



# Multi-Echo fMRI

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*DBIC*

## Topics

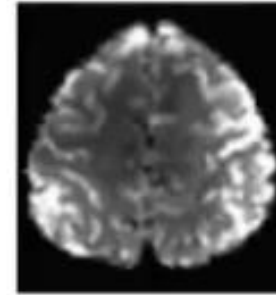
1. What and Why
2. How: Protocols and Data acquisitions
3. How: Data analysis

## Section 1: **What and Why?**

Single Echo



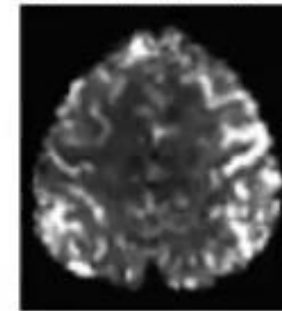
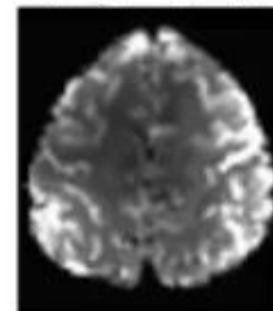
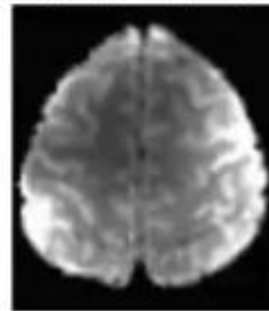
Standard  
Readout



Multi Echo

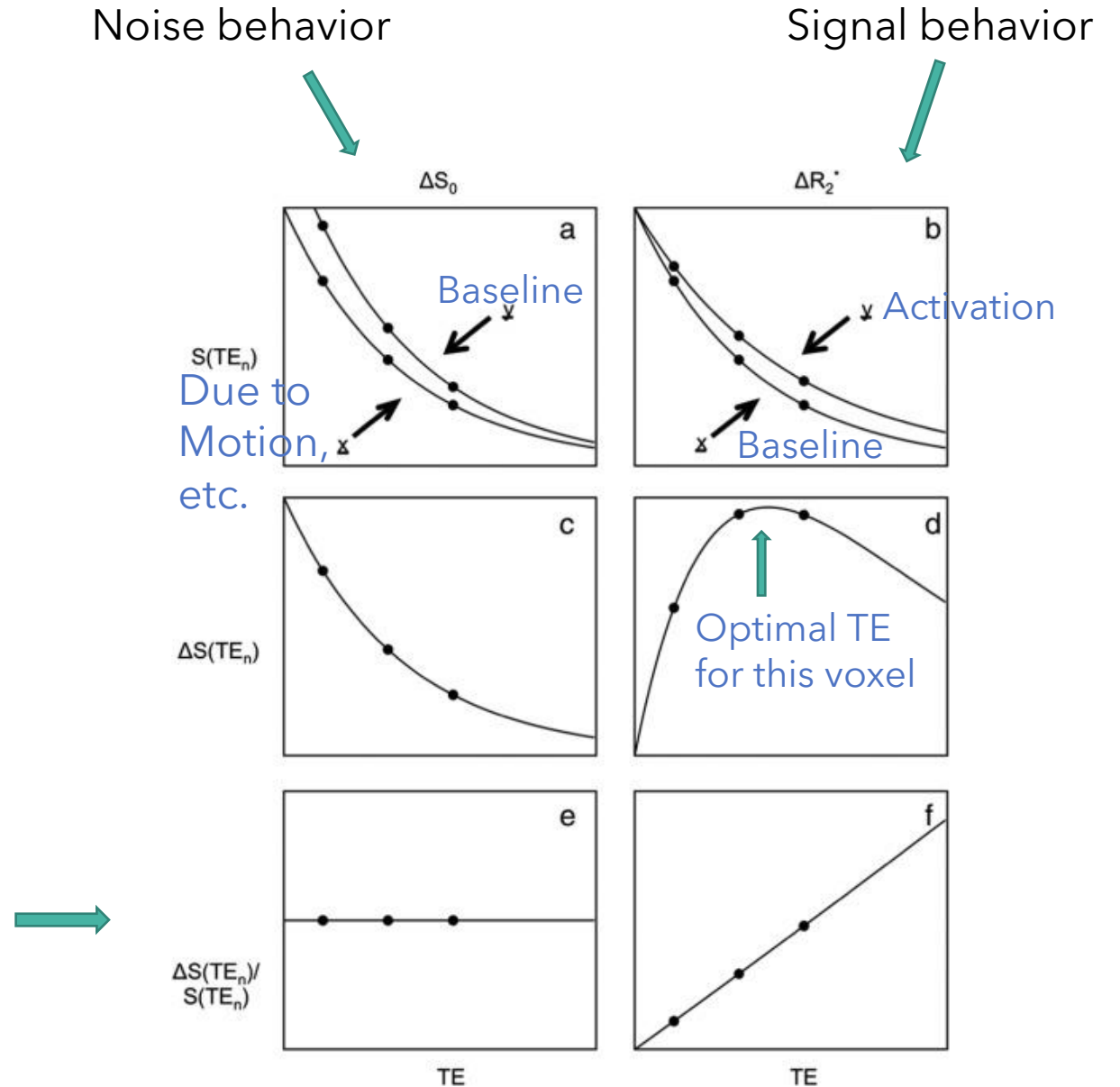


Multi-  
Echo  
Readout



Use already available information in T2\* decay profile to enhance fMRI preprocessing and analysis

Signal has a linear relationship with TE. Noise is independent of the TE.



## **Compare results**



1. Compare the results across the individual echoes.

## **Noise removal**



2. fMRI signal contains bold as well as non- BOLD signals.  
Non-BOLD - Noise :- participant motion and breathing, e.t.c

Because the BOLD signal decays at a set rate, multiple echoes allow us to assess the non-BOLD signal.

## **Optimal Combination**

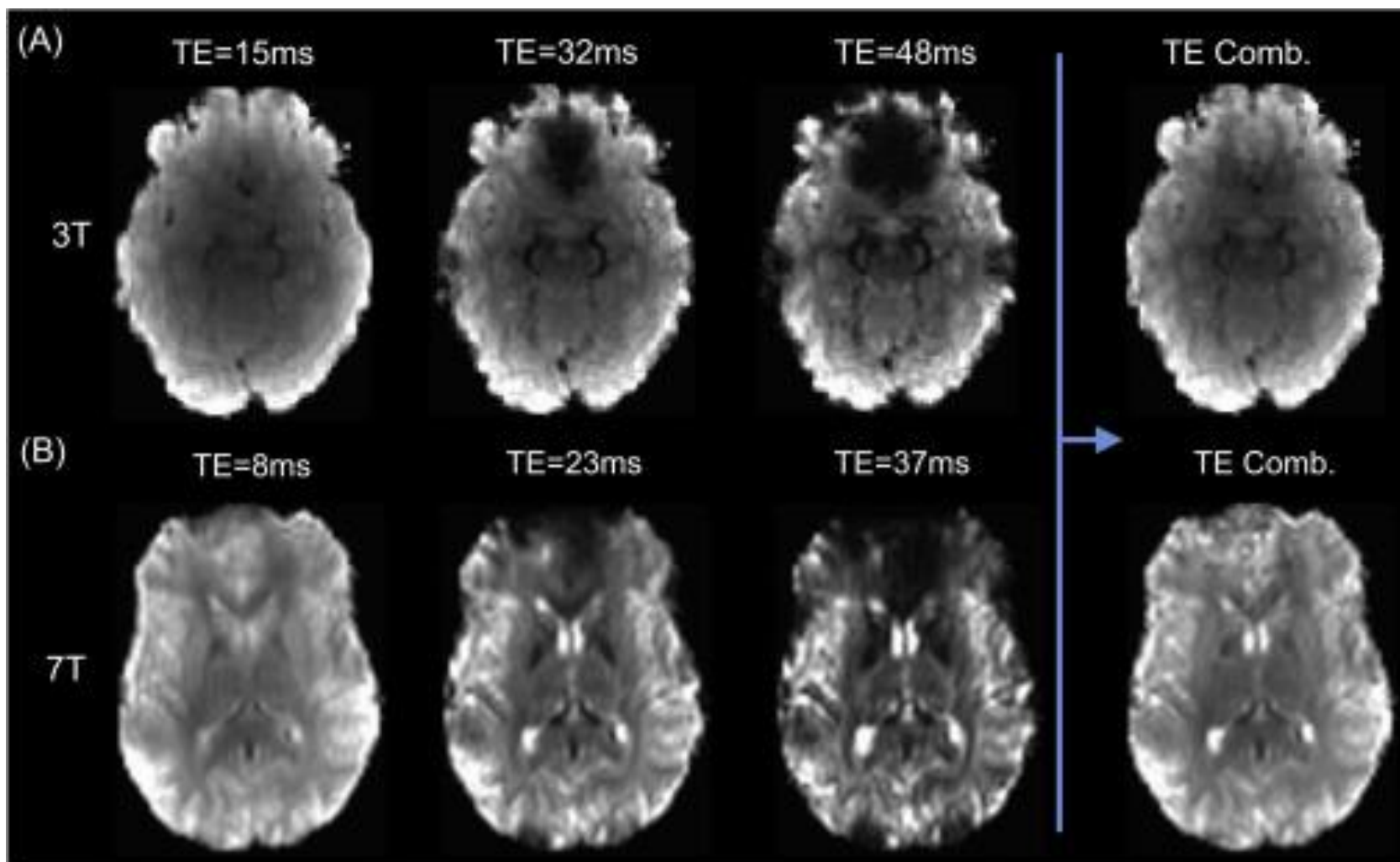


3. Combining the echoes to take advantage of the signal in the earlier echoes. Signal dropout due to T2\* decay can be recovered in high susceptibility-gradients regions.

# Optimal Combination

Not a difficult decision!

Vs.



## Costs and benefits of multi-echo fMRI

1. **Possible increase in TR** - 10% longer TR for three echoes
2. **Weighted averaging may lead to an increase in SNR**

### **Software:**

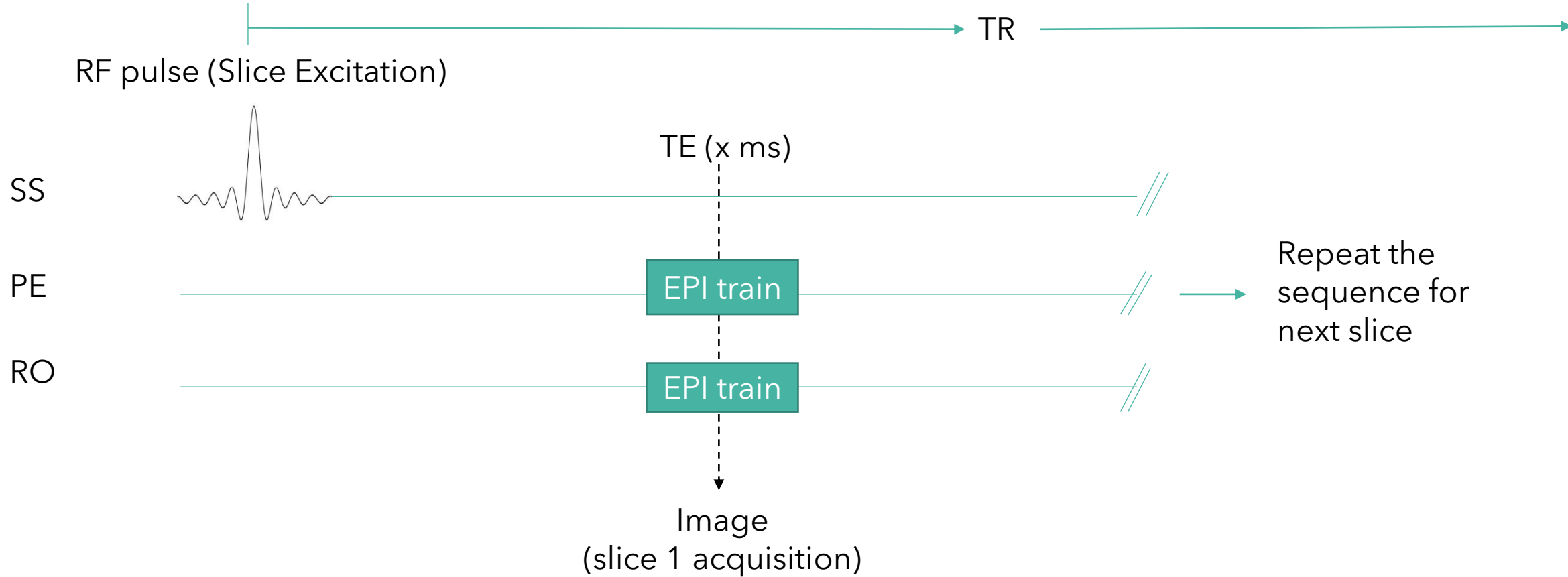
The optimal combination of echoes can currently be calculated in several software packages including **AFNI**, **fMRIPrep**, and **tedana**.



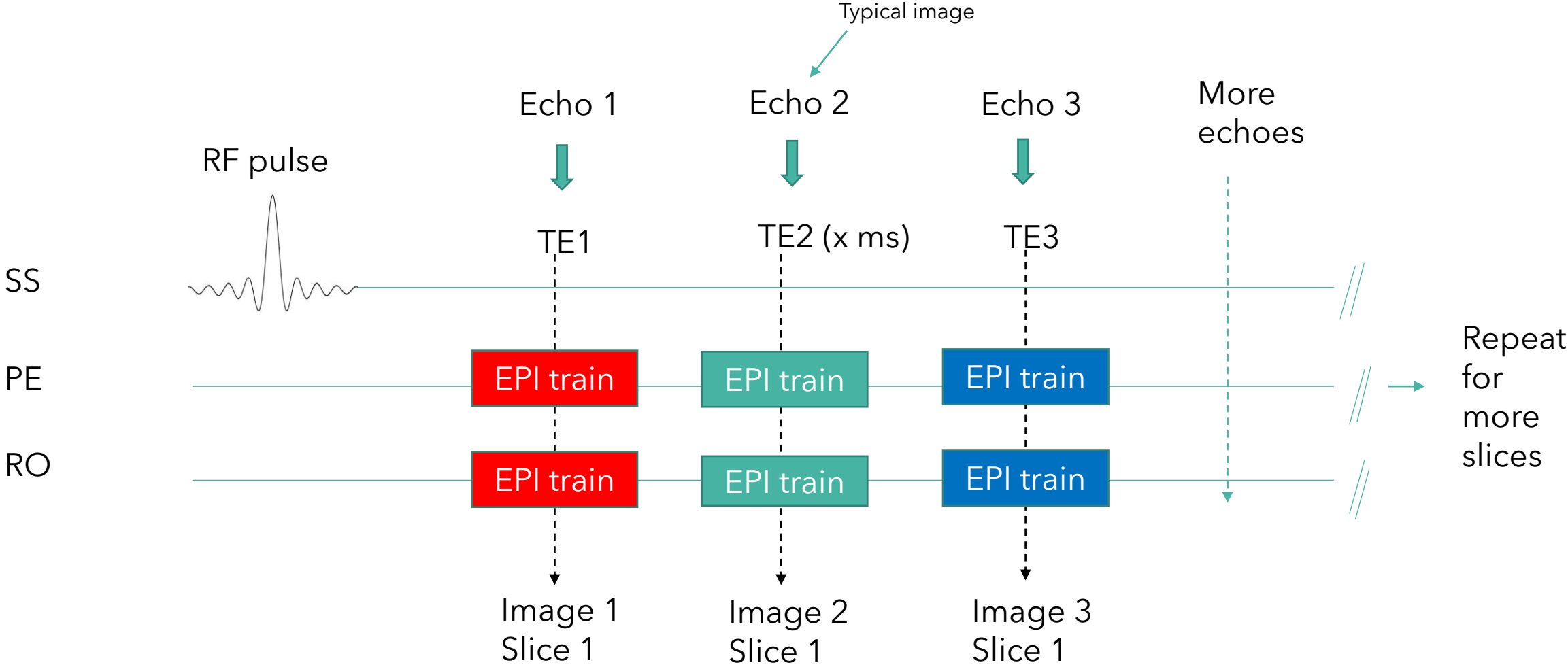
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## Section 2: **Single Echo vs Multi-Echoes and Acquisition**

# Single Echo EPI Acquisition



# Multi-Echo EPI



Dot Cockpit - Explorer

EXPLORER PROGRAM EDITOR

Browse Import Export

dbic

dbic

- QA
- pulse\_sequences
- 1000\_dbic-dataset
- dbic-animals
- Param\_check
- Fieldmap\_check
- cmrr\_sequences
  - cmrr
- Psych60
- \_moved\_under\_Gobbini

dbic » dbic » cmrr\_sequences » cmrr Edit

3 mm isotropic, 200 volumes

cmrr_mbep2d_bold-s1p2-3contrasts	08:41	TE1 = 14 ms, TE2 = 34 ms, TE3 = 64 ms
cmrr_mbep2d_bold-s1p2-pF-3contrasts	07:34	TE1 = 10.60 ms
cmrr_mbep2d_bold-s1p3-pF-3contrasts	05:42	TE1 = 7.54 ms
cmrr_mbep2d_bold-s2p2-pF-3contrasts	03:59	
cmrr_mbep2d_bold-s2p3-pF-3contrasts	03:03	
cmrr_mbep2d_bold-s2p2-3contrasts	04:34	
cmrr_mbep2d_bold-s4p2-pF-3contrasts	02:14	func_task-rest_acq-cmrr-mbep2d_rec-s2p2pF_3contrasts
cmrr_mbep2d_bold-s4p3-pF-3contrasts	01:47	
cmrr_mbep2d_bold-s4p2-3contrasts	02:33	
cmrr_mbep2d_bold-s4-3contrasts	04:07	

BIDS format

## Home Built Protocols

S = MB (sms) factor  
 P = GRAPPA factor  
 pF = Partial Fourier

Start building your protocol from one these!

Rename according to BIDS convention. If you don't, you will have a tough time running fMRIprep.

CMRR multi-band EPI pulse sequence:

The screenshot shows the 'Step Properties' dialog box for a CMRR multi-band EPI pulse sequence. The breadcrumb path is 'dbic » dbic » cmrr\_sequences » cmrr » cmrr\_mbep2d\_bold-s1p2-3contrasts'. The 'Sequence' tab is selected, showing parameters for 'Part 1'. The 'Contrasts' field is set to 3, which is highlighted by a yellow arrow and labeled 'Multi-echo factor'. Other parameters include Bandwidth (2500 Hz/Px), Flow comp. (No), Multi-slice mode (Interleaved), and Echo spacing (0.49 ms). A progress bar at the bottom shows the contrast sequence from 1 to 8, with the first 3 contrasts highlighted in green.

Multi-echo factor

CMRR multi-band EPI pulse sequences:

The screenshot shows the 'Step Properties' dialog box for a CMRR multi-band EPI pulse sequence. The breadcrumb path is 'dbc » dbc » cmrr\_sequences » cmrr » cmrr\_mbep2d\_diff'. The 'Routine' pane is selected, displaying various parameters. A red arrow points to the 'Multi-band accel. factor' parameter, which is set to 4. Below the arrow, the text 'MB factor is on the Routine pane.' is displayed.

Parameter	Value	Unit
TA	3:02	
PM	REF	
PAT	Off	
Voxel size	2.0x2.0x2.0mm	
Rel. SNR	1.00	
epse		
Slice group	1	
Slices	64	
Dist. factor	0	%
Position	L0.6 P16.6 H21.7	
Orientation	Transversal	
Phase enc. dir.	A >> P	
AutoAlign	Head > Basis	
Phase oversampling	0	%
Multi-band accel. factor	4	
Filter	None	
Coil elements	HEA;HEP	
FoV read	240	mm
FoV phase	100.0	%
Slice thickness	2.00	mm
TR	2560	ms
TE	88.00	ms

## Choosing GRAPPA

The screenshot shows the 'Step Properties' dialog box for a sequence named 'cmrr\_mbep2d\_bold-s1p2-3contrasts'. The 'Protocol Parameters' tab is active, and the 'Resolution' sub-tab is selected. The 'PAT mode' dropdown menu is set to 'GRAPPA', which is highlighted by a red arrow. Other parameters shown include 'Accel. factor PE' set to 2 and 'Ref. lines PE' set to 24. The 'Reference scan mode' is set to 'Single-shot'. The 'Close' button is visible at the bottom right.

dbic » dbic » cmrr\_sequences » cmrr » cmrr\_mbep2d\_bold-s1p2-3contrasts

General TA: 8:41 PM: REF PAT: 2 Voxel size: 3.0x3.0x3.0mm Rel. SNR: 1.00 : epfid

Protocol Parameters Routine Contrast Resolution Geometry System Physio BOLD Sequence

Voice Commands Common iPAT Filter Image Filter Rawdata

Execution

Image Management PAT mode GRAPPA

Auto Load Accel. factor PE 2 Reference scan mode Single-shot

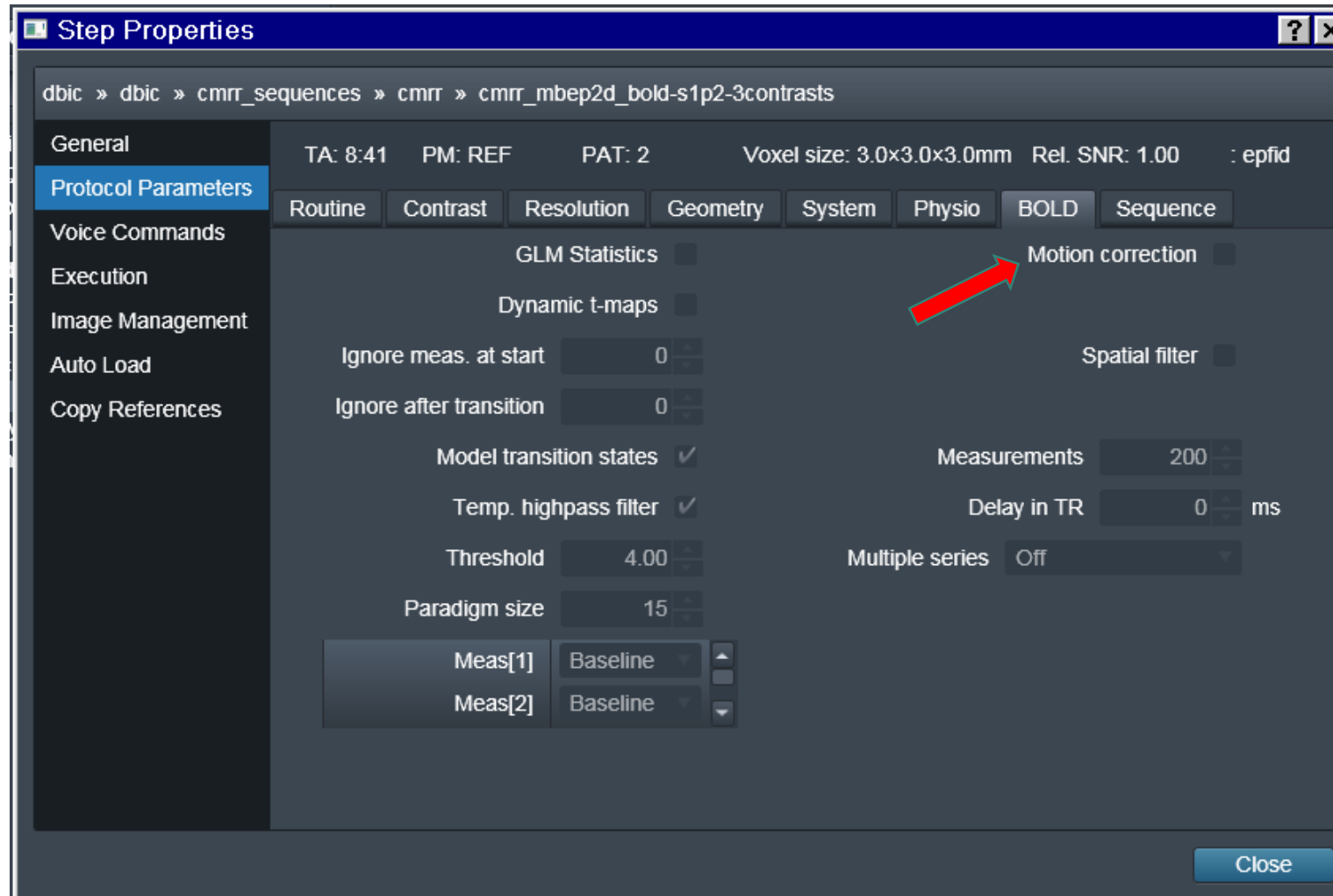
Copy References Ref. lines PE 24

Close

GRAPPA is at the usual spot



No motion correction with multi-echo data !



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## Section 3: **ANALYSIS**

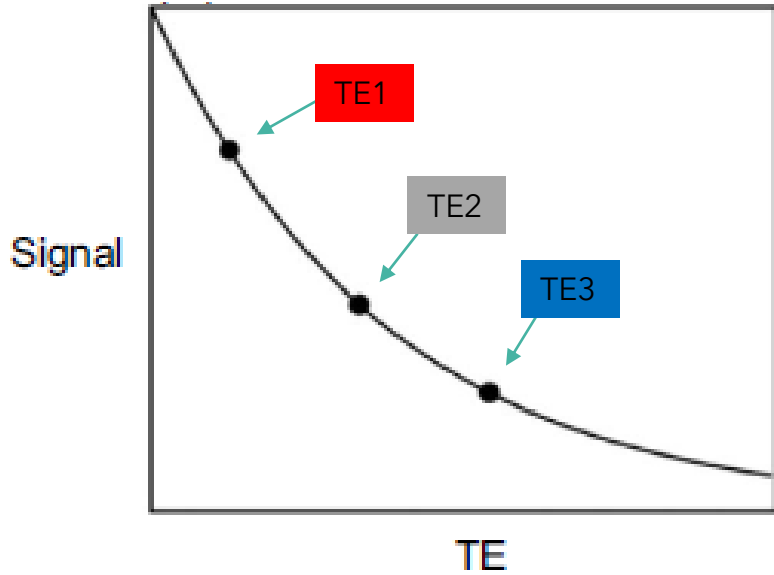
1. Optimal Combination
2. Deniosing

Optimal Combination

Experimental data



T<sub>2</sub><sup>\*</sup> Decay



Theoretical relationship



$$S(TE) = S_0 \exp(-TE/T_2^*)$$

Acquired Signal (per voxel)

Baseline Signal

Spin-spin (transverse) relaxation time

Voxel wise Fitting

T<sub>2</sub><sup>\*</sup>

T<sub>2</sub><sup>\*</sup> map

Weighted/optimal combination

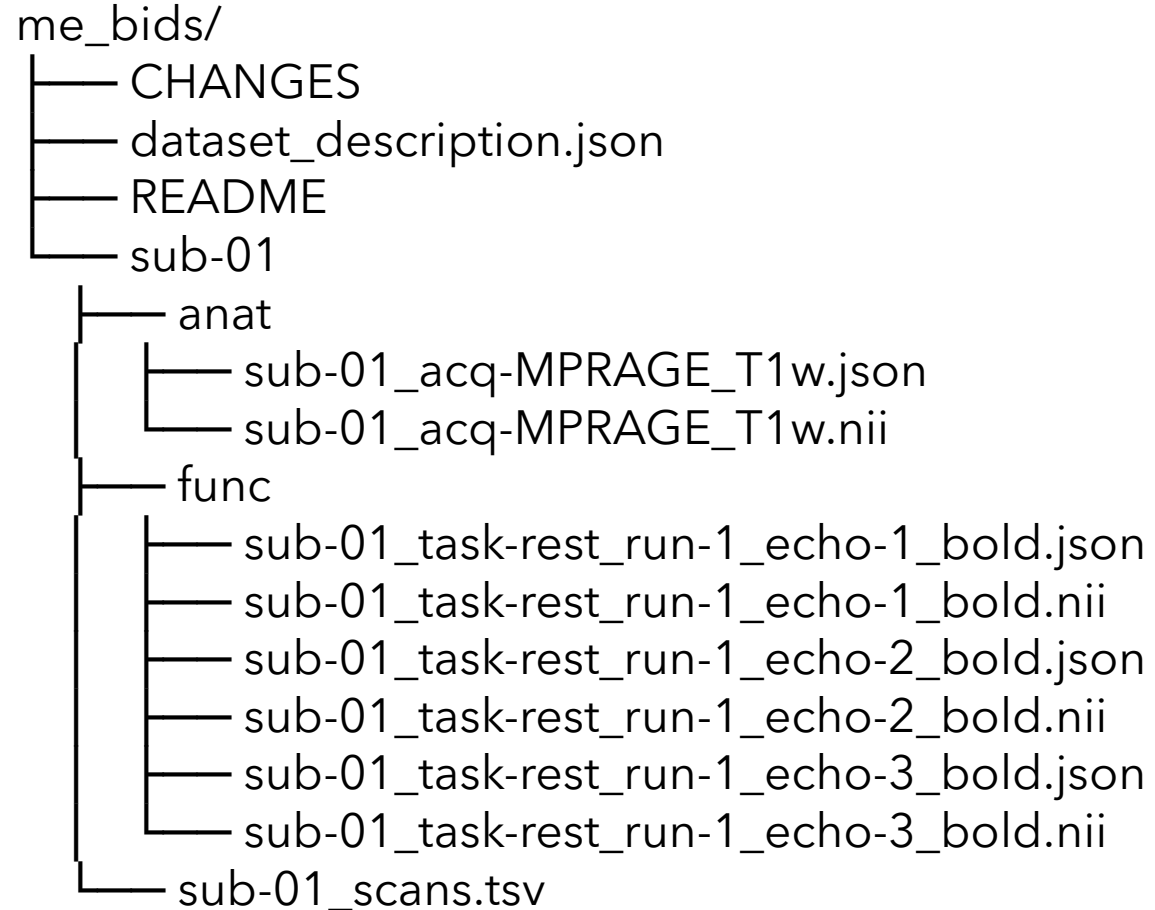


$$w(T_2^*)_n = \frac{TE_n \cdot \exp(-TE/T_{2^*(est)}^*)}{\sum_n TE_n \cdot \exp(-TE/T_{2^*(est)}^*)}$$

- BOLD effects modulate T<sub>2</sub><sup>\*</sup>  
- Activation increases T<sub>2</sub><sup>\*</sup>
- Artfactual fluctuations modulate S<sub>0</sub>  
- Artifacts affect base signal, and not much effect on T<sub>2</sub><sup>\*</sup>

# Optimal Combination: fMRIPrep

**BIDS layout of the dataset**



## fmriprep\_run.sh

```
#!/bin/bash

singularity run --cleanenv
/home/kodiweera/my_images/fmriprep-20.2.3.sif \
--participant_label sub-01 \
--bold2t1w-dof 9 \
--dummy-scans 3 \
--use-aroma \
--dummy-scans 3 \
--fs-license-file
/home/kodiweera/data/freesurfer_license.txt \
/home/kodiweera/data/multi_echo/me_bids
/home/kodiweera/data/multi_echo/out participant -w
/home/kodiweera/data/multi_echo/work
```

## Extraction from fMRIPrep-method report

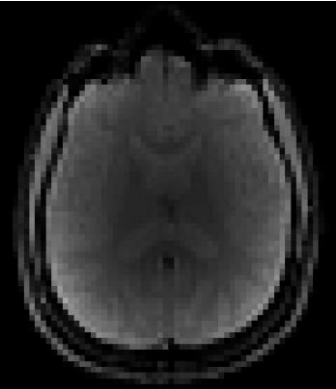
A  $T2^*$  map was estimated from the preprocessed BOLD by fitting to a monoexponential signal decay model with nonlinear regression, using  $T2^*/S0$  estimates from a log-linear regression fit as initial values. For each voxel, the maximal number of echoes with reliable signal in that voxel were used to fit the model. The calculated  $T2^*$  map was then used to optimally combine preprocessed BOLD across echoes following the method described in (Posse et al. 1999).

**The optimally combined time series was carried forward as the preprocessed BOLD.**

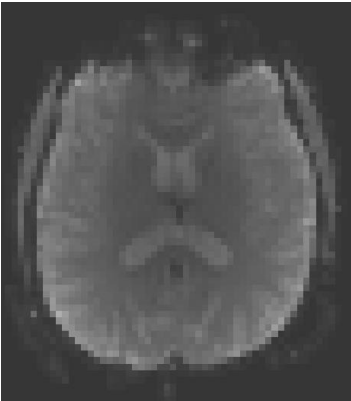


Protocol: s1p2; 200 volumes; 3 mm isotropic

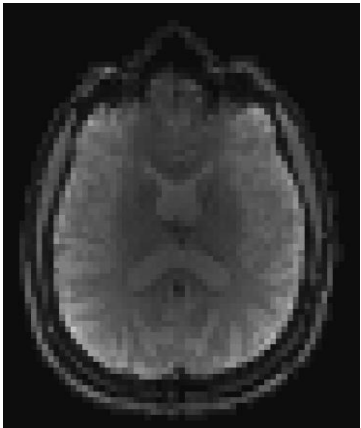
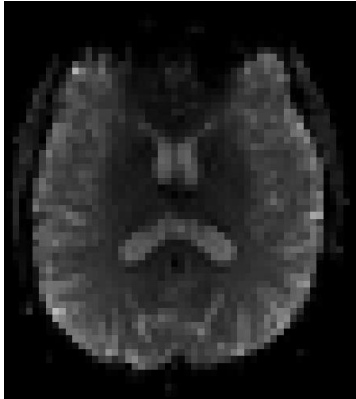
TE1 (TE = 14 ms)



TE2 (TE = 34 ms)



TE3 (TE = 64 ms)



← Enhanced SNR

Denoising

Installation: **pip install tedana**

<https://tedana.readthedocs.io/en/stable/installation.html>

Running a dataset:

This is my  
command



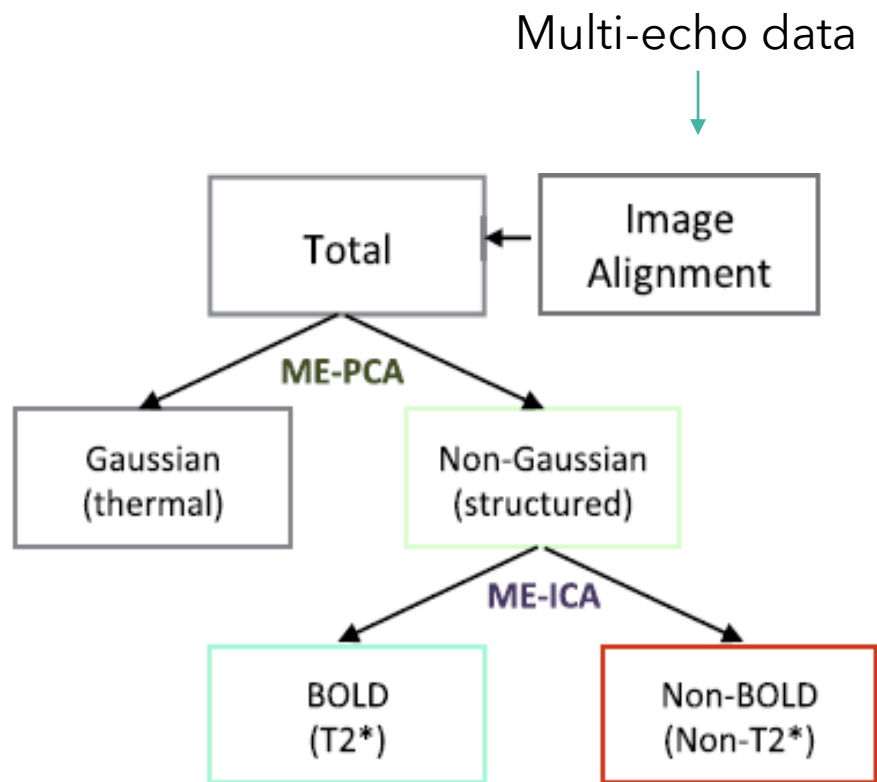
```
tedana -d sub-01_task-rest_run-1_echo-1_bold.nii sub-01_task-  
rest_run-1_echo-2_bold.nii sub-01_task-rest_run-1_echo-  
3_bold.nii -e 14 34 64 --out-dir /home/kodiweera/data/multi-  
echo/tedana_out
```

```
-d sub-01_task-rest_run-1_echo-1_bold.nii  
sub-01_task-rest_run-1_echo-2_bold.nii  
sub-01_task-rest_run-1_echo-3_bold.nii
```

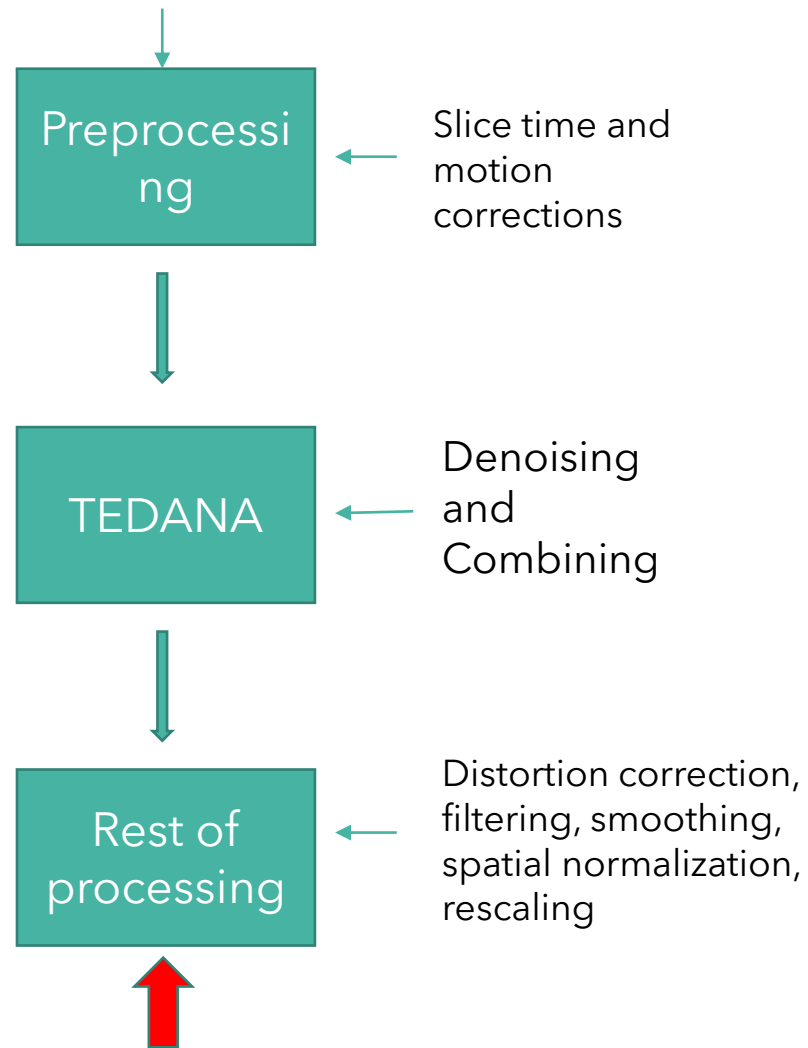
```
-e 14 34 64
```

```
--out-dir /home/kodiweera/data/multi-echo/tedana_out
```

T  
E  
D  
A  
N  
A

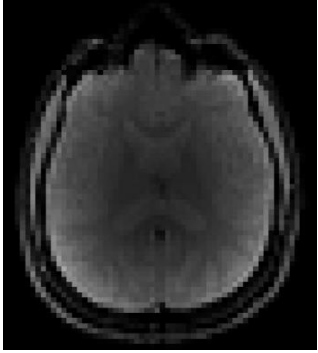


ME - Images



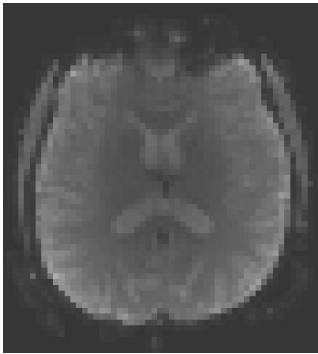
Don't do these steps before TEDANA

TE1



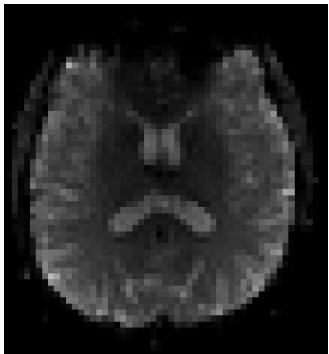
ME-ICA components (199)

TE2



ME-ICA components (199)

TE3



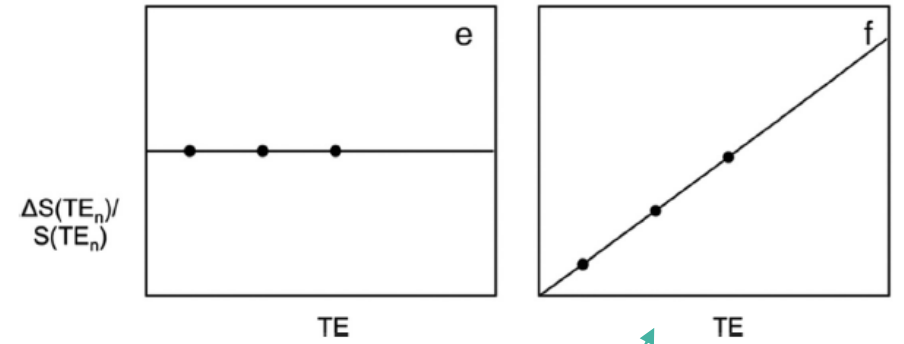
ME-ICA components (199)

Classify these components as noise

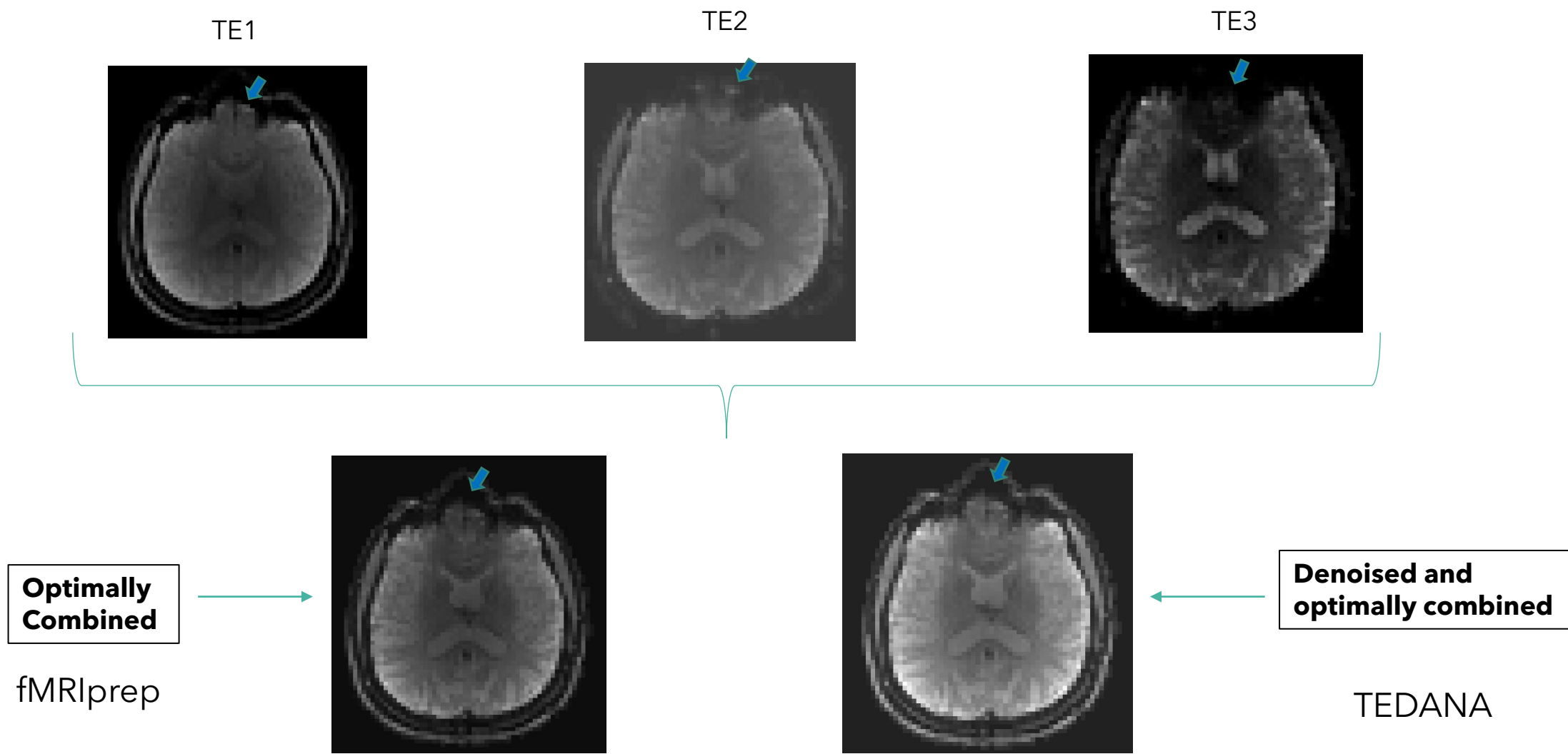
Classify the ICA components as signal and noise

noise

signal



Classify as signal and combine these components to produce de-noised image.



Your Resource



<https://tedana.readthedocs.io/en/stable/index.html>

TEDANA output files  **<https://tedana.readthedocs.io/en/stable/outputs.html>**

From TEDANA website:

*"If a data set is expected to be used for future analyses in later years, it is likely that more powerful approaches to multi-echo denoising will sufficiently mature and add even more value to a data set."*



***That's enough of multi-echo fMRI !***