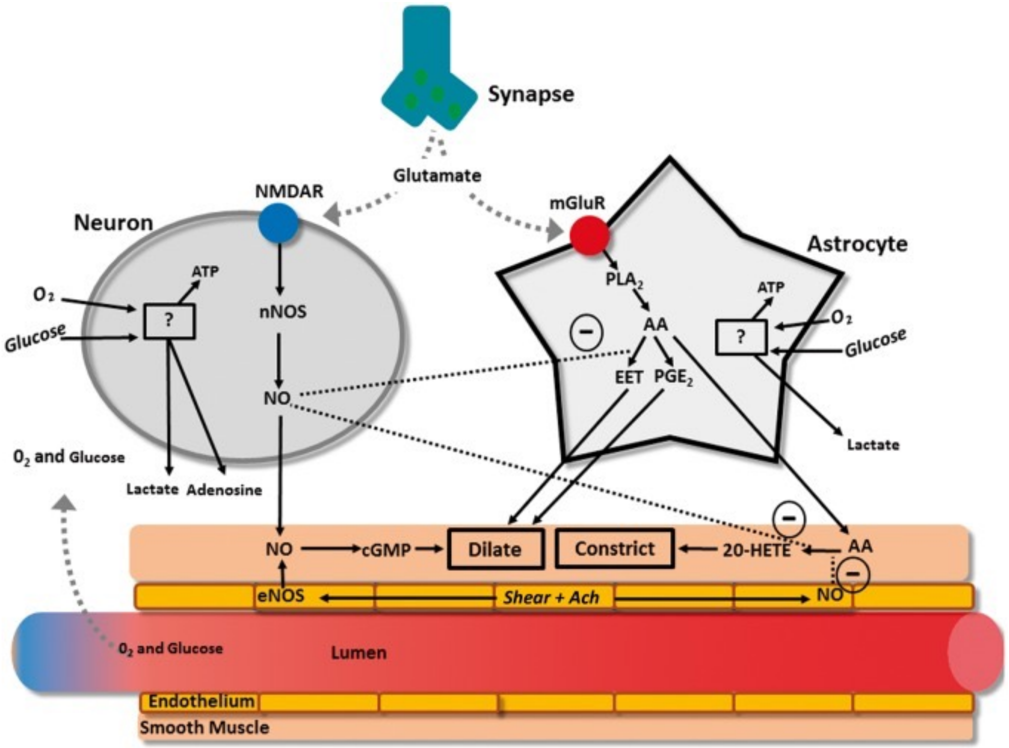
↓

(2) Increased energy production in the neuron requires glucose (GLC) and oxygen (O_2)

↓

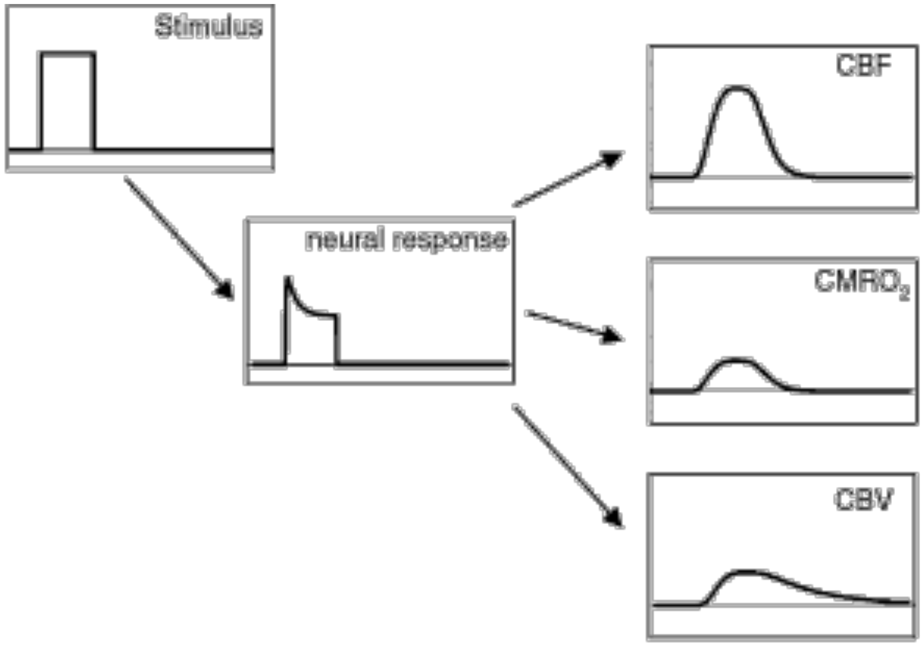
(3) Increased extraction of glucose and oxygen from the capillary blood



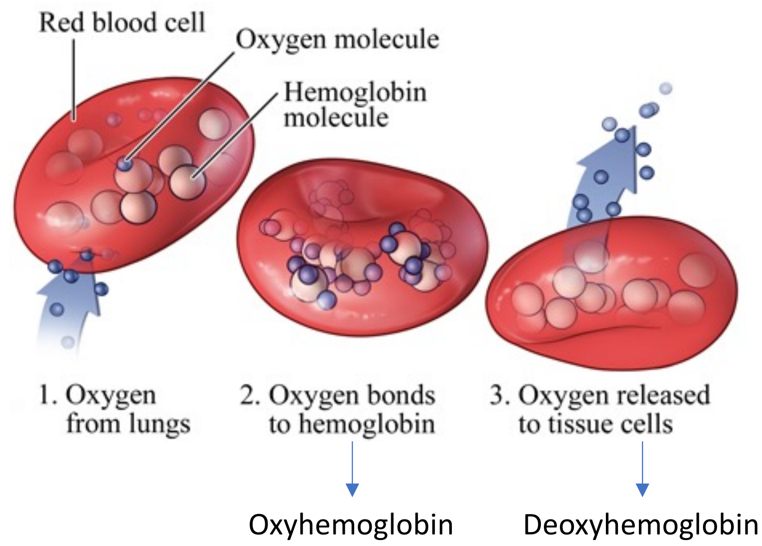


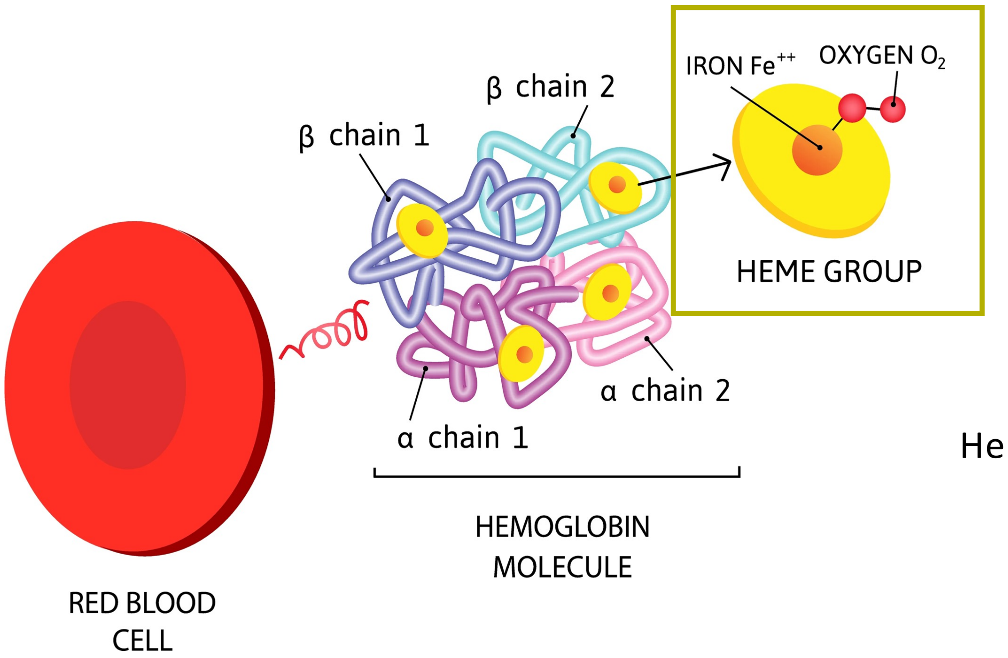
Neurovascular coupling:

- Due to the increased use of oxygen = increased $CMRO_2$
- Local dilatation of capillaries
  - Increased blood volume (CBV)
  - Increased blood flow (CBF)



Oxygen in the blood is transported by the hemoglobin molecule in the red blood cells





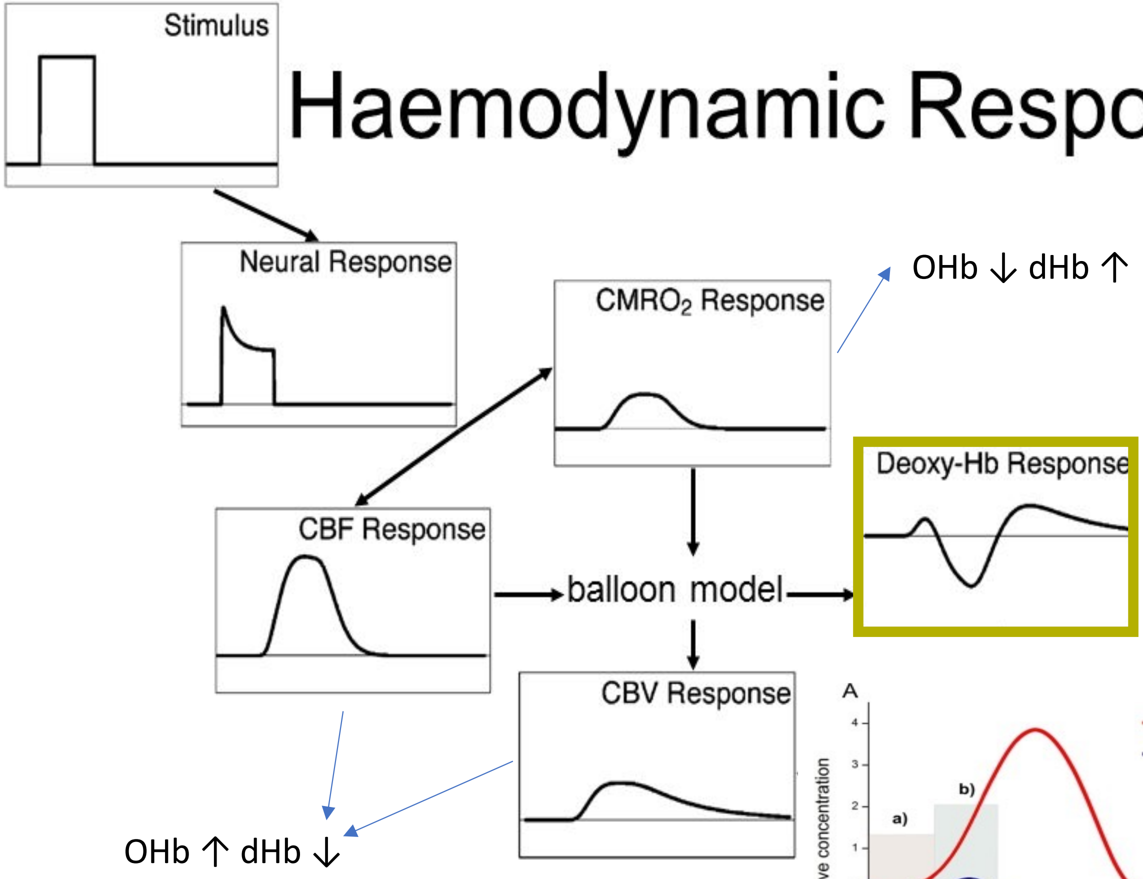
Hemoglobin = 4 chains with a heme group containing Fe^{++}

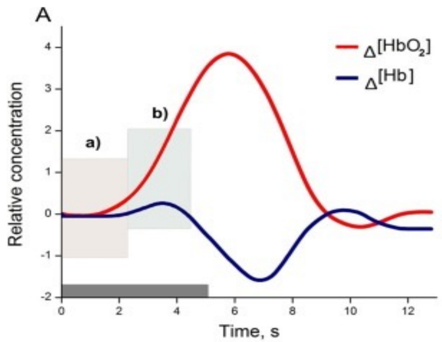
↓

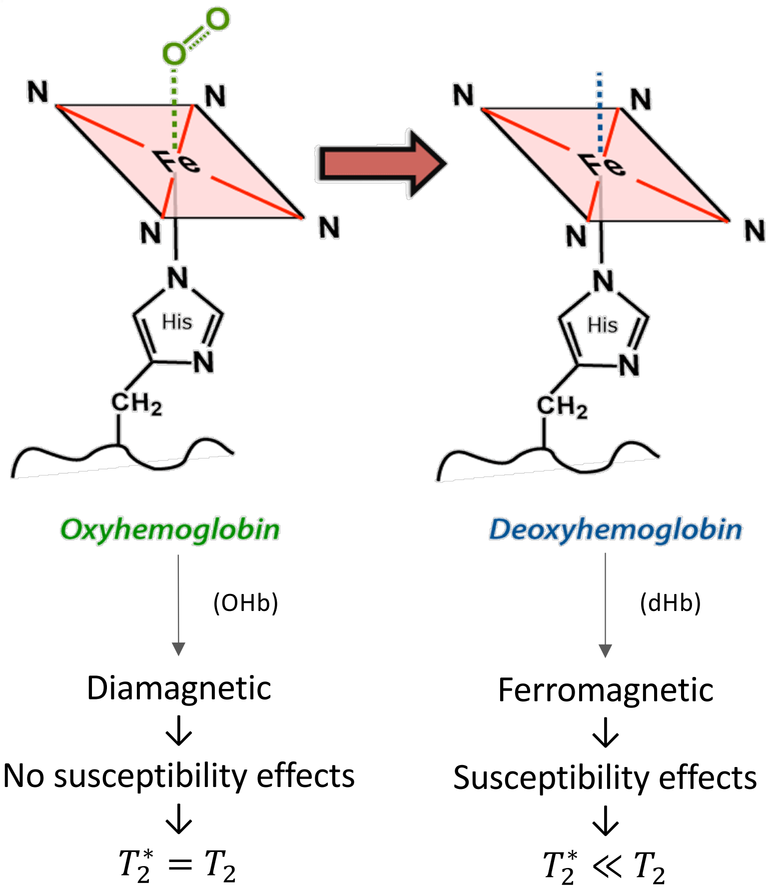
Deoxyhemoglobin (no oxygen bound to Fe) -> Fe^{++}

Oxyhemoglobin (oxygen bound to Fe) -> FeO_2

Haemodynamic Response

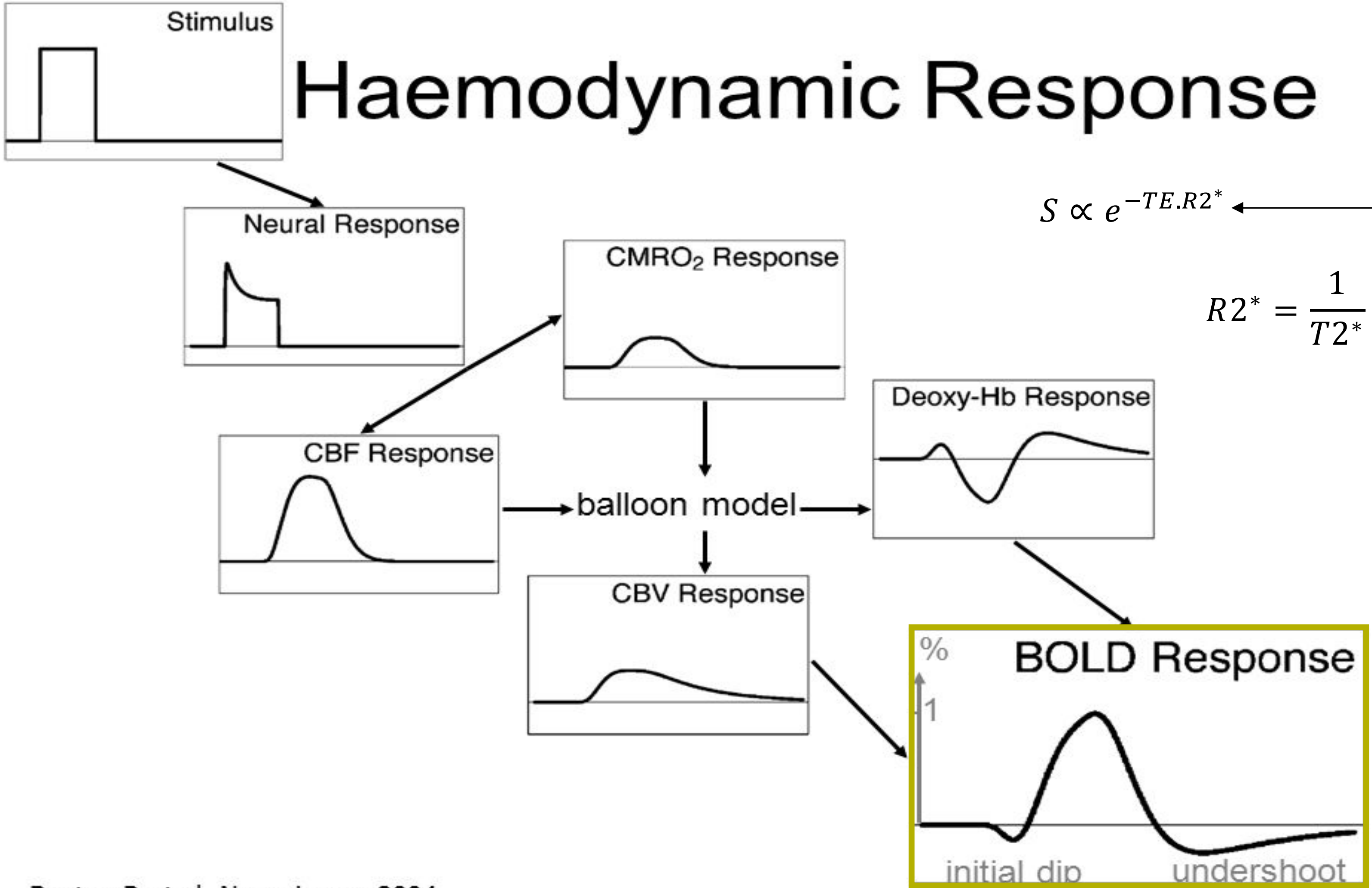






Buxton R et al. Neuroimage 2004

Haemodynamic Response



HRF

Buxton R et al. Neuroimage 2004

$$S \propto e^{-TE.R2^*}$$

$$R2^* = \frac{1}{T2^*} = r_2^*.\left[\frac{OHb}{dHb}\right]$$

$\frac{OHb}{dHB}\uparrow$ -> T2* $\uparrow$ -> S $\uparrow$

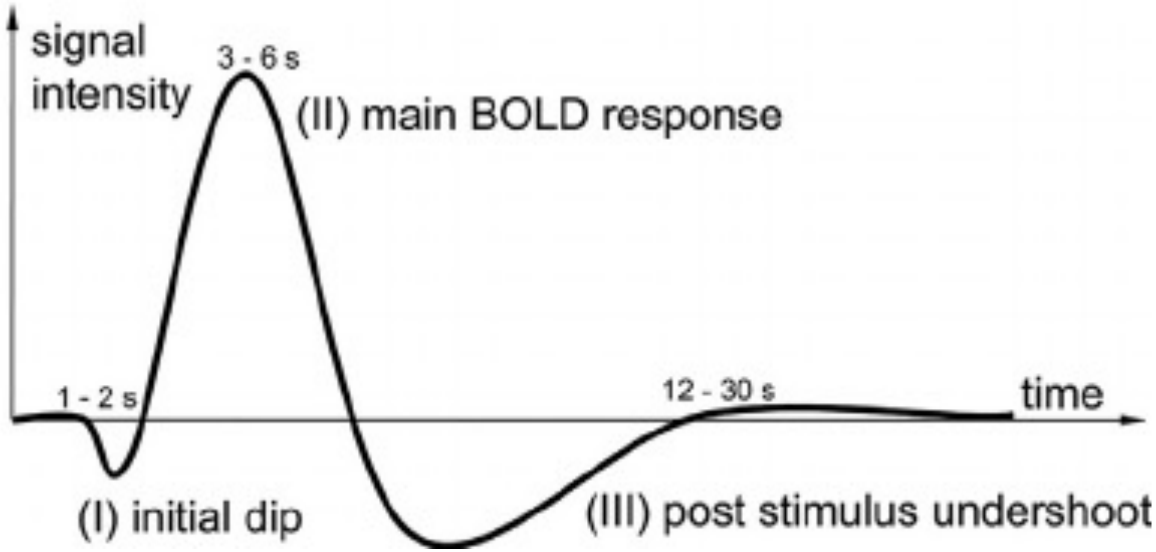
$\frac{OHb}{dHB}\downarrow$ -> T2* $\downarrow$ -> S $\downarrow$

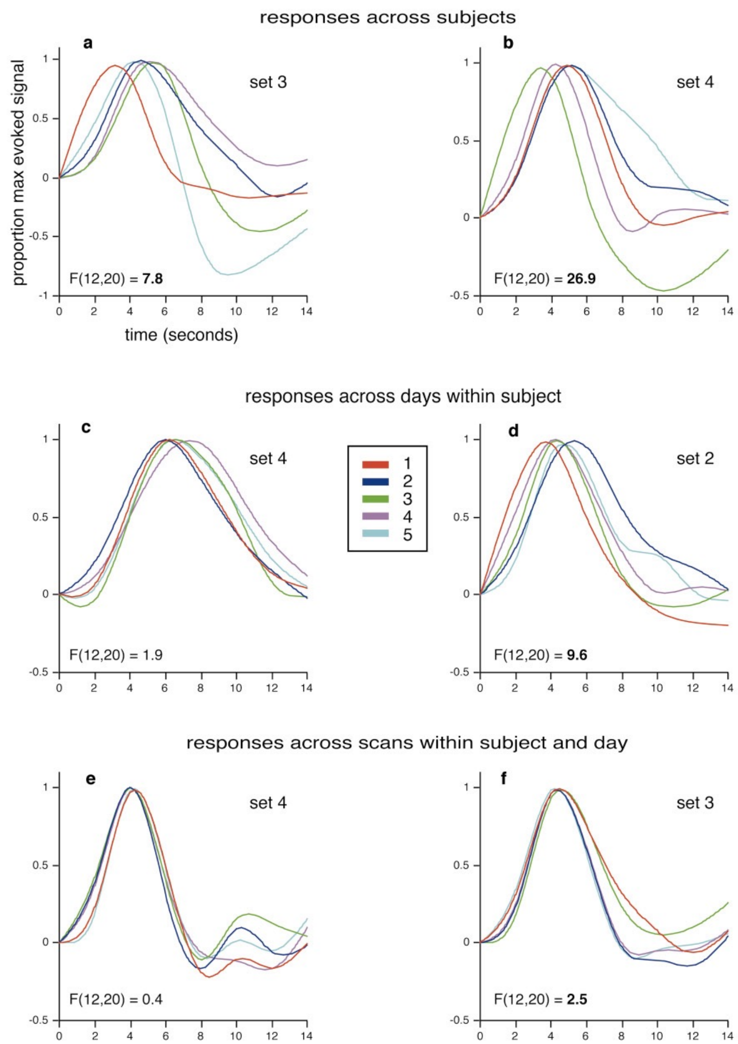
BOLD

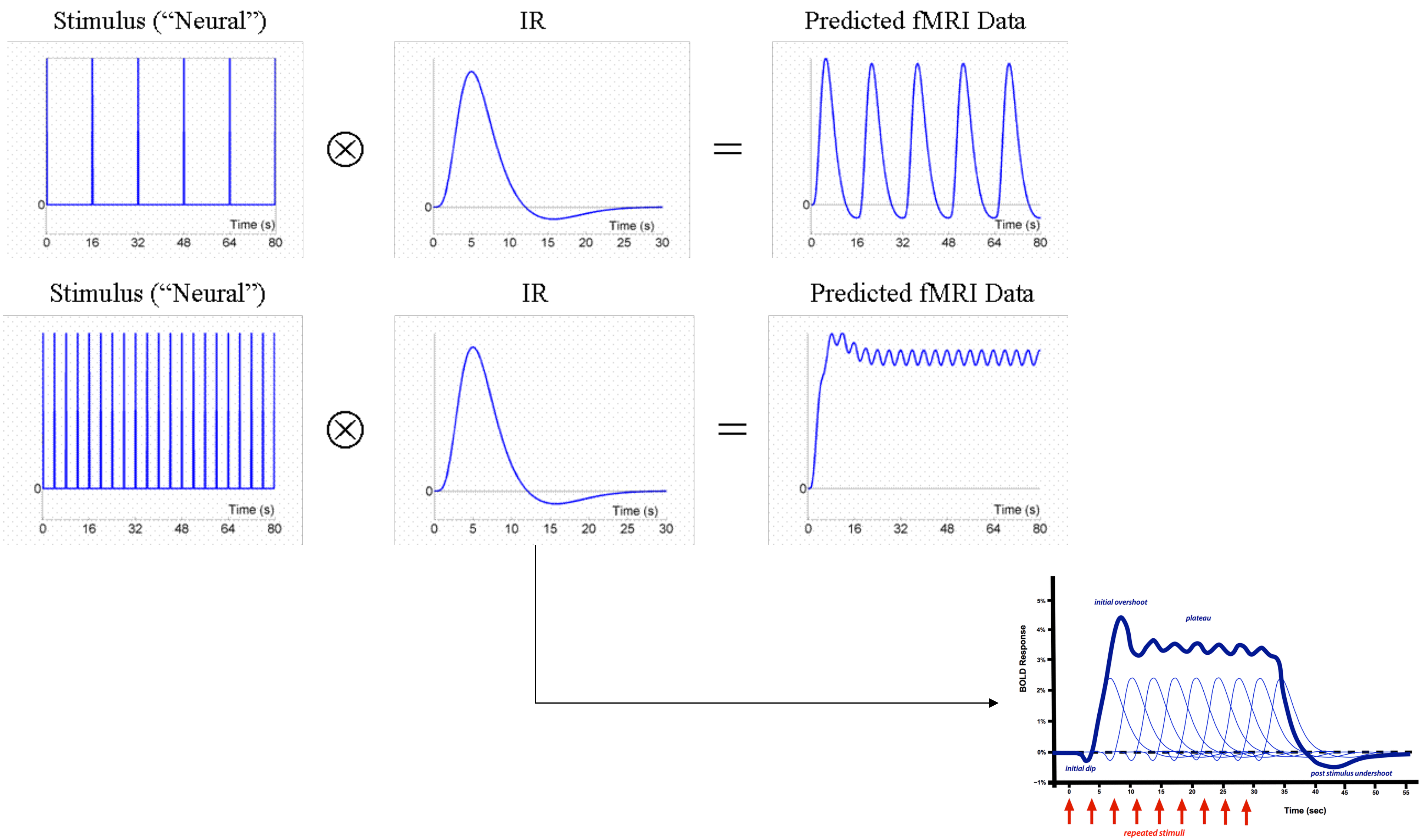
||

Blood Oxygen Level Depended

contrast


signal intensity
3 - 6 s
(II) main BOLD response
1 - 2 s
12 - 30 s
time
(I) initial dip
(III) post stimulus undershoot


responses across subjects
a
set 3
proportion max evoked signal
time (seconds)
F(12,20) = 7.8
b
set 4
F(12,20) = 26.9
responses across days within subject
c
set 4
F(12,20) = 1.9
d
set 2
F(12,20) = 9.6
1
2
3
4
5
responses across scans within subject and day
e
set 4
F(12,20) = 0.4
f
set 3
F(12,20) = 2.5


Stimulus (“Neural”)
IR
Predicted fMRI Data
Time (s)
Stimulus (“Neural”)
IR
Predicted fMRI Data
Time (s)
BOLD Response
initial overshoot
plateau
initial dip
post stimulus undershoot
Time (sec)
repeated stimuli

When neurons are constantly activated (constant neural activity)

a. The image contrast will increase
b. The image contrast will decrease
c. The image will remain constant

fMRI scan techniques

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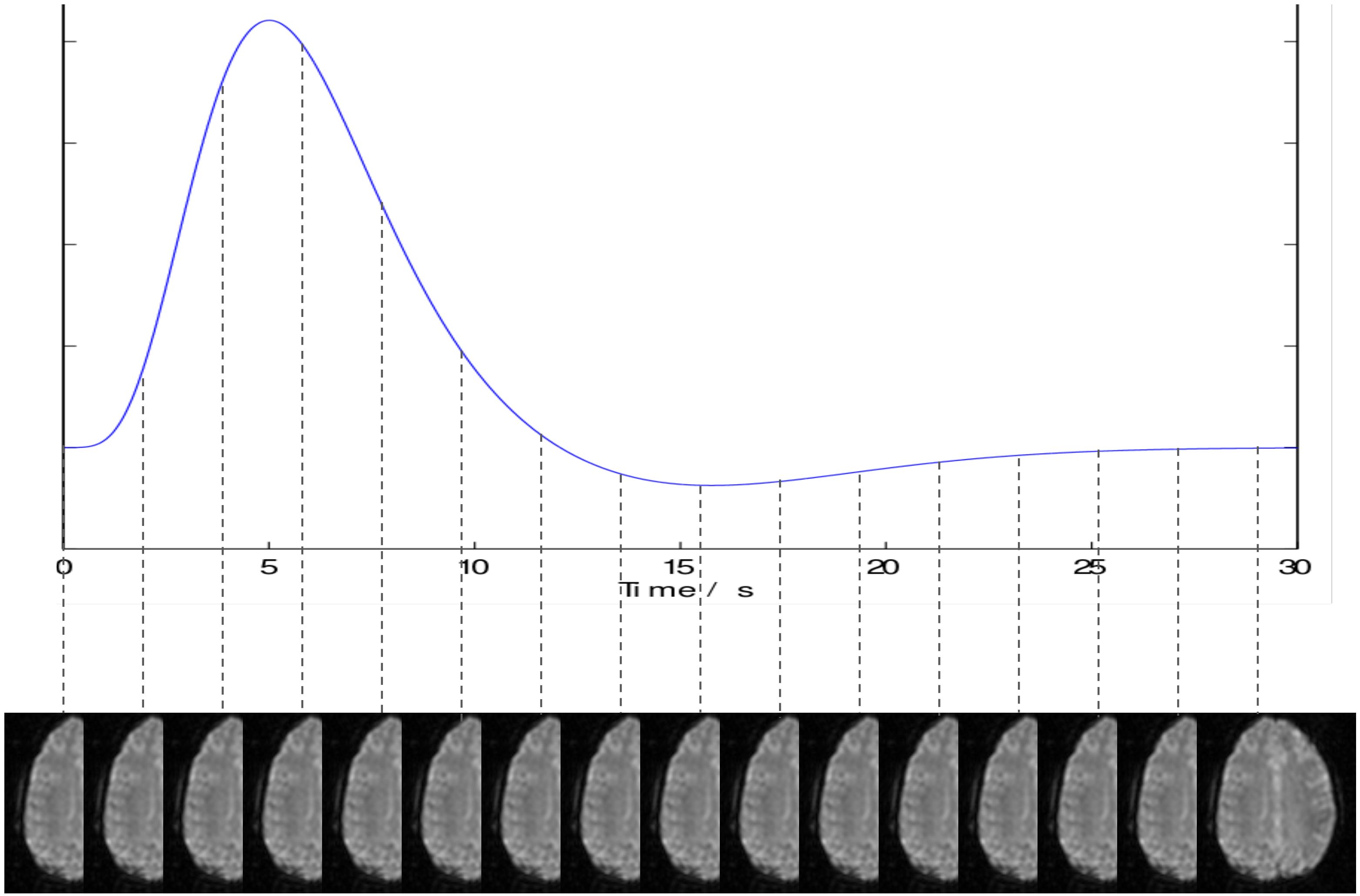
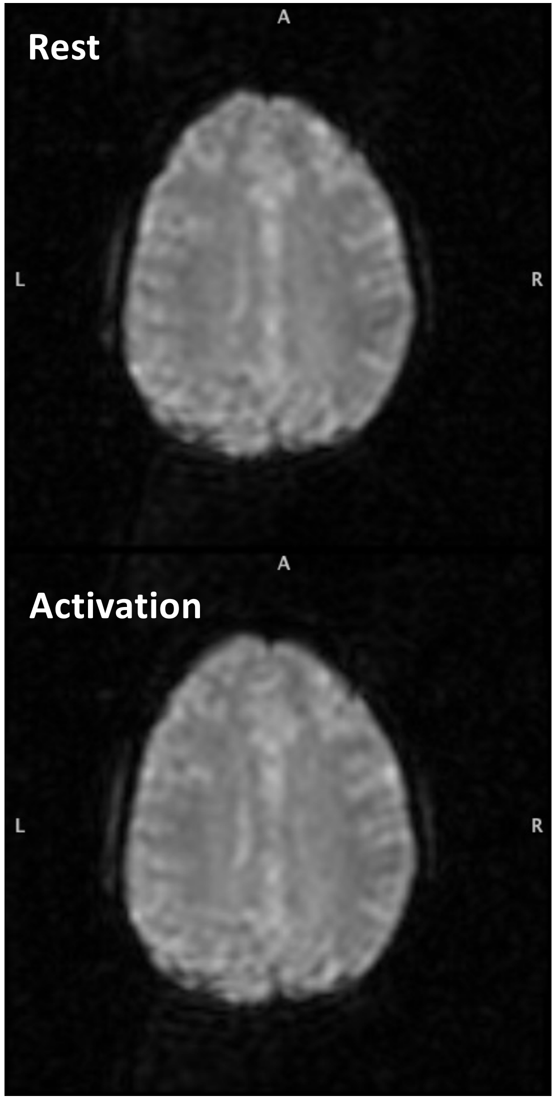
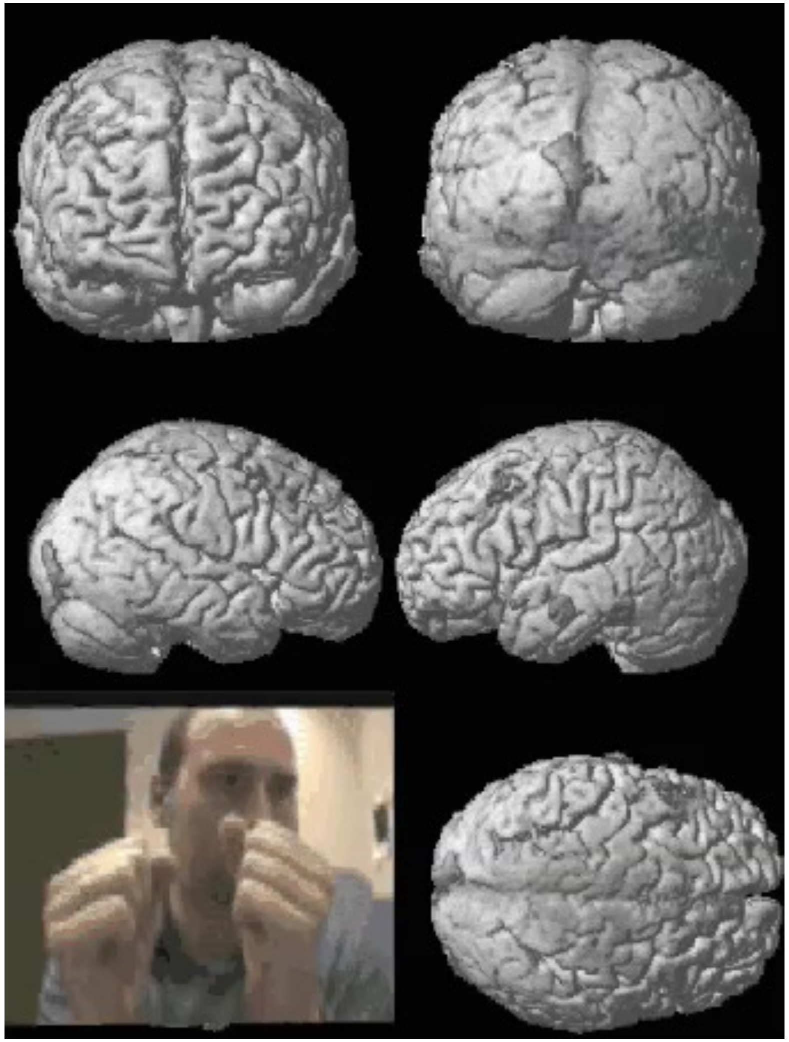
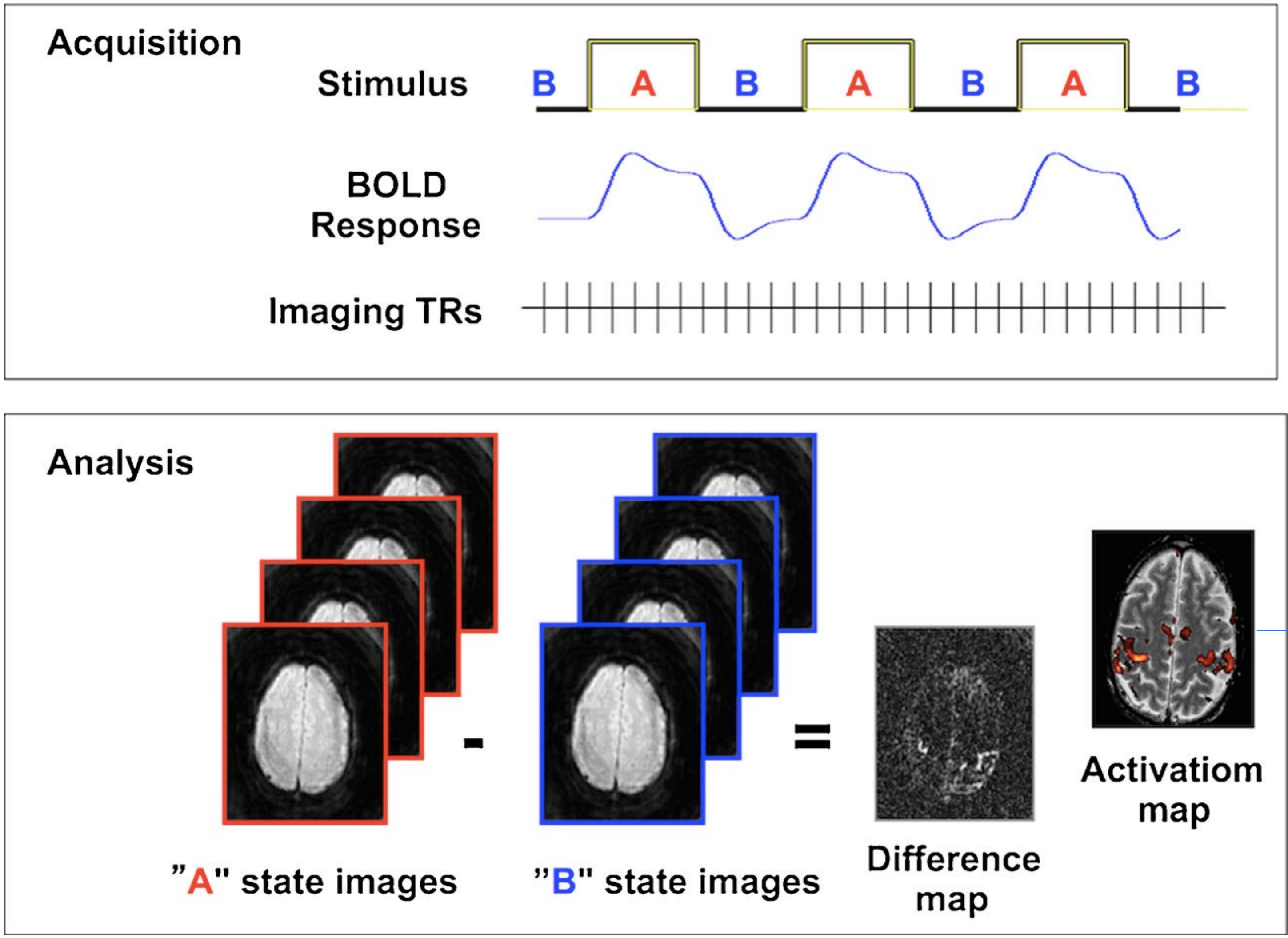


Δt = 0.5-3s

Statistical problem







T-test:

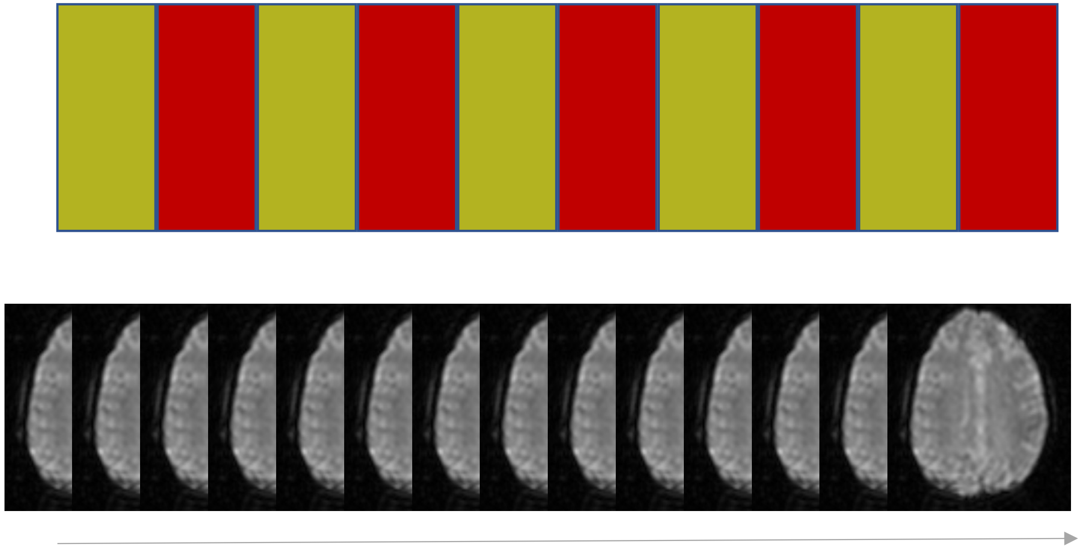
H0: mean(A) = mean(B)

H1: mean(A) $\neq$ mean(B)

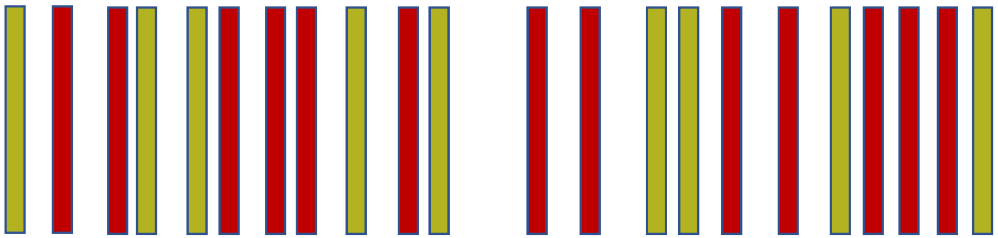
Task paradigm

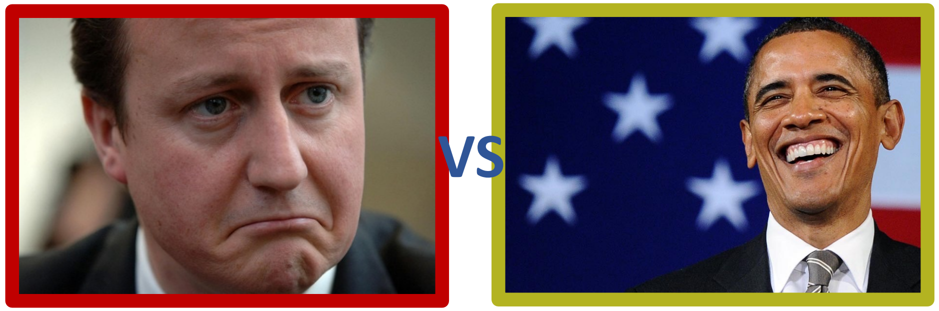
Task paradigm

Block design: sequence of task blocks



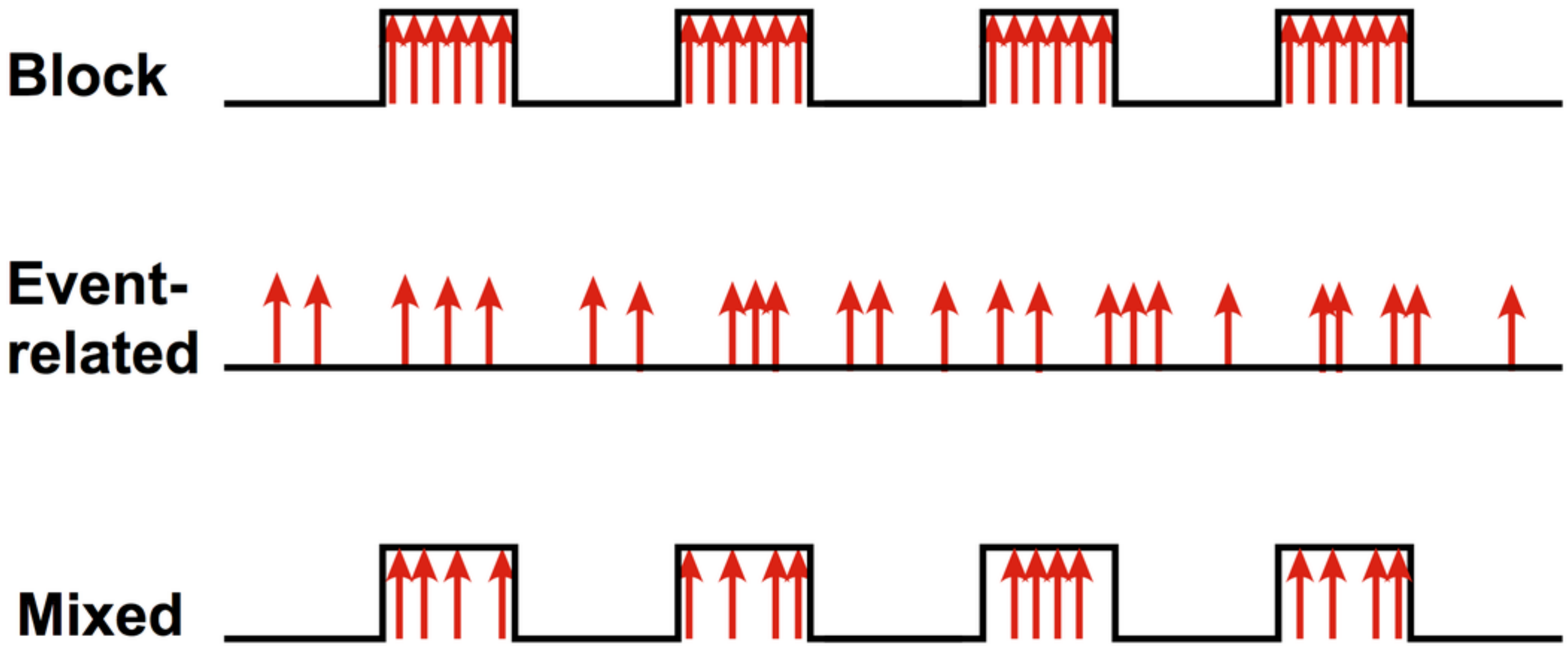
Time





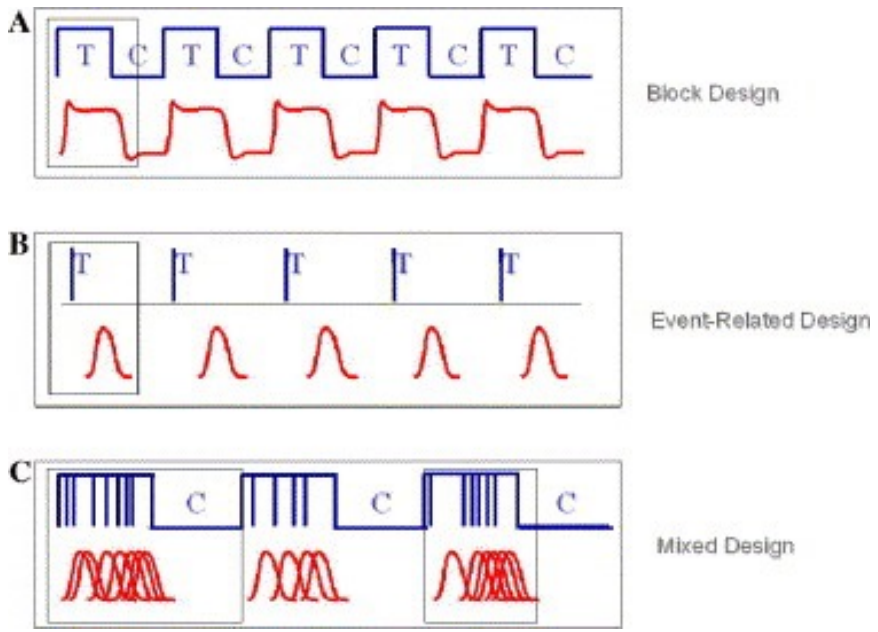
Event related design: sequence of random individual events

Paradigm design

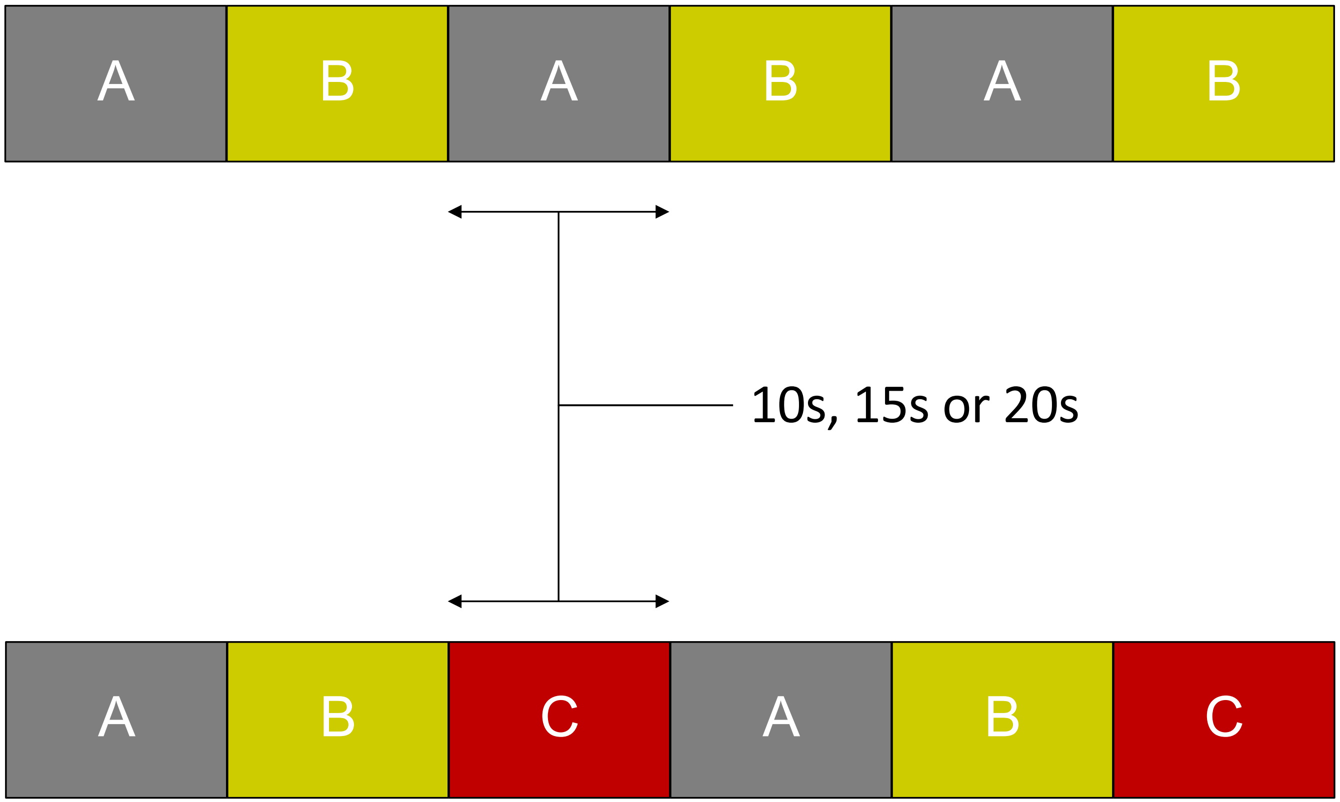


Comparison between paradigm designs

	Block	Event-related	Mixed
Detection power	High	Low	High
Estimation efficiency	Low	High	High
Predictability	High	Low	Medium
SNR	High	Low	Medium



Optimal block design



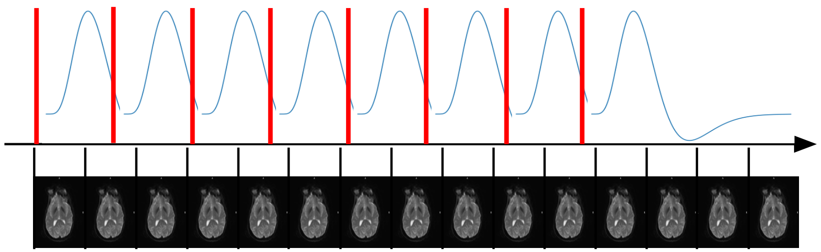
Optimal event-related design

Parameters to optimize

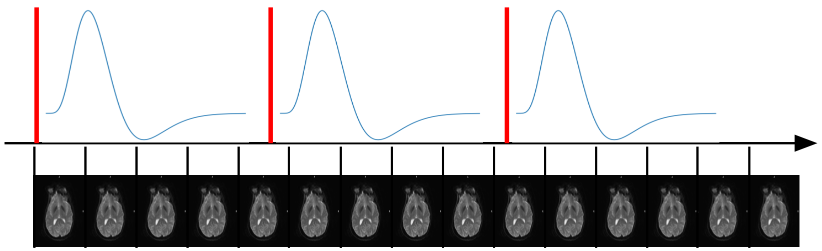
- Total scan duration
- Number of trials per condition
- Trial order
- Inter-stimulus interval (ISI) + jittering

To optimize for

- Detectability
- Efficiency
- Predictability



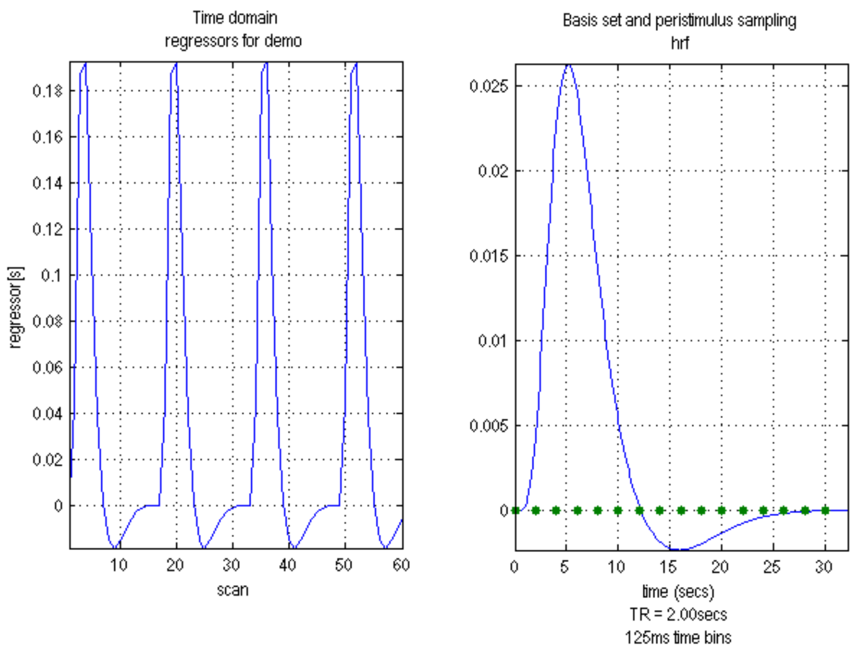
High detectability + low efficiency



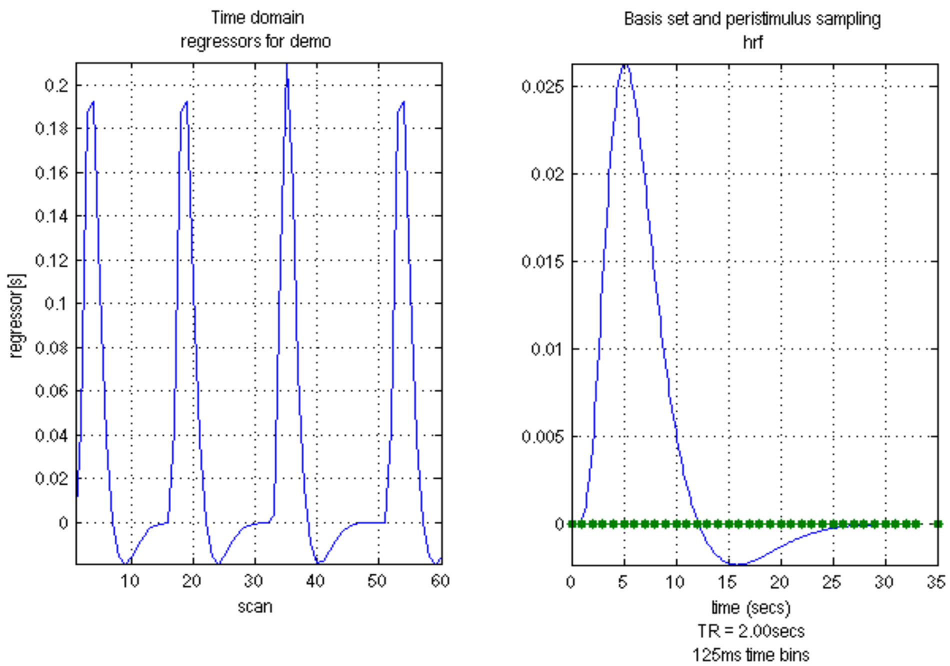
Low detectability + high efficiency

Jitter

Without jittering, TR=2s, ISI=32s



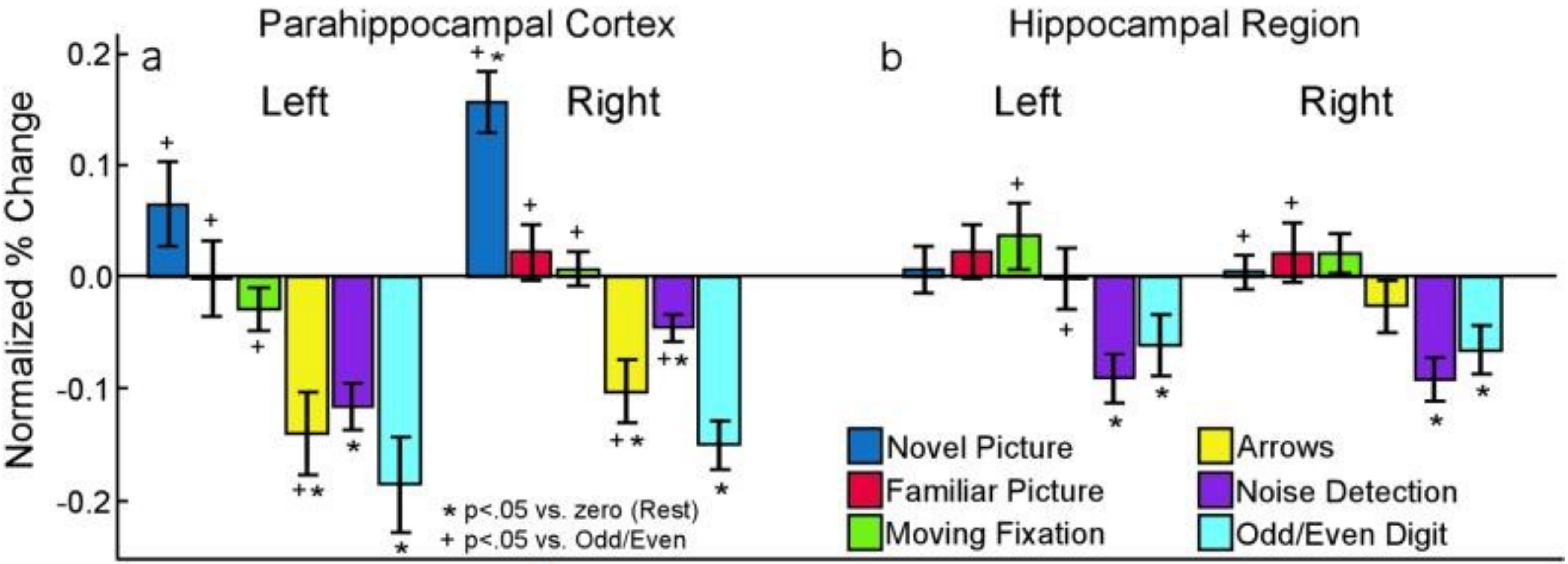
With jittering, TR=2s, Mean ISI=32s±7s



General rules of thumps for event-related designs

- Scan as long as possible
- Keep the subjects busy
- Do not contrast trials far apart in time
- Randomize trial order (and ISI)
- Log what happens and when during the fMRI scan

REST is never REST



The power of an fMRI study depends on

a. The difference between the active and rest task conditions
b. The number of trials (events)
c. The duration of the trials (events)
d. The total length of the experiment
e. The TR of the fMRI scan

Examples of fMRI paradigms

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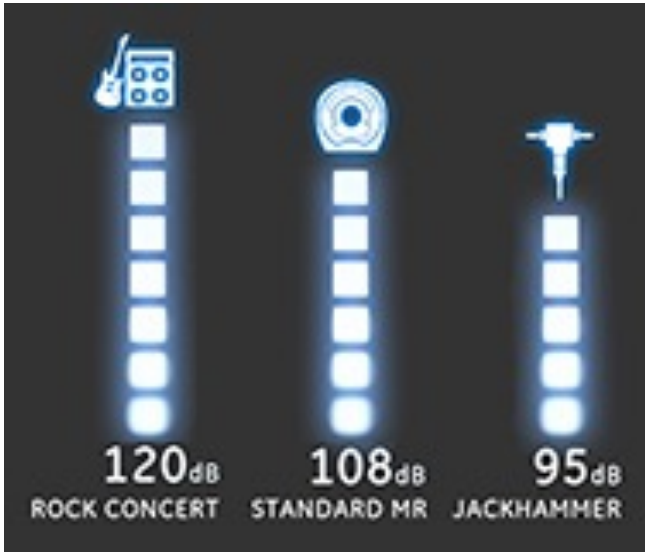
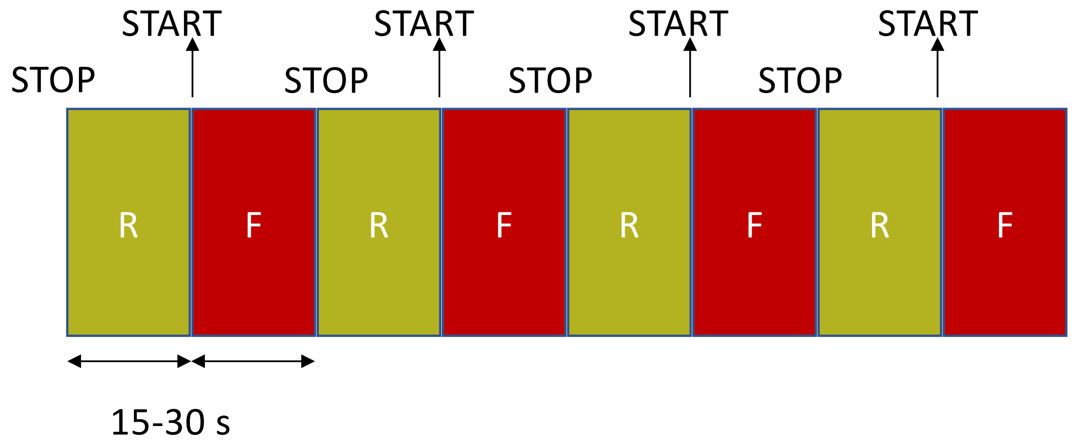
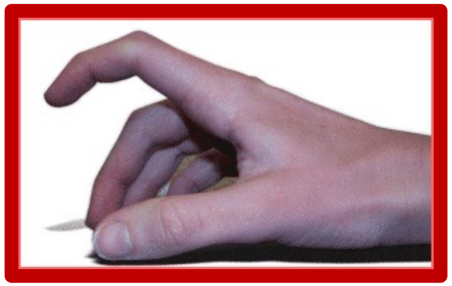
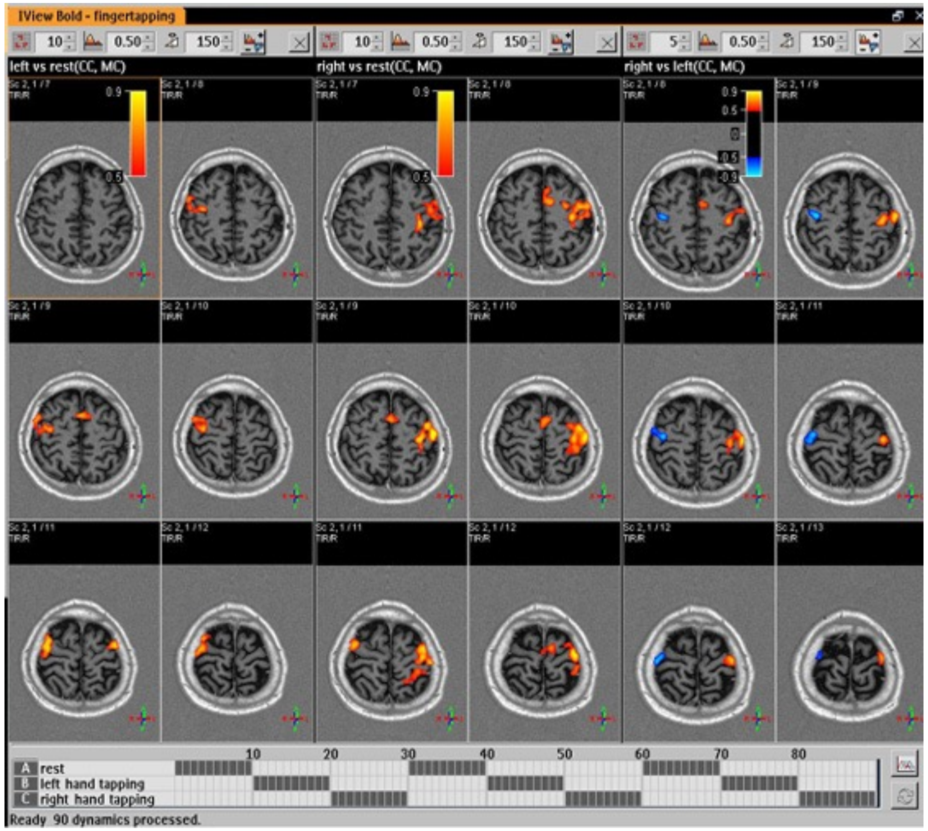

120dB
ROCK CONCERT
108dB
STANDARD MR
95dB
JACKHAMMER

Example 1: finger tapping -> motor cortex







Stathopoulos et al. Preoperative functional MRI of motor and sensory cortices: how imaging can save vital functions.
Review Article - Imaging in Medicine (2012) Volume 4, Issue 1

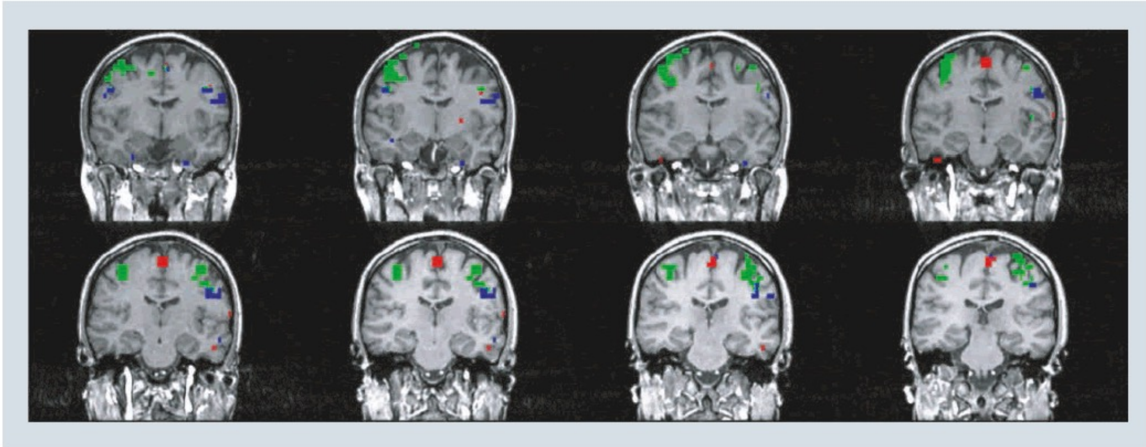


Figure 2. Localization of the different parts of the motor gyrus using functional MRI. The location of the foot homunculus is seen in red, the hand in green and face/tongue in blue, respectively.

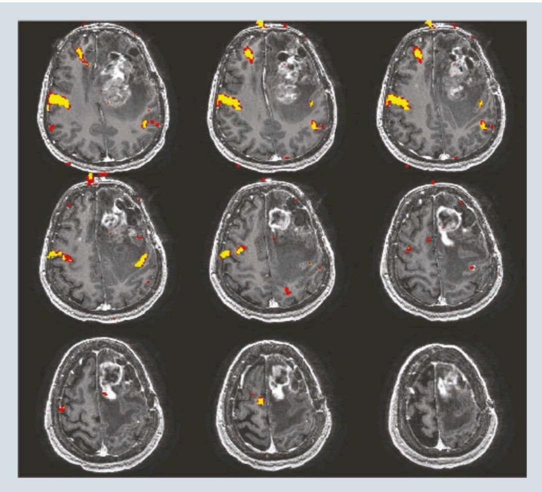


Figure 4. Left frontal glioblastoma. Notwithstanding the presence of motion artifact, prior surgery and abnormal tumor neovasculature the location of the ipsilateral motor gyrus is clearly depicted by functional MRI. The signal activation outside the brain is probably caused by motion artifact.

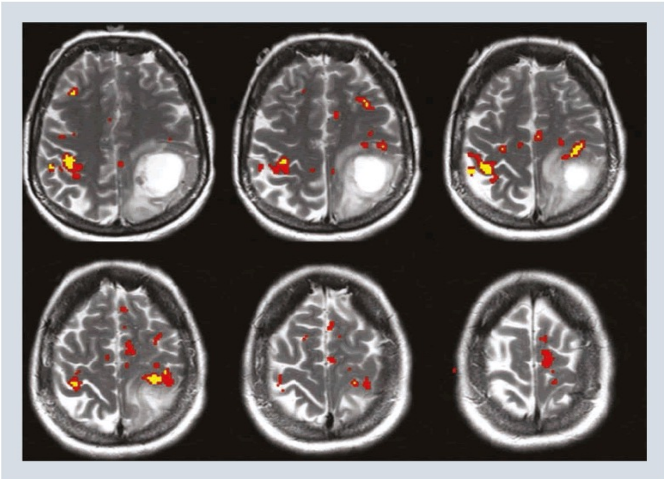


Figure 3. Patient with a left parietal glioblastoma. The patient's motor function was significantly compromised, which precluded the use of an active motor paradigm. Nevertheless, the location of the precentral (motor) gyrus could be deduced using a passive sensory functional MRI paradigm, which did not include any activity by the patient.

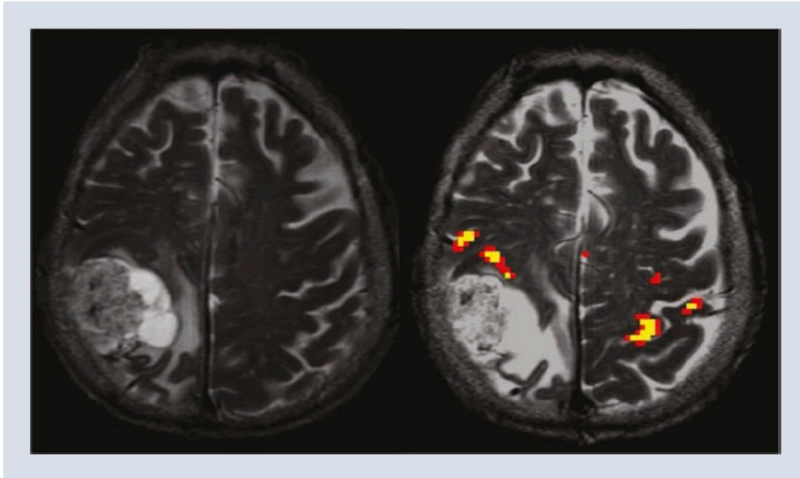
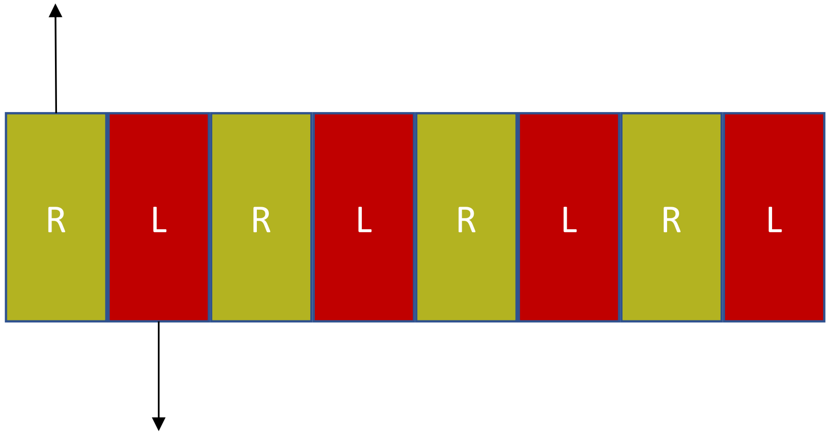


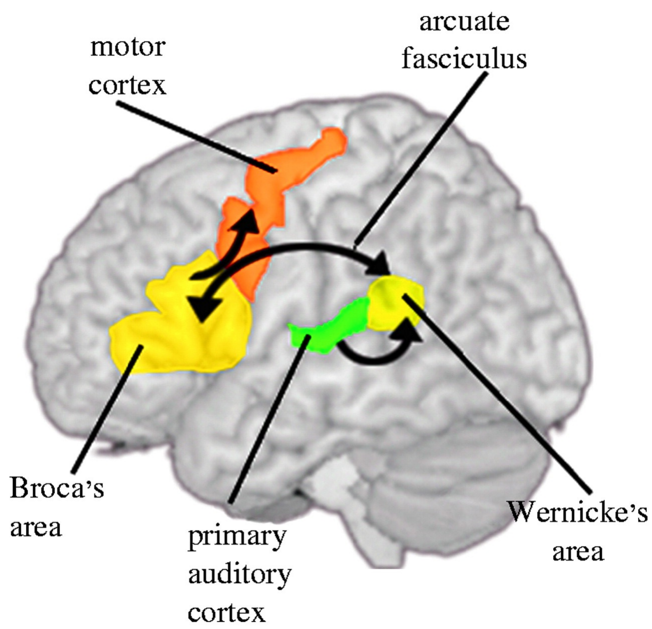
Figure 1. Glioblastoma of the right parietal lobe. The large tumor displaces the normal anatomy, making identification of the precentral (motor) gyrus difficult or impossible. Functional MRI clearly identifies the motor gyrus (yellow and red dots) and the relationship to the tumor.

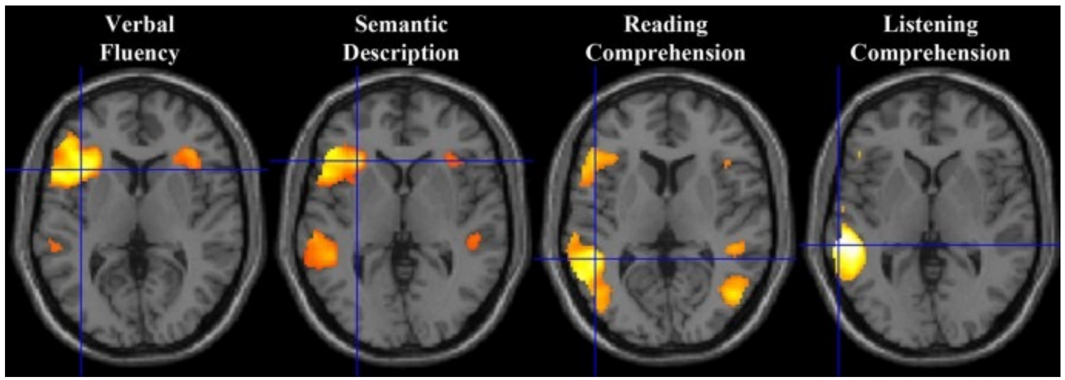
Example 2: Language -> Broca and Wernicke areas

- Rest
- Non-existing words

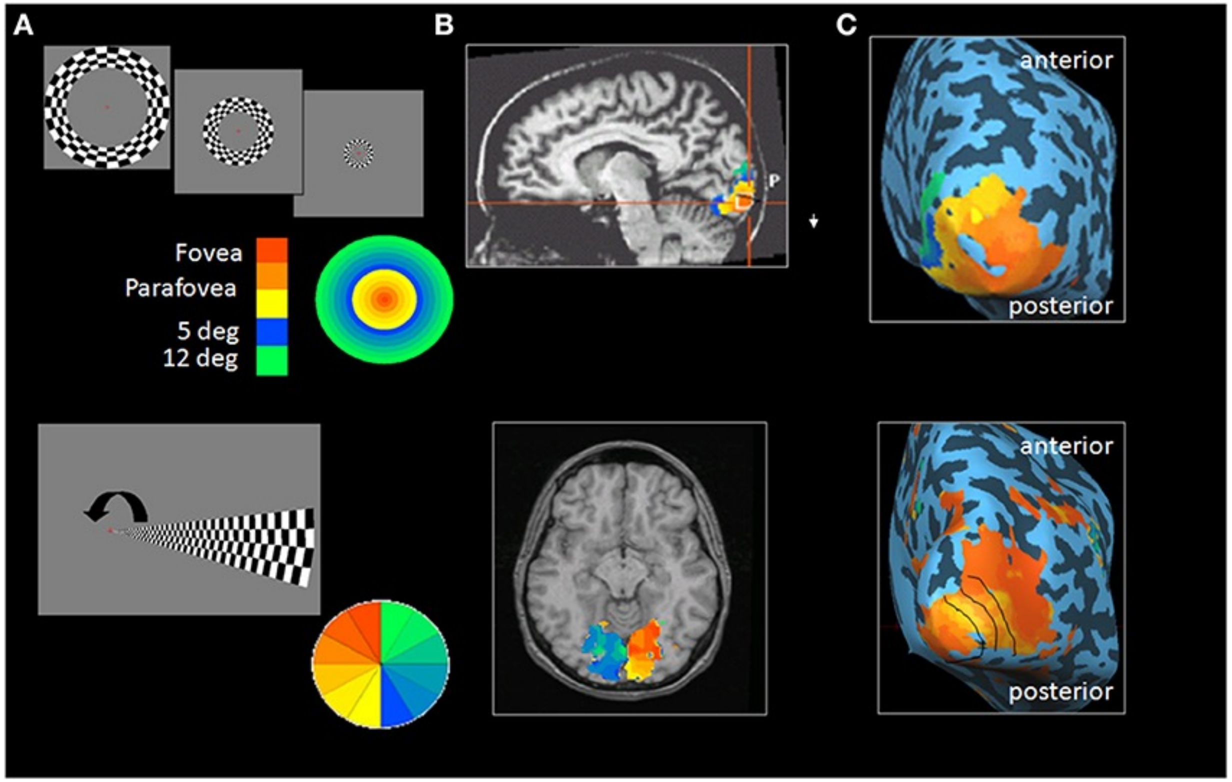


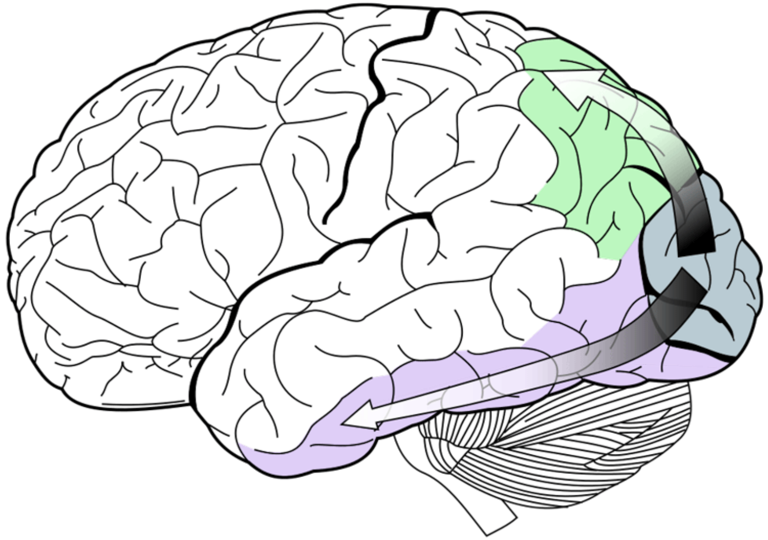
- Categories -> instruction: “Sports”
- Sentences -> instruction: “Tool used for writing”
- Words -> instruction: “Ball”





Example 3: The visual cortex





Examples of cognitive tasks

STROOP tasks

GREEN vs GREEN

8 4 vs 8 4

FLANKER task

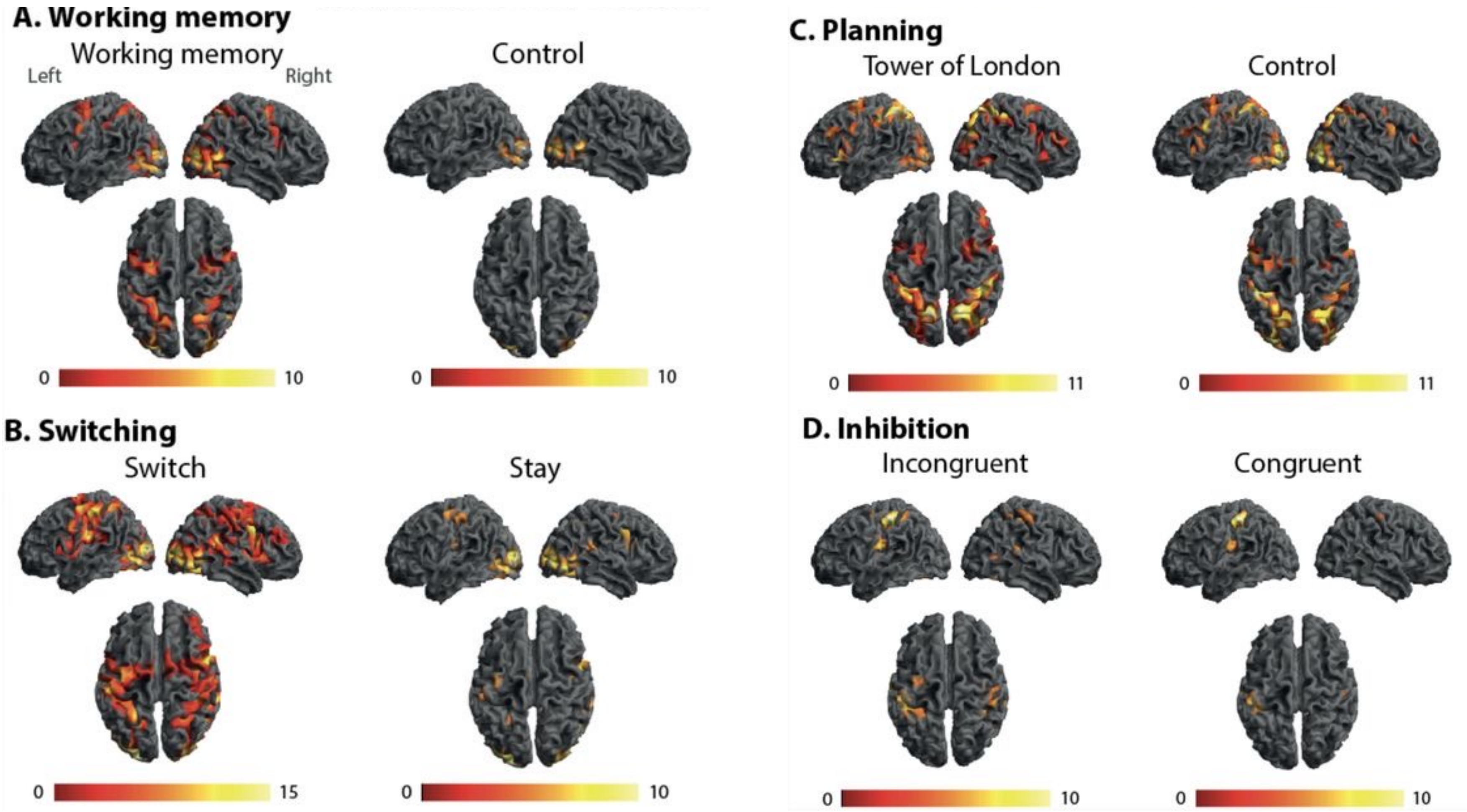
< < < < < > > > > > vs < < > < < > > < > >

Discriminate

emotional

expressions

Examples of cognitive tasks



fMRI processing tutorial:

Audiovisual Valence Congruence

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Task paradigm: Audiovisual Valence Congruence

What you see has the same valence (emotion) as what you hear (congruent)
Versus
What you see has the opposite valence (emotion) as what you hear (incongruent)
for positive versus negative stimuli
↓
2x2 design: (congruent - incongruent) x (positive - negative)

Visual stimuli (video) + Auditory stimuli (music)

Stimulation as individual events (3s long)

4 conditions:

1. Visual positive + Auditory positive
2. Visual positive + Auditory Negative
3. Visual negative + Auditory positive
4. Visual negative + Auditory negative

Congruent trials

Incongruent trials

12 trials / run / condition -> 48 trials / run

8 catch trials (no stimulus, but responses recorded -> attention test)

20 subjects (all healthy adult volunteers)

Positive valence

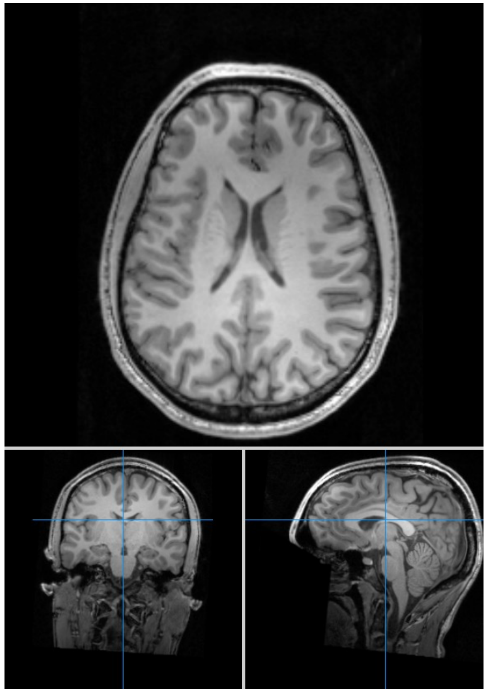
Negative valence

Gao, C., Weber, C. E., Wedell, D. H., & Shinkareva, S. V. (2020). An fMRI study of affective congruence across visual and auditory modalities. Journal of cognitive neuroscience, 32(7), 1251-1262
Chuanji Gao and Christine E. Weber and Douglas H. Wedell and Svetlana V. Shinkareva (2021). fMRI: Audiovisual Valence Congruence. OpenNeuro. [Dataset] doi: 10.18112/openneuro.ds003507.v1.0.1

Scan protocol (Siemens 3T)

T1 weighted anatomical scan

- 3D TGE (MPRAGE) (sagittal slices)
- Scan volume: 192 x 256 x 256 mm
- Matrix: 192 x 256 x 256
- Voxel dimensions: 1 x 1 x 1 mm

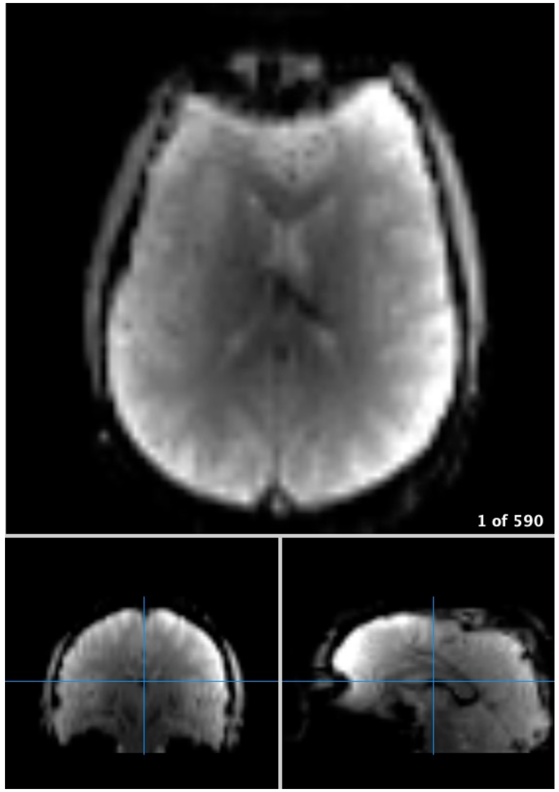


fMRI scan

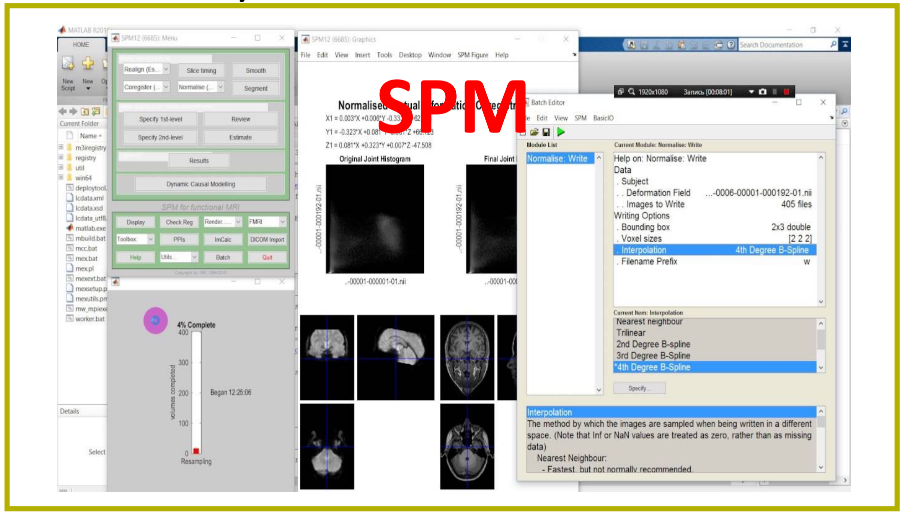
- GE-EPI (axial slices)
- Scan volume: 202 x 256 x 256 mm
- Matrix: 70 x 70 x 40
- Voxel dimensions: 3 x 3 x 3 mm
- Temporal resolution: 1s
- 590 dynamics
- HyperBand: 4

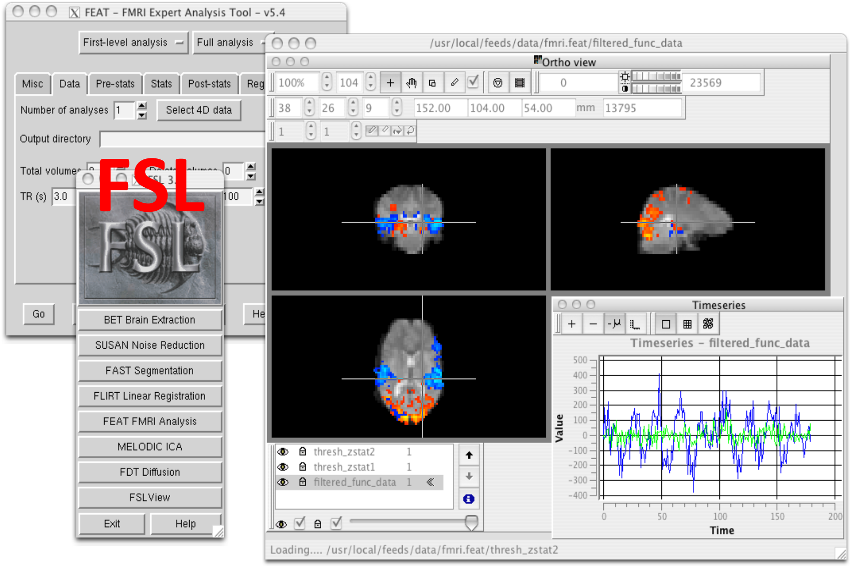
Fieldmap scan

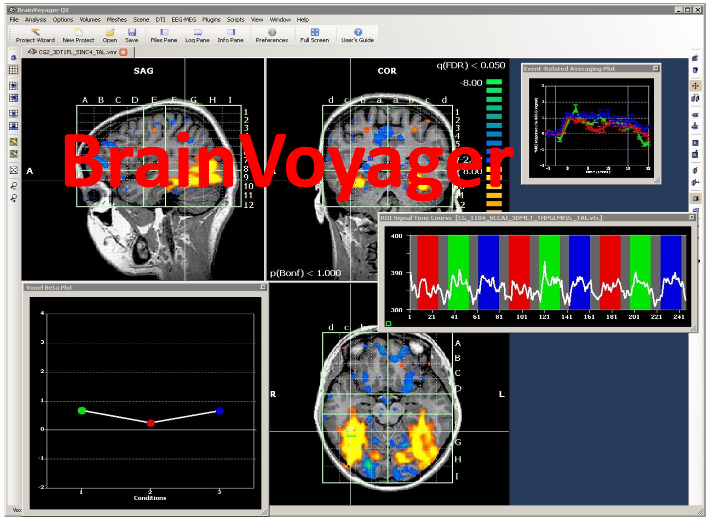
- 2x GE-EPI (axial slices)
- Scan volume: 202 x 256 x 256 mm
- Matrix: 70 x 70 x 40
- Voxel dimensions: 3 x 3 x 3 mm
- HyperBand: 4
- Phase encoding direction scan 1: AP
- Phase encoding direction scan 2: PA



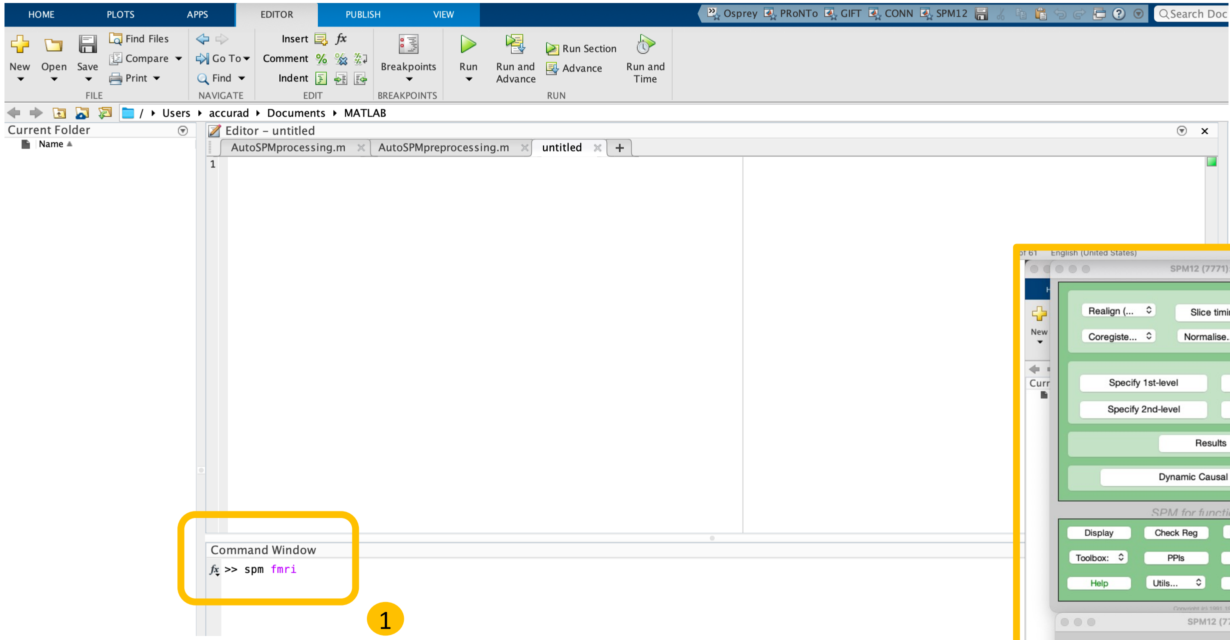
fMRI analysis software



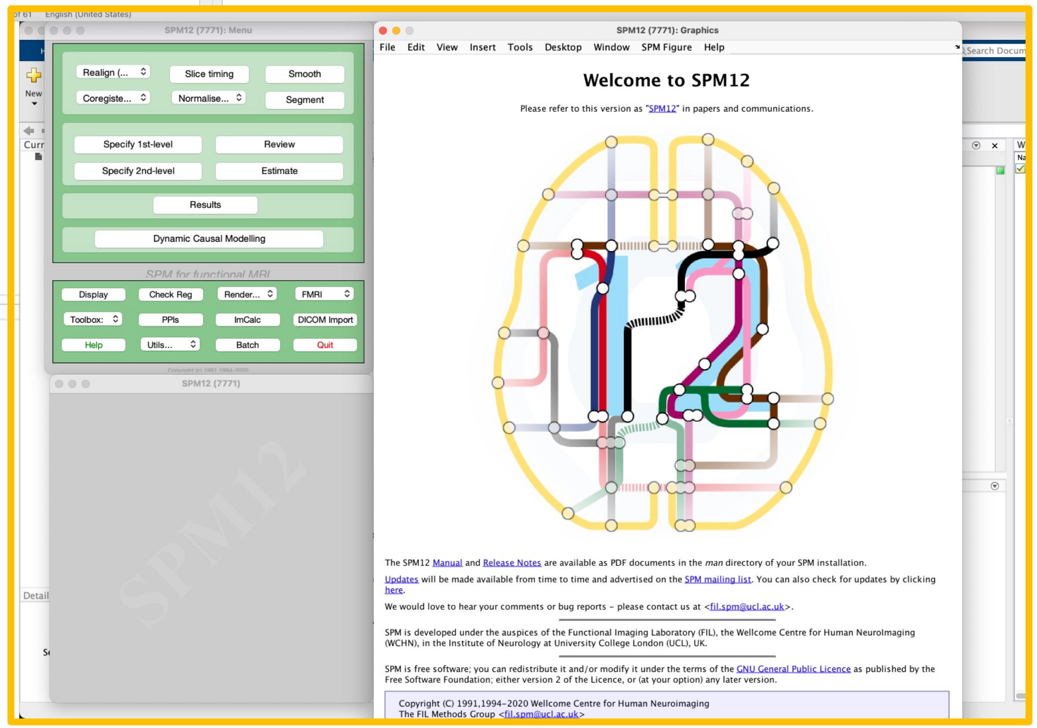




Starting SPM12



1



2

In Matlab

1. Type “spm fmri” in the Command Window
2. SPM should open

(after some output in the Command Window)

Preparing the fMRI data

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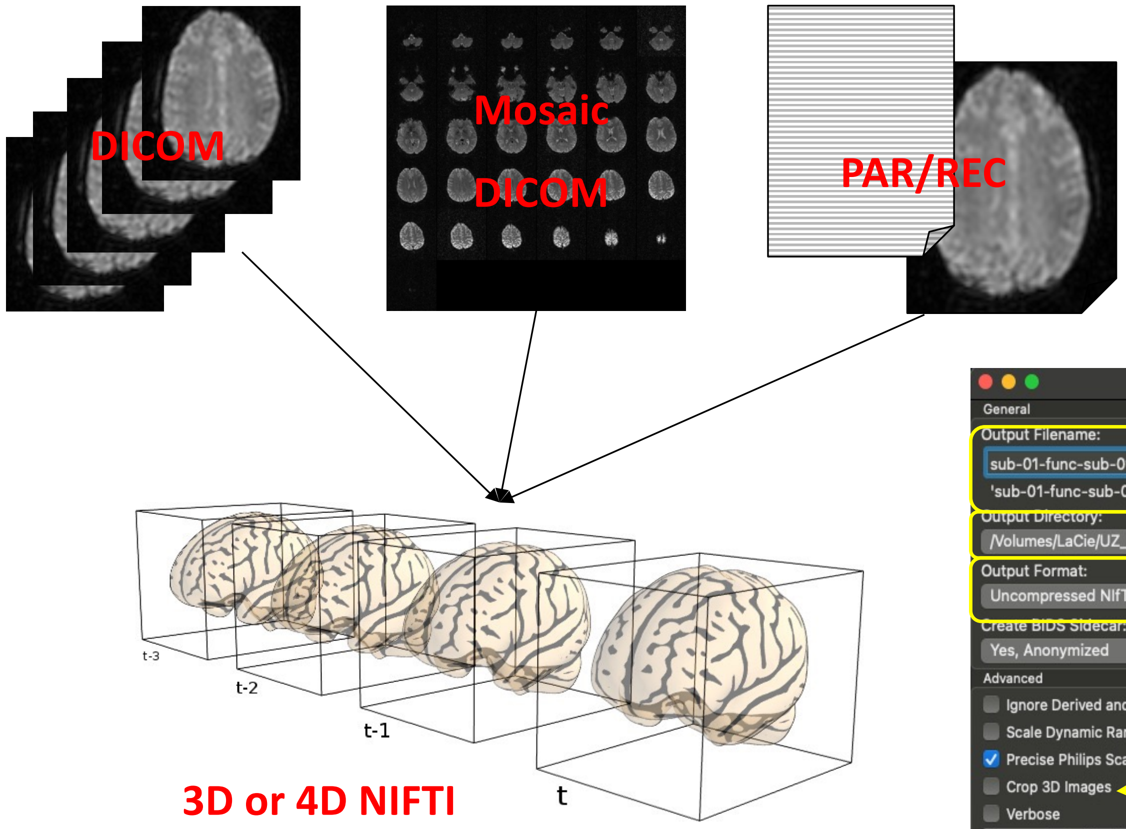
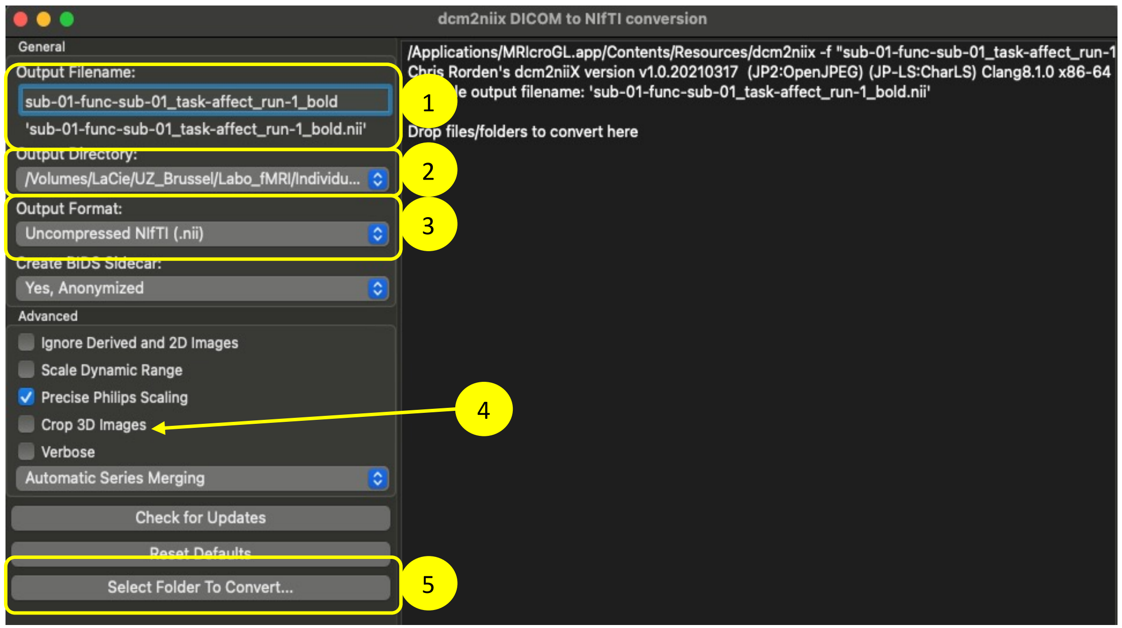
Converting data into NIFTI format

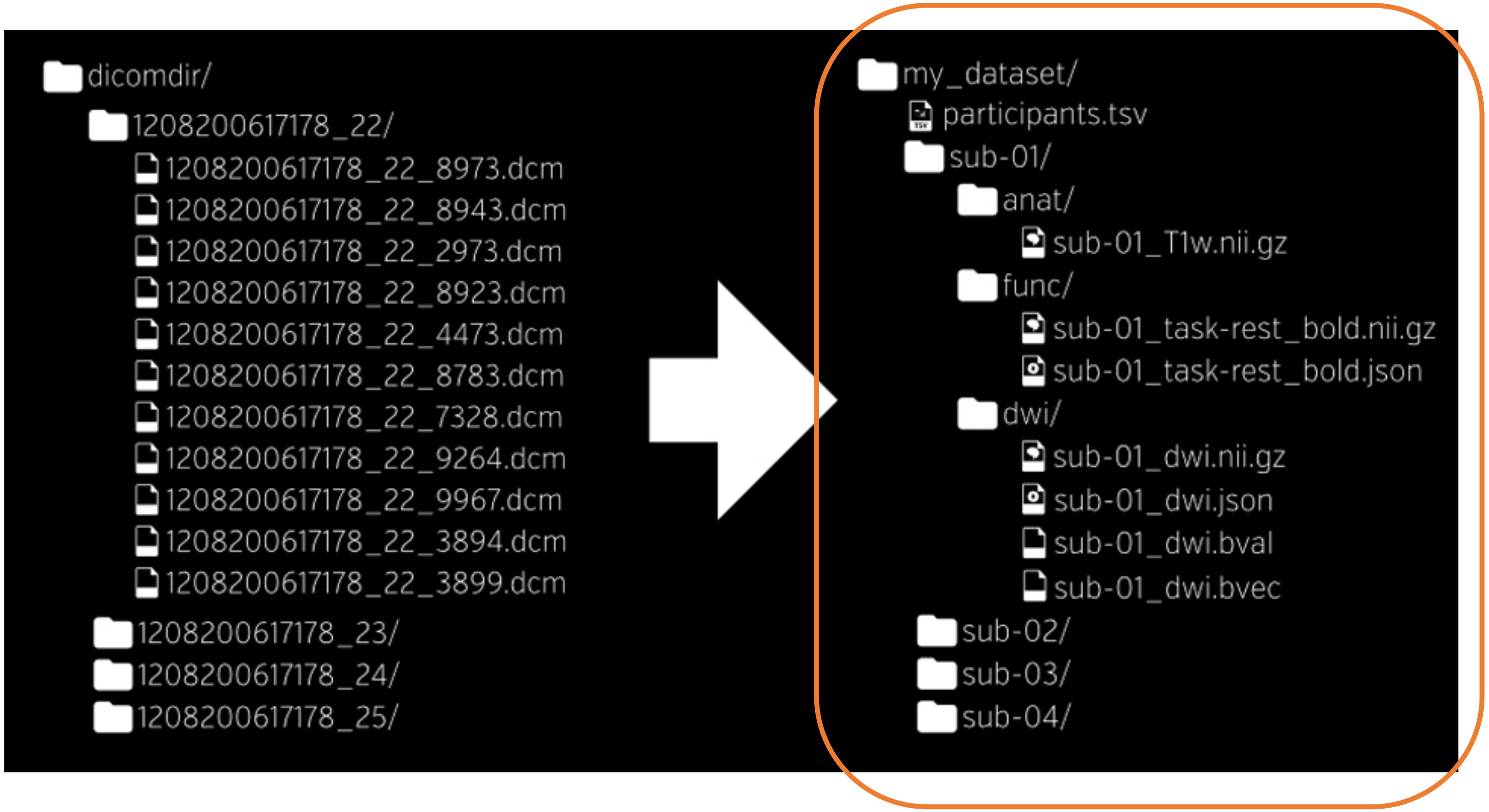


Using dcm2nix in MRIcroGL:

1. Set the output filename
2. Select the output data directory
3. Select Uncompressed NIFTI (.nii)
4. For the 3D T1 scan: Select 'Crop 3D Image
5. Select the dicom data folder

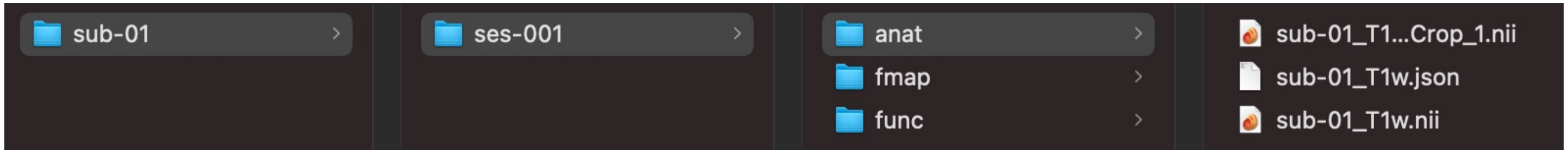


Organize data according to the BIDS standard



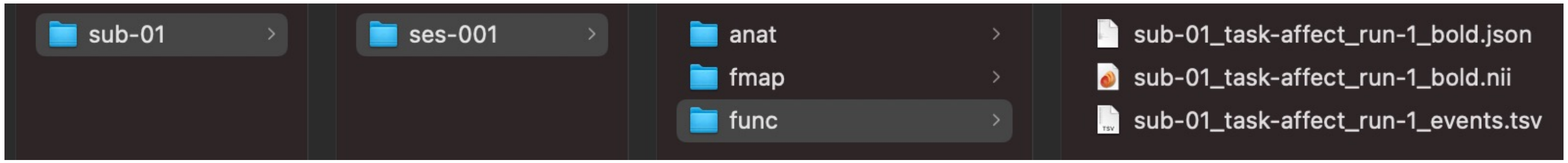
The individual data for subject 1

T1 weighted anatomical scan



Fieldmap scans

fMRI scan



.json file = text file with the fMRI scan parameters

.nii file = the actual image data

Events.tsv file = text file with the onsets and duration of the task conditions

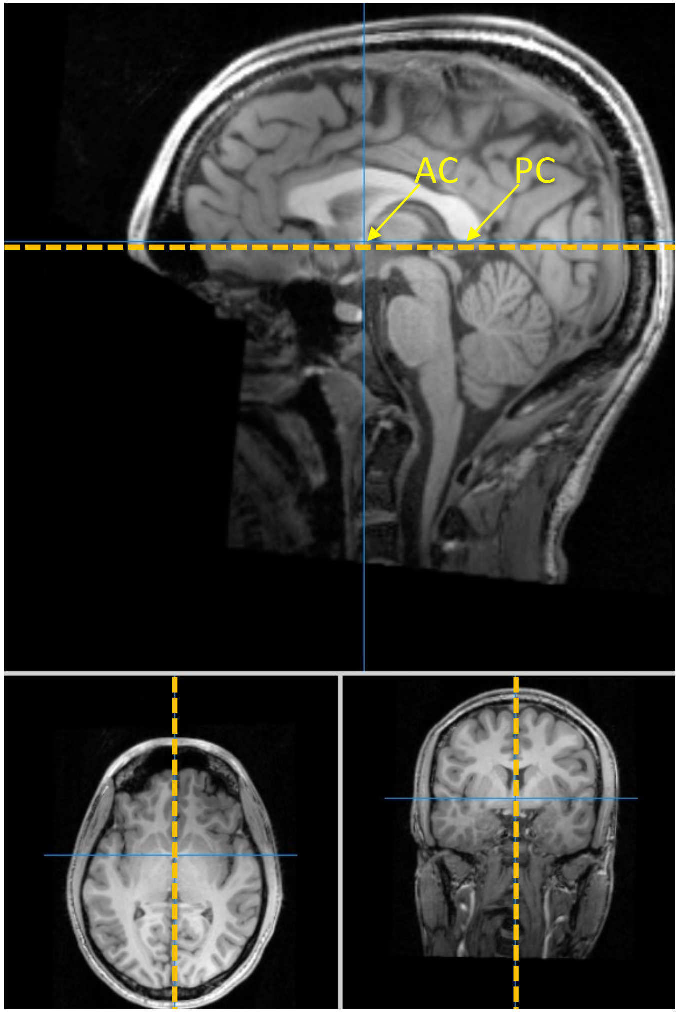
Preprocessing the data

Step 1: setting the image origin and orientation

To improve the image registration, segmentation and normalization steps, all scans should be set with the origin in the anterior commissure (AC) and oriented to put the head straight in all orientations.

Reference axes:

1. AC-PC line
2. Space between the left and rights hemispheres



Step 1: setting the image origin and orientation

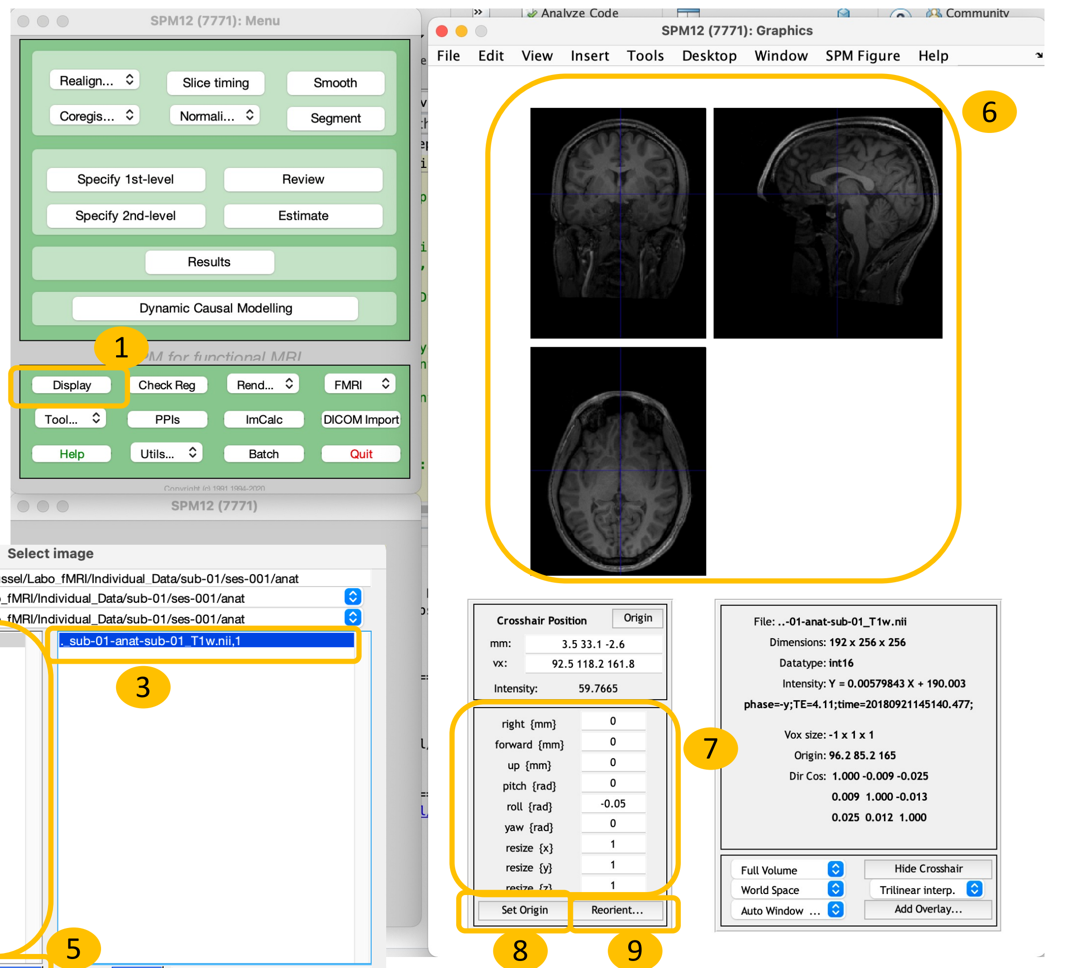
1. In SPM Menu: click ”Display”
2. In Select Image: go to the data folder in the left window
3. In Select Image: select the nifty file in the right window
4. In Select Image: the selected file should appear at the bottom
5. In Select Image: click “Done”
6. In Graphics Window: set the crosshair at the anterior commissure (AC)
7. In Graphics Window: set the head straight in all views using pitch, rol and yaw

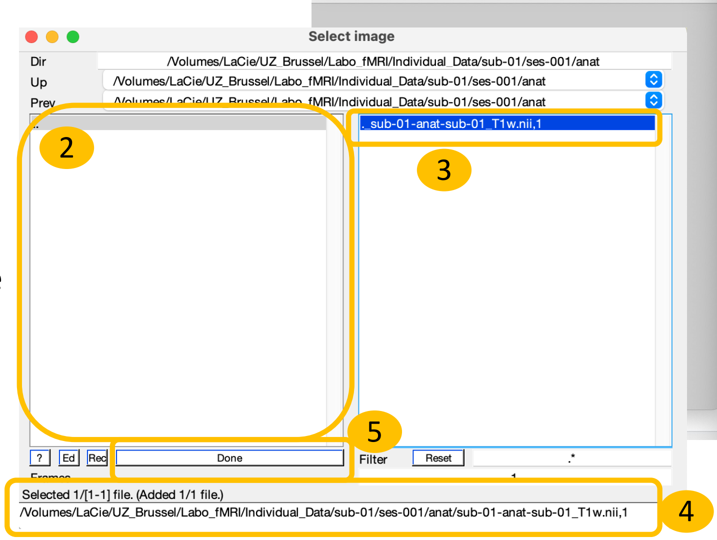
(Step 7 and 8 are done interactively)

If the crosshair is at the AC and all orientations are ok:

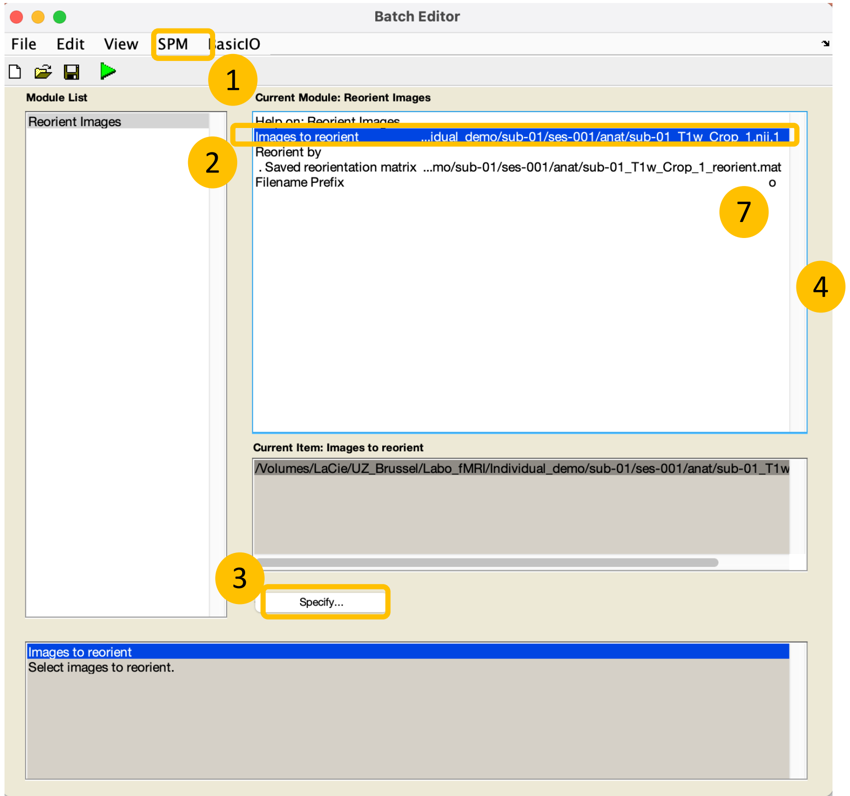
8. In Graphics Window: click “Set Origin”
9. In Graphic Window: click ”Reorient”
10. In Image(s) to reorient: deselect all files and click “Done”
8. In Save Matrix: click “Yes” and save the reorient.mat files inn the folder of the nifty file

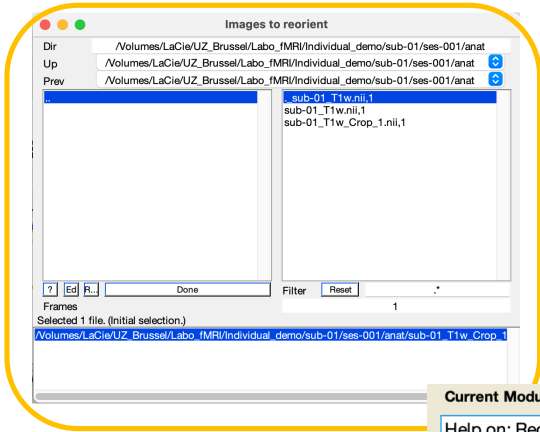
This step should be done separately for the anatomical scan, the fieldmap scans and the fMRI scan

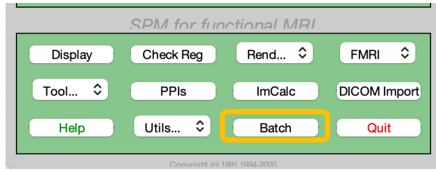




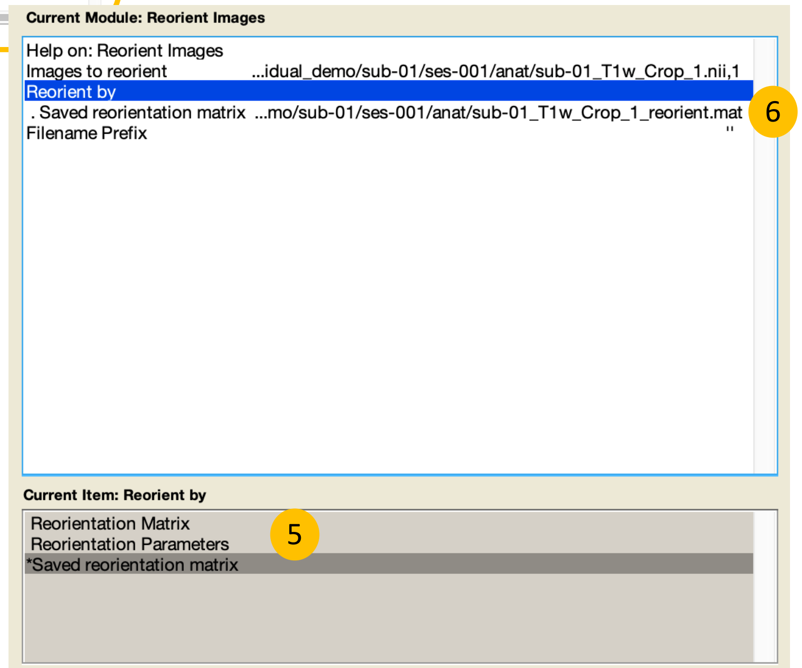
Step 1: setting the image origin and orientation for the 3D T1 scan







Open the Batch Editor

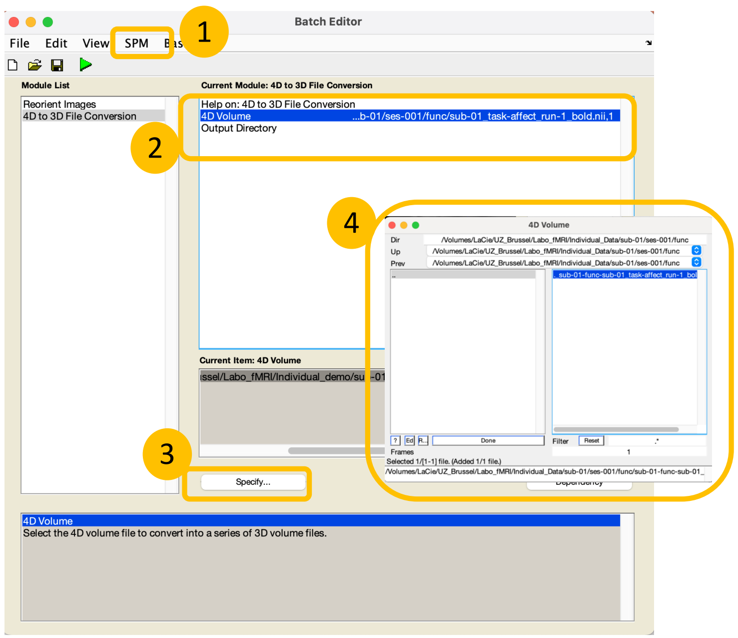


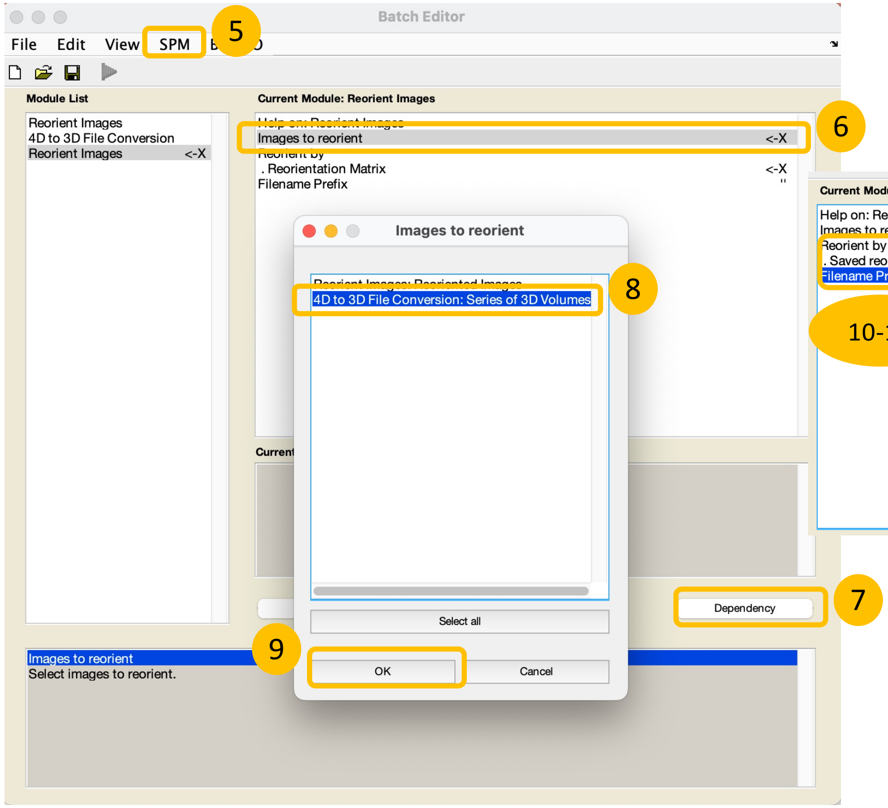
7. Optionally:
The orientation of the data will only change the orientation information in the header of the nifty file. Consequently, repeating the data processing multiple times can lead to wrong results. To overcome the overwriting of the original nifty file, and Filename Prefix for the reoriented data can be specified.

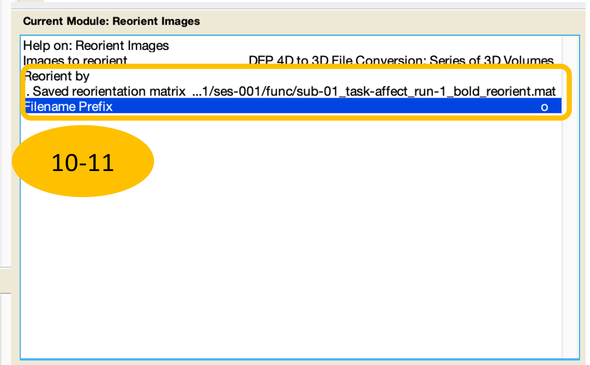
1. In the top Menus: select SPM -> Util -> Reorient Images
2. Select Images to reorient
3. Click “Specify”
4. In the data selection window: select the anatomical scan (advisable the cropped version)
5. Reorient by: select ‘Saved reorientation matrix’
6. Saved reorientation matrix: select the reorient.mat file for the anatomical scan

Step 1: setting the image origin and orientation for the func and fmap scans

4D to 3D conversion







1. In the top Menus: select SPM -> Util -> 4D to 3D File Conversion
2. Select "4D Volume"
3. Click "Specify"
4. In the data selection window: select the fMRI scan

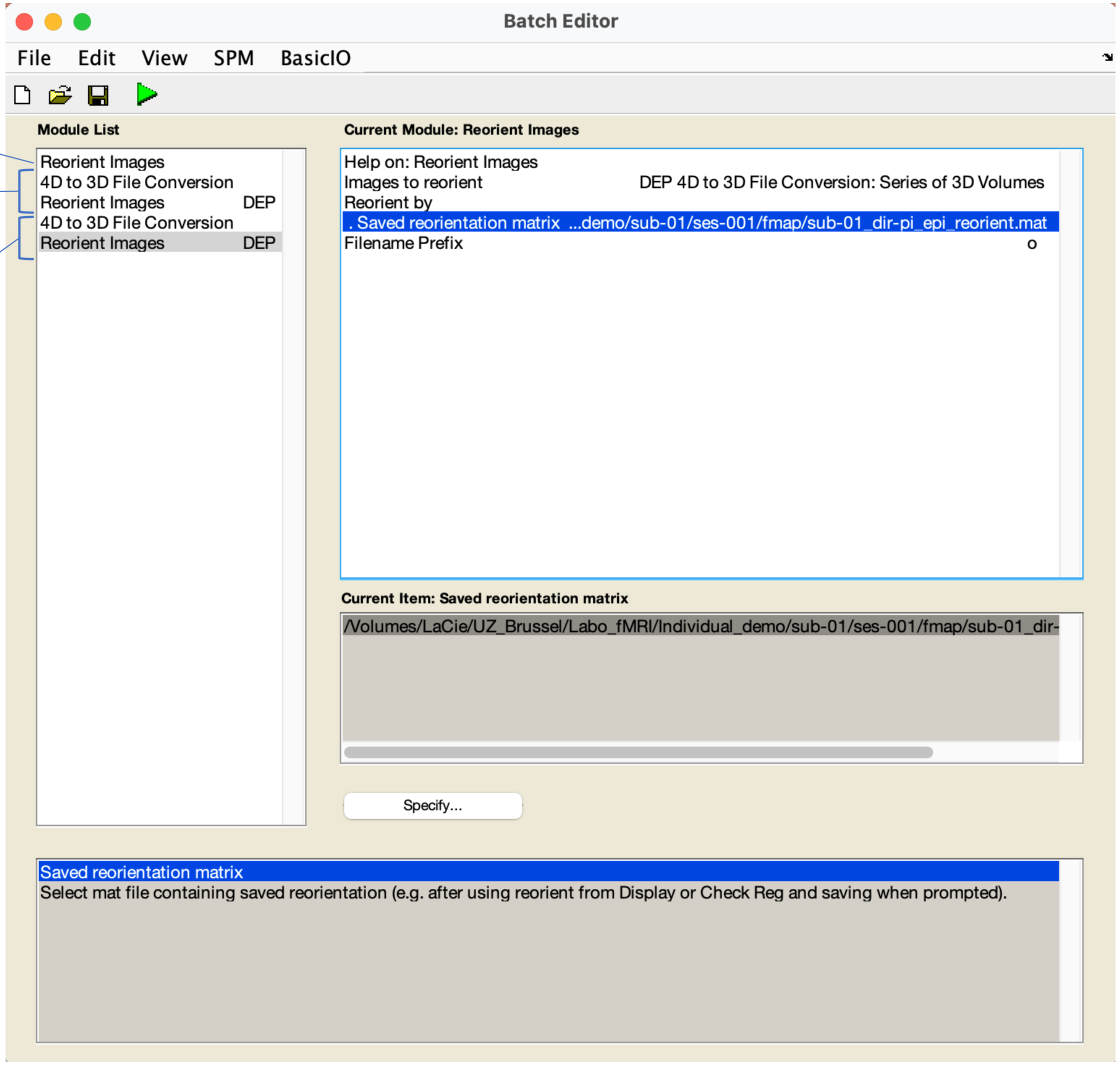
5. In the top Menus: select SPM -> Util -> Reorient Images
6. Select Images to reorient
7. Click "Dependency"
8. In the 'Image to orient' window: select '4D to 3D Conversion: Series of 3D Volumes'
9. Click 'Ok'
10. Reorient by: select 'Saved reorientation matrix'
11. Saved reorientation matrix: select the reorient.mat file for the func/fmap scan

Step 1: setting the image origin and orientation

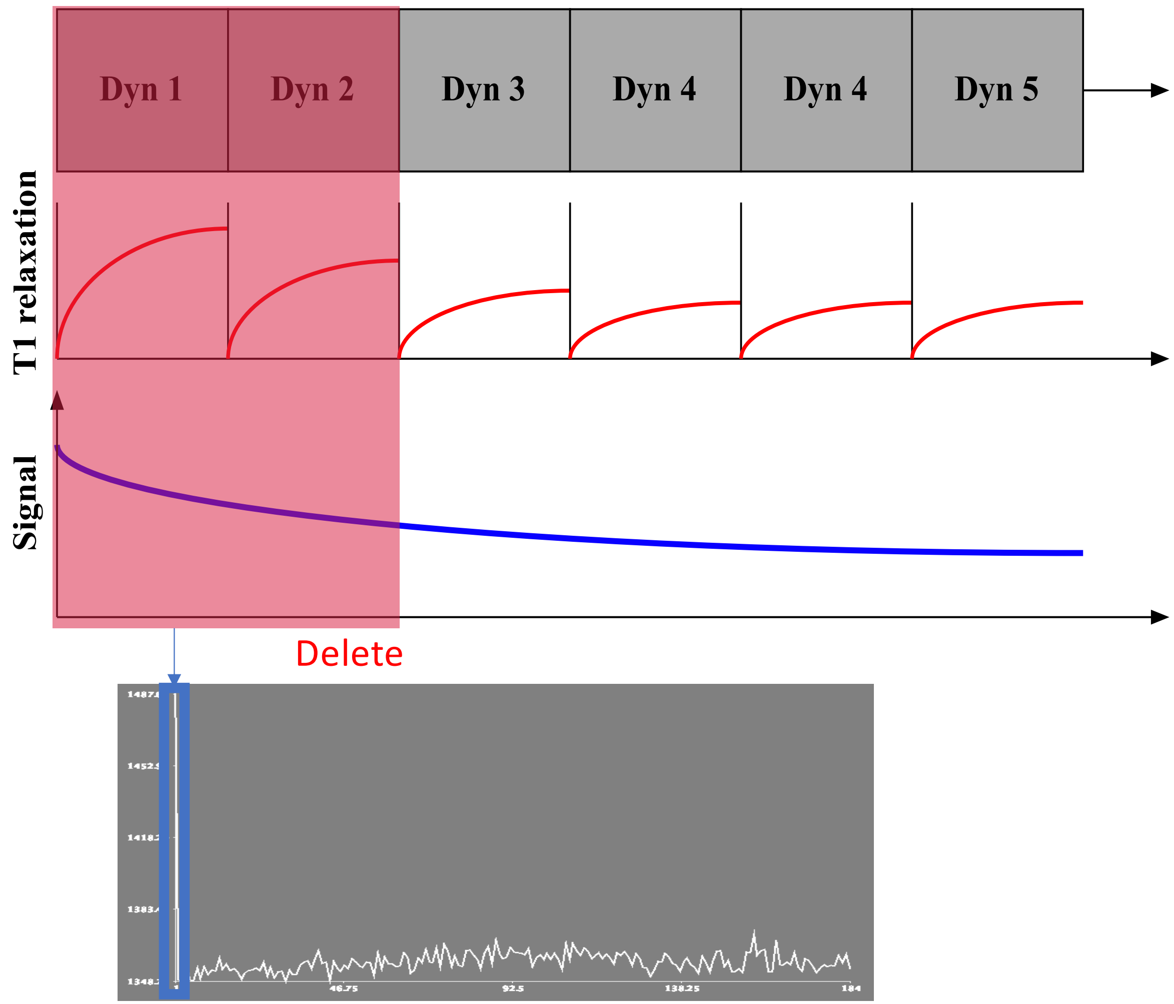
Reorient 3D T1 scan

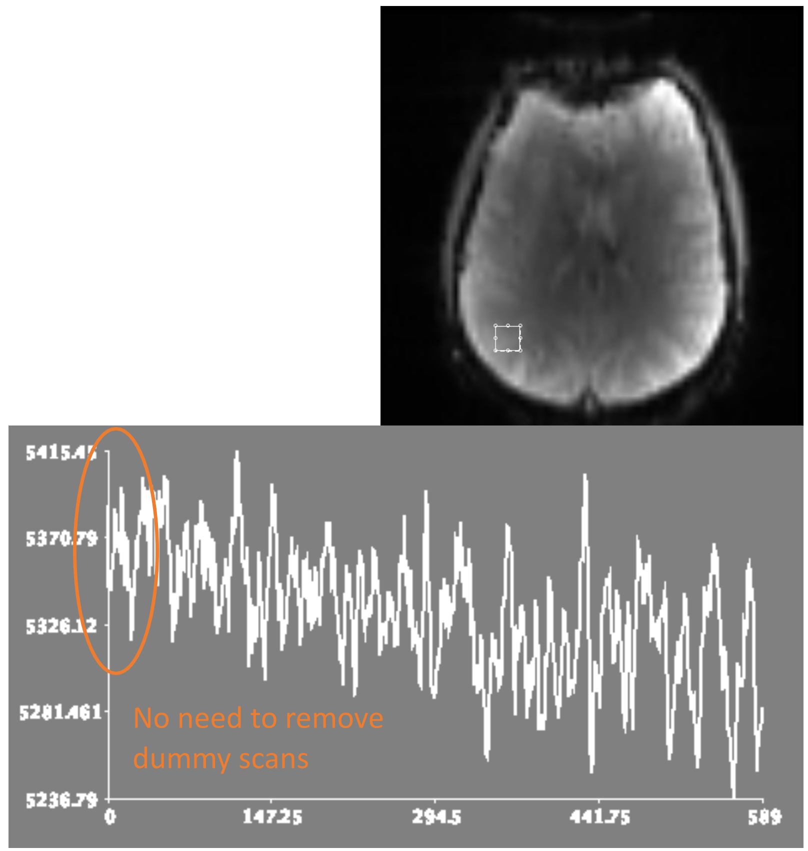
Reorient func scan

Reorient fmap scan

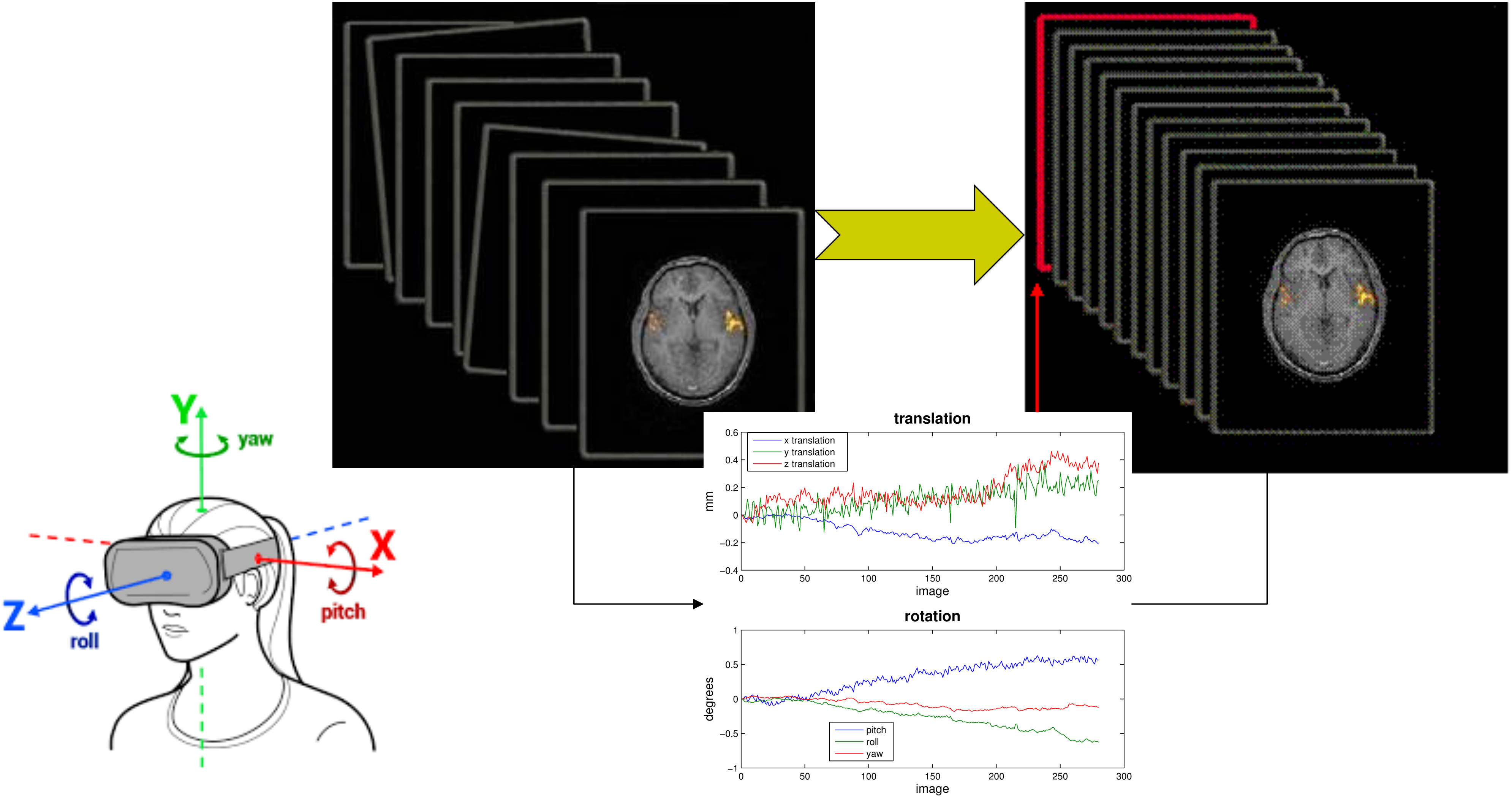


Step 2: Deleting the “dummy” scans

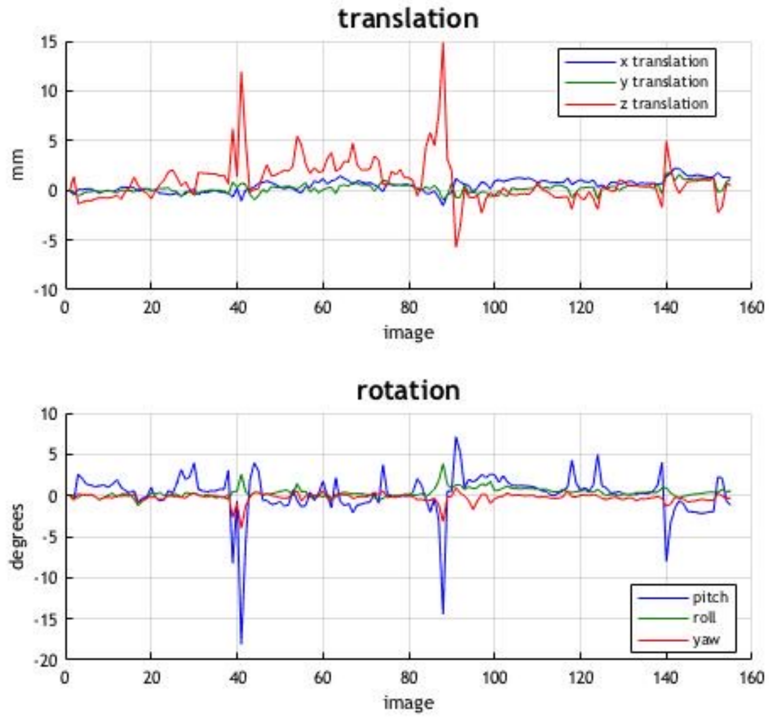


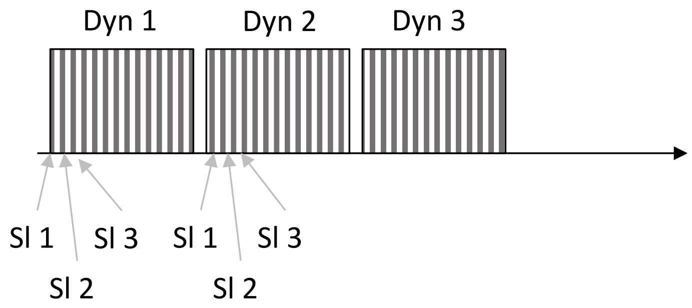


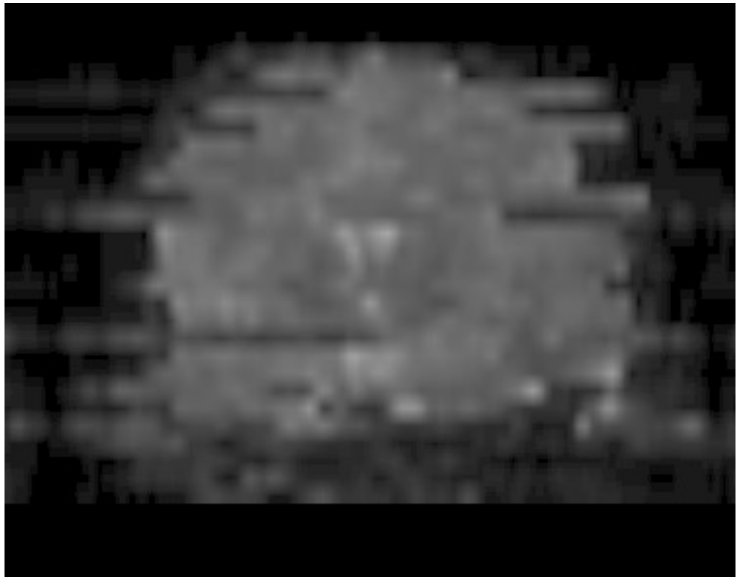
Step 3: Realignment: motion correction



But … if motion is too much …

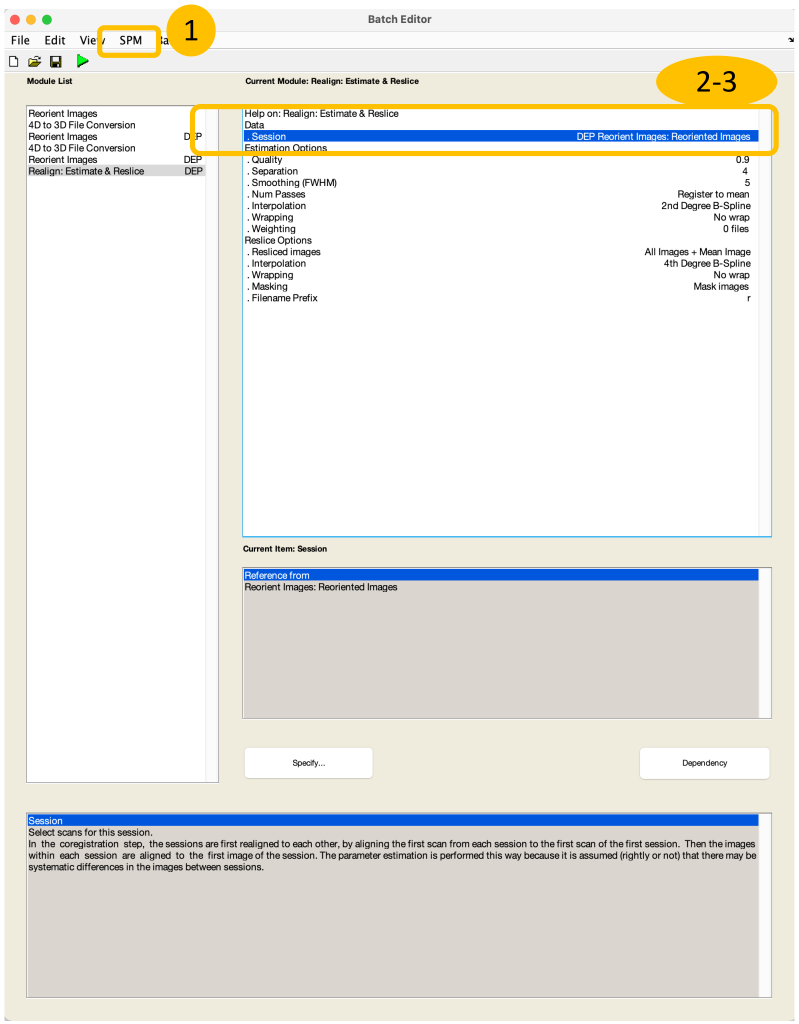




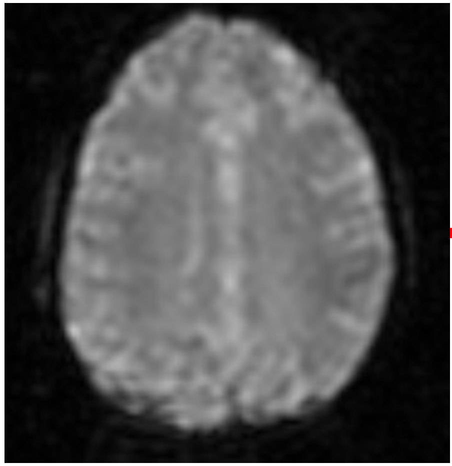


Step 3: Realignment: motion correction

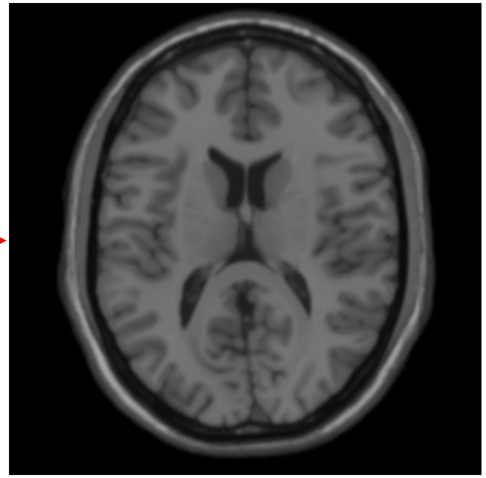
1. In the top menus: SPM -> Spatial -> Realign -> Realign: Estimate & Reslice
2. Data -> New: Session
3. Session: (using Dependency) -> Reoriented Images: Reoriented Images (from the func series!)



Step 4: Coregistration: within subject, between scans registration



Source

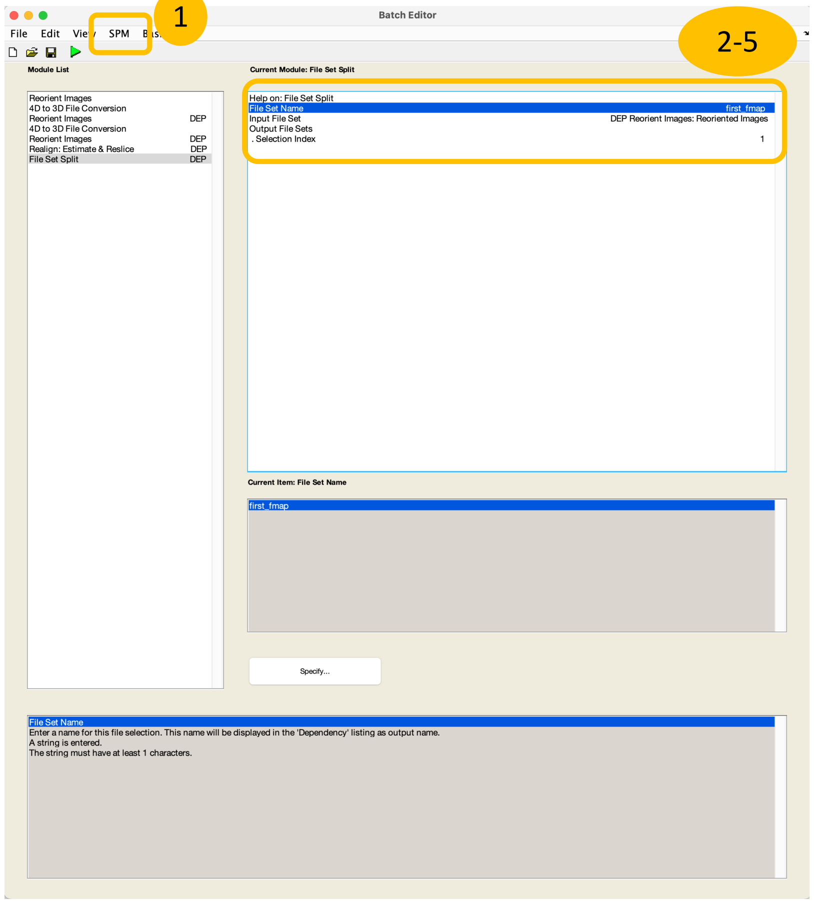


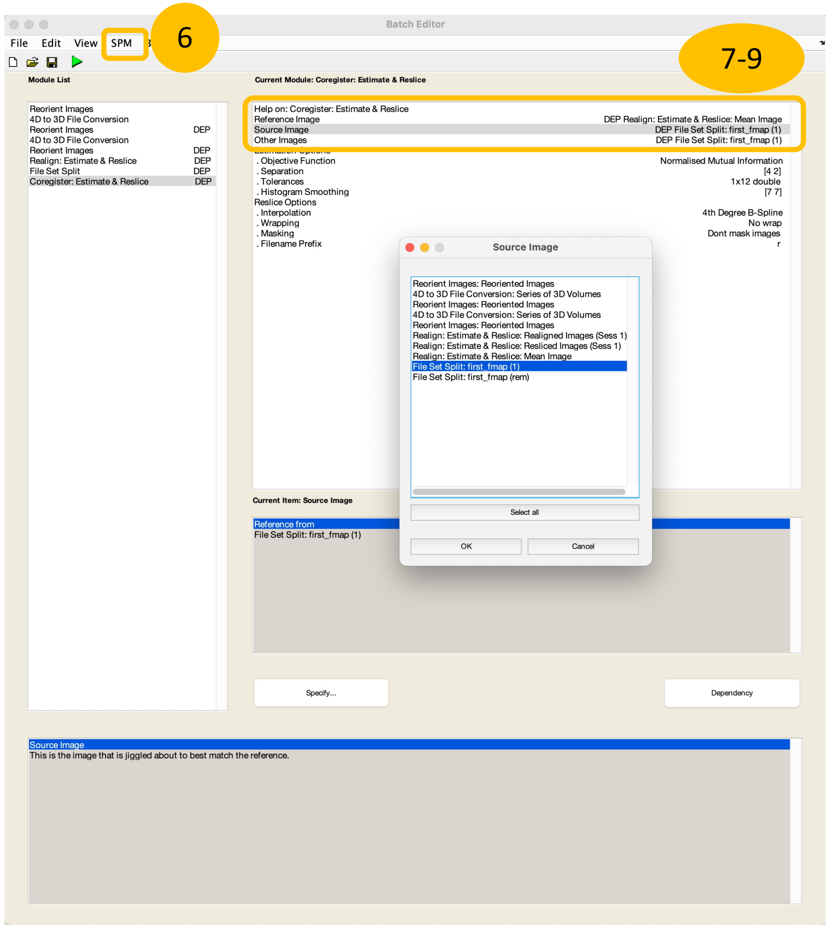
Reference

Rigid body transformation

Same orientation and position
Same FOV and resolution

Step 4: Coregistration: fmap to func

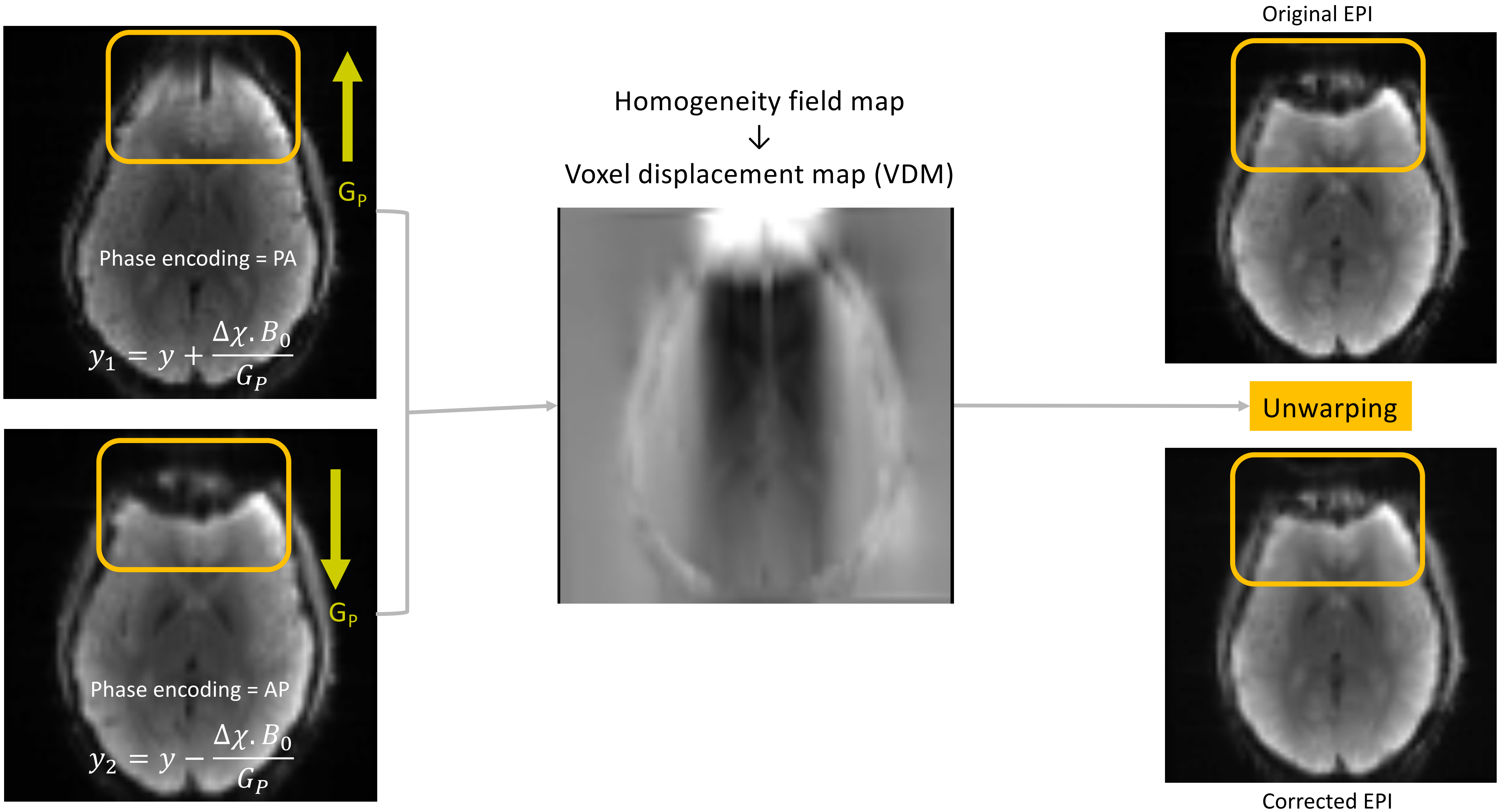




1. In the top Menus: select BasicIO -> File/Dir operations -> File Operations -> File Set Split
2. File Set Name: first_fmap
3. Input File Set: (using Dependency) Reorient Images: Reoriented Images (for the fmap data!)
4. Output File Sets: New: Selection Index
5. Selection Index: 1

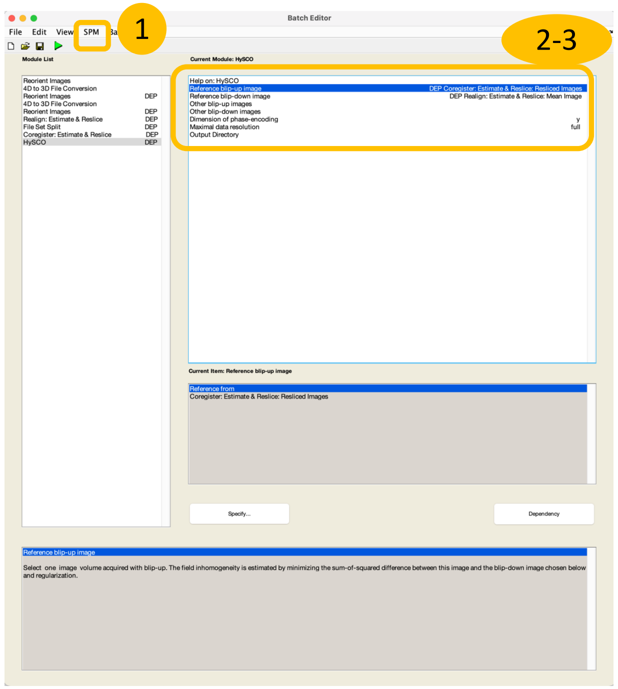
6. In the top Menus: select SPM -> Spatial -> Coregister -> Coregister: Estimate & Reslice
7. Reference Image: (using Dependency) Realign: Estimate & Reslice: Mean Image
8. Source Image: (using Dependency) File Set Split: fist_fmap (1)
9. Other Images: (using Dependency) File Set Split: fist_fmap (1)

Step 5: Correcting the geometric distortion



Step 5: Correcting the geometric distortion

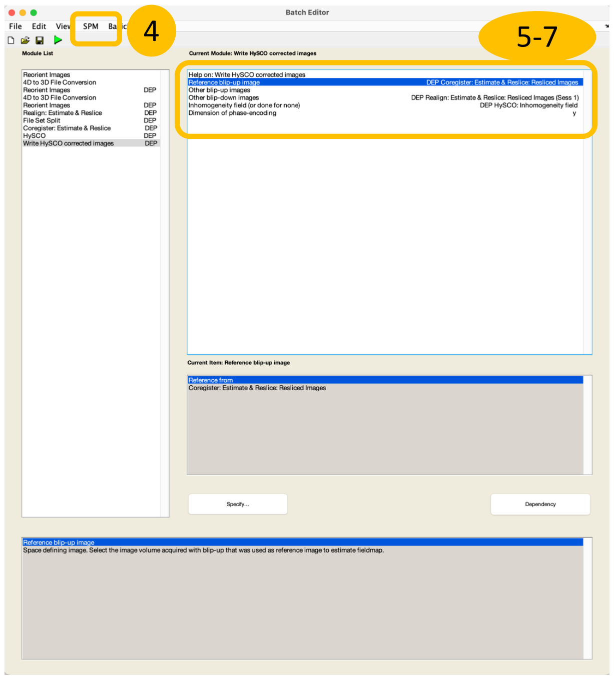
Determine homogeneity map



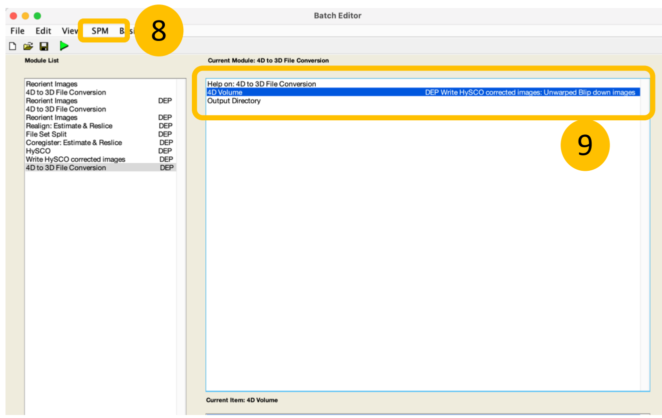
1. In the top Menus: select SPM -> Tools -> ACID Toolbox -> Pre-processing -> Choose HySCO options -> HySCO
2. Blip-up image (using Dependency): Coregister: Estimate & Resliced Images
3. Blip-down image (using Dependency): Realign: Estimate & Reslice: Mean Image

In the json file (for func and fmap):
"PhaseEncodingDirection": "j-" -> blip down
"PhaseEncodingDirection": "j" -> blip up

Apply to the func data

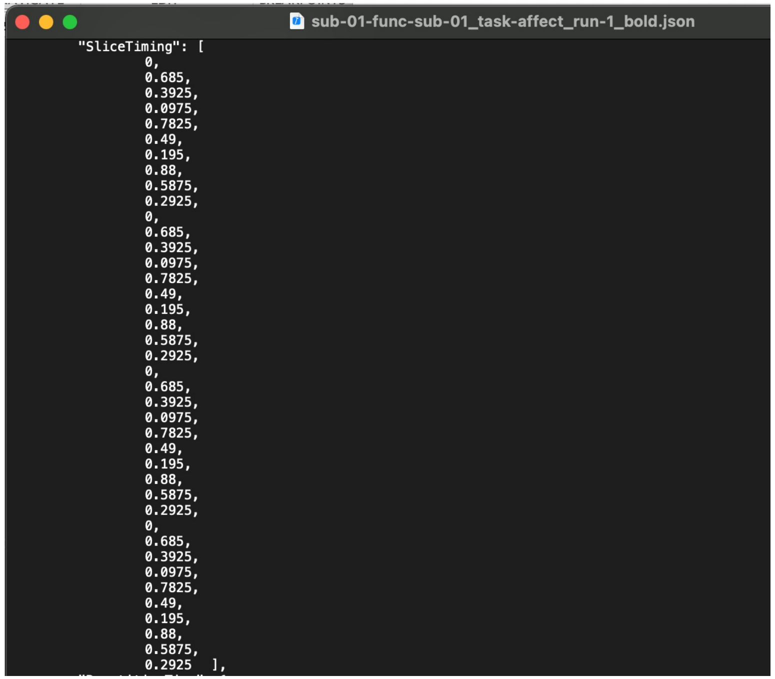


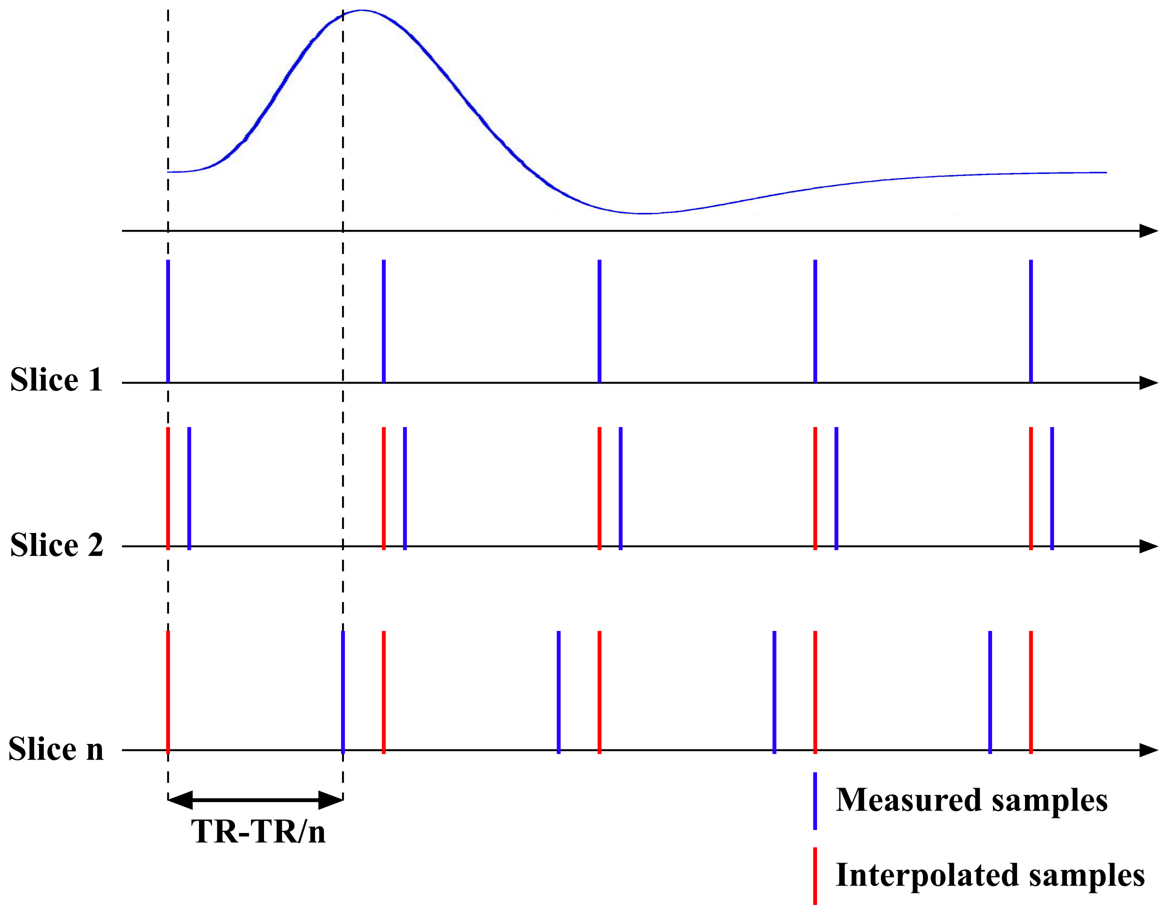
4. In the top Menus: select SPM -> Tools -> ACID Toolbox -> Pre-processing -> Choose HySCO options -> Write HySCO corrected images
5. Reference blip-up image: (using dependency) Coregister: Estimate & Resliced Images
6. Other blip-down images: (using dependency) Realign: Estimate & Reslice: Resliced Images (Sess 1)
7. Inhomogeneity field (or done for none): (Using dependency) HyCO: Inhomogeneity field



8. In the top Menus: select SPM -> Util -> 4D to 3D File Conversion
9. 4D Volume: (using dependency): Write HySCO corrected images: Unwarped Blip down images

Step 6: Slice time correction

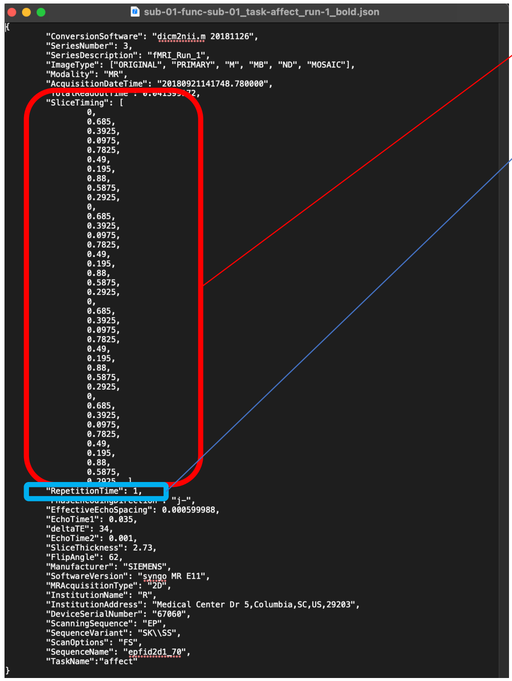

sub-01-func-sub-01_task-affect_run-1_bold.json
"SliceTiming": [
0,
0.685,
0.3925,
0.0975,
0.7825,
0.49,
0.195,
0.88,
0.5875,
0.2925,
0,
0.685,
0.3925,
0.0975,
0.7825,
0.49,
0.195,
0.88,
0.5875,
0.2925,
0,
0.685,
0.3925,
0.0975,
0.7825,
0.49,
0.195,
0.88,
0.5875,
0.2925,
0,
0.685,
0.3925,
0.0975,
0.7825,
0.49,
0.195,
0.88,
0.5875,
0.2925],



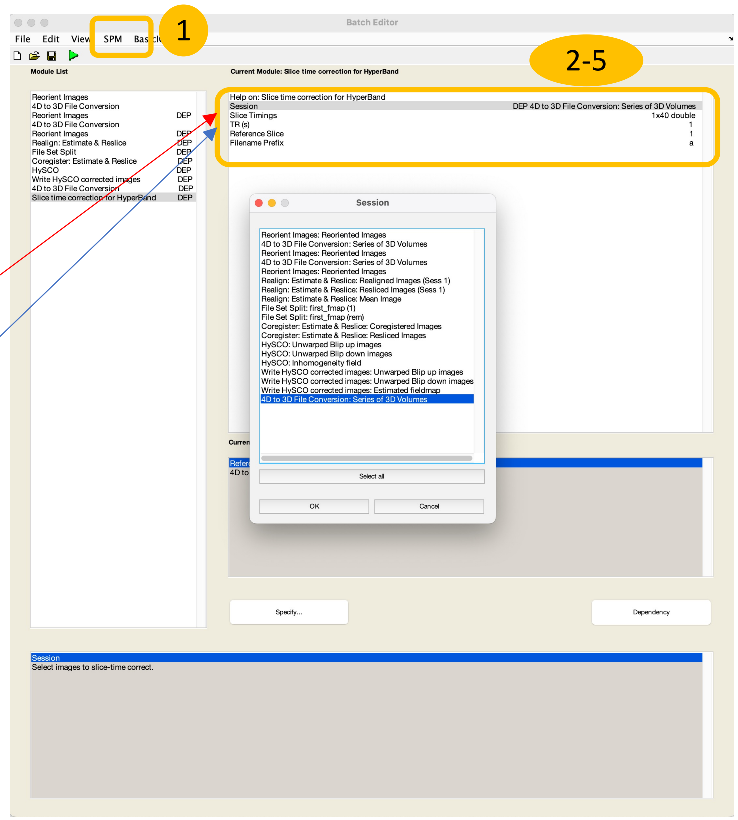
Step 6: Slice time correction

The standard slice time correction doesn't work for data scanned with HyperBand! Use my modified function*!

1. In the top Menus: select SPM -> Tools -> Multi echo & HyperBand -> Slice time correction for HyperBand
2. Session(using Dependency): Reoriented Images: 4D to 3D File Conversion: Series of 3D Volumes (from the previous step!)
3. Slice Timings: copy/paste the slice timings from the func.json file
4. TR (s): look up in the func.json file
5. Reference Slice: 1 (first slice)

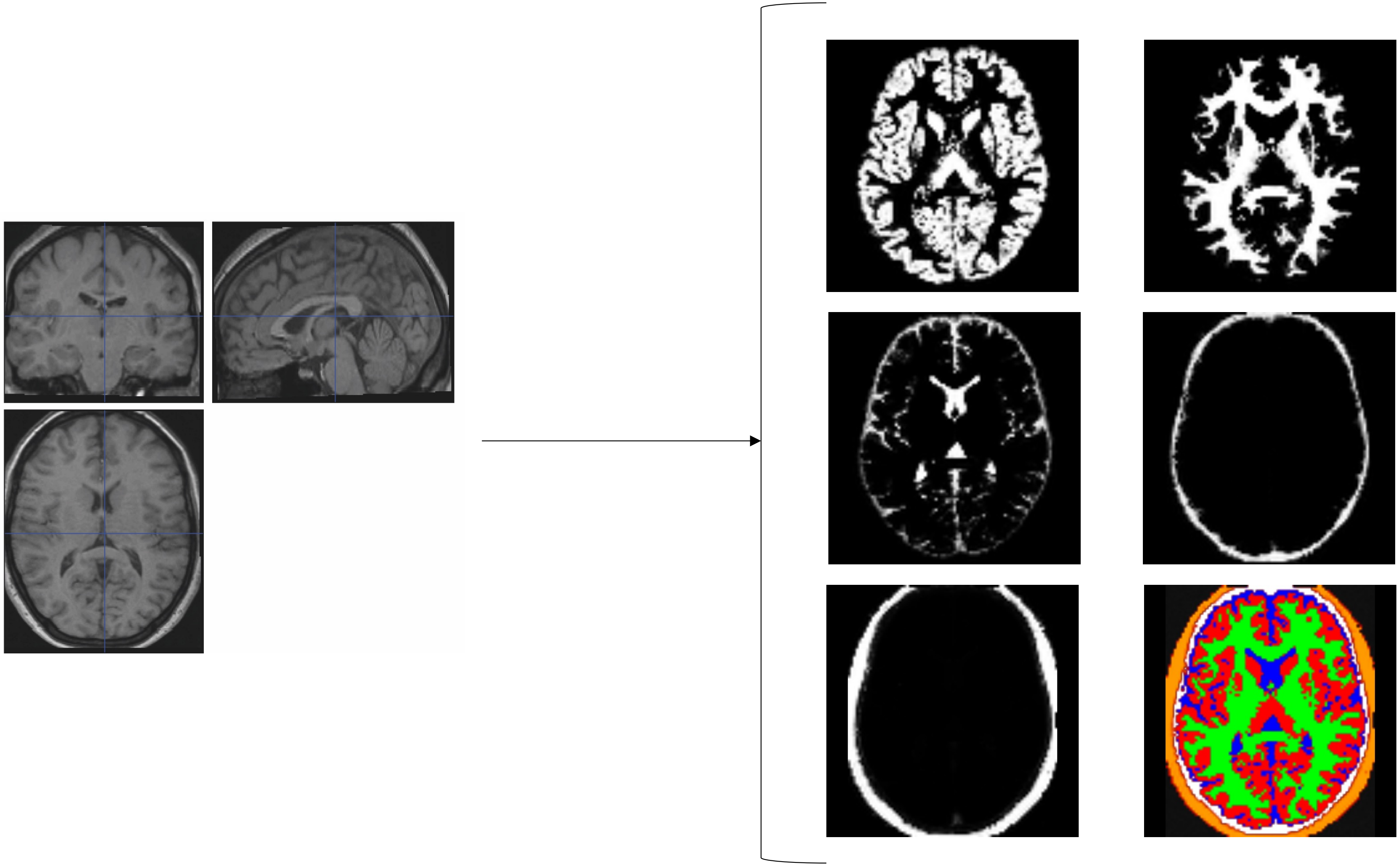

sub-01-func-sub-01_task-affect_run-1_bold.json

```
{
        "ConversionSoftware": "dicm2nii.m 20181126",
        "SeriesNumber": 3,
        "SeriesDescription": "fMRI_Run_1",
        "ImageType": ["ORIGINAL", "PRIMARY", "M", "MB", "ND", "MOSAIC"],
        "Modality": "MR",
        "AcquisitionDateTime": "20180921141748.780000",
        "SliceTiming": [
                0,
                0.685,
                0.3925,
                0.0975,
                0.7825,
                0.49,
                0.195,
                0.88,
                0.5875,
                0.2925,
                0,
                0.685,
                0.3925,
                0.0975,
                0.7825,
                0.49,
                0.195,
                0.88,
                0.5875,
                0.2925,
                0,
                0.685,
                0.3925,
                0.0975,
                0.7825,
                0.49,
                0.195,
                0.88,
                0.5875,
                0.2925,
                0,
                0.685,
                0.3925,
                0.0975,
                0.7825,
                0.49,
                0.195,
                0.88,
                0.5875,
                0.2925  ]
        "RepetitionTime": 1,
        "EffectiveEchoSpacing": 0.000599988,
        "EchoTime1": 0.035,
        "deltaTE": 34,
        "EchoTime2": 0.001,
        "SliceThickness": 2.73,
        "FlipAngle": 62,
        "Manufacturer": "SIEMENS",
        "SoftwareVersion": "syngo MR E11",
        "MRAcquisitionType": "2D",
        "InstitutionName": "R",
        "InstitutionAddress": "Medical Center Dr 5,Columbia,SC,US,29203",
        "DeviceSerialNumber": "67060",
        "ScanningSequence": "EP",
        "SequenceVariant": "SK\\SS",
        "ScanOptions": "FS",
        "SequenceName": "epfid2d1_70",
        "TaskName":"affect"
}
```



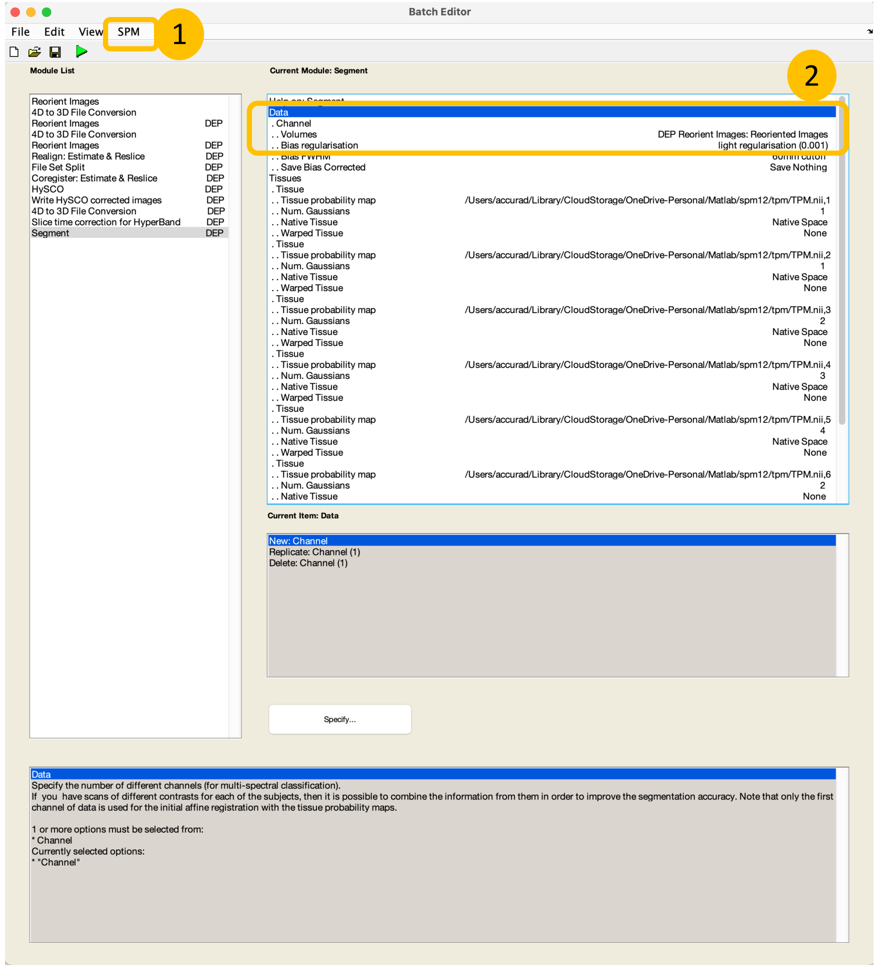
* Code available at https://github.com/P-VS/MEHBfMRI

Step 7: Segmentation

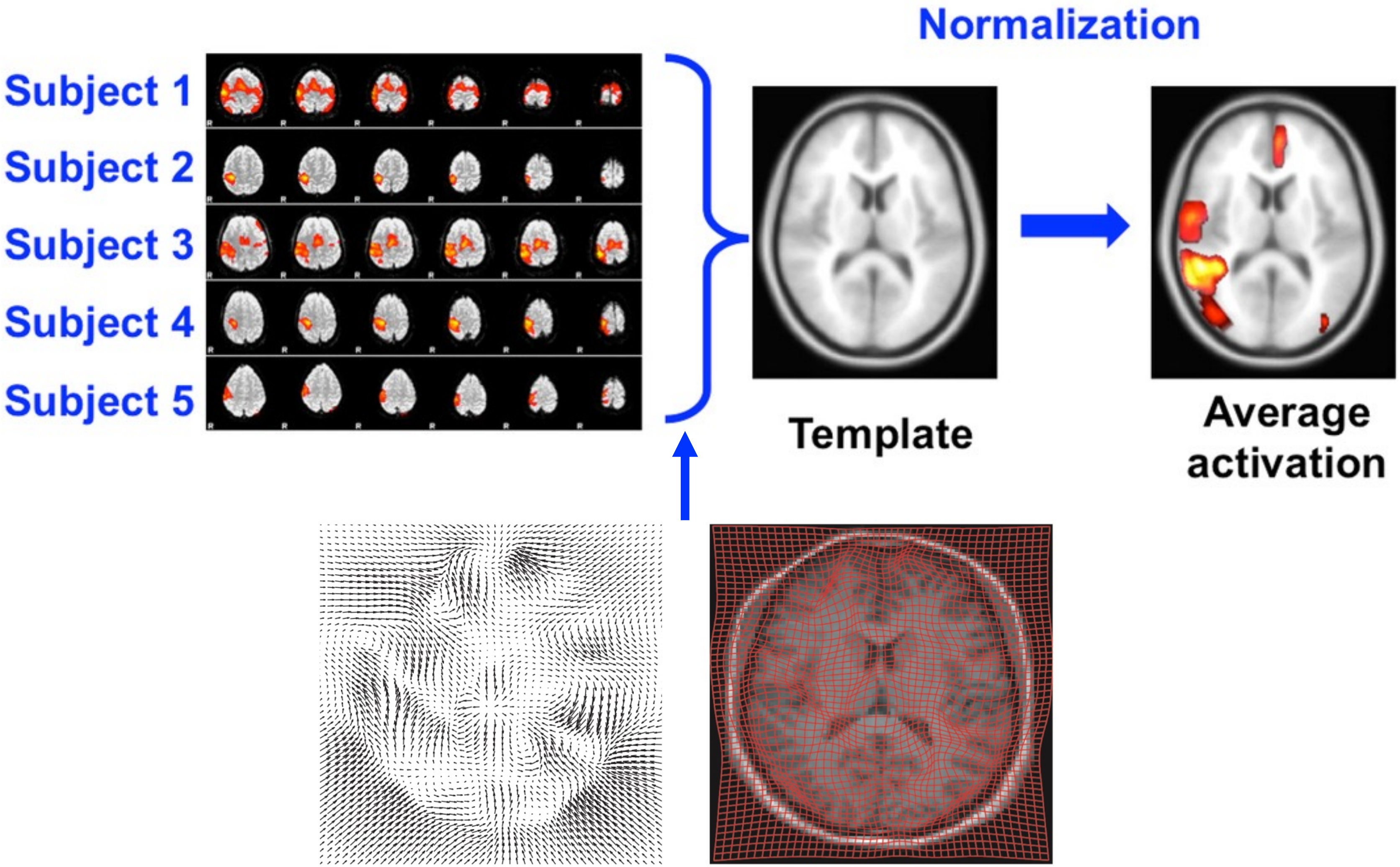


Step 7: Segmentation

1. In the top Menus: select SPM -> Spatial -> Segment
2. Volumes (using Dependency): Reorient Images: Reoriented Images (from the anatomical scan)

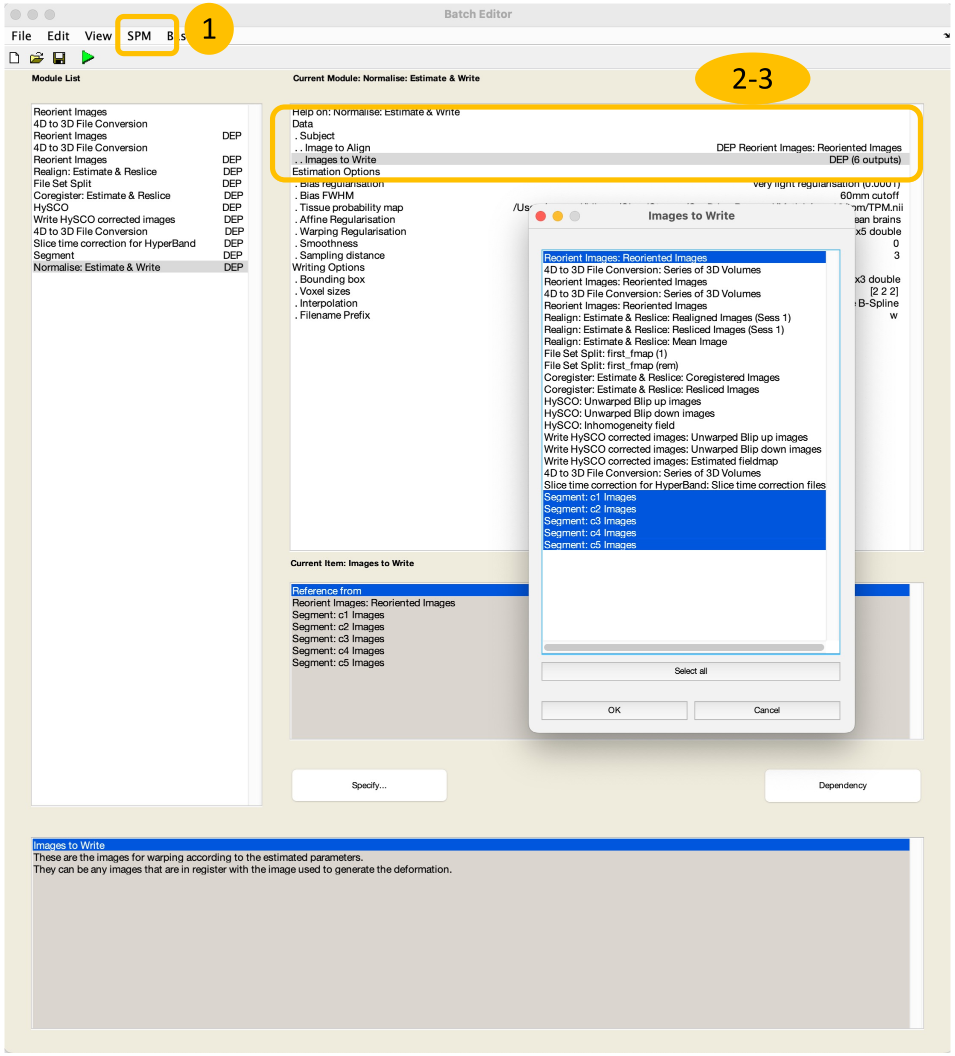


Step 8: Normalization

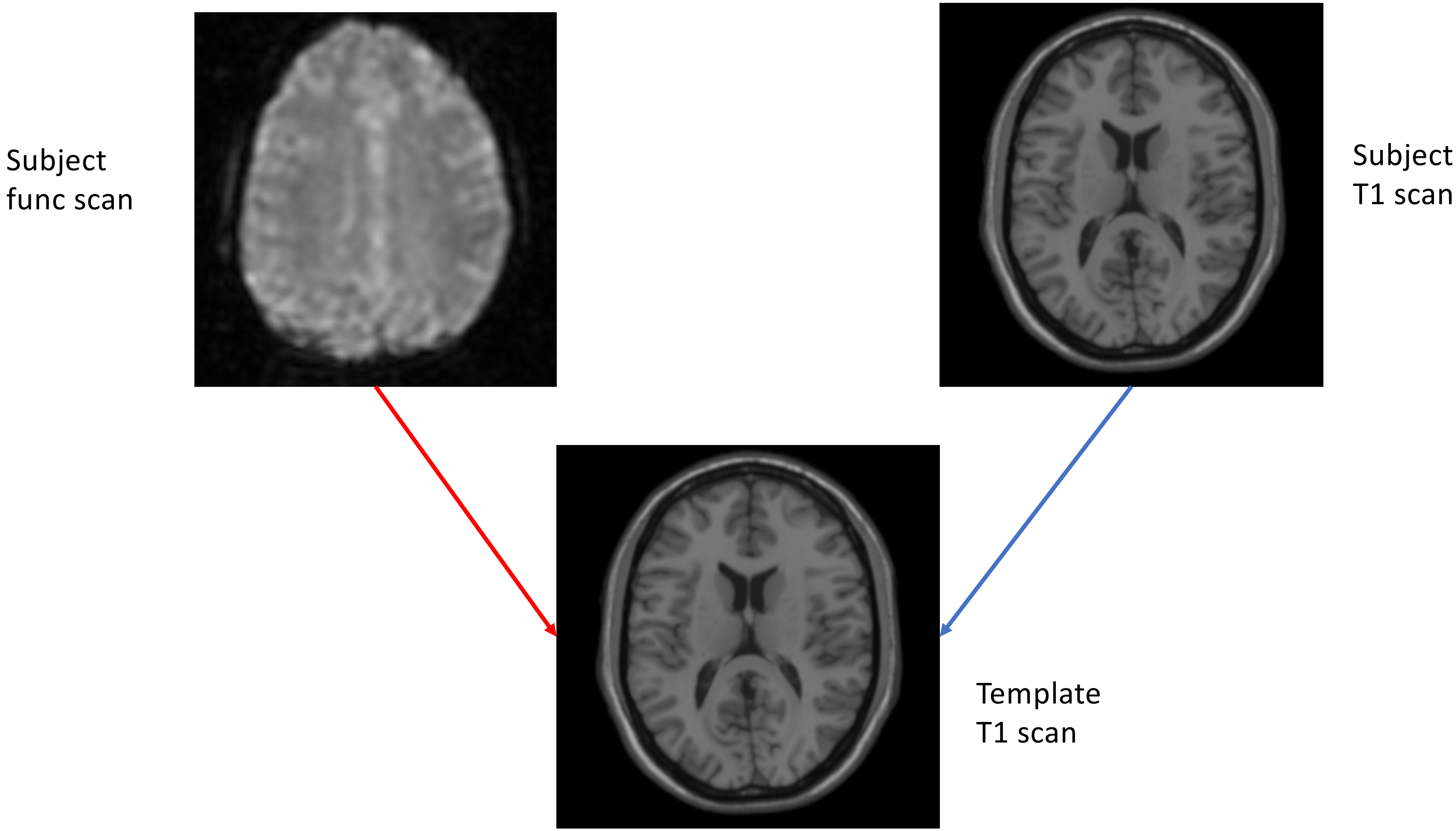


Step 8: Normalization: The anatomical scan and segmentation maps

1. In the top Menus: select SPM -> Spatial -> Normalise -> Normalise: Estimate & Write
2. Image to align: (using Dependency) Reorient Images: Reoriented Images (from anat scan!)
3. Images to write: (using Dependency) Reorient Images: Reoriented Images (from anat scan!) + Segment: c1 – c5 Images

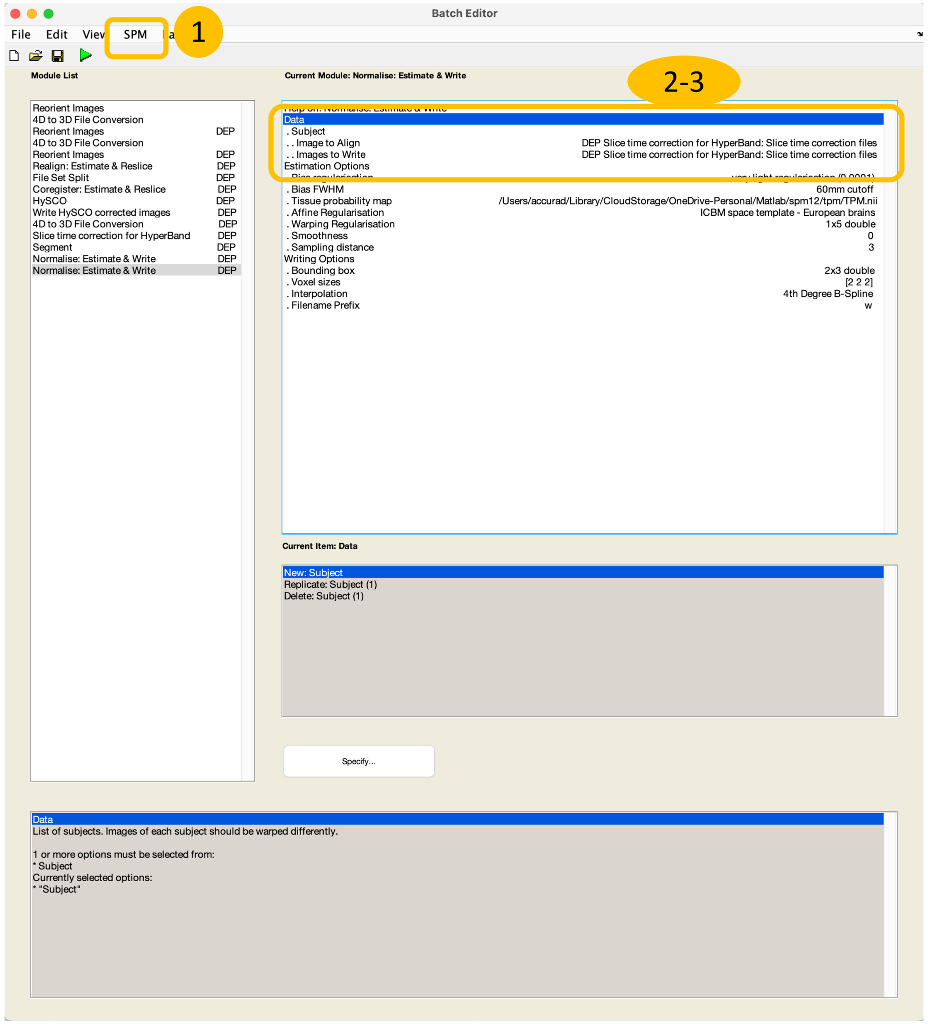


Step 8: Normalization: The fMRI scan

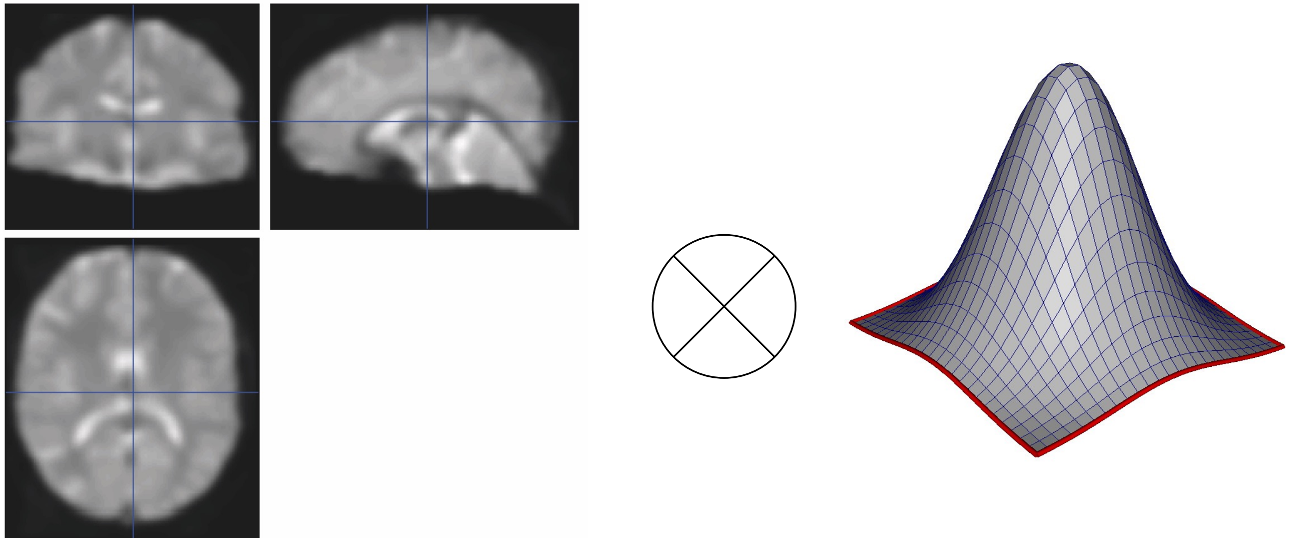


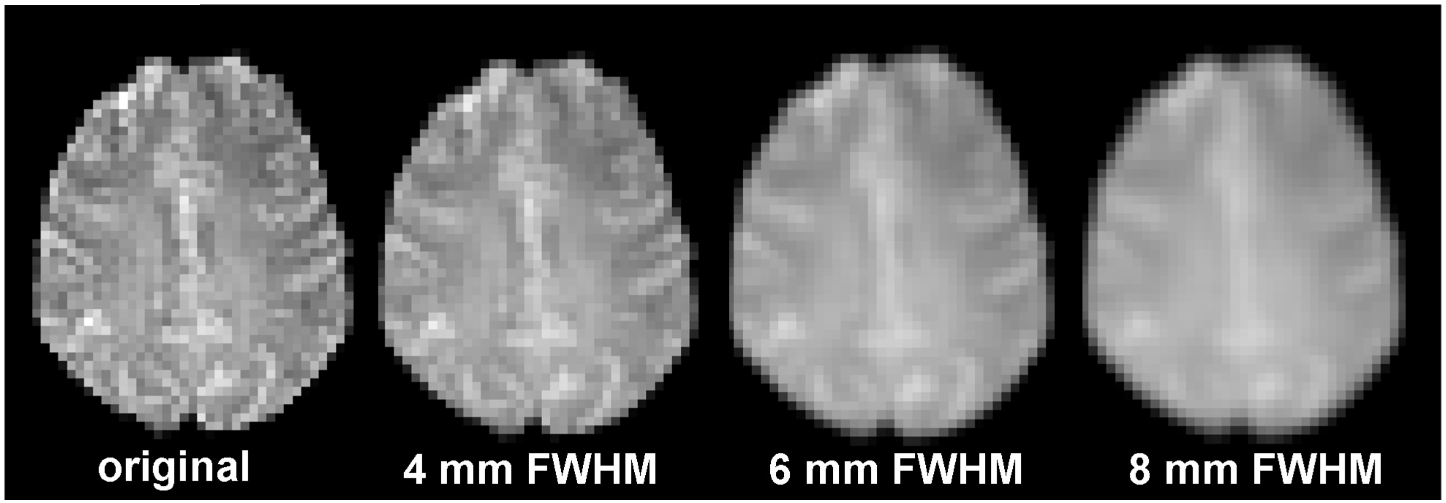
Step 8: Normalization: The fMRI data

1. In the top Menus: select SPM -> Spatial -> Normalise -> Normalise: Estimate & Write
2. Images to align: (using Dependency) Slice time correction for GyperBand: Slice time correction files
3. Images to write: (using Dependency) Slice time correction for GyperBand: Slice time correction files



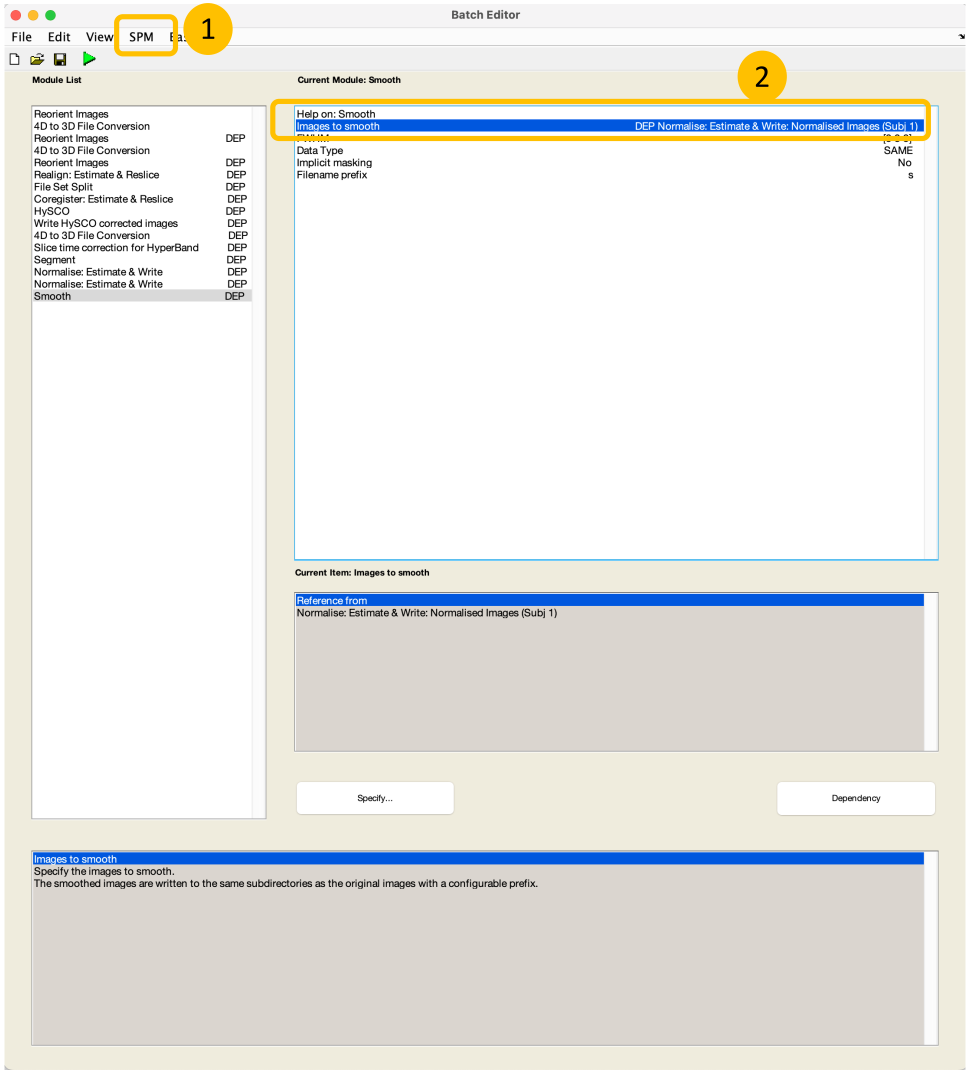
Step 9: Smoothing





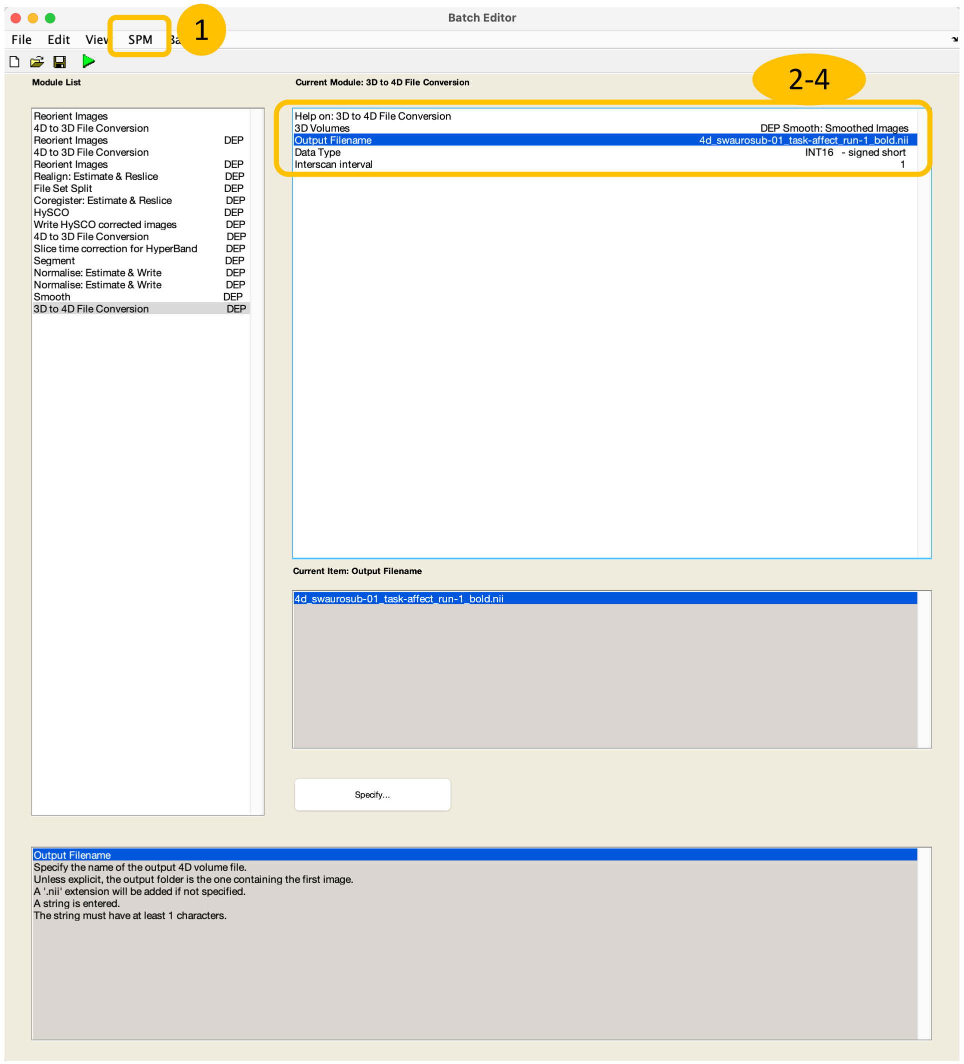
Step 9: Smoothing

1. In the top Menus: select SPM -> Spatial -> Smooth
2. Images to smooth: (using Dependency) Normalise: Estimate & Write: Normalised Images (Subj 1)



Step 10: Converting the result to a 4D nifti file

1. In the top Menus: select SPM -> Util -> 3D to 4D File Conversion
2. 3D Volume: (using dependency): Smooth: Smoothed Images
3. Output Filename: 4d_swaurosub-01_task-affect-run-1_bold.nii
4. Interscan interval: should be the TR (look up in the func.json file)

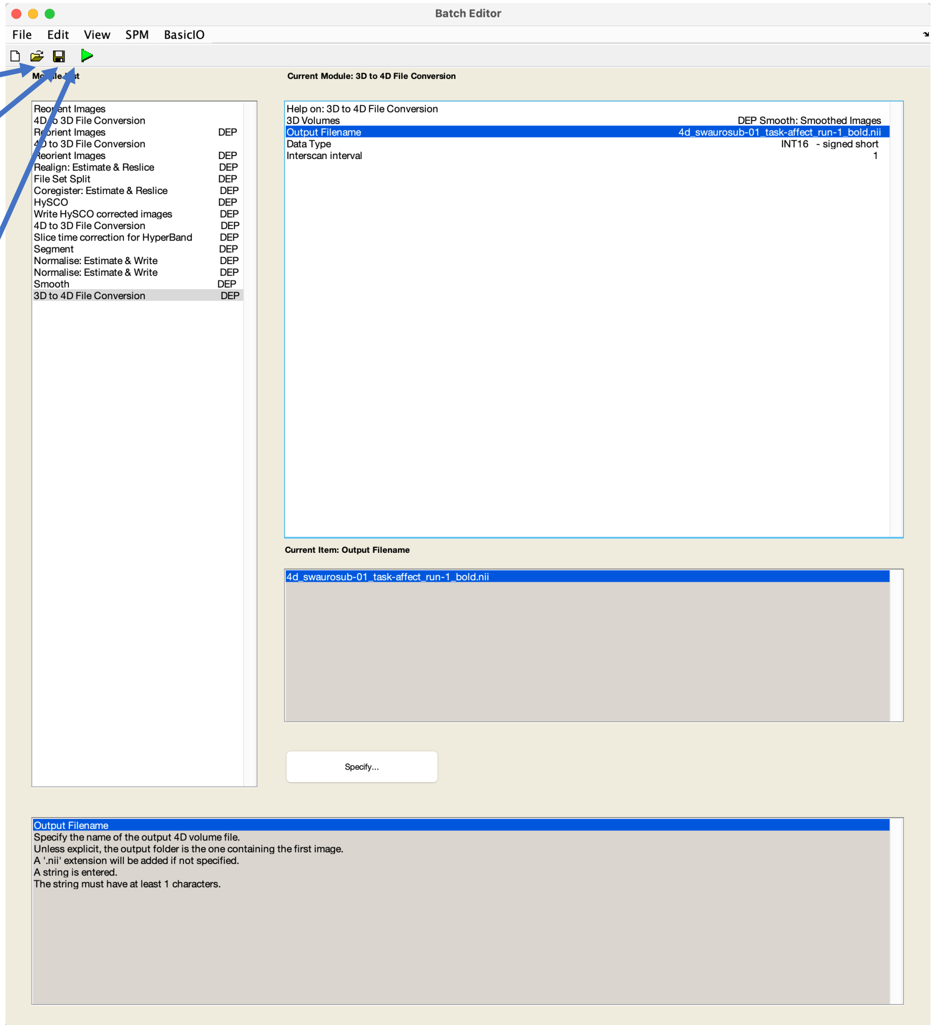


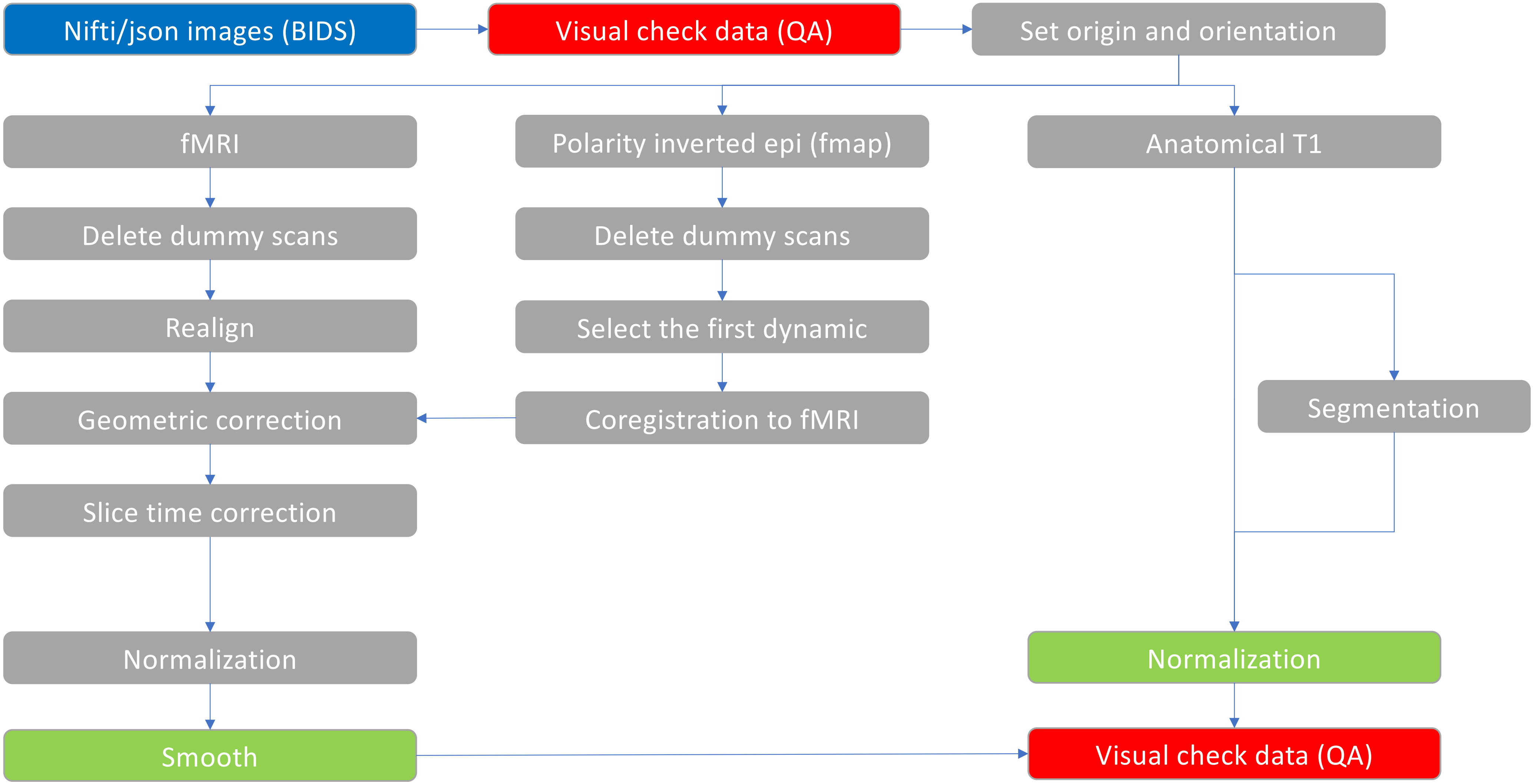
Run the batch (at home)

Load a saved BATCH file

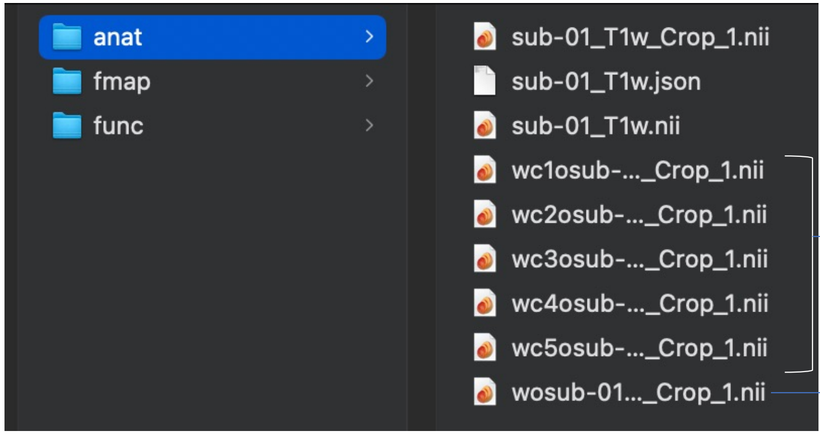
Save the BATCH as a file

Run the BATCH



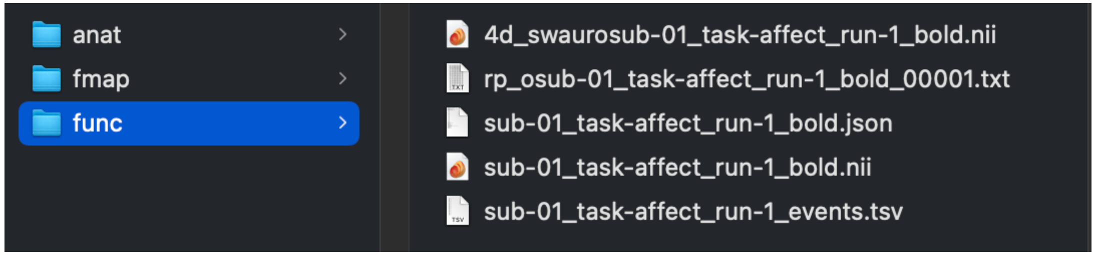

Nifti/json images (BIDS)
Visual check data (QA)
Set origin and orientation
fMRI
Polarity inverted epi (fmap)
Anatomical T1
Delete dummy scans
Delete dummy scans
Realign
Select the first dynamic
Geometric correction
Coregistration to fMRI
Segmentation
Slice time correction
Normalization
Normalization
Smooth
Visual check data (QA)

Cleaning up the results



The normalized segmentation maps

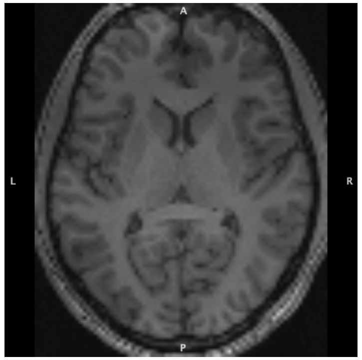
The normalized anatomical scan



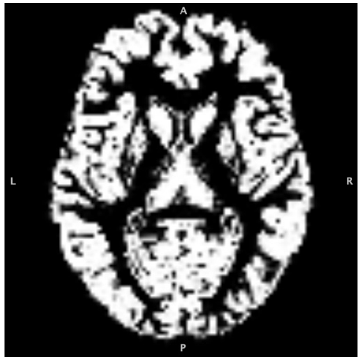
The preprocessed fMRI scan

The realignment parameters

The preprocessing results

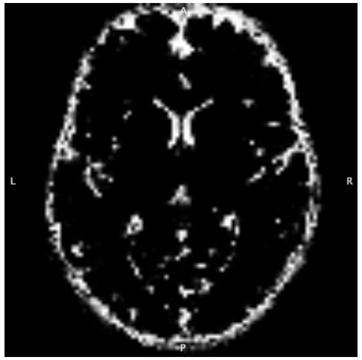


wosub-01_T1w

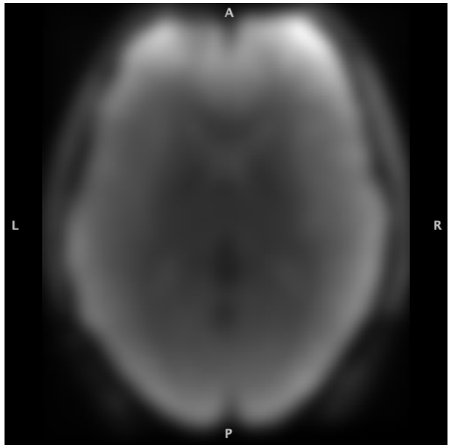


wc1osub-01_T1w

wc2osub-01_T1w



wc3osub-01_T1w



4d_swuraosub-01_task-affect-run-1_bold.nii

rp_aosub-01_task-affect_run-1_bold_00001.txt

Trans x	Trans y	Trans z	Rot x	Rot y	Rot z
0.0000000e+00	-4.7340067e-16	0.0000000e+00	0.0000000e+00	0.0000000e+00	1.2588970e-17
1.7513722e-02	-6.7856195e-03	6.0396937e-03	4.4362332e-04	-1.0208815e-04	3.4466021e-04
4.8461260e-02	-3.7386199e-02	6.2362634e-02	1.4502508e-03	-4.0640802e-04	9.5685461e-04
6.9180189e-02	-3.9071672e-02	6.4310601e-02	1.3979599e-03	-3.5460454e-04	1.4147925e-03
5.2091583e-02	3.2066219e-02	7.7718133e-02	4.3498257e-04	-9.9844301e-05	8.9267421e-04
5.7427248e-02	1.6258788e-02	7.6479140e-02	7.0090674e-04	1.6059046e-04	7.9906206e-04
8.6317280e-02	-3.5120548e-02	7.2283943e-02	1.3903804e-03	-2.0507305e-05	1.3339970e-03
1.1731055e-01	-3.0335500e-02	6.3979068e-02	1.7311331e-03	-1.9270127e-04	1.7468015e-03
8.0937031e-02	5.0152872e-02	9.1561197e-02	6.9045654e-04	2.2436062e-04	1.1304025e-03
6.3606665e-02	3.5731932e-02	7.7646949e-02	5.5901698e-04	1.8457663e-04	8.6840523e-04
5.2421874e-02	-1.0953733e-02	1.0717907e-01	9.7029852e-04	-6.1821191e-05	1.0495726e-03
7.4589833e-02	-4.0247471e-04	1.2320963e-01	7.9186069e-04	1.8275389e-05	1.1582123e-03
1.0715947e-01	-5.0387869e-02	1.0422207e-01	7.6870931e-04	-7.4170782e-05	1.4709182e-03
1.4121567e-01	-7.7419048e-02	1.3071721e-01	1.4501688e-03	-3.1955366e-04	1.8303812e-03
1.7744815e-01	-6.8792732e-02	5.1087038e-03	8.2285381e-04	-7.5366066e-05	2.0172927e-03
1.2917189e-01	1.7510493e-02	5.8319505e-02	-2.8877083e-06	-1.3831180e-05	1.5282397e-03
1.3561558e-01	3.8867613e-03	8.8903376e-02	6.1257401e-04	-2.0483346e-04	1.6858282e-03

Realignment parameters

DANK U - THANK YOU

Universitair
Ziekenhuis
Brussel