

A clinical and research 3T MRI protocol under 30 minutes

(Yes, it's possible!)

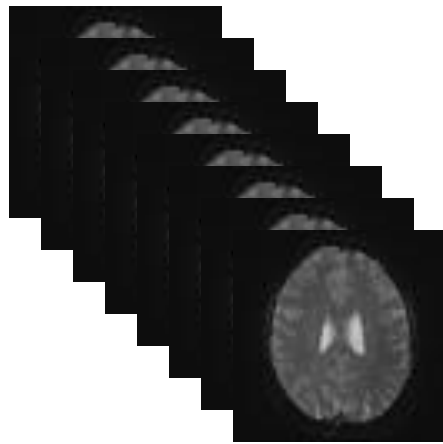
SK Larroque, M Carrière, C Martial, S Laureys
github.com/LRQ3000/mri_protocol



Coma Science Group
GIGA Consciousness
University & Hospital of
Liège, Belgium

CME 2019
Dortmund, September 23th 2019

What we do: MRI analyses



fMRI timeseries
(one per subject)



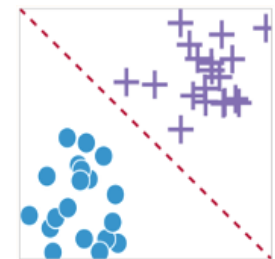
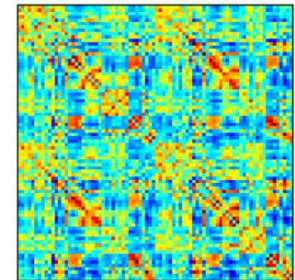
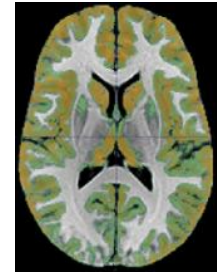
Preprocessing
(SPM12)



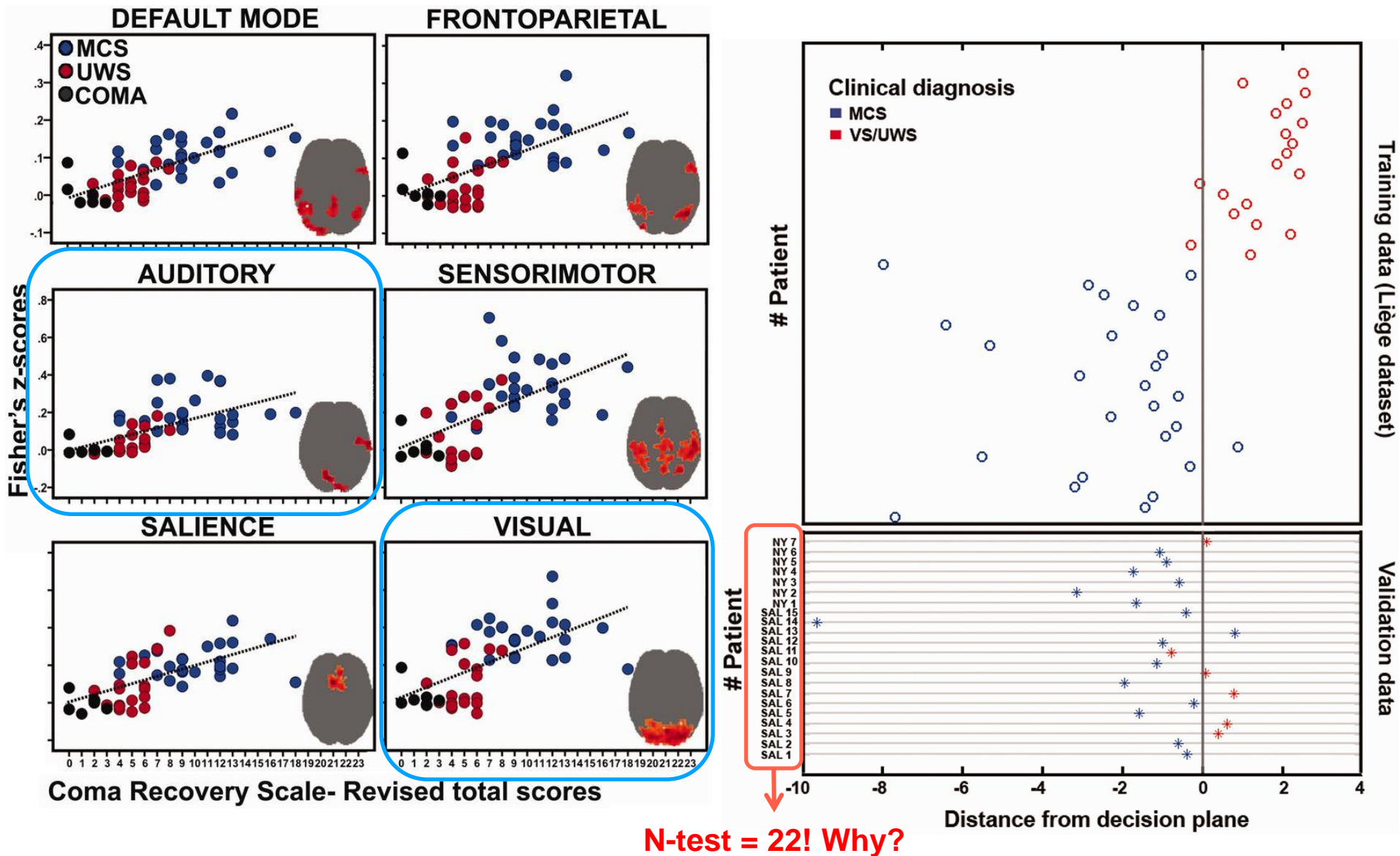
Analysis
(CONN)



Machine
learning
(SVM)



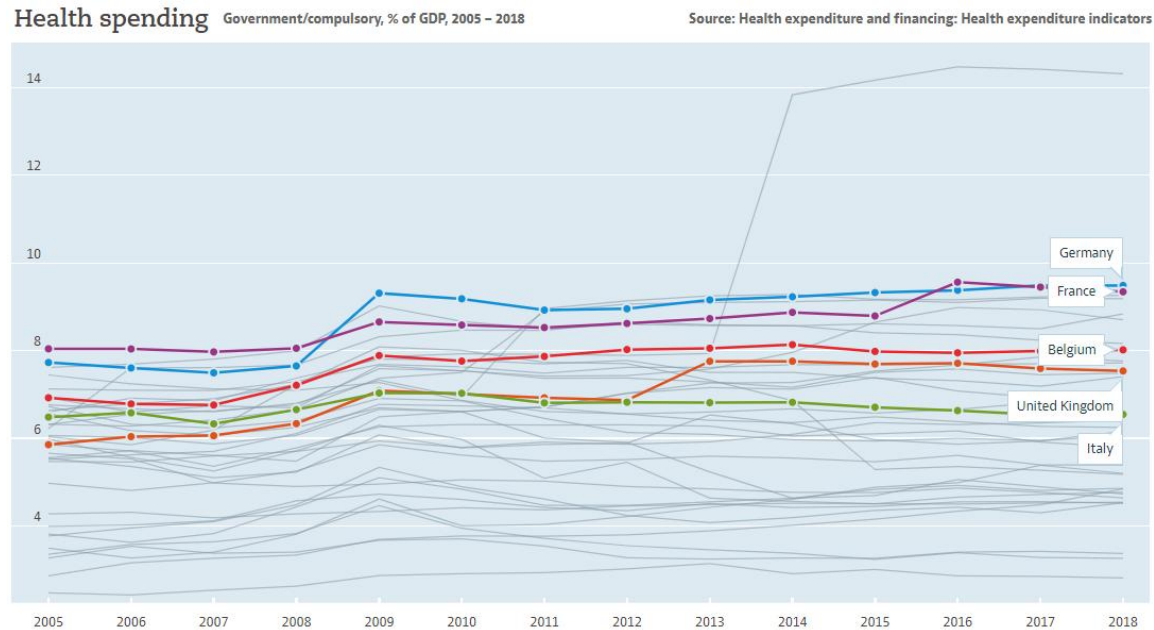
What we do: MRI analyses



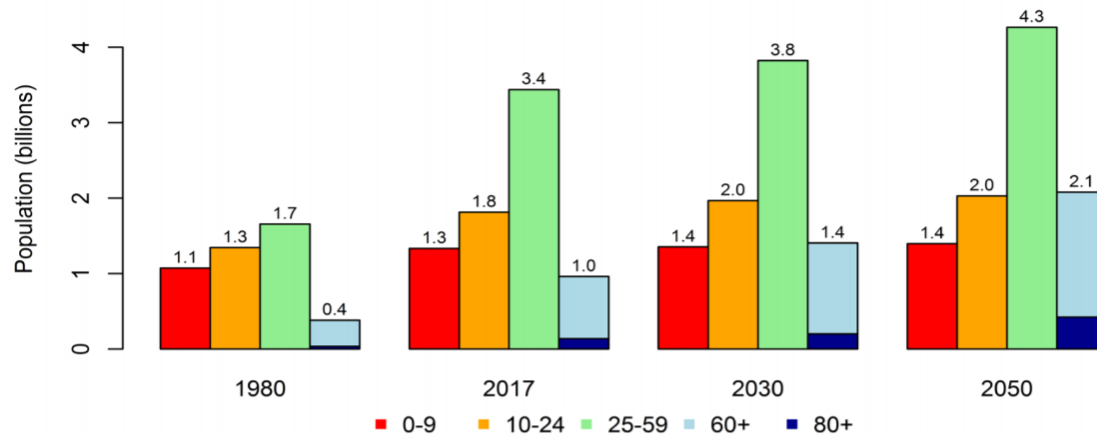
Limitations to sample size



1. Time & Cost



Global population by broad age group, in 1980, 2017, 2030 and 2050



Fee-for-service,
Diagnosis-related-
group payment^[4]

Limitations to sample size



1. Time
& Cost



Healthy volunteers: compliant, cognitively autonomous

2. Motion
& Sedation



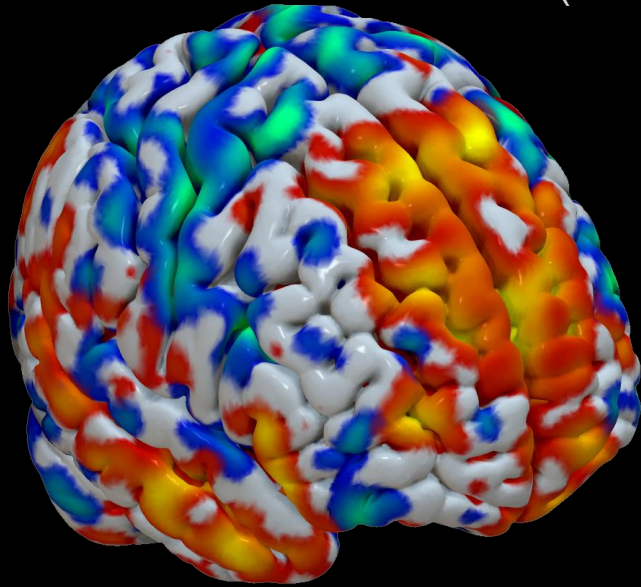
Patients: uncontrolling or non-compliant, discomfort, monitoring vital parameters

	Admitted	With MRI	Analyzable	Non-sedated
Over 10 years (%):	676 (100%)	465 (69%)	256 (38%)	~110 (16%)

→ Overcome limitations by optimizing acquisition?

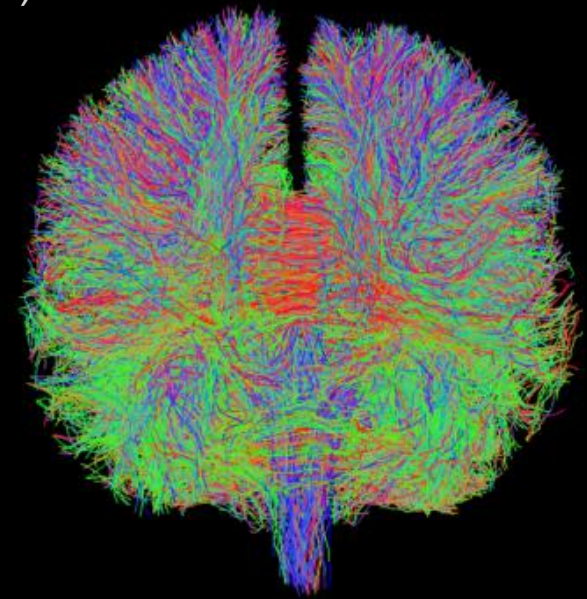
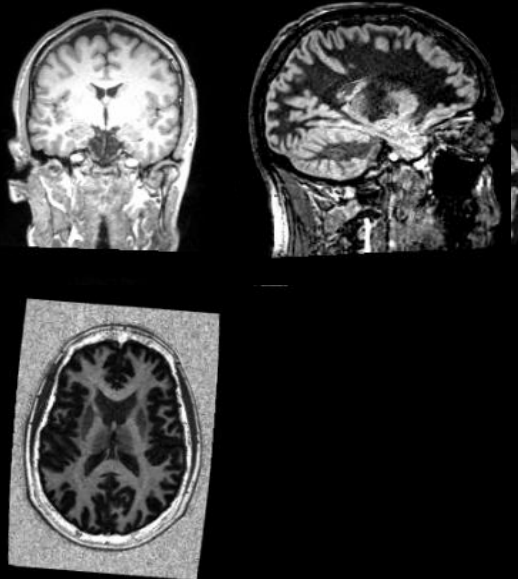
A 30 min cutting-edge, motion-resilient MRI protocol

(20-channel coil, 3T Siemens Vida)



Sub-second BOLD
TR 728ms
500 vols in 6:13

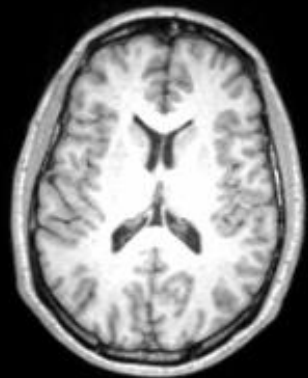
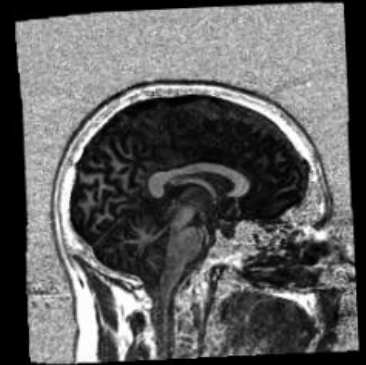
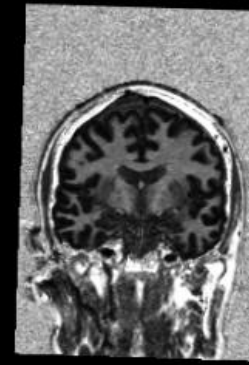
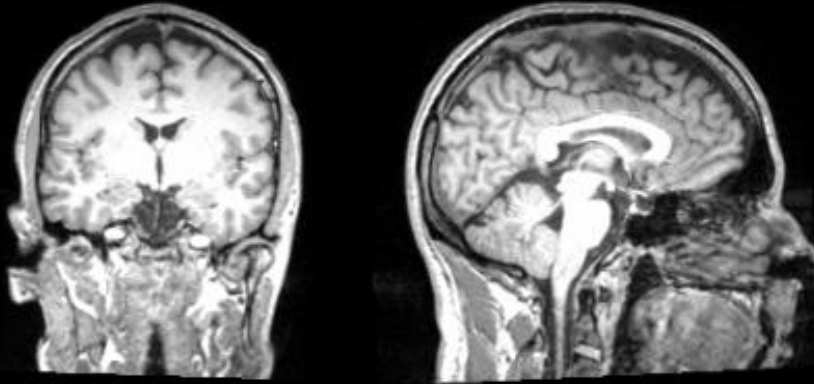
T1 FLAWS
5:02



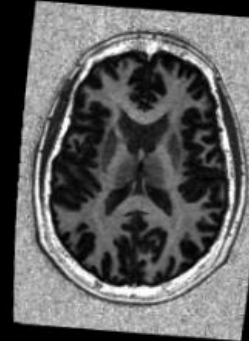
3-shells DWI
13:25

N=35 (8 test controls, 10 stable controls, 17 patients)

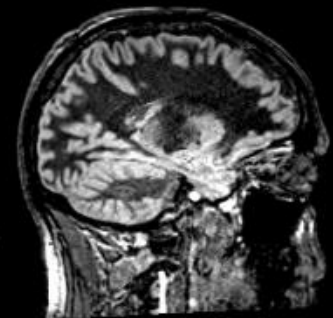
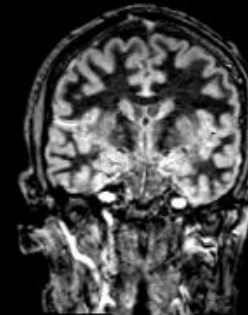
T1 FLAWS^[1] produces simultaneously:



MPRAGE
(inv2)
(structural, 1mm³ iso)

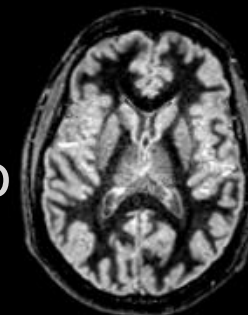


White Matter
(uni)



→ Physiological segmentation:

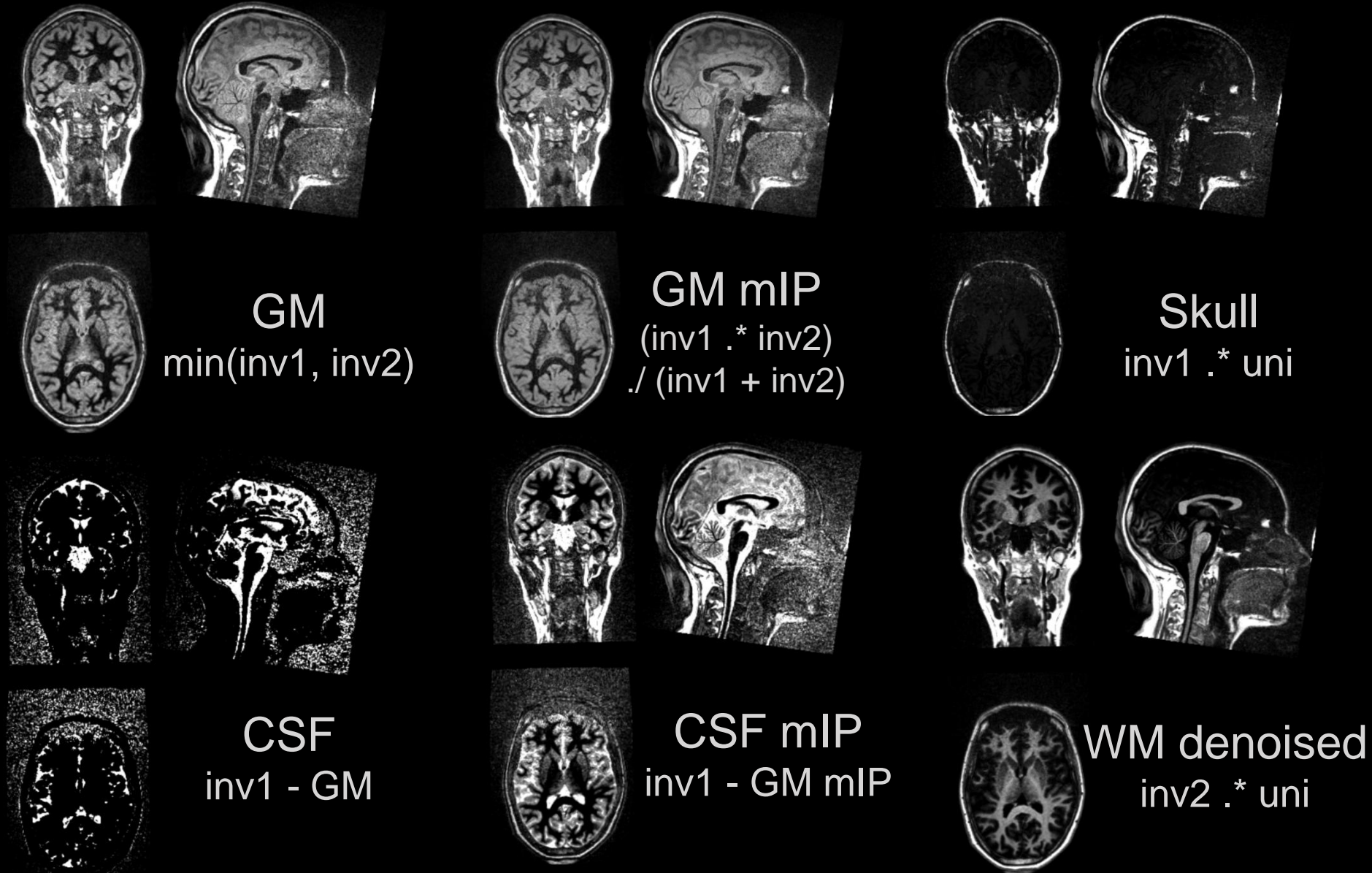
- No approximation (not computational!)
- In subject-space
- Always coregistered (even with motion)
- All in 5 min (on 3T), voxel size: 1mm iso
- More clinical infos (complement FLAIR)



Grey Matter
(inv1)

Our T1 FLAWS enhancements:

(see also alternatives in ^[1])



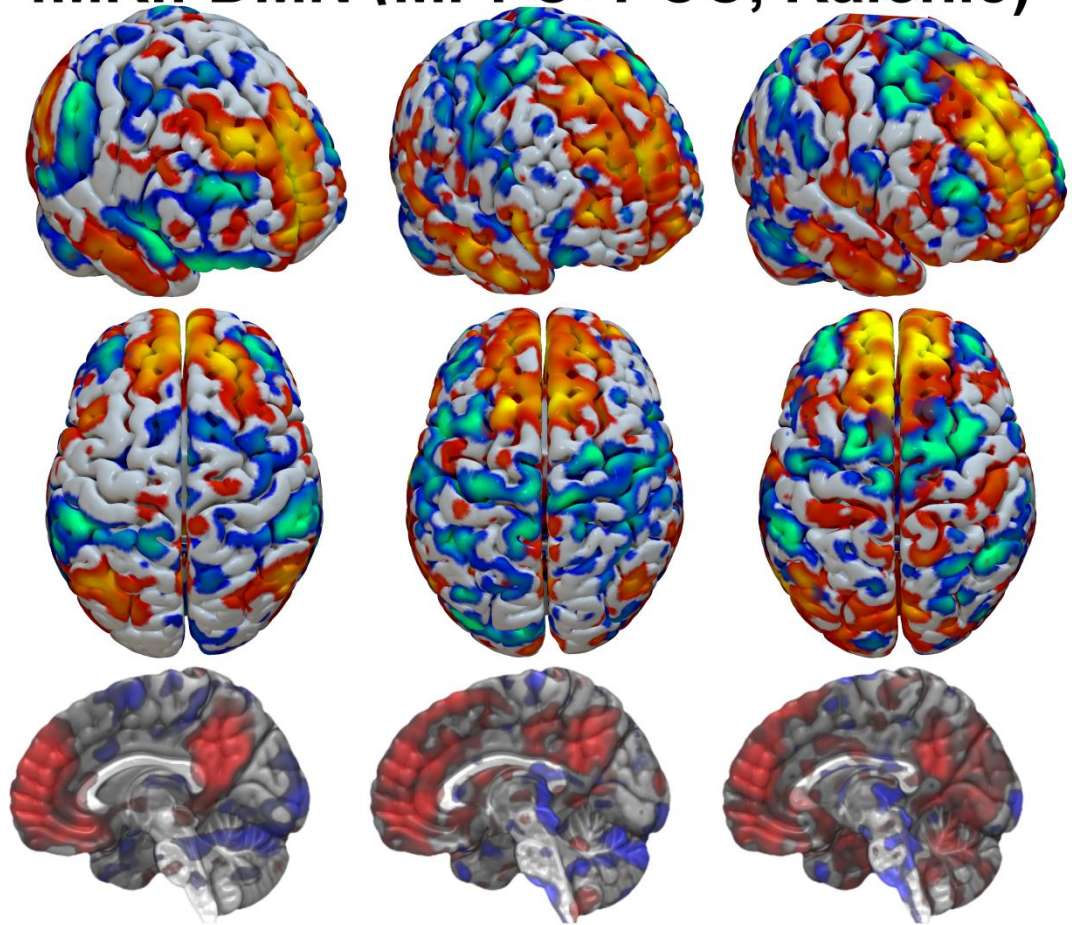
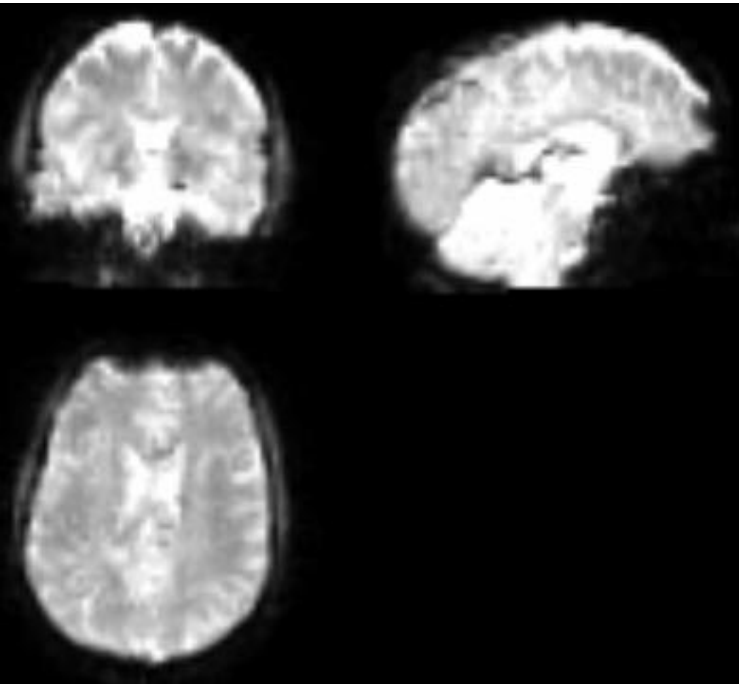
[1] Wang, Y., Wang, Y., Zhang, Z., Xiong, Y., Zhang, Q., Yuan, C., & Guo, H. (2018). Segmentation of gray matter, white matter, and CSF with fluid and white matter suppression using MP2RAGE. *Journal of Magnetic Resonance Imaging*.

Sub-second EPI Bold fMRI

(728 ms, SMS x3, PI x2, 3mm³ iso)



First-level seed-based
fMRI: DMN (MPFC+PCC, Raichle)



- Dynamic connectivity
- Bypass HRF (<1.5s)
- Motion resilient

OLD MRI

300 vols (10:00)

TR: 2s

NEW MRI

300 vols (3:47)

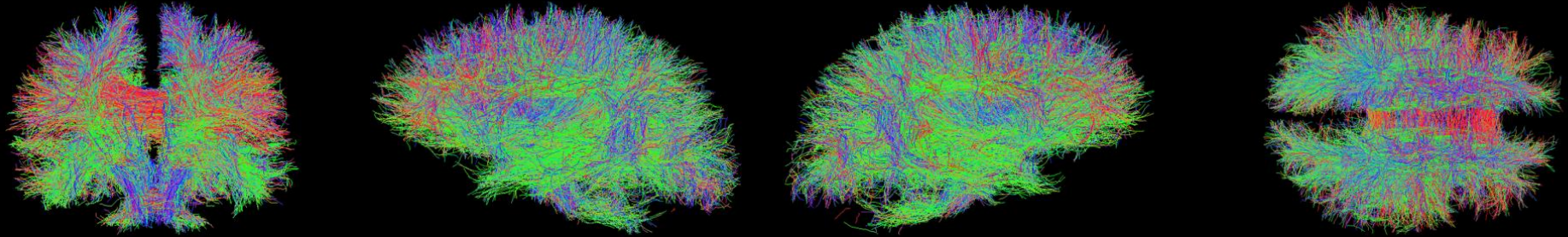
TR: 728ms

NEW MRI

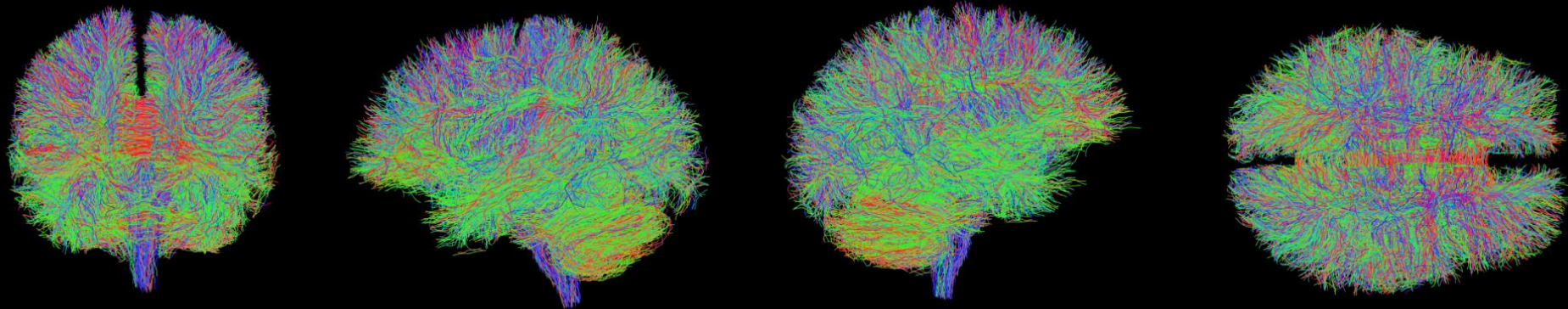
500 vols (6:13)

TR: 728ms

OLD MACHINE DTI (SINGLE-SHELL B1000, WITH ACT)



NEW MACHINE DTI (MULTI-SHELL 3-SHELLS, NO ACT)^[1]



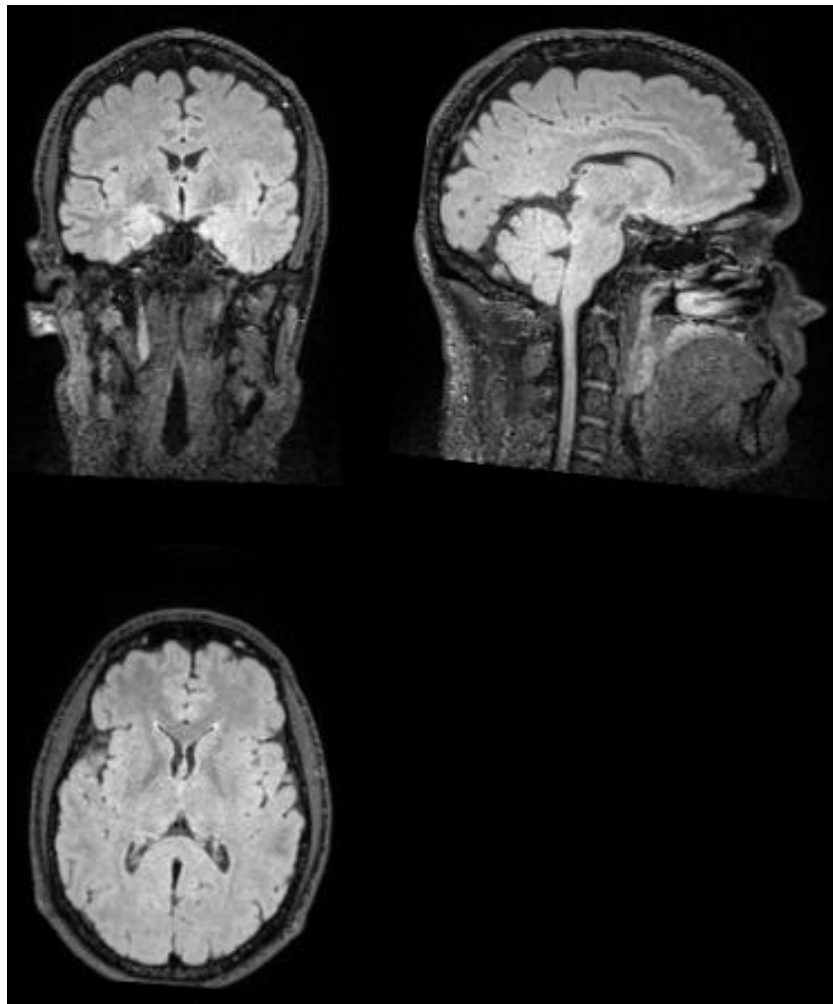
Optimizations:

- 3 shells: b700 30dir, b1000 64dir, b2000 64dir.
- b1000 is high quality (small TE), others: higher TE → faster TR.
- SMS x4.
- Partial fourier 7/8 (warning: prevents mrdegibbs!)

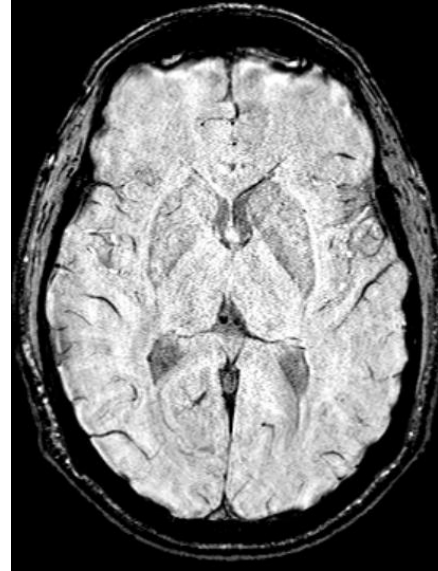
Great for:

- Clinical tissue assessment under varying diffusion bvals
- Worst case: degrades to single-shell
- Standalone (structural unnecessary)

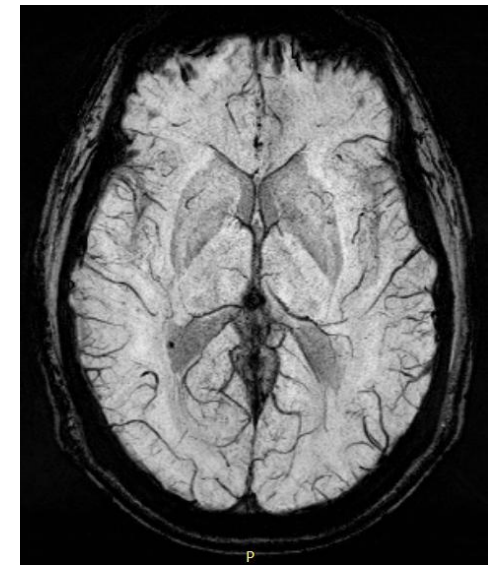
Clinical sequences: FLAIR, SWI, T2, ASL



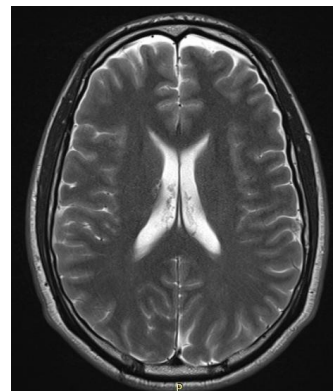
FLAIR
3:12, 1mm³



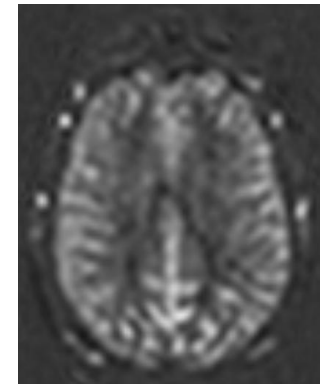
SWI
3:57, 0.6x0.6x2mm³



SWI/mIP



T2-TSE
1:21, 0.4x0.4x4.0mm³



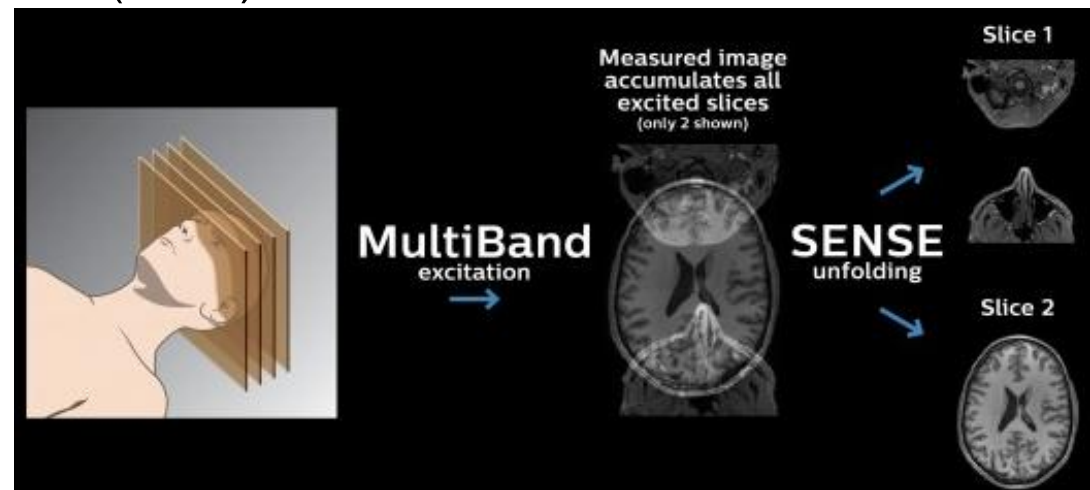
PC-ASL
2:17, 3mm³

How did we make it?



1) Technological optimizations:

- Modern **acceleration**:
GRAPPA + multiband (SMS)^[1]

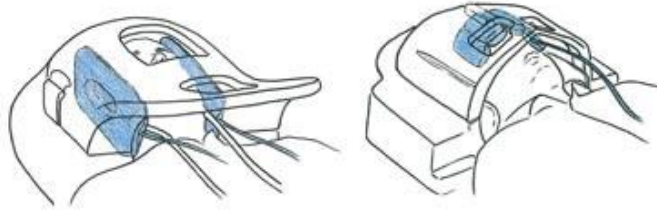


- Literature
MP2RAGE FLAWS, multi-shell DTI, multi-band BOLD
- Fine-tuning: calculations + **trial-and-error**
BOLD flip angle, time of inversion, bandwidth, filters, ...

How did we make it? - 2



2) Meta-protocol optimizations:

- Protocol programming:
 - › **Maximize speed** (motion resilience, avoids sedation & reacquisitions)
 - › Acquire BOLD first (unlikely sedated)
 - › Conditional naming
- Physical devices:
 - › **Head immobilizer**
 - 

(here: Pearltec MultiPad)
 - › Comfort pillows (reduces back pain), blanket, etc.



Take home message



- ▶ Cutting-edge research MRI under clinical constraints possible
- ▶ Quality-speed trade-off can be an opportunity
- ▶ **New analyses opportunities** in clinical populations
(dynamic connectivity, multi-tissues unconstrained DTI, ...)
- ▶ **Reduce risks** & ethical issues by **avoiding sedation**
- ▶ Future: compressed sensing, quantitative MRI, thermoplastic mask^[1], AI reconstruction

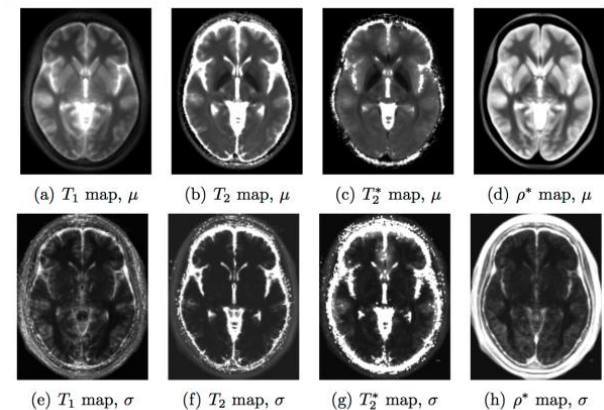


Figure: Mean and standard deviation templates of the T_1 , T_2 , T_2^* and ρ^* maps

- Full protocol for Siemens Vida (need SMS license)
& bibliography: github.com/lrq3000/neuro_slides/cme2019

Thank you for your attention!

github.com/LRQ3000/mri_protocol

Basic analysis scripts: github.com/LRQ3000/csg_mri_pipelines

Huge thanks to Jean-Marc Léonard
at Siemens Healthineers, Nathalie
Maquet and the Liège Hospital's
radiology department team and
Pearltec for their support!

Bonus slides

MRI: the time-quality conundrum



- ▶ Great polyvalence, for both research and clinical purposes
- ▶ **Wide array** of imaging contrasts: structural/function anatomy/connectivity, blood flow, lesions, etc.
- ▶ But clinical vs research needs are different:
 - **Limited acquisition time** (30 to 60 min) vs virtually unlimited (2h+)
 - Clinical pertinence (eg, lesions) vs **cutting-edge** (multi-shell DTI)
 - Uncooperative/uncontrolling patients (**motion, discomfort**, panic!) vs healthy volunteers (instruction compliance, no motion, calm)
- ▶ Usually results in a compromise: most sequences are clinical, some are for research with sub-optimal outdated (but faster) parameters

→ Can we make a MRI protocol both with cutting-edge research sequences and under clinical constraints?

How did we make it?



1) Technological optimization:

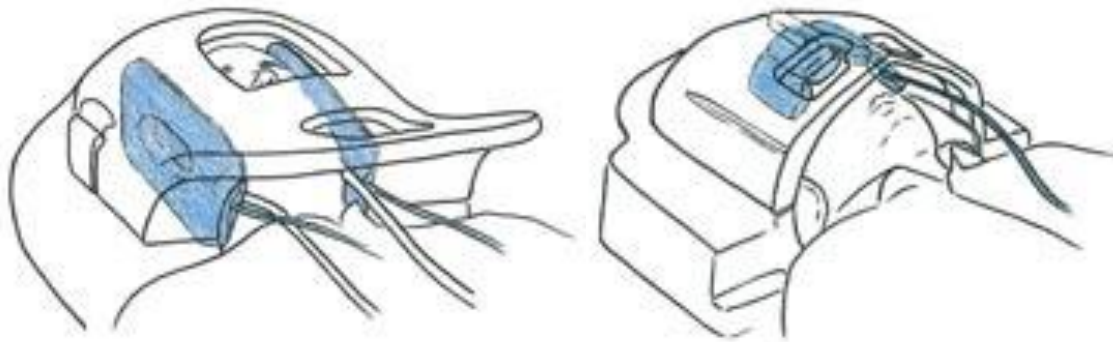
- Modern **acceleration** technologies:
GRAPPA parallel imaging + simultaneous multi-slice (SMS aka multi-band).
Beware of speed-quality trade-off!
- Literature for base sequences (MP2RAGE, FLAWS, multi-shell DTI, multi-band BOLD)
- Calculations + **trial-and-error** to fine-tune parameters (BOLD flip angle, time of inversion, bandwidth)



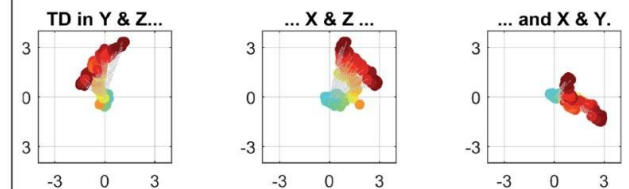
2) Meta-protocol optimization:

- Careful protocol programming:
 - › Maximize speed of sequence acquisition
(reduces risk of motion and need for sedation)
 - › Place BOLD first, structural/rest after
(ensures patient is awake, less distressed, always guarantees a non-sedated BOLD)
 - › Sequence renaming depending on choices (eg, sedated or not?) for automatic documentation stored in DICOMs
(bypass lack of conditional custom data storage in MRI software)
- Physical devices:
 - › Head immobilizer
 - › Comfort knee pillow (reduces back pain), blanket, etc.

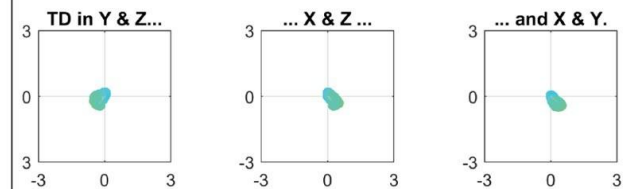
Inflatable 3D head immobilizer



Movement profile for conventional foam



Movement profile for Pearltec positioning system



Reduces:

- **motion** artifacts
- need for **sedation**

(see infants studies, eg,
Yamamura & Inatomi et al,
2018)



(here: Pearltec MultiPad)



Future:
Thermoplastic
masks?



(Mandija, Agata
et al 2019)

Take home message



- ▶ Possible to have a **cutting-edge research** MRI protocol under **clinical constraints**, through **careful optimization**
- ▶ Don't need perfection, just something that works with **sufficient quality** (speed-quality trade-off always applies)
- ▶ **New analyses opportunities** in clinical populations (dynamic connectivity, multi-tissues unconstrained DTI, accurate subject-level segmentation)
- ▶ **Reduce risks** & ethical issues by avoiding sedation
- ▶ Future: compressed sensing, quantitative MRI, thermoplastic mask^[1]

→ Full protocol for Siemens Vida (req SMS):
github.com/lrq3000/neuro_slides/cme2019



Additional advices



- ▶ Enable 3D distortion correction, for all!
- ▶ Use alternate streams, allows to save uncorrected versions at no cost! Eg, distortion correction + motion can mess FLAWS, nice to have the original!

TODO Add example FLAWS messed

- ▶ Enable **Prescan Normalize** for subcortical analysis (all sequences), disable other filters (Hamming etc)
- ▶ Disable PACE (prospective motion correction), as this prevents retrospective motion correction (ie, with external softwares such as ART)
- ▶ If lots of Gibbs noise (eg, in FLAWS or MP2RAGE), lower GRAPPA acceleration!
- ▶ For multi-shell DTI, acquire 3 different DTI sequences and bundle together with a Copy Reference to copy the acquisition parameters automatically (necessary for the multi-shell DTI to be valid)

Additional advices



- ▶ With uncooperative/uncontrollable populations, the speed-quality trade-off might be simpler: better to speed up and have a more stable (but lower resolution) image, than have a high-resolution image that fails most of the time to be acquired because of motion!
- ▶ Acquire with interpolation and rescale, eg: acquire at $0.5 \times 0.5 \times 1.0 \text{ mm}$ and rescale to 1.0 mm^3 , slight increase in SNR
- ▶ Increasing bandwidth reduces susceptibility to metal and chemical artifacts, useful for patients with potentially blood or metal infarcts

About free experimentation

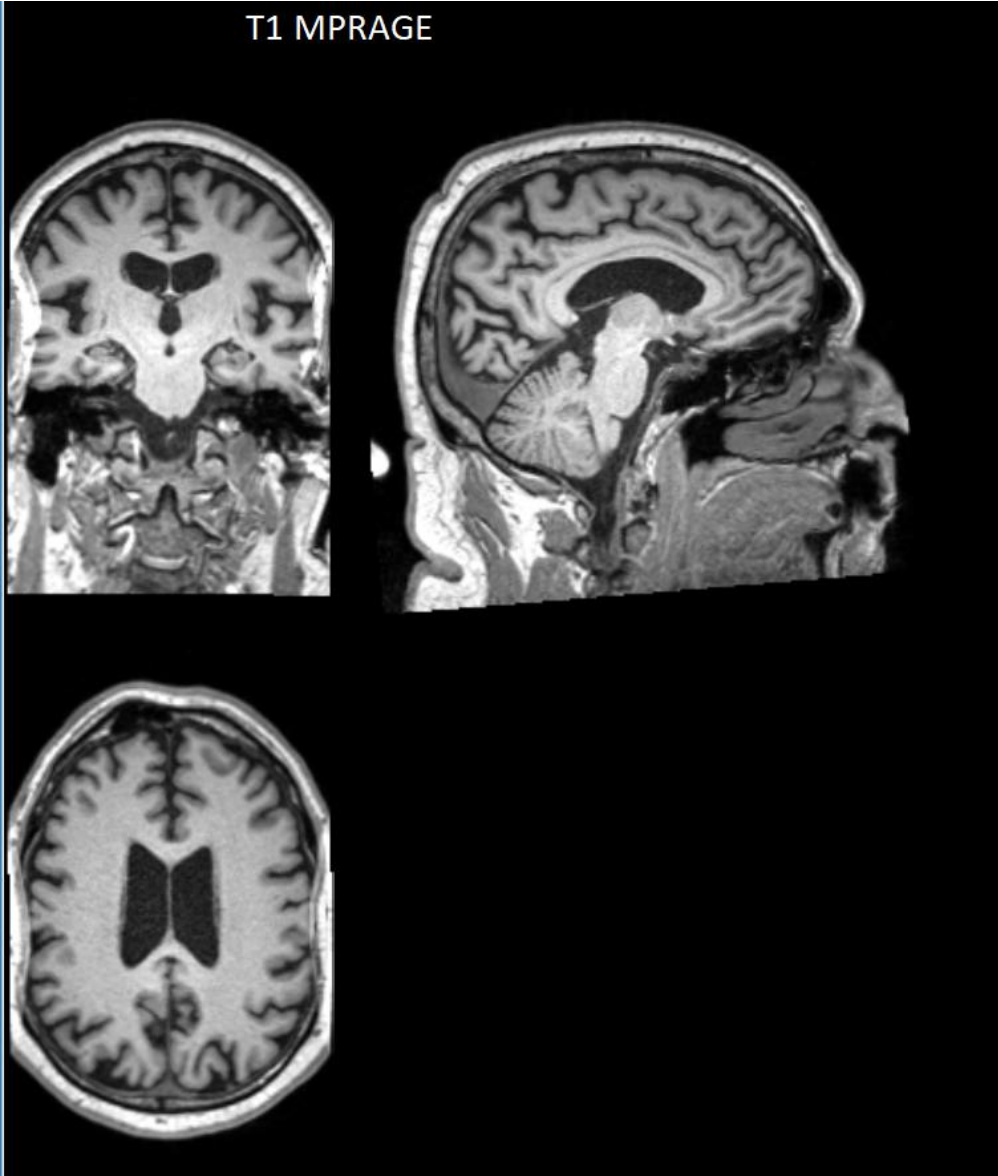


- ▶ Feel free to experiment with your protocol, often the sequences are not optimized for your machine and/or needs.
- ▶ How to proceed: no necessary need for calculations, trial and error is still the best approach (use bisection approach), but where available, calculations can save you some time instead.
- ▶ Try on a dummy or a healthy volunteer, under supervision from radiologists or MRI brand engineer to ensure no risks notably of tissue over-heating. Normally most modern machines implement safeguards that should in any case prevent these issues by warning the operator and change adequately the protocol.

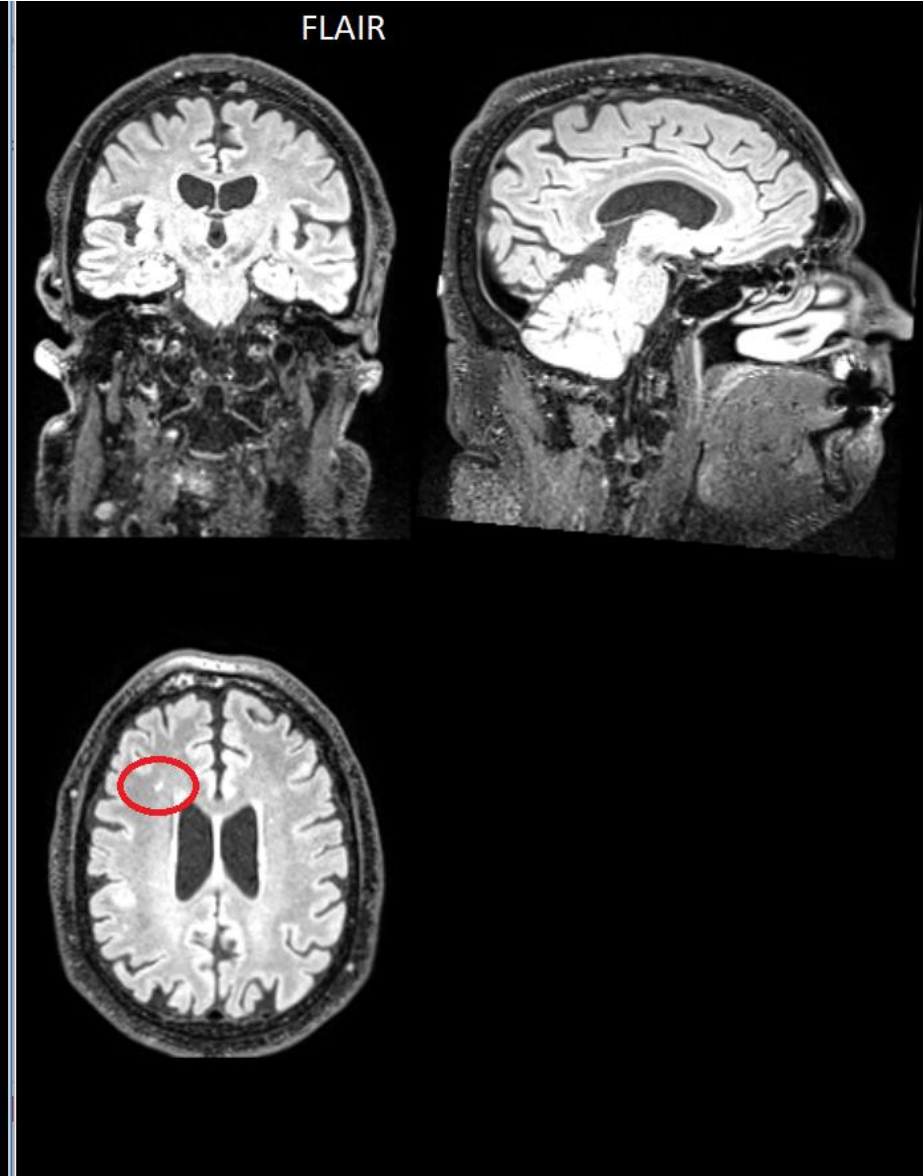
Clinical T1 FLAWS vs FLAIR



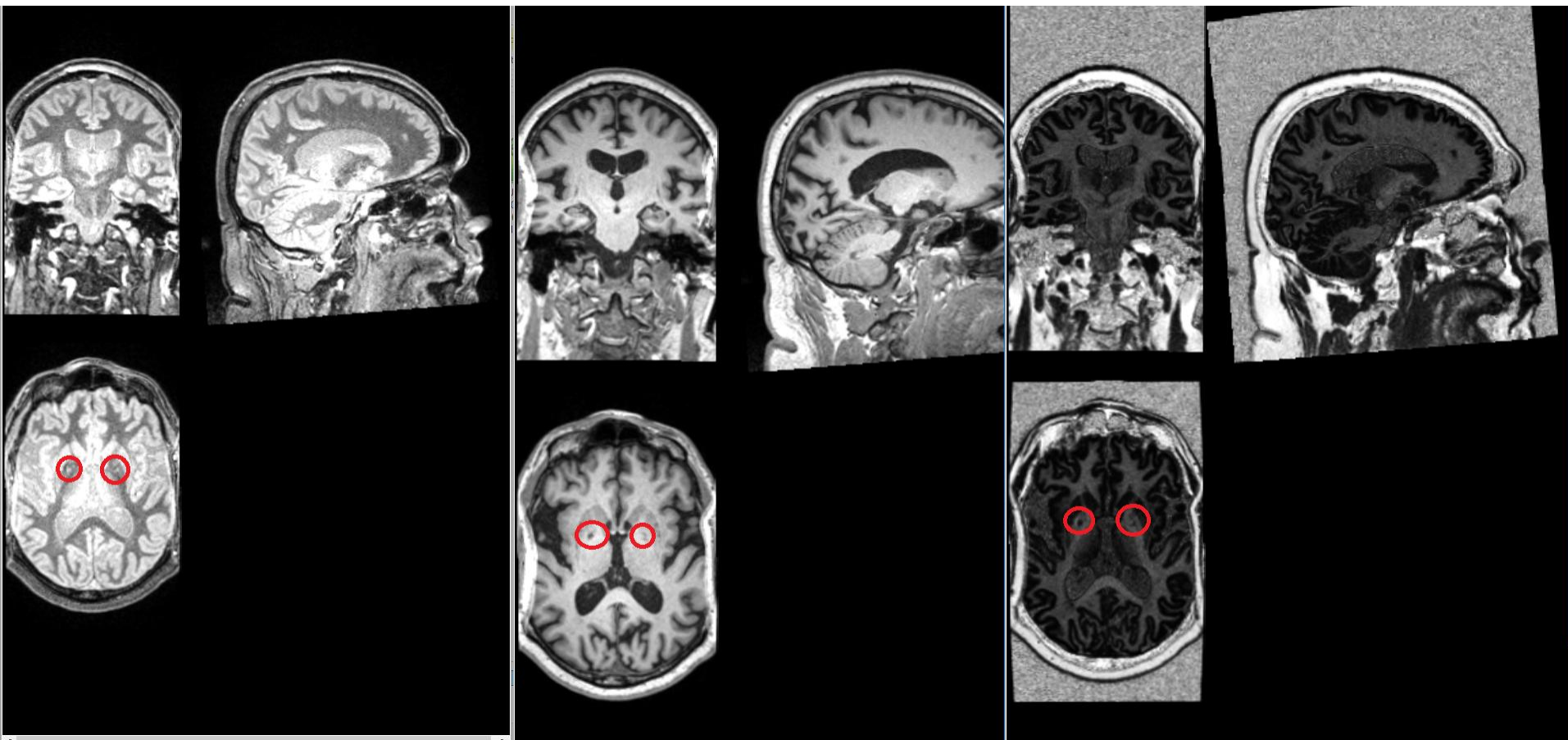
T1 MPRAGE



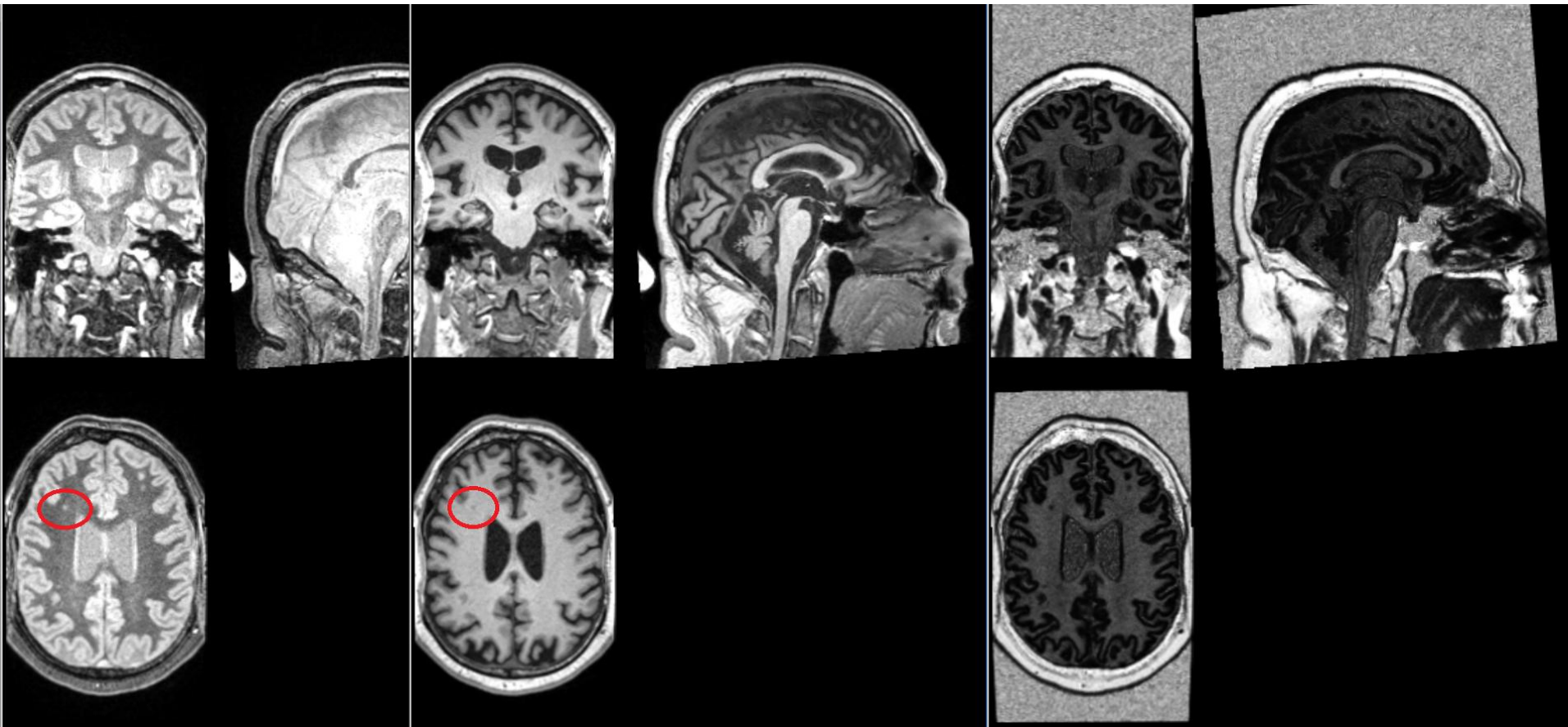
FLAIR



Clinical T1 FLAWS vs FLAIR



Clinical T1 FLAWS vs FLAIR



MRI protocol sequences list



1. AAhead_scout

2. Decision: Patient anesthetized?

Yes:

ep2d_bold_repos_moco_s3_p2_short
_avec_AG

No:

ep2d_bold_repos_moco_s3_p2_short
_sans_AG

3. Decision: Patient anesthetized?

Yes:

- ▶ AAhead_scout
- ▶ ep2d_bold_repos_moco_s3_p2_long_avec_AG

No:

- ▶ ep2d_bold_repos_moco_s3_p2_long_sans_AG

4. gre_field_mapping

5. t1_mp2rage_sag_p3_iso

6. t1_mp2rage_sag_p2_iso_FLAWS_fast

7. ep2d_diff_mddw_30_p2_s3_b700

8. ep2d_diff_mddw_64_p2_s3_b1000

9. ep2d_diff_mddw_64_p2_s3_b2000

10. t2_space_FLAIR_sag_p3_iso

11. t2_swi_tra_p3_1.5mm

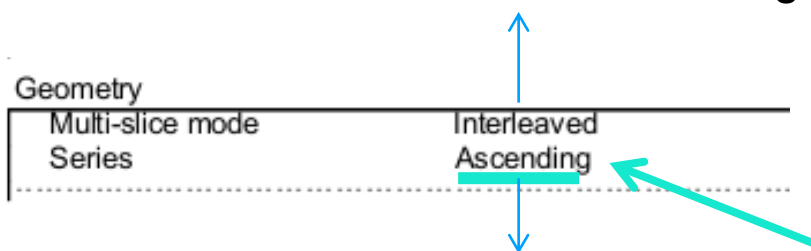
12. t2_tse_tra_512_p2

13. asl_3d_tra_fast

Slice order: check in the machine's printout!

\\USER\Head Lg\Study Neuro Lg\MyGroup Lg\ep2d_bold_rest	
TA: 10:06	PAT: Off
Voxel size: 3.0x3.0x3.0 mm	Rel. SNR: 1.00
SIEMENS: ep2d_bold	
Properties	Special sat. None
Prio Recon Off	System
Before measurement	Body Off
After measurement	HEP On
Load to viewer On	HEA On
Inline movie Off	
Auto store images On	Positioning mode REF
Load to stamp segments Off	Table position H
Load images to graphic segments Off	Table position 0 mm
Auto open inline display Off	MSMA S - C - T
AutoAlign Spine Off	Sagittal R >> L
Start measurement without further preparation On	Coronal A >> P
Wait for user to start single	Transversal F >> H
Start measurements	Coil Combine Mode Adaptive Combine
	Auto Coil Select Default
Routine	
Slice group 1	Shim mode Standard
Slices 32	Adjust with body coil Off
Dist. factor 25 %	Confirm freq. adjustment Off
Position Isocenter	Assume Silicone Off
Orientation Transversal	! Ref. amplitude 1H 353.882 V
Phase enc. dir. A >> P	Adjustment Tolerance Auto
Rotation 0.00 deg	Adjust volume
Phase oversampling 0 %	Position Isocenter
FoV read 192 mm	Orientation Transversal
FoV phase 100.0 %	Rotation 0.00 deg
Slice thickness 3.0 mm	R >> L 192 mm
TR 2000 ms	A >> P 192 mm
TE 30 ms	F >> H 120 mm
Averages 1	
Concatenations 1	Physio
Filter Prescan Normalize	1st Signal/Mode None
Coil elements HEA,HEP	
Contrast	BOLD
MTC Off	GLM Statistics Off
Flip angle 78 deg	Dynamic t-maps On
Fat suppr. Fat sat.	Starting ignore meas 0
	Ignore after transition 0
Averaging mode Long term	Model transition states On
Reconstruction Magnitude	Temp. highpass filter On
Measurements 300	Threshold 4.00
Delay in TR 0 ms	Paradigm size 30
Multiple series Off	Meas[1] Baseline
	Meas[2] Baseline
Resolution	Meas[3] Baseline
Base resolution 64	Meas[4] Baseline
Phase resolution 100 %	Meas[5] Baseline
Phase partial Fourier Off	Meas[6] Baseline
Interpolation Off	Meas[7] Baseline
	Meas[8] Baseline
PAT mode None	Meas[9] Baseline
Matrix Coil Mode Auto (CP)	Meas[10] Baseline
	Meas[11] Baseline
Distortion Corr. Off	Meas[12] Baseline
Unfiltered images Off	Meas[13] Baseline
Prescan Normalize On	Meas[14] Baseline
Raw filter On	Meas[15] Baseline
Elliptical filter Off	Meas[16] Active
Hamming Off	Meas[17] Active
	Meas[18] Active
Geometry	Meas[19] Active
Multi-slice mode Interleaved	Meas[20] Active
Series Ascending	Meas[21] Active
	Meas[22] Active
	Meas[23] Active

This « interleaved » means nothing!



Ascending = sequential ascending. Else it would be « interleaved » here for interleaved ascending.

Typical fMRI processing steps



Manual

- Select subjects, prepare demographics (age, gender, etiology, sedation, etc)
- Convert from DICOM to NIfTI
- Exclude bad subjects (too much motion, artifacts, brain surgery, metallic prosthesis, etc)

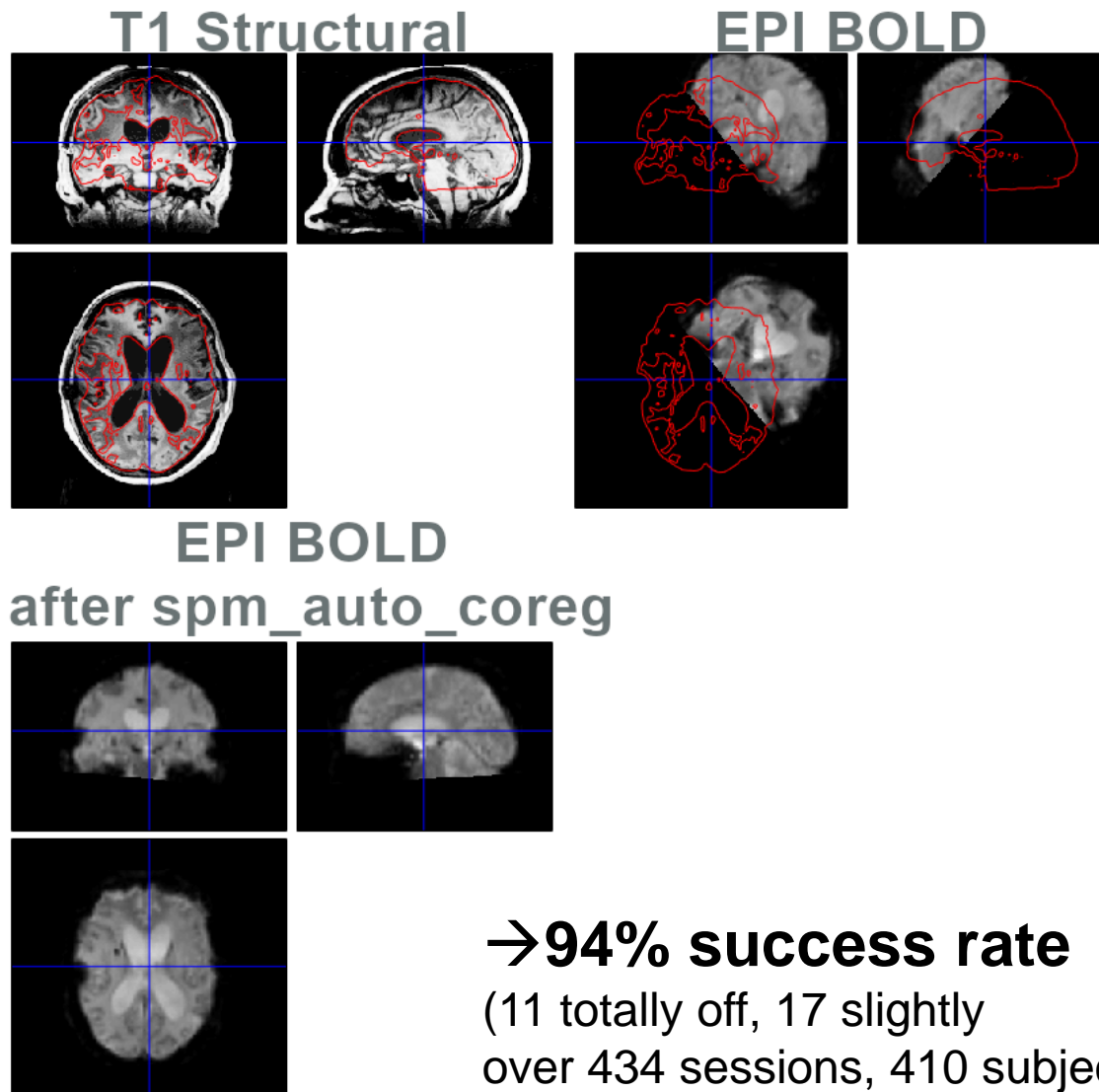
- T1 reorient
- EPI/DTI manual coregistration

**Takes > 90%
of the
analysis time!**

Automatic (mostly)

- Slice timing correction
- Realignment (motion correction)
- Auto coregistration
- Segmentation + Normalization (MNI 152)
- Smoothing
- Movement correction/rejection
- Denoising (PCA aCompCorr, ICA, etc.)

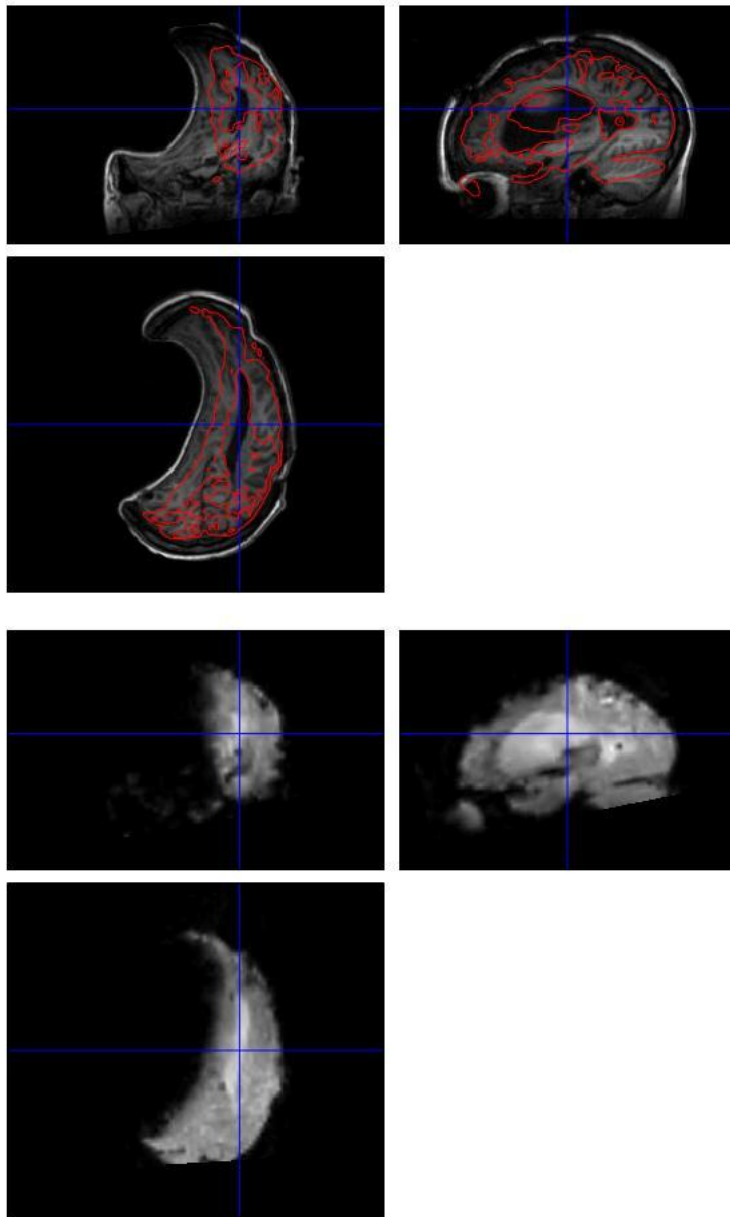
spm_auto_reorient_coregister: Enhanced automatic reorientation and coregistration on brain damaged patients with SPM12



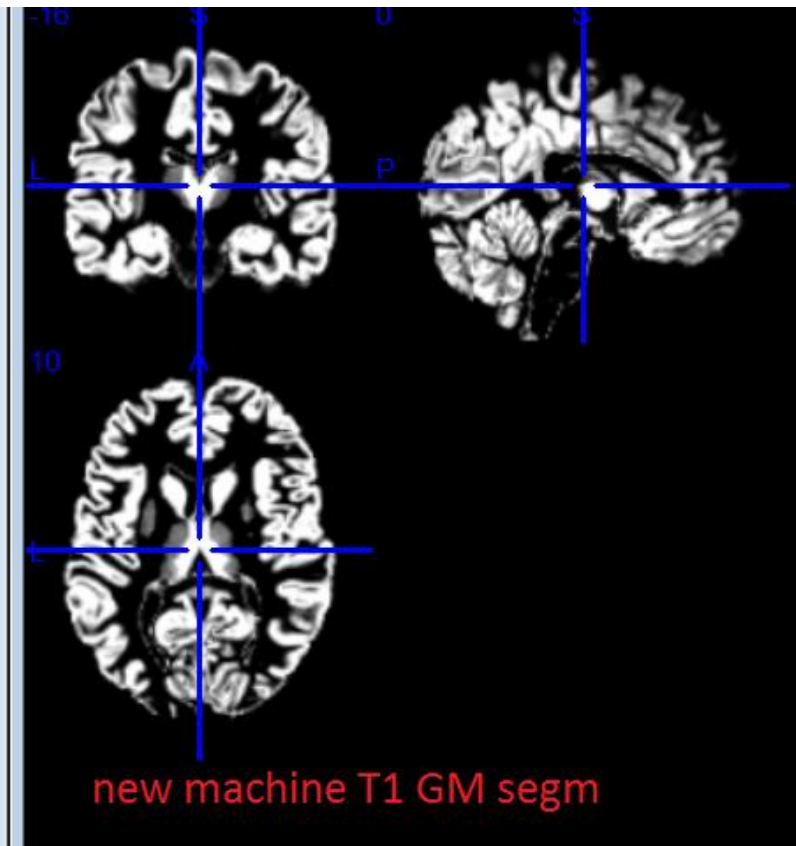
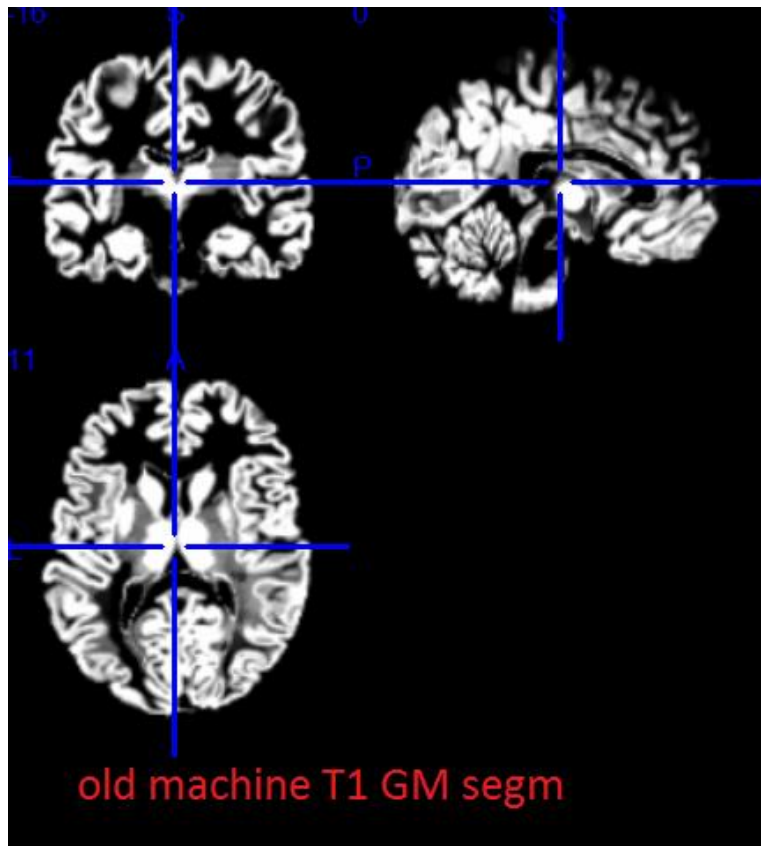
→94% success rate

(11 totally off, 17 slightly
over 434 sessions, 410 subjects)

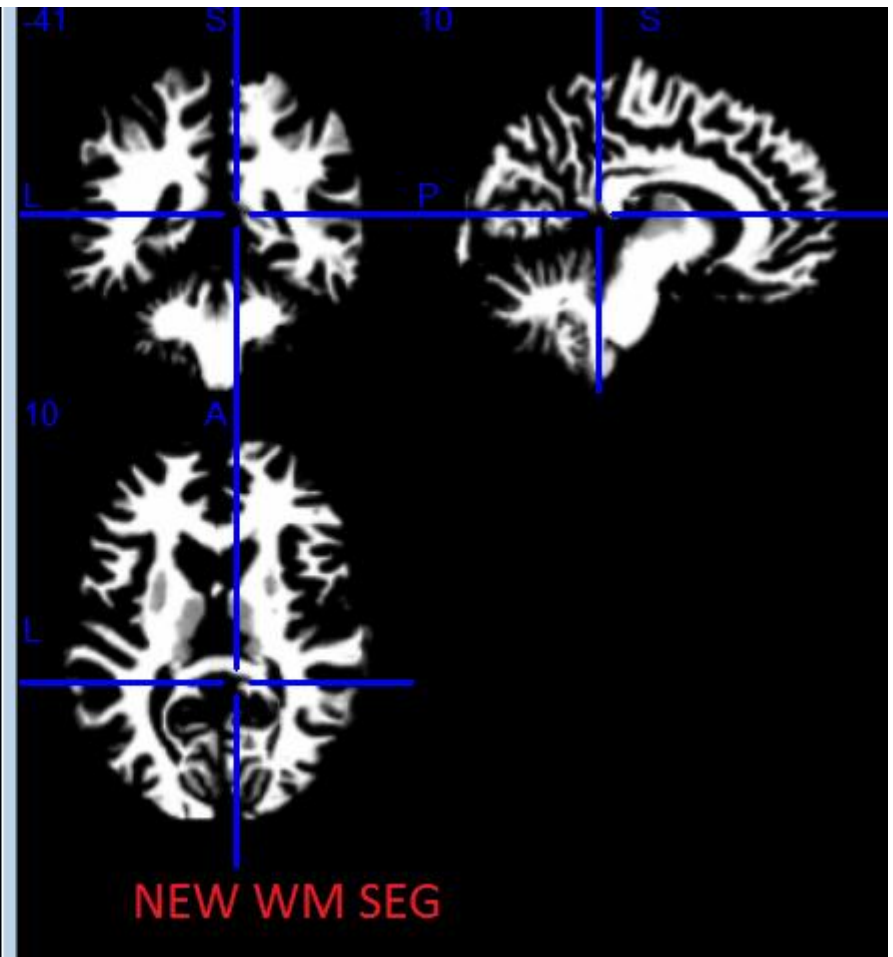
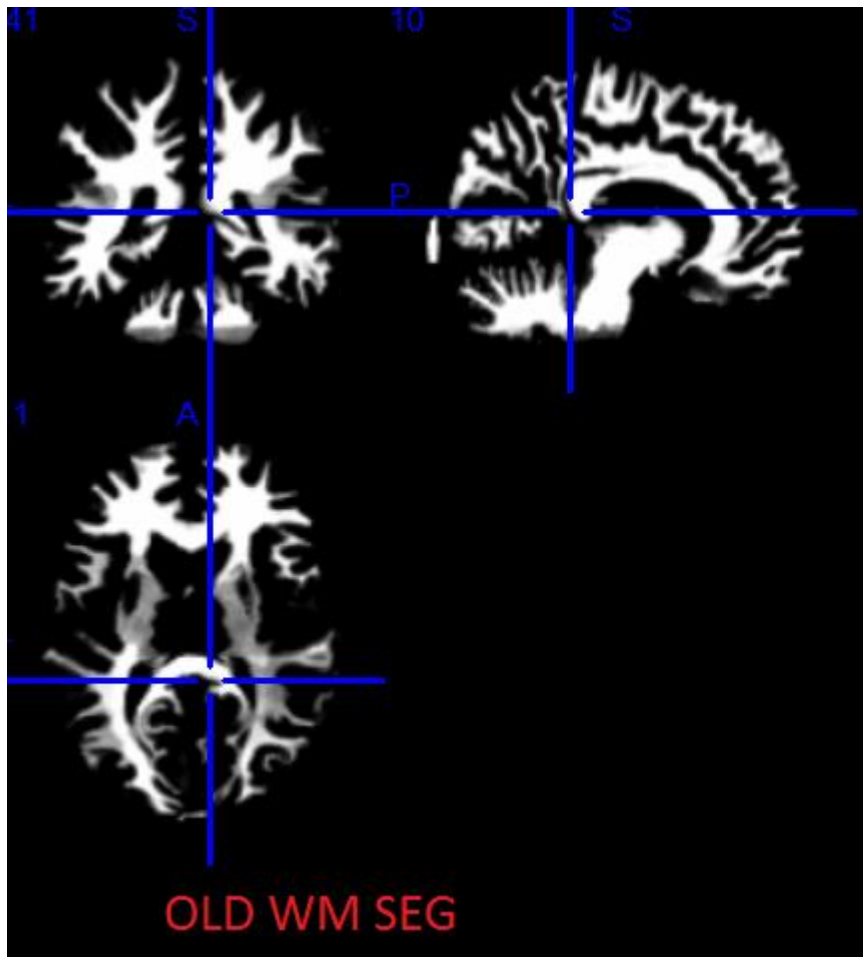
https://github.com/lrq3000/spm_auto_reorient_coregister



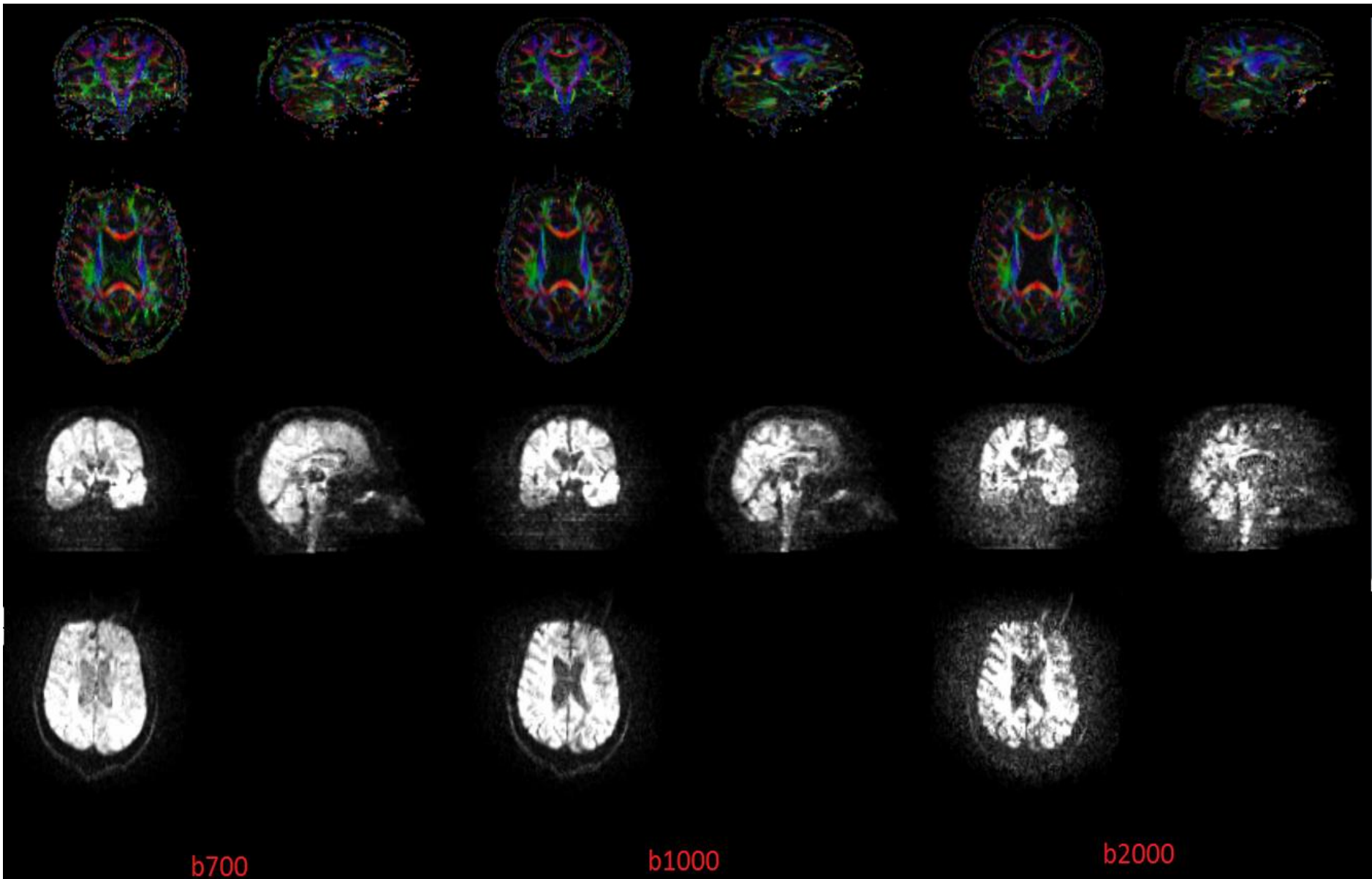
QA image example (same subject)



QA image example (same subject)



Multi-shell DTI



A 30 min cutting-edge MRI protocol

(20-channel coil)



AAhead_scout	00:14
<input checked="" type="radio"/> AutoAlign...	
Patient anesthesie pour 1er BOLD...	
<input checked="" type="radio"/> no <input checked="" type="radio"/> Basic Deci...	
ep2d_bold_repos_moco_s3...	03:48
Patient anesthesie pour 2e BOLD...	
<input checked="" type="radio"/> no <input checked="" type="radio"/> Basic Deci...	
ep2d_bold_repos_moco_s3...	06:13
gre_field_mapping	00:57
t1_mp2rage_sag_p3_iso	05:15
t1_mp2rage_sag_p2_iso_F...	05:02
ep2d_diff_mddw_64_p2_s3...	02:07
ep2d_diff_mddw_64_p2_s3...	05:35
ep2d_diff_mddw_64_p2_s3...	05:43
t2_space_FLAIR_sag_p3_is...	03:57
<input checked="" type="radio"/> MPR Assi...	
t2_swi_tra_p3_384_2mm	03:57
t2_tse_tra_512_p2	01:19
asl_3d_tra_fast	02:09
MPR Planning	
<input checked="" type="radio"/> MPR Planning	

Short BOLD 3min47: Non-sedated! (except if really problematic patient)
Better have motion than sedation! (we can correct motion, but not sedation!)

Might be sedated if necessary, but please avoid

Structural: Sedation OK!

Note: If sedated, please choose « yes » in the boxes highlighted here in red.

Please do not delete or replace any sequence!
(Sequence name will change according to sedation decision set here)

Note2: 3 DTI sequences go together ALWAYS!
If you need to redo DTI, please redo them all!

All sequences can be implemented on any 3T Siemens
with multiband and MP2RAGE (multi-echo T1) support (here
Vida)