

# fMRI User Guide

Version 1.03

[www.usa.siemens.com/healthcare](http://www.usa.siemens.com/healthcare)

**SIEMENS**

## Table of Contents

<b>1</b>	<b>Prerequisites for Running fMRI Studies</b>	<b>3</b>
1.1	Licenses	3
1.1.1	VB13A, VB15A, VB15B, VB17A	3
<b>2</b>	<b>Revisiting the BOLD Effect</b>	<b>4</b>
<b>3</b>	<b>Sequences</b>	<b>5</b>
3.1	EPI sequences for BOLD imaging	5
3.2	fMRI Acquisition	6
3.2.1	Trigger out for synchronization	6
3.2.2	Gating an EPI sequence	6
3.2.3	Interleaved slice reordering in EPI	6
3.2.4	Motion correction	7
3.2.5	Difference between ep2d_pace and ep2d_bold sequences	7
3.2.6	Analyzing data acquired using Motion Correction	7
3.2.7	Accessing motion detection parameters	8
3.2.8	Dummy scans	8
3.2.9	Slice timing	9
3.2.10	Slice time correction	9
3.2.11	Spatial filter specifications (conversion to mm)	10
3.2.12	Co-registration between data sets	10
3.3	fMRI data analysis	10
<b>4</b>	<b>Peripherals</b>	<b>11</b>
4.1	Response pad	11
4.2	Visual stimulus	11
4.2.1	Projector	11
4.2.2	LCD screen	12
4.3	Auditory	13
4.4	Eye tracker	13
4.5	Physiological monitoring	13
4.6	Synchronization	14
4.7	Installing peripheral devices	15
4.8	Identifying RF interference	16
4.8.1	RF noise tests	16
<b>5</b>	<b>Typical EPI Artifacts</b>	<b>17</b>
5.1	N/2 ghosting	17
5.2	Distortion	18
5.3	Spatial image shifts	18
5.4	Chemical shift artifact	19
<b>6</b>	<b>Setting up a basic fMRI experiment</b>	<b>19</b>
6.1	Study design	19
6.2	Running the study	20

### Important Note

This guide is for informational purposes only. Siemens does not endorse any specific third-party products that may be mentioned in this guide. These third-party products have not been officially approved by Siemens, and have been mentioned only as examples.

### Acknowledgement

Special thanks to Paul Keselman, Dept. of Neuroscience, UCSF, for his help in writing this guide.

## 1 Prerequisites for Running fMRI Studies

### 1.1 Licenses

1.1.1 VB13A, VB15A, VB15B, VB17A

#### Application Package

- Licenses
  - Features

#### Inline BOLD Imaging

- Inline BOLD Imaging
  - Single Shot EPI for BOLD Imaging (ep2d\_bold)
  - Inline BOLD Processing: Paradigm, GLM (General Linear Model), Spatial Filter, ART (Advanced Retrospective Technique)
  - Mosaic Image Format

#### 3D PACE

- 3D PACE
  - 2D Single Shot EPI for BOLD-Imaging with 3D PACE (ep2d\_pace)

#### BOLD 3D Evaluation

- MR BOLD Evaluation
  - BOLD Evaluation Taskcard for Neuro3D Evaluation
  - Evaluation with colored overlay representation
- MR 3D Offline fMRI
  - Neuro3D Taskcard (Offline Modus)
  - fMRI Offline Visualization and Analysis
- MR 3D Inline fMRI
  - Inline functionality based on Neuro3D Taskcard

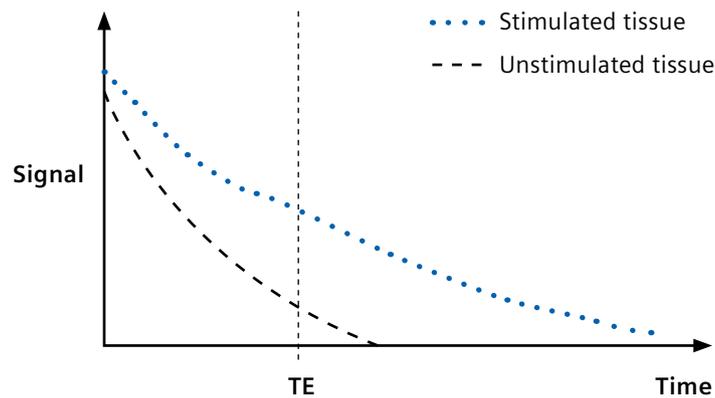
## 2 Revisiting the Bold Effect

fMRI uses the BOLD effect to detect neuronal activation. Let's review the basic facts:

- Oxygen is delivered to the cells attached to hemoglobin
- Oxygenated hemoglobin is diamagnetic – very small magnetic moment
- Deoxygenated hemoglobin is paramagnetic – has a significant magnetic moment

On activation, stimulated tissue undergoes an increase in blood flow. This in turn:

- Increases the delivery of oxygenated hemoglobin
- Decreases the amount of deoxygenated hemoglobin within the tissue, thus reducing the concentration of paramagnetic species
- Reduces the amount of susceptibility induced dephasing and therefore increases the  $T2^*$  of the stimulated tissue vs. the unstimulated tissue
- To detect these activations, brain activation studies are performed using  $T2^*$  weighted sequences
- On a  $T2^*$  image, the stimulated tissue will then have a brighter signal vs. the unstimulated tissue



**Figure 1.** Signal response from stimulated and unstimulated tissue. Increased blood flow and oxygenation increases  $T2$ , and thereby the signal intensity in stimulated regions.

## 3 Sequences

### 3.1 EPI sequences for BOLD Imaging

The following sequences are available as options for acquiring BOLD sensitive images:

#### ep2d\_fid

- Basic single-shot EPI sequence

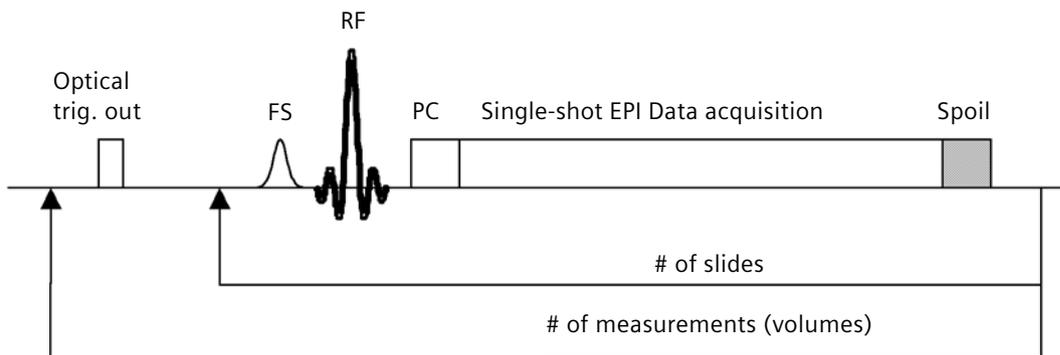
#### ep2d\_bold

- Single-shot EPI sequence with the BOLD imaging card • paradigm, GLM, t-test, spatial filter, etc.

#### ep2d\_pace

- Single-shot EPI sequence with the BOLD imaging card – paradigm, GLM, t-test, spatial filter, etc. and prospective motion correction

Here is a schematic of the EPI data acquisition scheme that is common to all three sequences:



FS = fat saturation

RF = radiofrequency pulse

PC = phase correction

**Figure 2.** Schematic of data acquisition scheme in EPI sequences. A fat suppression pulse (FS) is followed by a single-shot acquisition of the acquisition of all the slices. The fat suppression and acquisition of all slices are then repeated for the number of measurements desired. An optical trigger signal is generated for each measurement.

## 3.2 fMRI Acquisition

### 3.2.1 Trigger Out for Synchronization

The EPI sequences generate an optical TRIGGER\_OUT at the beginning of each volume (each measurement). The TRIGGER\_OUT pulse is of 10 $\mu$ s duration. This optical trigger signal is available at the U3 connection (only applicable for Tim™ Systems) on the LWL-Int board in the cabinet. Please ask your service engineer for assistance in locating this output. Typically, one needs to convert the optical signal to a TTL pulse in order to use it for synchronizing scanner activity with other devices. An optical to TTL “fMRI Trigger Converter” may be purchased from Siemens for this purpose. The output from this box is via a BNC or serial port. There are two different modes of TTL output on this box – impulse mode or toggle mode. Refer to the converter box manual for details. Please contact your local Inside sales representative to purchase this equipment.

### 3.2.2 Gating an EPI Sequence

The EPI sequence can be gated using either standard ECG or pulse triggering available through the scanner, or by means of an external trigger from another device. The external trigger can be fed into the scanner via the cinch jack trigger input on the left side of the front of the magnet cover. Of the two jacks, connect the external trigger signal to the jack that has the following symbol:



For specification on the desired shape and amplitude of the trigger signal, please refer to the System Manual, under “External Triggering.”

*Note:* The measurement is triggered by the rising edge of the external signal.

### 3.2.3 Interleaved Slice Reordering in EPI

If TOTAL # SLICES = EVEN, then the excitation order when “interleaved” is EVENS first, ODDS second, e.g. 2,4,6,8..... and then 1,3,5,7.....

If TOTAL # SLICES = ODD, then the excitation order when “interleaved” is ODDS first, EVENS second, e.g. 1,3,5,7..... and then 2,4,6,8.....

### 3.2.4 Motion Correction

MoCo checkbox controls motion correction in general. In the ep2d\_pace sequence, if MoCo is not checked, no motion correction is performed. Only the original EPI images are generated. If MoCo is selected, the following functions are performed in MotionCorrDecorator (ICE):

- DetectMotion3D
- SendPACEFeedback (controlled by m\_iPACE, set by sequence)
- CorrectMotion3D (write MoCo parameters to DICOM and log file)

If MoCo is not selected, then none of the above methods will be invoked. No motion correction takes place, neither prospective nor retrospective.

#### ep2d\_bold sequence:

MoCo ON: Retrospective motion correction, two series generated, original EPI series and MoCo series.

MoCo OFF: No motion correction, only original EPI series generated.

#### ep2d\_pace sequence:

MoCo ON: Prospective motion correction, two series generated, original EPI series (if motion is detected in a volume, all future volumes are prospectively corrected in this series) and a MoCo series (with those volumes in which motion is detected, being corrected).

MoCo OFF: No motion correction, only original EPI series generated.

### 3.2.5 Difference between ep2d\_pace and ep2d\_bold sequences

The difference between ep2d\_pace and ep2d\_bold is mainly in the sequence. ep2d\_pace retrieves the detected motion parameters in DetectMotion3D() and uses it to turn the gradients with the head (so called prospective, PACE). This now affects the original images, but only prospectively, i.e. only for the succeeding volumes.

Example:

Let's say motion occurred in volume 23. Using PACE (ep2d\_pace), volume 24 and following are turned with the motion, but volume 23 is NOT affected in the original series. In the MoCo series, volume 23 is corrected using CorrectMotion3D(). The following series do not need correction, since they are already acquired in the new tilted patient frame.

Not using PACE (ep2d\_bold), volume 24 and following still remain tilted in the original series. In the MoCo series, volumes 23 and all the following are corrected.

### 3.2.6 Analyzing data acquired using Motion Correction

If the ep2d\_pace sequence is used for acquiring data, and motion correction is checked ON, then one **must** use the MoCo series (e.g. bas\_MoCo, act\_MoCo) for data analysis, not the EPI series.

If the ep2d\_bold sequence is used, one may use the original EPI series or the MoCo series, depending on whether one wants to use the original data or retrospectively corrected data.

### 3.2.7 Accessing Motion Detection Parameters

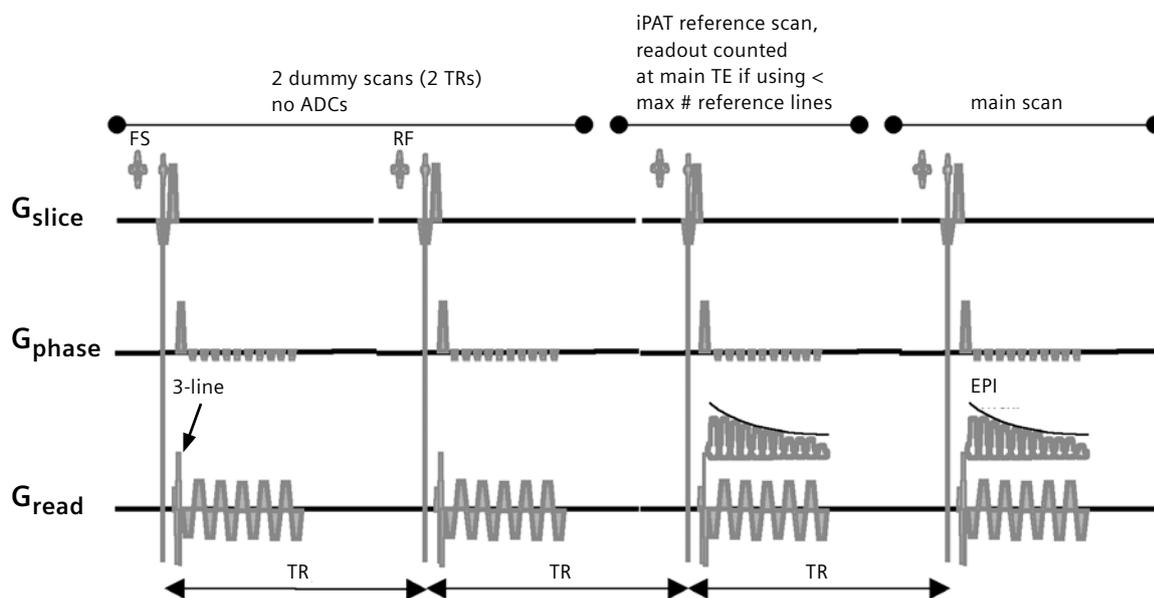
From the above explanation, it is obvious that there is only one set of motion parameters. The difference lies in whether they are used for prospective or retrospective motion correction. The motion parameters can be found under:

VB15: C:\Medcom\MCIR\Med\SimMeasData\MotionDetectionParameter.txt

VB13: C:\MRIR\Med\SimMeasData\MotionDetectionParameter.txt

VB12 and older baselines: C:\MedCom\Temp\MotionDetectionParameter.txt

### 3.2.8 Dummy scans



**Figure 3.** Schematic showing how the dummy cycles are performed in the EPI pulse sequence. Assumptions: TR = 2.5 s, iPAT = 2. Also, for simplicity, the number of slices is assumed to be 1. For a multislice protocol, the sequence of events will be identical, except that there will be multiple RF pulses and EPI readouts per TR (equal to the number of slices).

If the number of measurements or averages is greater than one, dummy scans are used. The numbers of dummy scans (used for stabilizing the signal) depend on the TR selected. The sequence takes the TR that is selected by the user, and then calculates how many repeats (so-called “dummy scans” or prep scans) to run based on a FIXED TIME of 3 seconds. No matter what the TR is, at least 1 dummy scan will always be performed. Then, based on the TR as it compares to 3 seconds, any additional dummy scans are determined. Finally, if iPAT is selected, there are one or more additional scans before data acquisition for acquiring the reference lines.

	= 1 + quotient[ 3/TR(in seconds) ]	if no iPAT
# of dummy scans	= 1 + quotient[ 3/TR(in seconds) ] + 1	if iPAT = 2
	= 1 + quotient[ 3/TR(in seconds) ] + 3	if iPAT = 3
	= 1 + quotient[ 3/TR(in seconds) ] + 4	if iPAT = 4

e.g.

Example:

If TR is 1500 ms, 2 more dummy scans will be performed (total of 3 dummy scans).

If TR is 2500 ms, 1 more dummy scan will be performed (total of 2 dummy scans).

If TR is 3000 ms, 1 more dummy scan will be performed (total of 2 dummy scans).

If TR is 3001 ms, no more dummy scans will be performed (total of 1 dummy scan).

If TR is 3500 ms, no more dummy scans will be performed (total of 1 dummy scan).

After the dummy scans, there are 1 or more scans (TRs) to acquire iPAT reference lines, depending on what iPAT factor is selected. In the EPI sequence, the iPAT reference lines are acquired separate from the imaging scans. These are acquired after the dummy scans and before the imaging scans.

### 3.2.9 Slice timing

Typically, a multislice protocol (multiple slices per measurement) is used for BOLD EPI scans. Since each slice is acquired at a different time, a “slice timing correction” must be applied to account for these differences in acquisition time in relation to the stimulus. In the MOSAIC display format though, the timing of each slice is not available, and only one time point is displayed for the entire volume. The acquisition time for each slice can be extracted from the image header in *syngo*<sup>®</sup> software version VB15A. For VB13A and earlier software versions, this time is not available in the header. The slices can be assumed to be distributed evenly in TR (Delay in TR).

Note: Take interleaved reordering when calculating slice timing, as described in Section 3.2.3.

#### 3.2.10 Slice Time Correction

This means to account for slice timing differences relative to the stimulus. This is possible with *syngo* software versions VB13A and later. See the BOLD Imaging Application Brochure, page 14, Covariates of no interest, column 5: Derivation of the activation pattern. It is necessary to model the offset in time while measuring the individual slices. Prerequisites: Parameter “Ignore after transition = 0”, and “Model transition states” active.

**3.2.11 Spatial Filter specifications (conversion to mm)**

From the BOLD Apps Brochure: Filter strength: A Gauss filter is used for image filtration. Smaller filter values effect a stronger limitation of high signal values and therefore a stronger filtration.

<u>Filter value</u>	<u>Effect</u>
2	weak
1.0	average
0.5	strong

From ICE programming manual:

```
<Label> "Filter Setting"
<Precision> 1
<LimitRange> {0.1 5.0}
// "Filter parameter for the 3D spatial filter. Please enter the value below (value must be > 0)."
```

// "Meaning: The filter window has reached zero for 'value'-times of the Nyquist frequency."

// "eff. resulting voxelsize is approx. = voxelsize \* sqrt( 1+4/(value^2) )"

// "Note: smaller value = stronger filter."

```
<Default> 1.0
```

So, for 2 mm isotropic voxels, a filter setting of 2 (weak) gives a resulting approximate voxel size of  $2 * \sqrt{1 + 4 / (2^2)} = 2.8$  mm isotropic. Average (1.0) gives 4.4 mm, strong (0.5) gives 8.2 mm.

**3.2.12 Co-registration between data sets**

There is no co-registration done in the Neuro3D taskcard. The recommendation is to use AutoAlign during data measurement. This will automatically place all the data sets in the same reference frame.

**3.3 fMRI Data analysis**

For details on how to analyze the BOLD data, please refer to the BOLD Imaging Application brochure.

## 4 Peripherals

A targeted search for brain activity requires precisely defined stimulation. Various stimuli are presented in fMRI such as visual, auditory, etc. and subject responses to these stimuli are registered, along with/without the subject's physiological information during the fMRI scan.

Following are some of the typical peripheral devices that are used for fMRI studies, and can be interfaced with the Siemens scanners:

1. Response pad
2. Visual stimulus (LCD screen, projector)
3. Auditory stimulus (headphones and microphone)
4. Eye tracker
5. Physiological monitoring (galvanic skin resistance (GSR), heart rate, respiration, pulse)

An illustration of a typical setup is shown in Figure 4.

### 4.1 Response Pad

This is a response pad that is used to register subject responses to stimuli. It acts as a keyboard input if interfacing with a stimulus computer. The signal from the response pad to the stimulus computer is typically carried over an optical cable, which prevents any introduction of external noise into the scanner room. A standard waveguide can be used to pass this cable from the scanner room to the control room.

### 4.2 Visual stimulus

Visual stimulus is generally presented by means of a projector or an LCD screen. If any of the electrical equipment is inside the scanner room, or electrical cables are running from the outside to the scanner room, care must be taken to shield the equipment and prevent contamination of the images by RF noise. Appropriate RF filters (typical attenuation > 60dB) must be used in the filter panel to pass electrical cables between the control and scanner rooms.

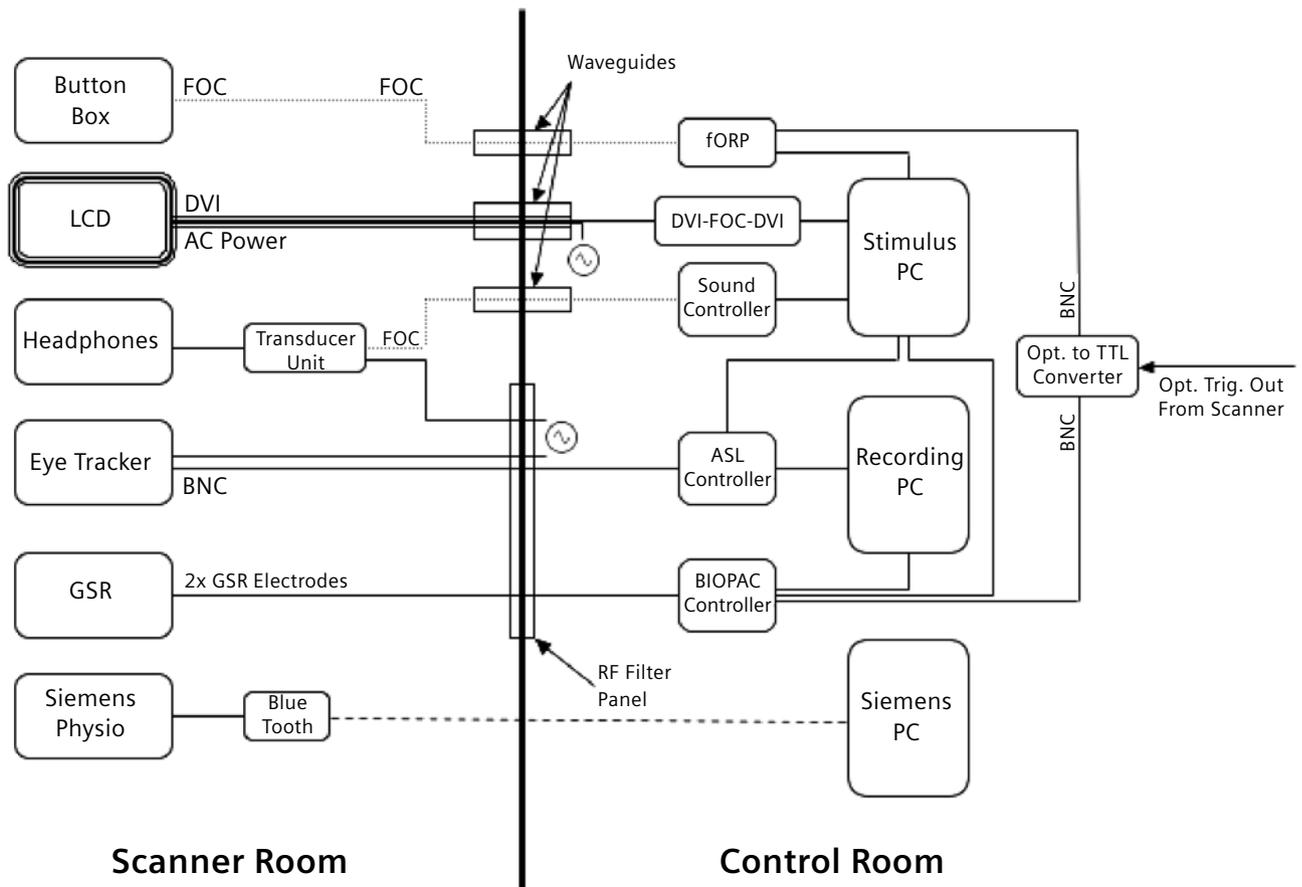
A number of commercial and free softwares are available to generate presentation scripts. These scripts are synchronized with the scanner activity by means of the TRIGGER\_OUT (optical converted to TTL) pulse generated by the EPI sequence.

#### 4.2.1 Projector

Projectors can be used in several ways. The simplest is to project through the scanner control window to a screen at the foot of the table with the lights lowered, and the subject looking at the screen with the head coil mirror. A more permanent setup is to project from outside the scanner room through a large waveguide to a screen placed at the head end of the magnet. Mirrors are required unless the waveguide enters the room from the head end of the magnet. A variety of projectors can be used, but they must be sufficiently bright and should allow additional lenses to be attached in order to minify the projection so that it is not too large when it reaches the screen. If the application demands, high-end projectors with superior contrast and resolution may be required. Depending on the type of projector and the scanner room layout, the projector can potentially be put inside a Faraday cage (an electrically conducting enclosure) and placed inside the scanner room, but care must be taken that this does not introduce significant RF noise.

#### 4.2.2 LCD Screen

An LCD screen placed near the foot end of the table or behind the bore may be used for visual stimulus presentation. This form of visual presentation has excellent quality in terms of visual clarity and signal fidelity. At the same time however, it is very challenging to install inside a magnet room compared to a projector screen, since there are many noise sources within the device that can affect image quality. First, the whole screen must be stripped of all ferromagnetic parts, and a Faraday cage must be built around it. The front of the LCD screen must also be RF shielded to prevent noise leaking through the front. This is achieved by using electrically conductive glass (min. attenuation desired > 60dB) to cover the front of the screen, and connecting it electrically to the Faraday cage. The power supply may be separated from the screen, since it is most susceptible to failure (iron core transformers) due to high magnetic fields.



**Figure 4.** An example of an fMRI peripheral equipment setup. GSR: galvanic skin resistance.

The cables carrying power and the video signals from the stimulus computer must connect to the screen by means of two filter panels, one between the scanner and control rooms, and the other on the Faraday enclosure around the screen. Despite all the measures, LCD monitors can still pose a challenge to contain RF noise completely.

### 4.3 Auditory

Auditory stimulus can be presented by means of special MR compatible headphones. A pair of headphones would usually require some kind of amplification to deliver an audio signal over a large distance. This amplification could either be done inside or outside the scanner room. If the amplification is done inside the room, care must be taken in delivering power to the amplification unit. Both DC and AC power can be easily supplied via a filter in the penetration panel. An extra AC power filter is available in the Siemens panel, but a custom penetration panel can be installed for other filtering needs. Inexpensive DC power filters can be purchased from any large electronics supplier. The audio signal itself could be delivered to the headphones in two ways. Optically, via a fiber optic cable through a waveguide, or electrically, through a filter in the penetration panel. Usually, well-shielded co-ax cables are sufficient for shielding the audio signal from external RF noise. However, it is still a good idea to use a low pass filter to take away any noise that might be coming from the sound control unit. Please be aware that depending on the construction of the headphones, any RF noise present in the scanner room could easily use the headphone wires as a conduit and introduce artifact in your images.

An optical microphone is a perfect candidate for recording subject voice responses. If recording must be done during a scan, a noise canceling option must be available for voice recording.

### 4.4 Eye Tracker

An eye tracker can be used to monitor subject eye movements in response to a given visual stimulus. In order to reduce the possibility of introducing artifacts into MR images, the eye tracker must be placed away from the scanner. Placing a unit at the back of the bore is ideal for scanner setup. However, due to the large distance from the eye, the tracking accuracy is not as good as one could achieve outside of the scanner. Again, care must be taken to filter both power and video signal. However, one must be careful not to over-attenuate the video signal as not to affect eye-tracking quality.

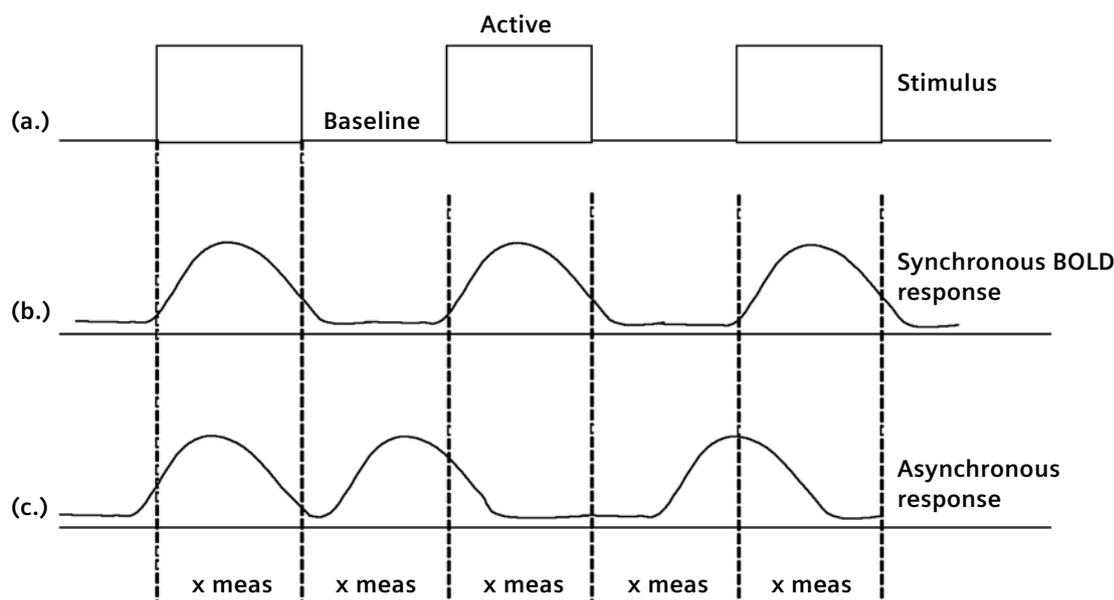
### 4.5 Physiological Monitoring

A few different physiological signals may be monitored during an fMRI exam. Signals such as heart rate, breathing, and pulse may be measured and correlated with data acquisition and stimuli. The galvanic skin resistance can also be measured as a form of subject response to stimuli. These physiological recordings can then be used as regressors in the fMRI analysis to remove signal changes extraneous to the presented stimulus.

ECG, respiration, and pulse monitoring are available through the Siemens scanner, while GSR monitoring (operating within a magnetic field) is available commercially as an external unit. For details on how to set up the Siemens wireless ECG, respiratory cushion, and pulse oximeter, please refer to the System manual of the scanner. The signals from these devices may be saved in the form of text files by using specialized sequences. This enables easy co-registration of the physiologic signals with data acquisition. All signals may be logged simultaneously.

#### 4.6 Synchronization

Usually, EPI data acquisition consists of multiple 2D slices, which are referred to as a volume or measurement. Each volume is acquired in 1 TR, and the data acquisition of a volume is repeated for the number of measurements specified. In a typical fMRI experiment, a stimulus may be presented for “x” measurements, then the stimulus may be switched OFF for the next “x” measurements, and ON again for the next set of “x” measurements, and so on. fMRI data analysis then tracks signal change in a voxel over time and correlates signal change to the stimulus presented, as a function of time. If signal change is found to be synchronous with stimulus change, then we say that we have a BOLD response (Figure 5).



**Figure 5.** Stimulus presented during an fMRI experiment (a) and how signal changes in a voxel are compared (b,c). In trace (b), the signal changes in the voxel correlate well with the stimulus presented, and we have a “synchronous” BOLD response. In trace (c), the signal change in a voxel is not correlated with the stimulus presented, and the signal may change due to factors other than the stimulus.

A critical aspect of the above evaluation is the knowledge of when our stimulus was presented with respect to the EPI data acquisition, in order to align the starting time points of both traces – the stimulus and the voxel signal change. To be able to correlate brain activity with stimuli, it is important that all events – stimuli, subject response, and physiological measurements – be synchronized.

There are two ways in which one can synchronize activities: manual or automatic. Manual synchronization is not accurate and is therefore not recommended. However, if it is absolutely necessary to manually synchronize your stimulus presentation with the EPI sequence, one first needs to calculate how many dummy scans the EPI sequence will be running (see Section 3.2.8). Based on this knowledge, one can start the sequence first, then count the measurements (dummy scans) by hearing the gradient sounds (each measurement will typically be a continuous sound, followed by a small break, and then followed by the next measurement), and start the stimulus presentation when the required numbers of measurements = dummy scans are completed. If the stimulus needs to be manually switched between “Baseline” and “Active” states (Figure 5, trace (a)), one can use the display at the bottom left on the screen, which displays either “B” (Baseline) or “A” (Active) to indicate what part of the paradigm is being acquired by the EPI sequence. This paradigm displays what is specified on the BOLD card in the protocol menu of the sequence. For example, if the total numbers of measurements is 60 in the EPI measurement, and the paradigm size is set to 20, with measurements 1 to 10 being “Baseline” and measurements 11 to 20 being “Active”, then you will see the display “B” at the bottom left of the screen for the first 10 measurements. On the 11th measurement this display will switch to “A” until the 21st measurement, when it will switch back to “B”, and so on. When “A” and “B” toggle, that is the cue for switching the stimulus between “Baseline” and “Active” states.

Automatic synchronization is usually done by means of a TTL signal that is fed to all the various equipments used, and serves as a reference signal for timing of stimulus, EPI data, physiological measurements, etc. In general, a separate computer, other than the scanner, controls the stimulus presentation. The physiological recordings can either be controlled by another separate computer (preferred) or the stimulus computer. Since different events are controlled by different machines, all events are synchronized by means of a timing pulse that is generated by the EPI sequence on the scanner, and is fed as input to all other computers that control either stimulus presentation or physiological monitoring. A TTL pulse can be read into a computer in several ways. Some data acquisition peripherals come with an analog input option. If free slots are available on the motherboard, an analog I/O card can be purchased. Or if one has access to an electronics shop, an adapter can be made for the parallel port that would drive a pin high or low when a pulse is sent. For details on the synchronization signal, please refer to Section 3.2.1.

#### 4.7 Installing peripheral devices

The major challenges to installing peripheral devices within the scanner room are the introduction of RF noise in the images, and the effect of a strong magnetic field on the device itself. The former may lead to a loss of SNR in the images, and may cause artifacts, while the latter may damage the peripheral device. RF noise causes degradation of image quality and may go undetected for a long time if it doesn't cause readily visible artifacts. Moreover, once all peripheral devices are installed, diagnosing the source of RF noise can be very laborious. Therefore, it is critical that utmost care be taken when installing the devices.

The higher the magnetic field, the higher the likelihood that any components in the device may fail. In general, the magnetic field drops rapidly as the distance from the scanner increases. Conversely, as the device is brought closer to the magnet, the magnetic field that the device experiences rises rapidly. Typically, electronic devices with inductors, transformers with iron cores, CRTs, metallic objects in motion, etc. will be affected the most by the magnetic fields.

## 4.8 Identifying RF interference

### 4.8.1 RF Noise tests

Please ask your local service engineer for details on how to run RF noise tests. Noise tests must be performed with the head coil and the table in either the home position or with the table positioned at its farthest end (head coil outside the bore). No phantom is necessary for this test. With the table positioned outside the bore, the test can be run only from the Service menu, with the Adjustments in Service mode. It is critical not to position the head coils inside the bore for these tests because of the Faraday shield in the magnet. This shield reduces the noise in the room from contaminating the images. If the head coil is positioned inside the bore, then one can get clean noise tests despite noise being present in the room. The same noise can then contaminate images once a patient is positioned on the table as the patient's body can act as an antenna and carry the noise inside the bore, reducing the effectiveness of the shield.

First, perform a baseline noise test without any external devices in the scanner room. Repeat the test 3 times. This data can serve as a reference data set. The noise test should be repeated after each new device is installed within the scanner room. Starting from a room with no external peripheral devices, install each peripheral one at a time, and run noise tests after each device is installed.

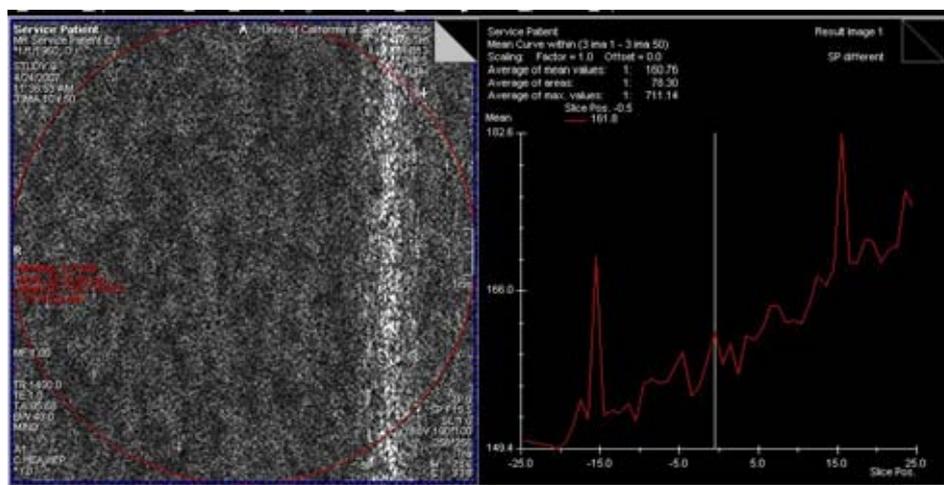


Figure 6. RF noise.

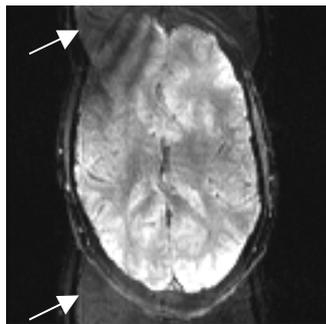
A typical RF noise artifact will appear as a bright line in the image. This pattern indicates that the RF noise is at a specific frequency. Such noise is easy to notice in an image as it is readily visible as an artifact. There may also be white noise (broadband noise) introduced by the peripherals, which will not appear as a distinct pattern, but will increase the overall level of the noise, and if it is high enough, can saturate the signal intensity in the image. This noise can go undetected if one only performs a visual inspection of the images. Therefore, in addition to visually analyzing the images, it is good practice to look at the mean intensities of the noise. This can be done by loading the images from the noise test series into the "Mean Curve", drawing a large ROI in the image, and plotting the intensities through the image series. An example is shown in Figure 6. In addition to the spikes that are observed in the plot, which indicate a frequency-specific noise, the mean intensity across the images (~100 in the example in Figure 6, which is normal) is also important as an indicator of the level of white noise. In the noise test, there may be no distinct noise pattern observed in the images, but the mean noise level may be much elevated compared to the baseline (e.g. ~ 1000). Usually, the Mean Curve plot will also show a somewhat linear variation in the noise across the images, which is mostly a characteristic of the coil, and is not consequential, unless the gradient is very large.

## 5 Typical EPI Artifacts

The most typical image artifacts in an fMRI exam may be:

- N/2 ghosting
- Distortion
- Spatial shifts
- Chemical shift

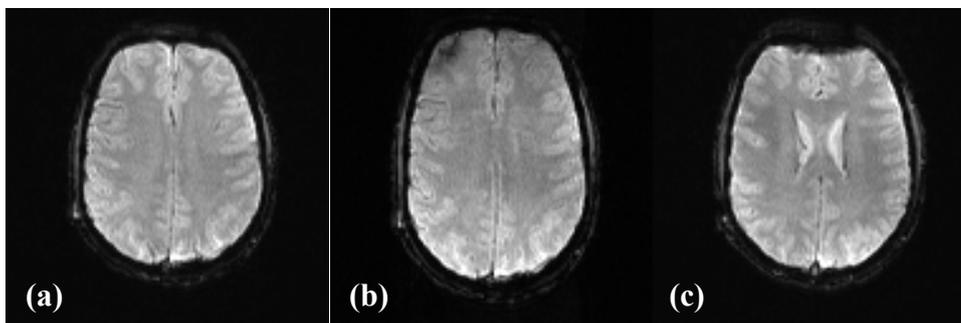
### 5.1 N/2 Ghosting



**Figure 7.** Example of N/2 ghosting in an EPI sequence.

These artifacts appear as ghosts of the main object, displaced by half the field-of-view (FOV). There are a number of reasons why one could get N/2 artifacts, but one of the main reasons is mechanical resonance of the scanner components. To avoid this, use an EPI echo spacing that does not fall within the mechanical resonance region of the scanner. Typically, for a Tim-TRIO system, the echo spacing in the range of 0.6-0.79 ms causes resonance, and should be avoided. Parallel imaging (iPAT) reconstruction artifacts could also manifest as N/2 ghosting. The numbers of reference lines could be increased (to 36-42) to improve the performance of iPAT reconstruction. In the EPI sequences, the iPAT reference lines are acquired separately, due to which there is no acquisition time penalty by increasing the number of reference lines acquired. However, the reconstruction time may increase.

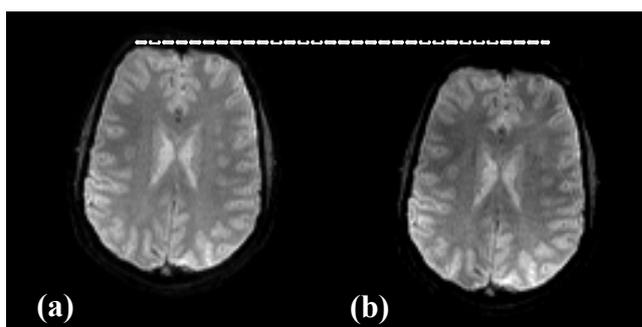
## 5.2 Distortion



**Figure 8.** Distortion in an EPI sequence. Image (a) (reference) was acquired after shimming and frequency adjustments were performed. The shim was intentionally disturbed in the y-direction to demonstrate global image distortion (stretching) in (b). Despite shimming, there are large susceptibility induced gradients near the sinuses due to air-tissue interfaces that cause local distortions in the frontal lobe (c).

Despite shimming, different areas of the brain may have different resonant frequencies due to susceptibility differences. These effects are pronounced especially near the sinuses due to the large susceptibility gradients induced by air-tissue interfaces. Due to spatially varying resonant frequencies, spins are incorrectly localized in the image, leading to distortion artifacts. A common method to reduce distortion is to use parallel imaging or partial Fourier acquisitions to shorten the echo train. A small level of distortion near the sinuses and frontal lobe is normal.

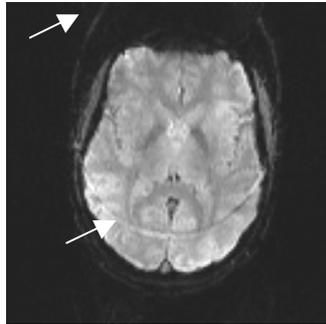
## 5.3 Spatial image shifts



**Figure 9.** Spatial image shift in EPI sequence. Image (a) (reference) was acquired using an EPI sequence after shimming and frequency adjustment. For image (b), the synthesizer frequency was intentionally shifted by 150 Hz to demonstrate the effect of mismatch between the Larmor frequency of the spins and the synthesizer frequency as a result of B0 drift. Note that image (b) is spatially shifted with respect to image (a).

Spatial shifts occur in EPI images due to B0 drifts, resulting in a mismatch between the Larmor frequency and the synthesizer frequency. The ep2d sequences have a built-in B0 drift correction that is applied during a scan. To minimize spatial shifts, it is important to perform frequency adjustments before each EPI scan, which is also done automatically by the EPI sequence.

## 5.4 Chemical shift artifact



**Figure 10.** Chemical shift artifact in EPI.

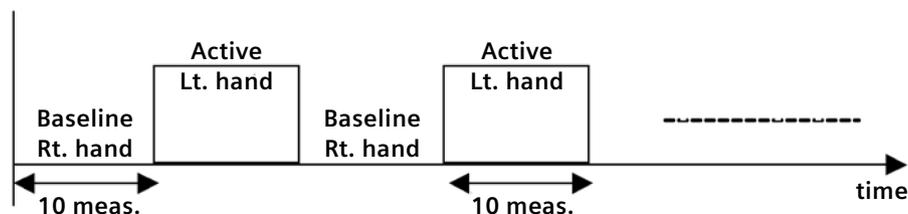
Note that the fat pixels are shifted spatially in the image in the phase-encoding direction due to their chemical shift frequency offset (440 Hz at 3T).

In an EPI sequence, the readout bandwidth is quite large, on the order of 1300-2000 Hz/pixel. At 3T, this results in a fat-water pixel shift of only approximately half a pixel. The bandwidth in the phase-encoding direction however is much lower, in the range of 20-30 Hz/pixel for a typical protocol. For these bandwidths, the fat pixels will be shifted by 10-20 pixels, or about 3-4 cm at typical spatial resolutions. To avoid chemical shift artifacts, a fat suppression pulse is implemented prior to each imaging volume.

## 6 Setting Up a Basic fMRI Experiment

### 6.1 Study design

Let's run a basic experiment to get started on fMRI. We will run a block design experiment, i.e. ON and OFF design, with a simple motor task such as finger tapping. In this task, the subject touches his/her thumb consecutively with the index, middle, ring, and little fingers of one hand at a time. After a specified time, the subject switches finger tapping to the other hand.



**Figure 11.** Block design finger tapping motor task.

We will set up the EPI sequence for a TR of 3s and 60 measurements. On the BOLD card on the protocol menu, define the GLM paradigm size as 20, with the first 10 measurements as "Baseline" and the next 10 measurements as "Active." What this defines then is our ON time and OFF time in the block design, i.e. we will now have (10 measurements x 3s) time of right-hand finger tapping (or "Baseline" state) and (10 measurements x 3s) time or left-hand finger tapping (or "Active" state). In data analysis, the BOLD signal variation is compared to the motor task timing to estimate correlation. For slice positioning, we have to cover the motor cortex. To minimize slice planning, we will scan a large number of slices, covering the whole brain.

The EPI sequence and the motor task can be synchronized manually by giving the subject instructions to "switch" hands through the microphone. Since our paradigm size is 20 measurements, with 10 measurements "Baseline" and 10 measurements "Active," the subject will have to switch hands every 10 measurements or 30s.

### 6.2 Running the study

1. Set up patient in the head coil.
2. Run a localizer scan from Exam Explorer->Siemens->Head->clinical libraries->general->localizer
3. Then run the MPRAGE scan (t1\_mpr\_ns\_sag\_p2\_iso) to get an anatomical reference scan. This sequence can be found under Exam Explorer->Siemens->Head->advanced applications->bold-imaging. Use sagittal orientation for the scan volume, and position the volume such that the whole brain is covered. See Figure 12 for reference.

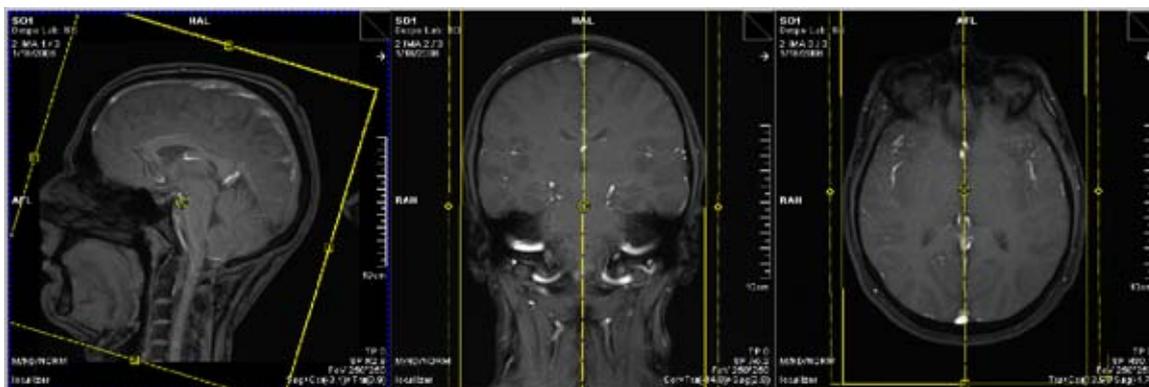


Figure 12. Adjusting scan plane for the anatomical reference T1-weighted MPRAGE scan.

4. Load the ep2d\_pace\_dynt\_moco protocol, found under Exam Explorer->Siemens->Head->advanced applications->bold-imaging. Open the protocol, and confirm the following parameters on the BOLD card: number of measurements = 60, paradigm size = 20, first 10 measurements = Baseline, next 10 measurements = Active (see Figure 13). Position the scan plane as shown in Figure 14.

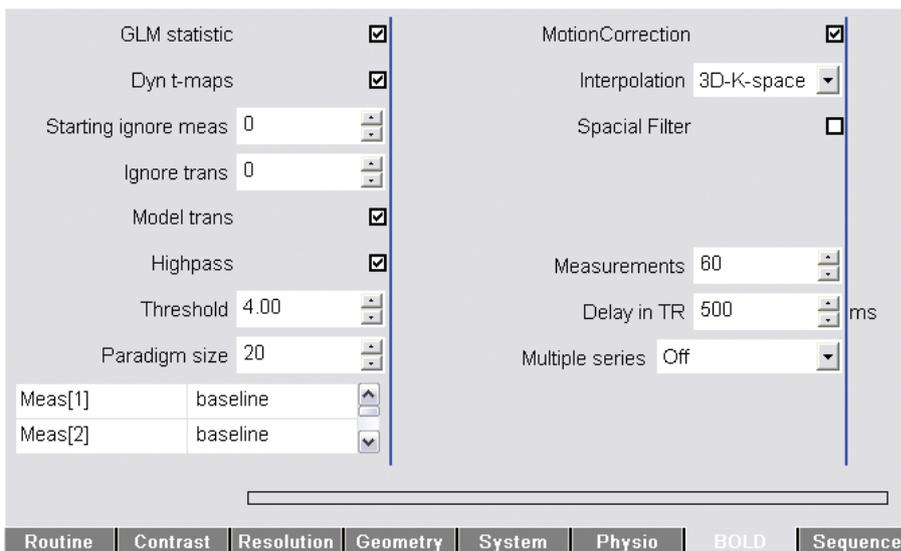
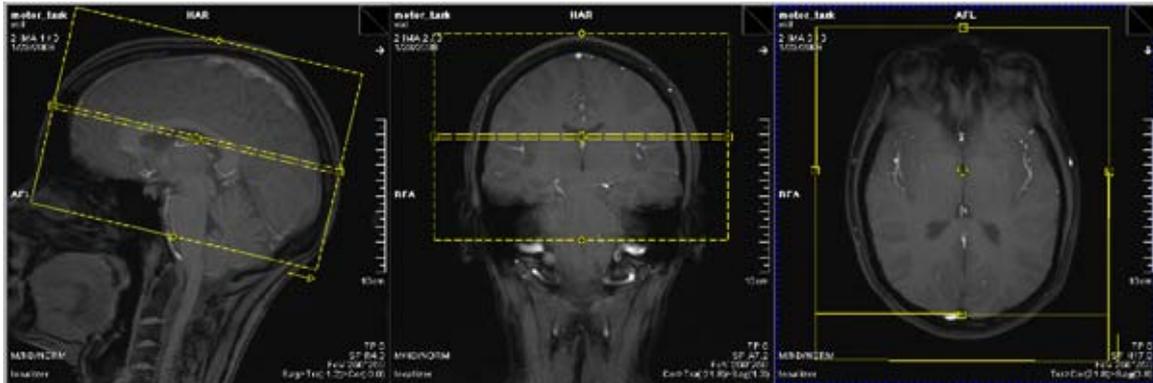


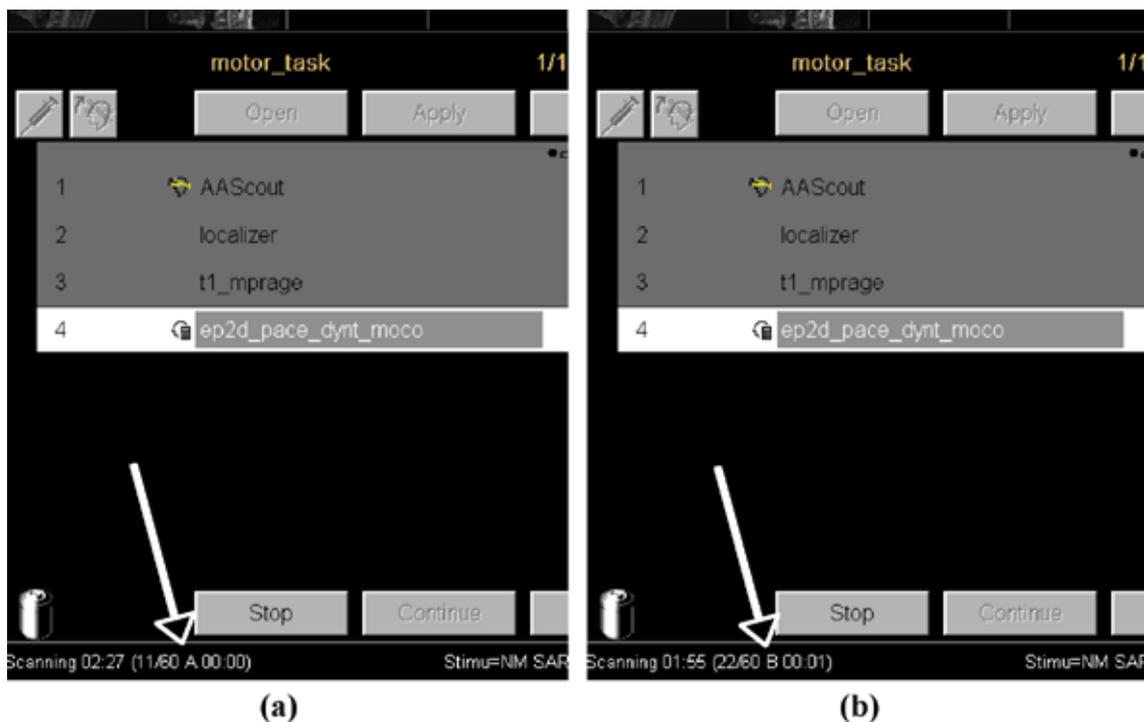
Figure 13. BOLD card of the EPI sequence.



**Figure 14.** Positioning scan for the EPI BOLD scan using finger tapping as the paradigm.

5. Ask subject to start finger tapping with his/her right hand, and then start the sequence.
6. The sequence will first run the prep scans. At the bottom left on the screen is a display that indicates what part of the paradigm is running, baseline ("B") or active ("A"), and the current measurement number (see Figure 15). The counter increments as the scan progresses with the measurements.

The experiment starts with the display "B", which indicates the Baseline state. In this experiment, we have a paradigm size of 20, with 10 Baseline and 10 Active states. Therefore, measurements 1 through 10 will be Baseline, then 11 through 20 will be Active (which completes one set of the paradigm of 20 measurements), 21 through 30 will be Baseline again, 31 through 40 Active, and so on. Therefore, when the 10th measurement is completed and 11th is about to begin, the display switches from "B" to "A", indicating the "Active" part of the paradigm. This is your cue to ask the subject to switch the finger tapping hand from right to left. Similarly, after the 20th measurement is completed, the display will switch from "A" to "B", and it is time to ask the subject to switch the finger tapping hand from left to right again. Keep repeating this procedure until the scan is completed.



**Figure 15.** Counter that indicates time when to switch hands for finger tapping. The sequence starts with displaying “B”, and will show the numbers of measurements counting up from 1 to 60 (total number of measurements). Image (a) shows the counter switching to “A” when the measurement number goes to 11 (since paradigm size is 10). In image (b), the counter switched back to “B” at measurement 21, and the sequence is now scanning measurement 22 of a total of 60. As soon as either “B” switches to “A”, or “A” switches to “B”, the subject should be asked to switch his/her finger tapping hand.

7. Once acquisition is completed, start the Neuro3D application from the “Applications” menu. Load the following series of images, in the indicated order:
  - (a) t1\_mpr\_ns\_sag\_p2\_iso (t1\_mprage)
  - (b) act\_MoCoSeries
  - (c) Eva\_GLM
8. Move the cutting planes to visualize the motor cortex as shown in Figure 16. Distinct activation will be seen in the motor cortex. (Note: The alpha value for statistical significance can be set in Visual->Functional Properties if activation is not seen clearly – it is typically approximately  $\pm 4$ ). Since our paradigm involved finger tapping with both hands, one at a time, activation can be seen in both hemispheres of the brain.



9. Now, switch ON “Start Evaluation Mode” on the Neuro3D card. A graph will be displayed in the bottom left square of the Neuro3D card. In this mode, one can draw ROIs in the activation areas to look at their signal variations through all the measurements. Draw two ROIs – one in the motor cortex of each hemisphere.

10. When these ROIs are drawn, the plot at the bottom indicates the block design of our experiment – our paradigm (in white), the signal changes in the right hemisphere (in red) and signal changes in the left hemisphere (in green) as a function of number of measurements. The plot shows that the signal variations in the ROIs are synchronous with the paradigm that we defined in the protocol, which was why a statistically significant activation was detected in these regions. For comparison, an ROI is also drawn in a region without any activation – note that the signal changes are random, and not associated in any way with the stimulus.

As we had described in the protocol, measurements 1 to 10 were “Baseline” or right-hand finger tapping, where we get high signal in (green), i.e. the left brain. During measurements 11 through 20, the subject is finger tapping with the left hand, and correspondingly the signal in the motor cortex in the right hemisphere increases (red), while that in the left hemisphere (green) decreases.

Also seen in these plots are the motion parameters (translation and rotations in x, y, and z) that were used for prospective motion correction (PACE), as a function of the numbers of measurements.

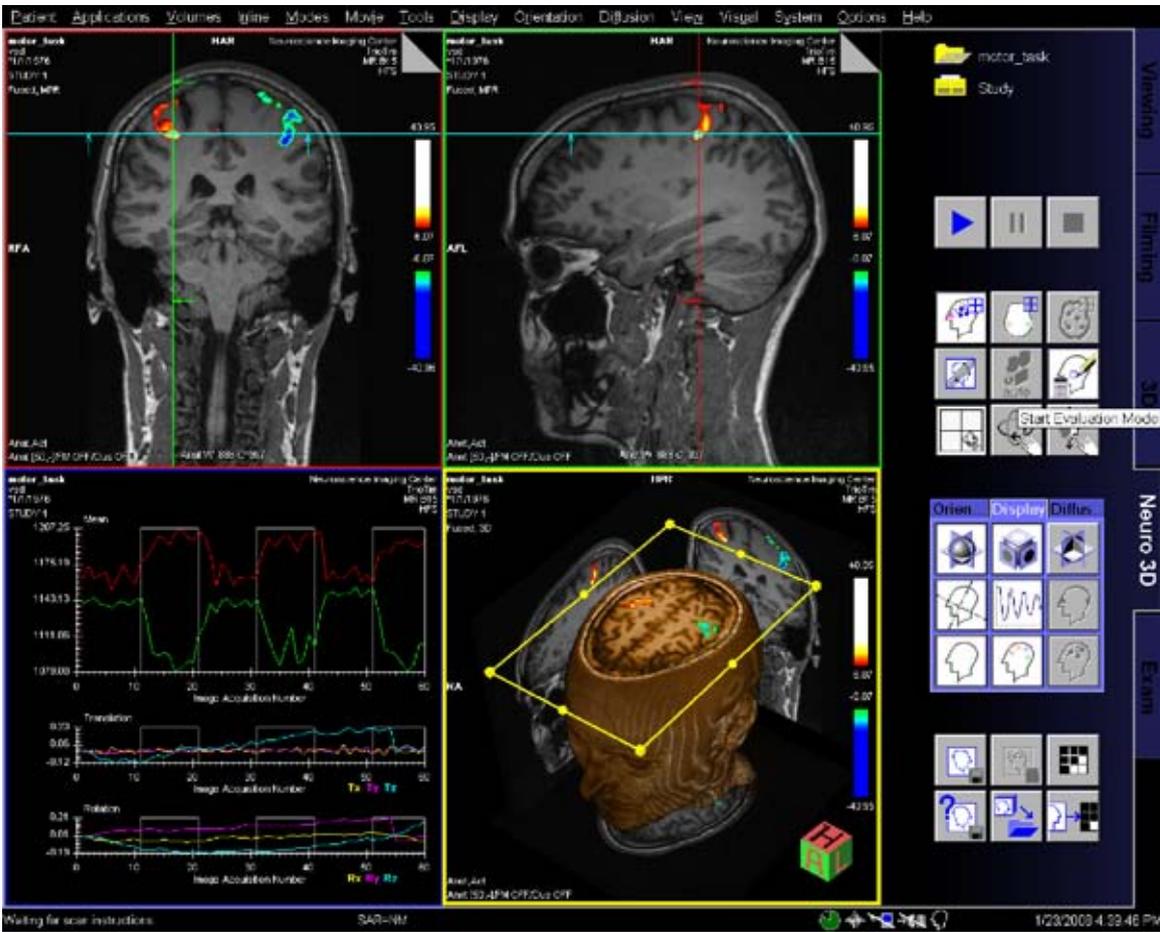


Figure 16. fMRI data processing in the Neuro3D taskcard. Location of the “StartEvaluationMode” button is also indicated.

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