

FIELDMAP TOOLBOX MANUAL – February 2007

| | | |
|---------|--|---|
| 1. | INTRODUCTION | 2 |
| 2. | DOWNLOADING THE FIELDMAP TOOLBOX..... | 2 |
| 3. | LATEST NEWS..... | 2 |
| 4. | CREATING FIELD MAPS USING THE FIELDMAP GUI..... | 3 |
| 4.1. | <i>Create field map in Hz.....</i> | 3 |
| 4.1.1. | <i>Load defaults file (FieldMap Version 2.0 for SPM5 only)</i> | 3 |
| 4.1.2. | <i>Data Input Format</i> | 3 |
| 4.1.3. | <i>File Selection</i> | 3 |
| 4.1.4. | <i>Short TE/Long TE (ms)</i> | 4 |
| 4.1.5. | <i>Mask brain</i> | 4 |
| 4.1.6. | <i>Calculate</i> | 4 |
| 4.1.7. | <i>Write</i> | 4 |
| 4.1.8. | <i>Load Pre-calculated</i> | 4 |
| 4.1.9. | <i>Field map value (Hz).....</i> | 5 |
| 4.2. | <i>Create voxel displacement map (VDM) and unwarp EPI</i> | 5 |
| 4.2.1. | <i>EPI-based field map - Yes/No</i> | 5 |
| 4.2.2. | <i>Polarity of phase-encode blips - +ve/-ve</i> | 5 |
| 4.2.3. | <i>Total EPI readout time (ms)</i> | 5 |
| 4.2.4. | <i>Load EPI image.....</i> | 5 |
| 4.2.5. | <i>Match VDM to EPI</i> | 5 |
| 4.2.6. | <i>Write unwarpd</i> | 5 |
| 4.2.7. | <i>Load structural</i> | 5 |
| 4.2.8. | <i>MatchStructural</i> | 5 |
| 4.2.9. | <i>Help.....</i> | 6 |
| 4.2.10. | <i>Quit</i> | 6 |
| 5. | USING THE PM_DEFAULTS FILE..... | 6 |
| 6. | USING THE SPM5 USER INTERFACE..... | 6 |
| 7. | USING THE FIELDMAP IN BATCH SCRIPTS..... | 6 |
| 8. | USING THE VDM FILE WITH UNWARP | 7 |
| 9. | APPENDICES..... | 7 |
| 9.1. | <i>Processing Hz field maps.....</i> | 7 |
| 9.2. | <i>Converting Hz field map to VDM.....</i> | 8 |
| 9.3. | <i>Matching field map data to EPI data</i> | 8 |
| 10. | REFERENCES | 9 |

1. Introduction

This manual describes how to use the FieldMap toolbox for creating unwrapped field maps that can be used to do geometric distortion correction of EPI images. The toolbox is designed to be interactive so that the user can see the effect of applying different field maps and unwarping parameters to EPI images. However, once a set of parameters has been established for a specific scanning protocol, the routines used by the toolbox can also be scripted. FieldMap Version 2.0 for SPM5 also supports the new SPM5 User-Interface allowing jobs to be created and scripted. The toolbox creates a voxel-displacement map that can be used with Realign & Unwarp for doing a combined static and dynamic distortion correction.

2. Downloading the FieldMap Toolbox

FieldMap Version 2.0 can now be downloaded as part SPM5:

<http://www.fil.ion.ucl.ac.uk/spm/software>

FieldMap Version 1.1 for SPM2 can be downloaded from

<http://www.fil.ion.ucl.ac.uk/spm/toolbox/fieldmap>

3. Latest News

Version 2.0 of FieldMap is now available for SPM5. To ensure full compatibility between the FieldMap toolbox and Realign & Unwarp in SPM5, please also update *spm_get_image_def.m* and *spm_config_realign_and_unwarp.m* in the main SPM5 distribution. The main changes are listed below:

a) The convention used to describe the direction of the k-space traversal is now based on the coordinate system used by SPM. In this coordinate system, the phase encode direction corresponds with the y-direction and is defined as positive from the posterior to the anterior of the head. The x-direction is defined as positive from left to right and the z-direction is defined as positive from foot to head. The polarity of the phase-encode blips describes in which direction k-space is traversed along the y-axis with respect to the coordinate system described here. The change in convention means that if previously the polarity of phase-encode blips in the FieldMap gui was usually set to be negative, it should now be positive and vice versa. This also applies to the default value for `pm_def.K_SPACE_TRAVERSAL_BLIPODIRECTION` in the `pm_defaults.m` file which should be set to -1 if it was +1 previously and vice versa.

b) In the previous version of FieldMap, there was a bug in the application of the Jacobian modulation when using an EPI-based field map. This has now been fixed.

The toolbox now allows the user to select a specified defaults file. This means it is possible to have more than one default file containing different sets of parameters relating to different field map and /or EPI sequences. This is particularly useful for sites where more than one sequence is routinely used.

c) The toolbox can be run using the new SPM5 User Interface. This will allow FieldMap jobs to be saved serving as a log about how the data was processed. It will also facilitate scripting and batching jobs.

d) The toolbox now reads and writes files in nifti format (as does SPM5).

The toolbox now save a `vdm5_*` file which will also be expected by Realign & unwarp. If doing Unwarp with multiple sessions, but a single `vdm5_*` file, it will be necessary to select this file for each session.

e) All versions of FieldMap and Unwarp are only designed to work with images collected with the phase-encode direction in y.

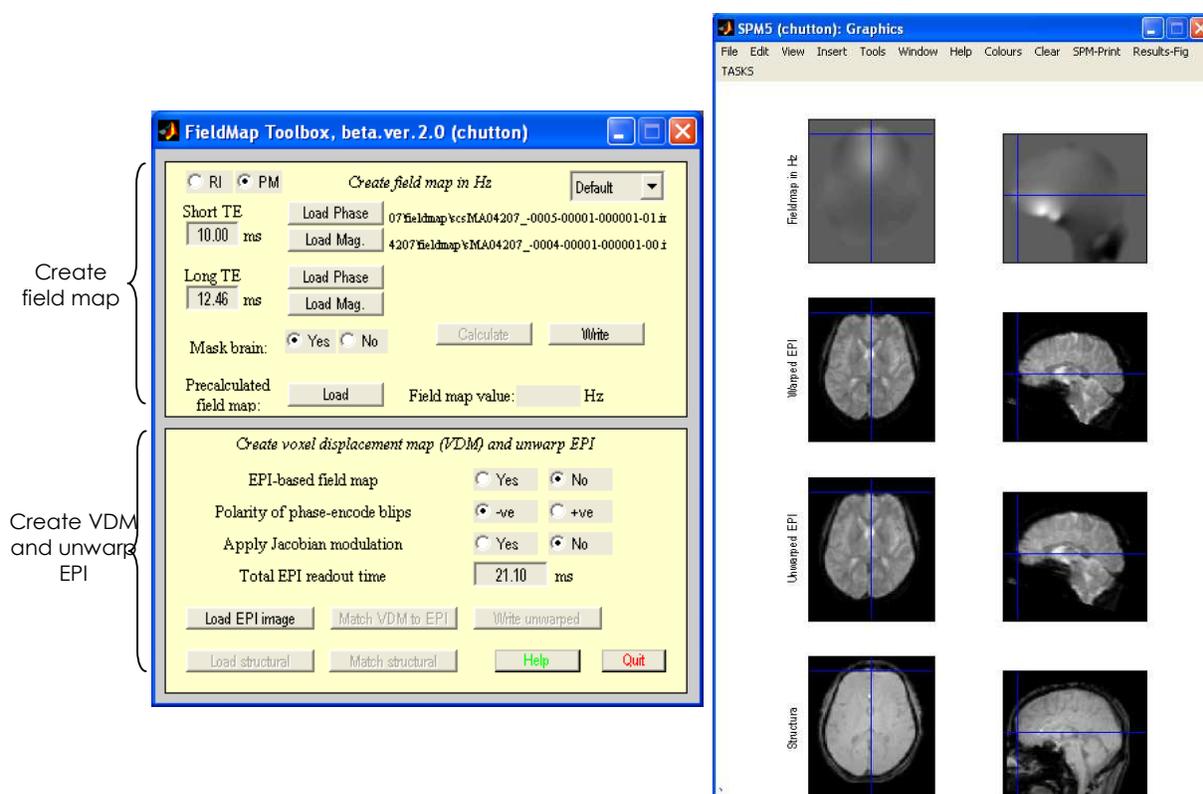


Figure 1 – FieldMap GUI and Results

4. Creating Field Maps Using the FieldMap GUI

The FieldMap Toolbox GUI is shown on the left figure 1. It is divided into two parts. The top part deals with creating the field map in Hz and the bottom part deals with creating the voxel displacement map (VDM) and unwarping the EPI. The toolbox can be used by working through the different inputs in the following order:

4.1. Create field map in Hz

4.1.1. *Load defaults file (FieldMap Version 2.0 for SPM5 only)*

Select the defaults file from which to load default parameters. If necessary, the parameters used to create the field map can be temporarily modified using the GUI. To change the default parameters, edit **pm_defaults.m** or create a new file called **pm_defaults_NAME.m** (as described in section 5).

4.1.2. *Data Input Format*

PM – The acquired field map images are in phase and magnitude format. There may be a single pair of phase and magnitude images (i.e. 2 images) in which case the phase image has been created by the vendor sequence from two echo times acquisitions. Alternatively there may be two pairs of phase and magnitude images, one for each echo time (ie 4 images). The units for the phase images **MUST BE RADIANS BETWEEN +pi and -pi**. FieldMap version 1.1 and 2.0 will ask user if this is required when the images are selected.

RI – The acquired field map images are in real and imaginary format. Two pairs of real and imaginary image volumes, one for a shorter and one for a longer echo time (ie 4 images).

NB If using SPM2, the data input format can only be changed by editing the **pm_defaults.m** file. This is described in section 5.

4.1.3. *File Selection*

Select Analyze format images for SPM2 and Nifti format images for SPM5. Generally, the acquired scanner files will be in dicom format which can be correctly converted using the dicom converter in the corresponding version of SPM. DICOM and other image formats can also be converted to using MRIcro:

<http://www.cla.sc.edu/psyc/faculty/rorden/mricro.html>

If the data input format is **PM**, load Phase and Magnitude images:

- a) Single phase image OR phase of short echo-time image.
- b) Single magnitude image OR magnitude of short echo-time image.
- c) LEAVE EMPTY if input consists of a single phase and magnitude pair OR phase of long echo-time image.
- d) LEAVE EMPTY if input consists of a single phase and magnitude pair OR magnitude of long echo-time image.

OR

If the data input format is **RI**, load Real and Magnitude images:

- a) Real part of short echo-time image.
- b) Imaginary part of short echo-time image.
- c) Real part of long echo-time image.
- d) Imaginary part of long echo-time image.

4.1.4. Short TE/Long TE (ms)

Specify the short and long echo times in ms associated with the field map acquisition. Both of these values are required even if a single phase and magnitude image is used as input.

4.1.5. Mask brain

Specify yes to generate a brain mask using the magnitude data which will be used to exclude regions of the field map outside of the brain.

4.1.6. Calculate

Calculate an unwrapped field map in Hz which is stored in memory. This represents the map of phase changes associated with the measured field map data. The processing is described in more detail in Appendix 9.1 and involves some or all of the following steps (as specified in **pm_defaults.m**):

- a) calculation of a Hz fieldmap from input data
- b) segmentation to exclude regions outside of the brain
- c) phase unwrapping
- d) smoothing and dilation of the processed fieldmap

The processed field map (in Hz) is displayed in the graphics window (top row, right figure 1) and the field at different points can be explored. The field map in Hz is converted to a VDM (voxel displacement map) using the parameters shown in the FieldMap GUI and saved with the filename **vdm_NAME-OF-FIRST-INPUT-IMAGE.img** (or **vdm5_NAME-OF-FIRST-INPUT-IMAGE.img** for version 2.0) in the same directory as the acquired field map images. The VDM file is overwritten whenever the field map is recalculated or when any parameters are changed. The resulting VDM file can be used for unwarping the EPI using **Realign & Unwarp** in SPM2 or SPM5 (see section 8).

4.1.7. Write

Write out the processed field map (in Hz) as an Analyze format image in SPM2 or a Nifti format image in SPM5. The image will be saved with the filename **fpm_NAME-OF-FIRST-INPUT-IMAGE.img** in the same directory as the acquired field map images.

4.1.8. Load Pre-calculated

Load a precalculated unwrapped field map (**fpm_*.img**). This should be a single image volume with units of Hz and in Analyze format for SPM2 or Nifti format for SPM5. The precalculated field map may have been created previously using the FieldMap toolbox or by other means. Once loaded, the

field map is displayed in the graphics window (top row, right, figure 1) and the field at different points can be explored.

4.1.9. *Field map value (Hz)*

Interrogate the value of the field map in Hz at the location specified by the mouse pointer in the graphics window.

4.2. Create voxel displacement map (VDM) and unwarp EPI

When any of the parameters below are changed, a new VDM is created and written out as **vdm_NAME-OF-FIRST-INPUT-IMAGE.img**. The **vdm_NAME-OF-FIRST-INPUT-IMAGE.mat** file is not updated unless 'Match VDM to EPI' is selected as described in section 4.2.5.

4.2.1. *EPI-based field map - Yes/No*

Select Yes if the field map is based on EPI data or No otherwise. Most scanner vendor field map sequences are non-EPI.

4.2.2. *Polarity of phase-encode blips - +ve/-ve*

Select +ve or -ve blip direction. When images are acquired K-space can be traversed using positive or negative phase-encode blips. This direction will influence the geometric distortions in terms of whether the affected regions of the image are stretched or compressed.

Apply Jacobian modulation - Yes/No

Select Yes to do Jacobian Modulation to adjust the intensities of voxels that have been stretched or compressed. In general this isn't recommended for unwarping EPI data at this stage.

4.2.3. *Total EPI readout time (ms)*

Enter the total time in ms for the readout of the EPI echo train which is typically 10s of ms. This is the time taken to acquire all of the phase encode steps required to cover k-space (ie one image slice). For example, if the EPI sequence has 64 phase encode steps, the total readout time is the time taken to acquire 64 echoes:

$$\text{total readout time} = \text{number of echoes} * \text{echo spacing.}$$

This time does not include i) the duration of the excitation, ii) the delay between the excitation and the start of the acquisition or iii) time for fat saturation.

4.2.4. *Load EPI image*

Select a sample EPI image (in Analyze format for SPM2 and Nifti format for SPM5). This image is automatically unwarped using the VDM calculated with the current parameters. The warped and the unwarped image are displayed in the graphics window underneath the field map (middle rows, right, figure 1).

4.2.5. *Match VDM to EPI*

Select this option to match the field map magnitude data to the EPI image before it is used to unwarped the EPI. In general, the field map data should be acquired so that it is as closely registered with the EPI data as possible but matching can be selected if required. If at step 4.1.3, a precalculated field map was loaded then the user is prompted to select a magnitude image in the same space as the field map. If at step 4.1.3, real and imaginary images were selected, the toolbox automatically creates a magnitude image from these images and saves it with the name **mag_NAME-OF-FIRST-INPUT-IMAGE.img**.

4.2.6. *Write unwarped*

Write unwarped EPI Analyze image with the filename **uNAME_OF_EPI.img**.

4.2.7. *Load structural*

Load a structural image for comparison with unwarped EPI. This is displayed in the graphics window below the other images (bottom row, right fig 1).

4.2.8. *MatchStructural*

Coregister the structural image to the unwarped EPI and write the resulting transformation matrix to the .mat file of the selected structural image.

4.2.9. Help

Call `spm_help` to display `FieldMap.man`.

4.2.10. Quit

Quit the toolbox and closes all windows associated with it.

5. Using the `pm_defaults` file

Input parameters and the mode in which the toolbox works can be customised in the defaults file called **`pm_defaults.m`**. FieldMap version 2.0 for SPM5, allows different defaults files to be selected. This means that it is possible to have more than one set of default parameters, e.g. to accommodate different scanners or sequences. To be recognised by the FieldMap toolbox, these files must be named **`pm_defaults_NAME.m`** and have the same format as the existing **`pm_defaults.m`**. These defaults files can be loaded using the FieldMap GUI (as described in section 4.1.1) or selected when filling in the job fields using the new SPM5 User-Interface (as described in section 6).

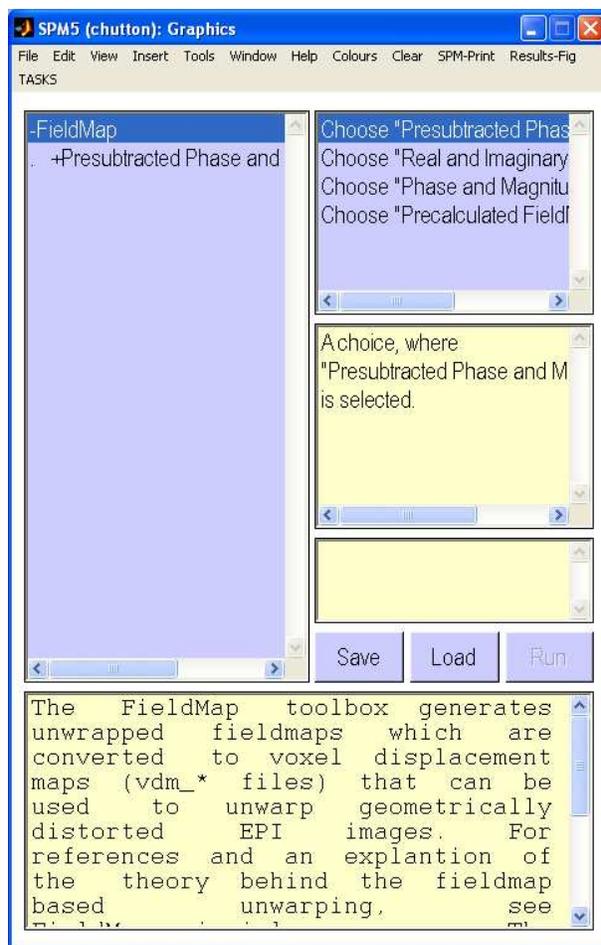


Figure 2 – FieldMap using the SPM5 User Interface

To run the script, make sure your matlab path includes the directory where the FieldMap toolbox is installed. This can be done using the **Set Path** option under **File** in the matlab windows manager or using the command:

```
addpath '/whatever/spm/toolbox/FieldMap'
```

6. Using the SPM5 User Interface

FieldMap version 2.0 for SPM5 can be run using the new SPM5 UI (figure 2). To do this, from the top menu on the SPM5 Graphics window, select **TASKS**, then **Tools** then **FieldMap**. Select the type of FieldMap job to run from 1) Presubtracted Phase and Magnitude Data (this means a single phase and magnitude pair), 2) Real and Imaginary Data, 3) Phase and Magnitude Data (this means a double phase and magnitude pair) and 4) Precalculated FieldMap. Double click on the job type in the left panel, highlight **Data** in the left panel then select **New “Subject”** in the right panel, then double click on **Subject** in the left panel to fill in the different job fields. All fields marked with an **X** must be filled in. The other fields can be optionally filled or contain default values which can be changed if required. To fill in a field, highlight it in the left panel and then click on the **Specify...** in the top right hand corner to select a file, a menu option or enter a value etc. Once all of the fields have been specified the job can be saved and run. It can also be loaded at a later date and edited for another set of data etc.

7. Using the FieldMap in Batch scripts

FieldMap_preprocess.m which calls **FieldMap_create.m** give an example of how to run the FieldMap toolbox without using the GUI.

To run the FieldMap batch script, in matlab enter the following command:

```
VDM = FieldMap_preprocess(fm_dir,epi_dir, [te1, te2, epifm, tert, kdir, mask, match] );
```

where

fm_dir - name of directory containing fieldmap images.(e.g. fm_dir =
'/home/chutton/study1/subj1/fieldmap')

epi_dir - name of directory containing epi images. (e.g. epi_dir =
'/home/chutton/study1/subj1/images')

te1 - short echo time (in ms)

te2 - long echo time (in ms)

epifm - epi-based fieldmap - yes or no (1/0)

tert - total echo readout time (in ms)

kdir - blip direction (1/-1)

mask – do brain segmentation to mask field map (1/0)

match – match vdm file to first EPI in run (1/0).

NB: FieldMap will match the field map to the first epi image in the time series (after removing the dummy scans). Therefore, epi_dir must be the directory that contains the epi run that all other images will be realigned to.

The script will create an fpm* file, a vdm* file and an unwrapped version of the EPI saved with the prescript 'u'.

8. Using the VDM file with Unwarp

In SPM, select the Realign + Unwarp option. When requested, select the vdm_* or vdm5_* file for the subject and/or session. If you acquired more than one session and a field map for each session, select the vdm file for each corresponding session. If you acquired more than one session but only one fieldmap, select the vdm file for the first session and then when asked to select the vdm file for the other sessions, select the first one again. For more information about Unwarp see:

<http://www.fil.ion.ucl.ac.uk/spm/toolbox/unwarp>

9. Appendices

9.1. Processing Hz field maps

Processing field maps involves a series of steps for which certain parameters in the **pm_defaults** file must be set. a) If the acquired field map data comprises two complex images, the phase difference between them is calculated.

b) The phase map is unwrapped using the method specified by **pm_def.UNWRAPPING_METHOD = 'Mark3D' or 'Mark2D' or 'Huttonish'**. For a description of these different methods see **pm_unwrap.m** or **FieldMap_principles.man**. The default option is **'Mark3D'**.

c) A mask is created so that unwrapping only occurs in regions where there is signal. If necessary, this mask can be expanded so that any voxel that hasn't been unwrapped and is less than **pm_def.PAD/2** voxels away from an unwrapped one will be replaced by an average of the surrounding unwrapped voxels. This can be done by setting the parameter **pm_def.PAD** to a value greater than 0. The default value is 0 but a value > 0 (eg 10) may be necessary if normal smoothing is chosen instead of weighted smoothing (as explained in the next step).

d) If required a mask can be generated to exclude regions of the fieldmap outside of the brain (in addition to the unwrapping mask described above). This step uses SPM segmentation for which the parameters in

pm_def.MFLAGS can be set. For example, if the segmentation fails, (maybe because the fieldmap magnitude image doesn't have enough contrast), **pm_def.MFLAGS.REG** can be increased to say 0.05). The other parameters control morphological operations to generate a smooth brain mask and have been set empirically.

e) The unwrapped phase map is scaled by $1/(2*\text{PI}*\text{difference in echo time})$ to convert it to Hz.

f) A weighted gaussian smoothing (weighted by the inverse of the noise) is performed on the unwrapped phase-map if the parameter **pm_def.WS = 1**. If **pm_def.WS = 0**, a normal smoothing is done. The weighted smoothing is particularly slow on large data sets ie high resolution. If field maps are acquired at high resolution then it is recommended to use **pm_def.WS = 0** and do some padding of the intensity mask eg **pm_def.PAD = 10**. The size of the Gaussian filter used to implement either weighted or normal smoothing of the unwrapped maps is usually set to **pm_def.FWHM = 10**.

9.2. Converting Hz field map to VDM

a) The field map in Hz is multiplied by the total EPI readout time (in ms,) of the EPI image to be unwrapped, resulting in a VDM. The readout time is specified by **pm_def.TOTAL_EPI_READOUT_TIME** (eg typically 10s of ms). The total EPI readout time is the time taken to acquire all of the phase encode steps required to cover k-space (ie one image slice). For example, if the EPI sequence has 64 phase encode steps, the total readout time is the time taken to acquire 64 echoes, e.g. total readout time = number of echoes * echo spacing. This time does not include i) the duration of of the excitation, ii) the delay between the excitation and the start of the acquisition or iii) time for fat saturation etc.

b) The VDM is multiplied by +/-1 to indicate whether the K-space traversal for the data acquisition has a +ve or -ve blip direction. This will ensure that the unwarping is performed in the correct direction and is specified by **pm_def.K_SPACE_TRAVERSAL_Blip_DIR = +/- 1**.

c) The toolbox must know if the field map is based on an EPI or non-EPI acquisition. If using an EPI-based field map, the VDM must be inverted since the field map was acquired in warped space. This is specified by **pm_def.EPI_BASED_FIELDSMAPS = 1 or 0**.

d) Jacobian Modulation can be applied to the unwrapped EPI image. This modulates the intensity of the unwrapped image so that in regions where voxels were compressed, the intensity is decreased and where voxels were stretched, the intensities are increased slightly. The modulation involves multiplying the unwrapped EPI by $1 + \text{the 1-d derivative of the VDM in the phase direction}$. An intensity adjustment of this nature may improve the coregistration results between an unwrapped EPI and an undistorted image. This is specified by **pm_def.DO_JACOBIAN_MODULATION = 0 or 1**.

e) When any of the above conversion parameters are changed or a new EPI is selected, a new VDM is created and saved with the filename **vdm_NAME-OF-FIRST-INPUT-IMAGE.img**. Any previous copy of the .img file is overwritten, but the corresponding .mat file is retained. It is done this way because the VDM may have already been coregistered to the EPI (as described below). Then, for an EPI-based VDM, the match between the VDM and the EPI will still be valid even if any of the above parameters have been changed. If the VDM is non-EPI-based and any of the above parameters are changed, the match between the VDM and the EPI may no longer be valid. In this case a warning is given to the user that it may be necessary to perform the coregistration again.

9.3. Matching field map data to EPI data

a) If required, the fieldmap can be matched to the EPI. This is done slightly differently depending on whether the field map is based on EPI or non-EPI data. If using an EPI field map, the magnitude image is coregistered to the EPI. The resulting transformation matrix is used to sample the VDM file in the space of the EPI before unwarping.

b) If using a non-EPI field map, the VDM is used to forward warp the magnitude image which is then coregistered to the EPI. The forward warped image is saved with the filename **wfmag_NAME-OF-FIRST-INPUT-IMAGE.img**.

10. References

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