

Application Note 242: ECG Signal Processing During fMRI

This application note is concerned with the recording of real-time ECG during a fMRI investigation.

Equipment

- MP150WSW data acquisition system with AcqKnowledge®
- MECMRI-BIOP MRI-compatible cable/filter set
 - ECG100C electrocardiogram amplifier module
 - LEAD108B or C electrode leads (15 cm or 30 cm)
 - EL508 MRI-compatible/radiotranslucent electrodes
- Insulating barrier—LEAD108s are designed for MRI, and are designed to minimize circulating currents, and although they have never been known to get hot (or even warm), it's always wise to put safety first and assume that they *might* get hot or warm. The insulating barrier should be at least 0.5 cm thick and its principle purpose is to keep the electrode leads from touching the bare surface of the subject's skin. Material options include: simple foam mat, like a thin exercise mat; a small towel folded over a few times; or foam piping insulation, for 1/4" OD copper tubing, to slide around the electrode leads.

Setup

- 1) Prepare the skin surface.
Remove hair and lightly abrade the skin surface (using ELPAD) to create a good conductive path between electrode and skin surface.
- 2) Apply EL508 MRI-compatible/radio translucent electrodes.
Place EL508 electrodes to the subject's torso. Place the electrodes so they are as close to the heart as possible, but still far enough away to accurately characterize the desired ECG vector.
 - For HRV evaluations, it may be most helpful to acquire a LEAD II ECG
- 3) Connect LEAD108B or C (15 cm or 30 cm) radio translucent electrode leads to the EL508 electrodes.
 - a. **Do not twist the electrode leads together or loop them**—just run the leads parallel with each other from the MECMRI cable attachment point to the subject electrodes. It's OK to have the leads touch each other, just try to keep the leads all running in the same direction and not looped.
 - b. Place an insulating barrier between the electrode lead and skin surface.
- 4) Connect the leads to the MECMRI-1 cable.
 - a. Insert the electrode leads into the receiving end of the MECMRI-1 chamber cable and fix (tape) the cable to the MRI subject slide table or the subject's clothing—**do not twist the leads together or loop them**.
 - b. Insert the other (plastic DSUB-9) end of the MECMRI-1 chamber cable to the respective mating connector on the connector panel between the chamber room and control room.
 - Typically, the exposed connector will be provided by the MRIRFIF, unless mating 9 pin DSUB connectors are already mounted in the panel.
- 5) Set the ECG100C amplifier module.
Set the ECG100C to the lowest gain (500) and the band from 0.5 Hz to 150 Hz.
 - Do not use the 35 Hz LPN—the ECG amplifier notch filter will cause an unhelpful ringing and integration of MRI artifact.
- 6) Set the acquisition sample rate in AcqKnowledge.
ECG source channel: sample rate of 5,000 Hz or higher.
 - Sampling at $\geq 5,000$ Hz is necessary to properly characterize the MRI artifact generated during EPI.

Recording Guidelines

When the subject is slid into the MRI coil, the shape of the ECG complex will change fairly significantly. This is due to the superposition of cardio-ballistic effects and the electrocardiogram. The mechanical movement of the heart will cause the generation of an associated electrical signal, because the heart is perfused with blood, a conductive fluid. Ultimately, the movement of a conductive fluid through the magnetic field gradient associated with the MRI will result in an associated potential. It is this potential which is being superimposed on the actual ECG to create the distorted shape of the ECG complex when the subject's heart is present in the MRI coil.

If the subject moves in the MRI, the resulting distortion to the ECG signal can be profound. In the same fashion as the cardio-ballistic effects, potentials are generated simply because the body, which is basically conductive, is moving in a strong magnetic field. The subject must remain very still if reliable ECG data is required.

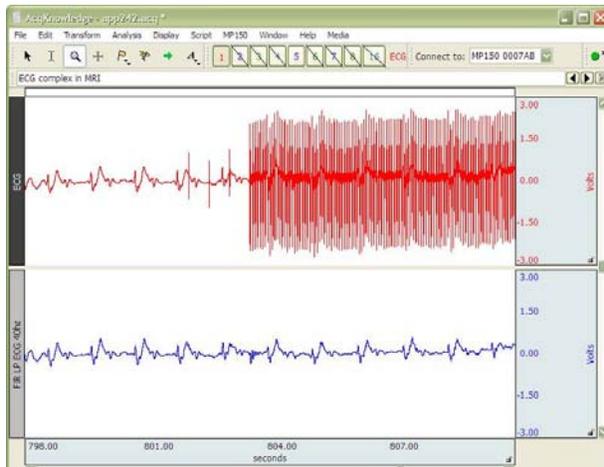
Respiratory breathing will generate distorting signals in the ECG waveform, due to chest wall motion and associated movements of the ECG leads. Subjects should try to keep breathing smooth and regular. Filtering the ECG data with a Highpass IIR filter (1 Hz Q=0.5) will help remove breathing distortion of this type.

Removing ECG Artifact

The resulting ECG source data can be processed to remove artifact, either in post-processing or real-time.

- 1) Determine the interfering frequencies of the artifact.
 - Perform an FFT on the ECG source data during EPI.
 - Look for repeating spikes in the spectrum.
- 2) Run a Comb Band Stop filter on the source data.
 - Set the start frequency to the interfering frequency.
 - Set all harmonics out to Nyquist (2,500 Hz, for a 5,000 Hz sample rate).

For example If the Tr (repetition time of the MRI sequence) is 2000 ms (2 seconds) and the number of slices per repetition is 33, then the interfering frequencies will be located at every (33/2) or 16.5 Hz.



The graph at left illustrates the power of this method:

MRI EPI begins roughly half-way into this data graph, as clearly evidenced by the top ECG waveform. The ECG waveform is significantly corrupted by EPI generated artifact.

The lower graph is the identical ECG waveform, but processed with a Comb Band Stop filter.

- These filters can be performed on the ECG data in real time or in post-processing.

An examination of the modified source data will show that the bulk of artifact on the ECG, during EPI, has been removed

- 3) Run the data through an IIR or FIR Low Pass filter set to 40 Hz to further process it.

The resulting data from this step shows the cleaned-up ECG data; the QRS waves are clearly visible.

Extracting Heart Rate

Respiratory breathing will generate distorting signals in the ECG waveform, due to chest wall motion and associated movements of the ECG leads. If breathing was kept smooth and regular, then these distorting signals can more easily be removed from the ECG waveform via IIR filtering. Typically, filtering the ECG data with a 1 Hz IIR Highpass, Q=0.5, will help remove breathing distortion of this type.

To extract heart rate from the ECG data, a few more processing steps are required.

- 1) Start with the waveform output of the last data processing step (IIR or FIR LP at 40 Hz)
- 2) Run data through a IIR Band Pass Filter, set to a Frequency of 17 Hz and Q=5
 - This step isolates the QRS complex from the surrounding noise.
- 3) Run data through an Absolute Value Converter, followed by a IIR Low Pass Filter, set to a Frequency of 3 Hz.
 - This step identifies the energy and orients it to a positive polarity.
- 4) Run data through a Band Pass Filter set to a frequency of 1 Hz, Q=5
 - This step performs a smoothing of the energy, to remove erratic artifact. This step essentially performs a predictive function to perform an estimation of the location of the actual QRS wave complex, even if it might be a bit distorted, due to unresolved artifact. The higher the Q, for this step, the more robust the estimator. However, if the Q is set too high, then the estimator will not be sufficiently sensitive to quick changes in heart rate. A Q of 5, for a 1 Hz band pass filter, results in an effective tracking bandwidth of (1/5) or 0.2 Hz for HRV studies. Accordingly, as long as the studies are looking at 0.2 Hz and lower, a Q of 5 will not appreciably distort the HRV result.
- 5) Run a simple RATE function on the data, using a threshold of 0 volts.

