tedana Multi-echo software and communal resources

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tedana.readthedocs.io

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INTRODUCTION

Multi-echo fMRI acqusition and methods to combine echoes and improve BOLD sensitivity have been used for over two decades [Posse 1999, Poser 2006]

Multi-echo denoising methods, starting with MEICA [Kundu et al 2012], plus wider access to multi-echo fMRI pulse sequences have led to a recent increase of interest in multi-echo fMRI

Accessabilty and adaptability of software has limited the growth of these methods

Three years ago, an international group of researchers created a community-driven, open source multi-echo denoising software repository based on the MEICA algorithm. This collaboration is centered on tedana (TE Dependent ANAlysis)

tedana is

1. Open software in a best practice based development framework to test and improve multi-echo methods

2. A community and resources for people interested in multi-echo fMRI whether or not they use tedana software

Narration of this poster

https://github.com/ME-ICA/tedana-ohbm-2020

REFERENCES

Kundu, P., et al. (2012). "Differentiating BOLD and non-BOLD signals in fMRI time series using multi-echo EPI." NeuroImage 60(3): 1759-1770.
Kundu, P., et al (2017). "Multi-echo fMRI: A review of applications in fMRI denoising and analysis of BOLD signals." NeuroImage 154: 59-80.
Li, Yi-Ou (2007). "Estimating the Number of Independent Components for Functional Magnetic Resonance Imaging Data" Human Brain Mapping 28(11): 1251-1266.
Poser, B., et al. (2006). "BOLD contrast sensitivity enhancement and artifact reduction with multiecho EPI: parallel-acquired inhomogeneity-desensitized fMRI." Magn Reson Med 55(6): 1227-35.
Posse, S., et al. (1999). "Enhancement of BOLD-contrast sensitivity by single-shot multi-echo functional MR imaging." Magn Reson Med 42(1): 87-97.

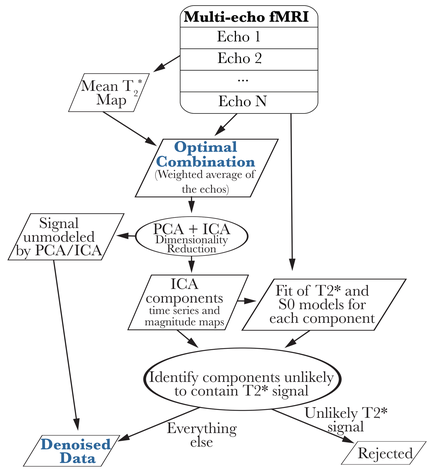
A list of other useful resources and 102 and counting publications using multi-echo fMRI is at: https://tedana.readthedocs.io/en/latest/resources.html

ACKNOWLEDGEMENTS

The November 2019 tedana coding sprint and continued tedana work at the AFNI Code Convergence was supported by the NIMH Section on Functional Imaging Methods, Scientific and Statistical Computing Core, and Scientific Director

TEDANA SOFTWARE

What the software does



Data alignment and other low-level preprocessing steps before tedana. Easily automated in AFNI and fMRIPrep

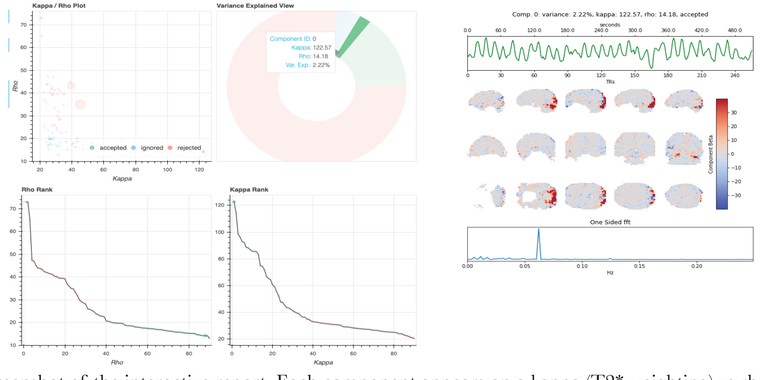
Optimal combination is just a weighted average of the echoes and results in better BOLD responses than single echo [Poser 2006; Multi-echo symposium @ OHBM2020]

ICA is used to split the data into components that can be removed if they empirically show little T2* weighting. This denoising approach can be powerful [Kundu 2017] and is also under continued development

Everything can be run with one call to *tedana* and steps can be run with modular functions

Improvements in the last year

Interactive reports make it easier to examine and understand the results of denoising



Screenshot of the interactive report. Each component appears on a kappa (T2* weighting) vs rho (S0 weighting) scatter plot, line plots, and as a share of variance. Clicking on a component shows the time series and map. This interactive report and the jupyter notebook that created it can be explored at https://github.com/ME-ICA/tedana-ohbm-2020

Bug in dimensionality reduction in PCA step was fixed. The moving average (stationary Gaussian) process method [Li 2007] was ported from GIFT (Matlab) to Python

Progress towards making the calculation of metrics and ICA component selection tree that uses those metrics fully modular and easily adaptable.

Multiple improments to developer documentation so that experienced or new open source software developers are welcomed as contributors

Software development testing code had multiple improvements and improved documentation for new developers, laying groundwork for future advances

TEDANA COMMUNITY

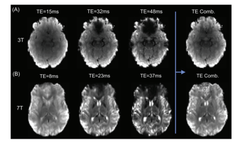
In response to discussions at OHBM 2019, we significantly expanded our documentation to provide resources for anyone who is interested in using multi-echo fMRI whether or not they use tedana software

General educational material

What is multi-echo fMRI?
Most echo-planar image (EPI) sequences collect a single brain image following a radio frequency (RF) pulse, at a rate known as the repetition time (TR). This typical approach is known as single-echo fMRI. In contrast, multi-echo (ME) fMRI refers to collecting data at multiple echo times, resulting in multiple volumes with varying levels of contrast acquired per RF pulse.

The physics of multi-echo fMRI
Multi-echo fMRI data is obtained by acquiring multiple echo times (commonly called TEs) for each MRI volume during data collection. While fMRI signal contains important neural information (termed the blood oxygen-level dependent, or BOLD signal, it also contains "noise" (termed non-BOLD signal) caused by things like participant motion and changes in breathing. Because the BOLD signal is known to decay at a set rate, collecting multiple echos allows us to assess non-BOLD.

The image below shows the basic relationship between echo times and the image acquired at 3T (top, A) and 7T (bottom, B). Note that the earliest echo time is the brightest, as the signal has only had a limited amount of time to decay. In addition, the latter echo times show areas in which is the signal has decayed completely ('drop out') due to inhomogeneity in the magnetic field. By using the information across multiple echoes these images can be combined in an optimal manner to take advantage of the signal in the earlier echoes (see processing pipeline details).



Adapted from Kundu et al. (2017).

https://tedana.readthedocs.io/en/latest/multi-echo.html

Practical advice for multi-echo users

Considerations for ME-fMRI
Multi-echo fMRI acquisition sequences and analysis methods are rapidly maturing. Someone who has access to a multi-echo fMRI sequence should seriously consider using it.

Costs and benefits of multi-echo fMRI
The following are a few points to consider when deciding whether or not to collect multi-echo data.

Possible increase in TR
The one difference with multi-echo is a slight time cost. For multi-echo fMRI, the shortest echo time (TE) is essentially free since it is collected in the gap between the RF pulse and the single-echo acquisition. The second echo tends to roughly match the single-echo TE. Additional echoes require more time. For example, on a 3T MRI, if the T2* weighted TE is 30ms for single echo fMRI, a multi-echo sequence may have TEs of 15.4, 29.7, and 44.0ms. In this example, the extra 14ms of acquisition time per RF pulse is the cost of multi-echo fMRI.

One way to think about this cost is in comparison to single-echo fMRI. If a multi-echo sequence has identical spatial resolution and acceleration as a single-echo sequence, then a rough rule of thumb is that the multi-echo sequence will have 10% fewer slices or 10% longer TR. Instead of compromising on slice coverage or TR, one can increase acceleration. If one increases acceleration, it is worth doing an empirical comparison to make sure there isn't a non-trivial loss in SNR or an increase of artifacts.

Weighted averaging may lead to an increase in SNR
Multiple studies have shown that a weighted average of the echoes to optimize T2* weighting, sometimes called "optimally combined," gives a reliable, modest boost in data quality. The optimal combination of echoes can currently be calculated in several software packages including AFNI, fMRIPrep, and tedana. In tedana, the weighted average can be calculated with t2smap If no other acquisition compromises are necessary to acquire multi-echo data, this boost is worthwhile.

Consider the life of the dataset
If other compromises are necessary, consider the life of the data set. If data is being acquired for a discrete study that will be acquired, analyzed, and published in a year or two, it might not be worth making compromises to acquire multi-echo data. 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.

Other multi-echo denoising methods, such as MEICA, the predecessor to tedana, have shown the potential for much greater data quality improvements, as well as the ability to more accurately separate visually similar signal vs noise, such as scanner based drifts vs slow changes in BOLD signal. More powerful methods are still being improved, and associated algorithms are still being actively developed. Users need to have the time and knowledge to look at the denoising output from every run to make sure denoising worked as intended.

https://tedana.readthedocs.io/en/latest/multi-echo.html#considerations-for-me-fmri

Multi-echo resources besides tedana

Other software that uses multi-echo fMRI
tedana represents only one approach to processing multi-echo data. Currently there are a number of methods that can take advantage of or use the information contained in multi-echo data. These include:

3dMEPFM: A multi-echo implementation of 'paradigm free mapping', that is detection of neural events in the absence of a prespecified model. By leveraging the information present in multi-echo data, changes in relaxation time can be directly estimated and more events can be detected.
For more information, see the following paper.

Bayesian approach to denoising: An alternative approach to separating out BOLD and non-BOLD signals within a Bayesian framework is currently under development.

Multi-echo Group ICA: Current approaches to ICA just use a single run of data in order to perform denoising. An alternative approach is to use information from multiple subjects or multiple runs from a single subject in order to improve the classification of BOLD and non-BOLD components.

Dual Echo Denoising: If the first echo can be collected early enough, there are currently methods that take advantage of the very limited BOLD weighting at these early echo times.

qMRLab: This is a MATLAB software package for quantitative magnetic resonance imaging. While it does not support ME-fMRI, it does include methods for estimating T2*/S0 from high-resolution, complex-valued multi-echo GRE data with correction for background field gradients.

Datasets

A number of multi-echo datasets have been made public so far. This list is not necessarily up to date, so please check out OpenNeuro to potentially find more.
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Publications using multi-echo fMRI
You can view and suggest additions to this spreadsheet here This is a volunteer-led effort so, if you know of a excluded publication, whether or not it is yours, please add it.

https://tedana.readthedocs.io/en/latest/resources.html#multi-echo-preprocessing-software

Guidance for people to contribute to resources or code

Contributing to tedana
This document explains contributing to tedana at a very high level, with a focus on project governance and development philosophy. For a more practical guide to the tedana development, please see our contributing guide.

Governance
Governance is a hugely important part of any project. It is especially important to have clear process and communication channels for open source projects that rely on a distributed network of volunteers, such as tedana.

tedana is currently supported by a small group of five core developers. Even with only five members involved in decision making processes, we've found that setting expectations and communicating a shared vision has great value.

By starting the governance structure early in our development, we hope to welcome more people into the contributing team. We are committed to continuing to update the governance structures as necessary. Every member of the tedana community is encouraged to comment on these processes and suggest improvements.

As the first interim Benevolent Dictator for Life (BDFL), Elizabeth DuPre is ultimately responsible for any major decisions pertaining to tedana development. However, all potential changes are explicitly and openly discussed in the described channels of communication, and we strive for consensus amongst all community members.

Code of conduct
All tedana community members are expected to follow our code of conduct during any interaction with the project. That includes—but is not limited to—online conversations, in-person workshops or development sprints, and when giving talks about the software.

As stated in the code, severe or repeated violations by community members may result in exclusion from collective decision-making and rejection of future contributions to the tedana project.

tedana's development philosophy
In contributing to any open source project, we have found that it is hugely valuable to understand the core maintainers' development philosophy. In order to aid other contributors in on-boarding to tedana development, we have therefore laid out our shared opinion on several major decision points.
1. Which options are available to users?,
2. Structuring project developments,
3. Is tedana backwards compatible with MEICA?,
4. How does tedana future-proof its development?, and
5. When to release a new version

https://tedana.readthedocs.io/en/latest/contributing.html

Ask questions: https://neurostars.org with the 'multi-echo' or 'tedana' tags
Subscribe to the tedana (low volume) newsletter: http://tinyletter.com/tedana-devs
Join the conversation: https://gitter.im/ME-ICA/tedana
Documentation: http://tedana.readthedocs.io
Code and resources are open source. Contribute at:
https://github.com/ME-ICA/tedana "good first issue" label for new contributors

OHBM Symposium, July 3-4:
"Two is better than one (and many are better): Multi-echo fMRI methods and applications"
https://www.humanbrainmapping.org/files/2020/OHBM_Two.pdf