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A checklist for fMRI acquisition methods reporting in the literature

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💬 **0 REVIEWS**

I present a checklist of acquisition parameters for inclusion in the methods section of an fMRI paper. The current list expands and updates the list that was given in the **2008 paper from Poldrack et al.** (I have reproduced below the section on acquisition that appeared in that 2008 paper.) The emphasis is on fMRI experiments that use 1.5 to 3 T scanners with standard hardware available today, but the list should work reasonably well for 7 T experiments as well. I further assume that fMRI is performed with 2D multi-slice EPI or spiral scanning and uses BOLD contrast, but parameter reporting for 3D sequences and other k-space trajectories as well as non-BOLD contrast should be feasible.

The first full version of the checklist, **version 1.1**, was presented in January, 2013. **Version 1.2** was released in December, 2014. This version is denoted 1.3 and will be the final series 1.x release. Release notes for this version appear below. The checklist was initially developed based on my experience with Siemens scanners but I have attempted to use generic descriptions as far as possible. Version 2.0 is planned for the end of 2015 and will include vendor-specific nomenclature under each parameter.

INTRODUCTION

This is version 1.3 of a checklist that was developed at practiCalfMRI.blogspot.com. Changes since version 1.2 are explained in release notes, below.

Scope: The current list deals with experimental parameters used in the fMRI data acquisition, as well as any processing steps that might be performed on the scanner before data is exported offline. Data processing steps performed after acquisition but before statistical modeling are typically called "pre-processing" by the fMRI community but "post-processing" by physicists. I have abided by the fMRI community's convention but have used quotation marks to emphasize those areas where there may be ambiguity. For example, spatial smoothing or filtering might be performed on the scanner or offline; it is important to know the entire provenance of the data submitted to subsequent analysis. This list does not deal with "pre-processing" exhaustively, however, because most steps – slice timing correction, realignment for motion correction, etc. - are generally performed after the data have been exported from the scanner. Guidelines for complete reporting of "pre-processing" steps, as well as experimental design and statistical modeling, can be found in the Poldrack reference.

Categories: Parameters are sorted into Essential and Supplemental categories based on value to a typical reader of an fMRI paper. Within each category the parameters are loosely sorted by functional similarity. In the Essential category are parameters whose omission would challenge a reader's ability to comprehend the experiment. Thus, there are several acquisition options - sparse EPI for auditory stimulus delivery is one example - classified under Essential even though they are rarely used. The assumption is that everyone would report all the Essential parameters used, *i.e.* that **a reviewer should be expected to fault a paper that doesn't contain all the Essential parameters**. Supplemental parameters can be extremely useful in assisting others in designing follow-up studies. Their inclusion may also demonstrate a solid understanding of the acquisition.

RELATIONSHIP TO PRIOR CHECKLISTS

Here is the list of parameters recommended for reporting according to Poldrack *et al.* in 2008:

RELATED ARTICLES

Concomitant physiologic changes as potential confounds for BOLD-based fMRI: a checklist
practiCal fMRI, The Winnower , 2014

PLOS Science Wednesday: Hi Reddit, We're Ben Inglis and JB Poline, and we're here to discuss methods for fMRI acquisition and analysis — Ask Us Anything!
PLOSScienceWednesday et al., The Winnower , 2015

A guide to quantifying head motion in DTI studies
Do Tromp, The Winnower , 2016

The Cardiology Show From ACC

Data acquisition
  Image properties—as acquired

MRI system:
  Manufacturer, field strength (in Tesla), model name
MRI acquisition:
  Number of experimental sessions and volumes acquired per session
  Pulse sequence type (gradient/spin echo, EPI/spiral)
  If used, parallel imaging parameters (e.g., method [SENSE/GRAPPA]
    and acceleration factor)
  Field of view, matrix size, slice thickness, interslice skip
  Acquisition orientation (axial, sagittal, coronal, oblique; if axials
    co-planar with AC–PC, the volume coverage in terms of Z in mm)
  Whole brain? if not, state area of acquisition (preferably with a figure)
  Order of acquisition of slices (sequential or interleaved)
  TE/TR/flip angle

The current list is more expansive in acquisition technical terms. However, some of the items included by Poldrack *et al.* don't feature here because they relate more closely to the experimental design. Specifically, the number of experimental sessions and the volumes acquired per session (as well as the number of separate time series acquisitions per session, which wasn't included previously) is usually a function of the task, not the scanner performance. Likewise, the scanner's performance is the same whether the slice prescription is whole brain for an adolescent or part-brain for an adult. These parameters should be described separately in the larger description of the experiment, leaving us with the task of what the scanner is doing during each time series acquisition. However, for the most part the Essential column of the current list matches the previous suggestions given above. I refer you back to Poldrack *et al.* for considerations on experimental design reporting.

RELEASE NOTES FOR VERSION 1.3

The current version (v1.3) of the checklist is available as a PDF under *Additional Assets* at the end of this paper. You can access earlier versions of the checklist (with version history) via the blog post for version 1.2. Parameter explanations appear in the final section.

Updates/changes from v1.2:

- The "Pre-scan normalization" parameter has been renamed "Signal intensity correction/normalization."

- Reviewed and revised explanatory notes.

- New parameters: RO partial Fourier scheme, Number of echoes, Saturation bands, Gradient non-linearity correction, Z-shim gradient correction, On-resonance adjustment.

ABBREVIATIONS

BOLD – blood oxygenation-level dependent (contrast)

EPI – echo planar imaging

fMRI – functional magnetic resonance imaging

FOV - Field-of-view

GRAPPA – generalized autocalibrating partially parallel acquisitions

MB - Multi-band

N/2 - Half-FOV (for Nyquist ghosts)

PE - Phase encode

RF – radiofrequency

RO - readout

Rx - Radiofrequency (RF) receiver

SENSE – sensitivity encoding

SER - Simultaneous echo refocusing

SIR - Simultaeous image refocusing

SMS - Simultaneous multi-slice

T – tesla

T_1 – Spin-lattice relaxation time

Tx - Radiofrequency (RF) transmitter

TE - Echo time

TR - Repetition time

VARIABLE NAMES AND EXPLANATORY NOTES

NB the explanatory notes below do not contain the entirety of the checklist! Some obvious variables do not appear below! Please see the PDF for the full list.

ESSENTIAL – SCANNER

Magnetic field strength: Given in tesla (T). In lieu of magnetic field strength the scanner operating frequency (in MHz) might be considered acceptable if proton (1-H) fMRI can be assumed.

Console type/model: The product name of the console/platform used as the pulse sequence controller, e.g. TIM/Trio, HDx, Achieva. Any upgraded or non-standard hardware should be reported.

ESSENTIAL – HARDWARE OPTIONS

Rx coil type: For standard coils provided by the scanner vendor, a simple description consisting of the number of independent elements or channels should suffice, *e.g.* a 12-channel phased array coil, a 16-leg birdcage coil. Custom or third-party coils might warrant more detailed information, including the manufacturer. Most head-sized coils are Rx-only these days, but specifying Rx-only doesn't hurt if there could be any ambiguity, *e.g.* a birdcage coil could quite easily be Tx/Rx.

ESSENTIAL – IN-PLANE SPATIAL ENCODING

Pulse sequence type: A generic name/descriptor is preferred, *e.g.* single-shot EPI, or spiral in/out.

Number of shots (if > 1): Multi-shot EPI isn't a common pulse sequence; single-shot EPI is by far the most common variant, even if acquired using parallel imaging acceleration. I include this option to reinforce the importance of reporting the spatial encoding accurately.

PE acceleration factor (if > 1): This is usually called the acceleration factor, R in the literature. Vendors may use their own branded notation, *e.g.* iPAT factor, ASSET factor.
PE acceleration type (if > 1): Generic names for parallel imaging methods, such as SENSE or GRAPPA, are preferred. Trade names may be acceptable provided that the actual (published) method can be deciphered from the scanner vendor and console type.

PE partial Fourier scheme (if used): Convention suggests listing the acquired portion/fraction of k-space rather than the omitted fraction. Any fraction that makes sense could be used, e.g. 6/8 or 48/64 are clearly equivalent. It is useful to specify whether early or late echoes were omitted. Also, reconstruction other than zero filling, e.g. conjugate synthesis, should be specified.

RO partial Fourier scheme (if used): While uncommon, the continued development of fMRI at 7 T may popularize this method of shortening the echo train in EPI. Reporting should follow the guidelines for PE partial Fourier.

ESSENTIAL – SPATIAL PARAMETERS

In-plane matrix: This should be the acquired matrix. If partial Fourier is used then it is beneficial to report the corresponding full k-space matrix as well as the partial Fourier fraction. (See also the *In-plane reconstructed matrix* parameter in the Supplemental section.)

In-plane filtering (if any): Non-experts may be unaware that filtering might be applied to their "raw" images before they come off the scanner. It is imperative to check and report whether any

spatial smoothing or filtering was applied on the scanner.

Slice thickness: For now I would use the numbers reported by the scanner, even though there may be some small variation across scanner vendors and across pulse sequences. For example, some vendors may use full width at half slice height while others may use a definition of slice width at or near the base.

Inter-slice gap: Best specified in mm. And as for the Slice thickness, there may be some small discrepancy between nominal and actual values depending on implementation.

Slice acquisition order: *Interleaved* or *contiguous* would be sufficient, although explicit descending (*e.g.* head-to-foot) or ascending (*e.g.* foot-to-head) options for contiguous slices would be acceptable, too. Presumably, the use of slice timing correction will be reported under the subsequent "pre-processing" steps.

Slice prescription: The orientation of the slice packet described in either logical (e.g. transverse) or anatomical (e.g. axial, coronal) terms.

ESSENTIAL – TIMING PARAMETERS

TR: For single-shot EPI with no sparse sampling delay the TR also happens to be the acquisition time per volume of data. But if sparse sampling or multiple shot-acquisition is being used then the TR should be clearly reported relative to these options. The conventional definition of TR is the time between successive RF excitations of the same slice. Ensure proper reporting of the TR (which affects the signal properties through T_1 relaxation) and the per volume acquisition time, if different. The latter time is of importance in statistical modeling and unless otherwise specified a reader may assume the per volume acquisition time equals TR.

TE: By convention the TE is defined as the time at which the center of k-space is acquired. If spin echo BOLD is used then any offset of the k-space origin from TE (that is, asymmetric spin echo) should be specified.

No. of volumes in time series: Dummy scans (not saved to disk) should be reported separately. Likewise, the use or rejection of the first n volumes for task-related reasons, *e.g.* to allow a subject to acclimatize to the scanner sounds, should also be reported separately in the post-processing segment of the experiment.

No. of averages per volume (if > 1): The majority of fMRI experiments use one signal average per TR for single-shot EPI/spiral. Use of more than one signal acquisition per k-space segment (or entirety of k-space) must be reported explicitly.

Number of echoes (if > 1): Dual and multi-echo acquisitions are being used to model BOLD from non-BOLD signal components. Include the array of TEs, any in-plane acceleration, etc.

ESSENTIAL – RF & CONTRAST

Fat suppression scheme: It's sufficient to state that fat saturation or fat suppression was used, for example. Further details aren't required unless the scheme was non-standard, *e.g.* a custom spatial-spectral excitation scheme.

Saturation bands (if used): An uncommon approach to attain reduced FOV imaging with minimal/no signal aliasing.

ESSENTIAL – SLICE ACCELERATION

SMS/MB acceleration factor: The number of slices excited simultaneously, equivalent to the spatial acceleration in the slice dimension. The total number of slices (Number of slices parameter) will be divisible by the SMS/MB acceleration factor. Note that the slice dimension acceleration (this parameter) is independent of any in-plane acceleration (*e.g.* SENSE, GRAPPA) and should be reported independently. For example, GRAPPA with R=2 should be reported as suggested in the In-Plane Spatial Encoding section, while slice acceleration should be reported here. It is unacceptable to combine the parameter reporting as one grand, overall acceleration because the practical consequences of each option are very different.

Sequence/recon name &/or version: Unlike many single-shot EPI sequences that are vendor products, most SMS/MB sequences are being actively developed and change frequently. It is imperative to report version numbers for both the acquisition and, if they aren't coupled, the reconstruction. If reconstruction is performed offline, report the method used, and any version number, in full.

ESSENTIAL – CUSTOMIZATION

Sparse sampling delay (if used): One version is called "Delay in TR" on the Siemens interface. Used most often for auditory fMRI. Other sparse sampling schemes may involve a single gap over multiple TR periods, or the in-plane imaging gradients may be disabled leaving the slice selection operational to preserve the T_1 steady state. The scheme should be described in full.

Prospective motion correction scheme (if used): PACE is one commercial option. These schemes change the nature of the time series data that is available for subsequent processing and should be distinguished from retrospective (post-processing) corrections, *e.g.* affine registration such as MCFLIRT in FSL. It is also critical to know the difference between motion correction options on your scanner. On a Siemens Trio running VB17, for instance, selecting the MoCo option enables PACE *and* a *post hoc* motion correction algorithm if you are using the sequence, ep2d_pace whereas only the *post hoc* motion correction algorithm - no PACE - is applied if you are using the ep2d_bold sequence. There's more detailed information on these options in my user training guide/FAQ.

Cardiac gating (if used): An uncommon procedure for fMRI, and should be differentiated from the recording of cardiac information during the time series.

SUPPLEMENTAL – HARDWARE OPTIONS

Gradient set type: It should be possible to infer the gradient coil from the scanner model. If not, *e.g.* because of a custom upgrade or use of a gradient insert set, then the specifications of the actual gradient coil should be reported independently.

Tx coil type (if non-standard): Most experiments use the built-in body Tx coil. It should be possible to infer the Tx coil from the scanner model. If not, *e.g.* because of a custom upgrade or use of a combined Tx/Rx coil, then the Tx coil should be reported independently. I would also advocate including the drive system used if the coil is used in anything but the typical quadrature mode.

Matrix coil mode (if used): A method for reducing the number of independent channels by combining in analog the signals from multiple coil elements. There are typically different default modes when using un-accelerated or accelerated (*e.g.* GRAPPA, SENSE) imaging.

Coil combination method: Almost all fMRI studies using phased-array coils use root-sum-of-squares (rSOS) combination, but other methods exist. The image reconstruction is changed by the coil combination method (as for the matrix coil mode above), so anything non-standard should be reported.

SUPPLEMENTAL – IN-PLANE SPATIAL ENCODING

PE direction: In EPI the phase encode direction determines the image dimension affected by distortion and N/2 ghosts. It can usually be inferred from raw data but is difficult to discern once data are processed or mapped to standard space. If in doubt, report it.

Phase oversampling (if used): The addition of extra phase encoding that can be trimmed after acquisition to a smaller final image without signal aliasing. This parameter is sometimes used for 3D anatomical scans but isn't very useful for EPI because it adds, then discards, information. If aliasing is a problem then saturation bands or changing the FOV is more efficient.

RO gradient bandwith: Not an intrinsically useful parameter on its own, it does have value if reported in conjunction with the echo spacing. (An alternative to this single parameter would be the read gradient strength (in mT/m) and the digitizer bandwidth (in kHz).)

Echo spacing: In milliseconds, the time between successive gradient echo readout periods in the EPI k-space train. Rarely reported but really useful! This number, in conjunction with the FOV and acquired matrix size, allows a reader to estimate the likely distortion in the phase encode direction of EPI.

Pulse sequence name: Could be invaluable for someone wanting to replicate a study. There may be multiple similar pulse sequences available, all capable of attaining the specifications given, but it is entirely feasible that only one of the sequences has a particular quirk in it!

k-space scheme: Readers will assume linear (monotonic) k-space steps in the PE direction unless indicated to the contrary. Centric ordering, fly-back EPI or other atypical schemes should be indicated, especially in concert with multiple shots if the *Number of shots* parameter is greater than one.

RO gradient strength: Could be useful in conjunction with information about the ramp

sampling percentage and echo spacing time, otherwise probably of limited value to most readers.

Ramp sampling percentage: Ramp sampling can increase the N/2 ghost level considerably if there is appreciable gradient and digitization (data readout) mismatch. But determining the percentage of readout data points that are acquired on the flat vs. the ramp portions of each readout gradient episode can be difficult.

Ghost correction method: N/2 ghost correction usually happens invisibly to the user, but there are some options becoming available, especially useful for large array coils (*e.g.* 32-channel coils) where there may be local instabilities with some ghost correction methods. If known, and if non-standard, then it would be nice to report. Fly-back EPI, which uses unipolar readout gradients and doesn't exhibit N/2 ghosts, should be reported explicitly if it is used.

Partial Fourier reconstruction method: If the scanner offers more than one reconstruction option, e.g. zero filling or conjugate synthesis, then the chosen option should be reported.

SUPPLEMENTAL – SPATIAL PARAMETERS

In-plane resolution: This field is redundant if the reconstructed matrix (*In-plane matrix* parameter) and FOV are reported, but I for one wouldn't object to seeing the nominal in-plane pixel size given anyway. It may make the paper a faster read.

In-plane reconstructed matrix: This is for reporting of zero filling (beyond the zero filling that may have been done for a partial Fourier acquisition) to a larger matrix than acquired, prior to 2D FT. May also be called interpolation on the scanner interface.

Gradient non-linearity correction (if used): Not generally used in EPI. May be called distortion correction on the scanner interface. It is critical to disambiguate between the PE dimension distortion correction performed offline, most often with a field map, and this gradient non-linearity correction.

SUPPLEMENTAL – TIMING PARAMETERS

No. of dummy scans: This is the number of dummy scans used to establish the T_1 steady state. Many fMRI experiments also use acquired volumes following the (unsaved) dummy scans for neuroscientific reasons, *e.g.* to allow definition of a BOLD baseline or for a subject to acclimatize to the scanner noise. "True" dummy scans and "unused volumes" should be reported separately.

SUPPLEMENTAL – RF & CONTRAST

Excitation RF pulse shape and **Excitation RF pulse duration:** Not critical for standard pulse sequences on commercial scanners, but if atypical values are set in order to achieve very thin slices, for example, then reporting these parameters may be useful. These two parameters are essential, however, when reporting SMS/MB EPI.

Signal intensity correction/normalization: Termed "pre-scan normalization" on a Siemens scanner. Typically achieved with a pair of low-resolution gradient echo scans to remove the receive field heterogeneity, the actual process may be invisible to the user. Instead, activating pre-scan normalization may simply require selection of the appropriate option. (This is the case on Siemens scanners.)

SUPPLEMENTAL – SLICE ACCELERATION

SMS/MB reconstruction type: Report details of the reconstruction type if possible, *e.g.* the kernel size for a GRAPPA-style reconstruction.

FOV shift: The sequence may use blipped controlled aliasing along the slice direction to assist in the separation of the simultaneous slices. The blips are set to produce a fixed partial FOV shift, typically FOV/2, FOV/3 or FOV/4. The FOV shift may be user-controlled or set to a fixed default.

SIR/SER factor: If simultaneous image (or echo) refocusing is used in addition to SMS/MB (as in Feinberg *et al.*, PLoS One, 2010), report the SIR/SER acceleration factor as well as the SMS/MB acceleration.

SUPPLEMENTAL – CUSTOMIZATION

Image reconstruction type: Unless specified to the contrary, most readers will assume that magnitude images were taken from the 2D Fourier transform that yielded each individual EPI. If

you use complex data - magnitude and phase - then that option should be specified along with the particular processing pipeline used to accommodate the atypical data type.

Shim routine: If manual shimming or an advanced phase map shimming routine was used, especially to improve the magnetic field over a restricted brain volume, then this information should be reported.

Z-shim gradient correction (if used): In addition to optimization of the static magnetic field – true shimming – some pulse sequences may have an option to modify empirically the imaging gradients so that dephasing is minimized. The optimal imaging gradient amplitudes may differ from theoretical values due to magnetic susceptibility gradients. These methods are most commonly applied to the slice select gradient but PE and RO options exist.

On-resonance adjustment: Conventional time series acquisitions are preceded by a single shim optimization and single on-resonance adjustment. But some sequences may use a separate on-resonance adjustment per volume (i.e. per TR) to reduce the effects of frequency drifts arising from heating in the magnet, gradient set and passive shims.

Receiver gain: Most scanners use some form of autogain to ensure that the dynamic range at the receiver is acceptable. If manual control over receiver gain is an option and is used then it should be reported because erroneous gain could lead to artifacts that aren't typically seen in EPI, and a reader could subsequently attribute certain image features to other artifact sources.

ADDITIONAL ASSETS

PARAMETER_REPORTING_V1P3.PDF	71.7 KB

REVIEWS

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