Multi-Echo fMRI

Chandana Kodiweera, Ph.D.

DBIC
Topics

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

(A) TE=15ms  TE=32ms  TE=48ms  TE Comb.
  3T

(B) TE=8ms  TE=23ms  TE=37ms  TE Comb.
  7T
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.
Purposely left blank
Section 2: Single Echo vs Multi-Echoes and Acquisition
**Single Echo EPI Acquisition**

- **RF pulse (Slice Excitation)**
- **TE (x ms)**
- **EPI train**
- **Image (slice 1 acquisition)**
- **Repeat the sequence for next slice**

**Parameters:**
- SS
- PE
- RO

**Sequence:**
1. RF pulse (Slice Excitation)
2. TE (x ms)
3. EPI train
4. Image (slice 1 acquisition)
5. Repeat the sequence for next slice
Multi-Echo EPI

RF pulse

SS

Echo 1

TE1

EPI train

Image 1
Slice 1

Echo 2

TE2 (x ms)

EPI train

Image 2
Slice 1

Echo 3

TE3

EPI train

Image 3
Slice 1

More echoes

Repeat for more slices
3 mm isotropic, 200 volumes

- TE1 = 14 ms, TE2 = 34 ms, TE3 = 64 ms
- TE1 = 10.60 ms
- TE1 = 7.54 ms

BIDS format

func_task-rest_acq-cmrr-mbep2d_rec-s2p2pF_3contrasts

Start building your protocol from one of these!

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

S = MB (sms) factor
P = GRAPPA factor
pF = Partial Fourier
CMRR multi-band EPI pulse sequence:

Multi-echo factor
CMRR multi-band EPI pulse sequences:

**Step Properties**

<table>
<thead>
<tr>
<th>Protocol Parameters</th>
<th>Multi-band accel. factor</th>
<th>Filter</th>
<th>Coil elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine</td>
<td></td>
<td>None</td>
<td>HEA,HEP</td>
</tr>
<tr>
<td>Contrast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diff</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sequence</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Multi-band accel. factor**: 4
- **Filter**: None
- **Coil elements**: HEA,HEP

**Routine Pane**

- **Slice group**: 1
- **Slices**: 64
- **Dist. factor**: 0%
- **Position**: L.6 P.16.6 H.21.7
- **Orientation**: Transversal
- **Phase enc. dir.**: A >> P
- **AutoAlign**: Head > Basis
- **Phase oversampling**: 0%
- **FoV read**: 240 mm
- **FoV phase**: 100.0%
- **Slice thickness**: 2.00 mm
- **TR**: 2560 ms
- **TE**: 88.00 ms

MB factor is on the Routine pane.
Choosing GRAPPA

GRAPPA is at the usual spot.
No motion correction with multi-echo data!
Section 3: **ANALYSIS**

1. Optimal Combination
2. Deniosing
Optimal Combination
Theoretical relationship

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

- **BOLD effects modulate $T_2^*$**
  - Activation increases $T_2^*$
- **Artifactual fluctuations modulate $S_0$**
  - Artifacts affect base signal, and not much effect on $T_2^*$
Optimal Combination: fMRIPrep

BIDS layout of the dataset
#!/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
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`


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-1Echo-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
```
Multi-echo data

Total

Image Alignment

ME-PCA

Gaussian (thermal)

Non-Gaussian (structured)

ME-ICA

BOLD (T2*)

Non-BOLD (Non-T2*)

ME - Images

Preprocessing

Slice time and motion corrections

TEDANA

Denoising and Combining

Distortion correction, filtering, smoothing, spatial normalization, rescaling

Rest of processing

Don’t do these steps before TEDANA
Classify the ME-ICA components (199) as signal and noise.

Classify these components as noise.

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

Classify the ICA components as signal and noise.
Optimally combined fMRIprep TEDANA

Denoised and optimally combined TEDANA
"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."

From TEDANA website:
That’s enough of multi-echo fMRI!