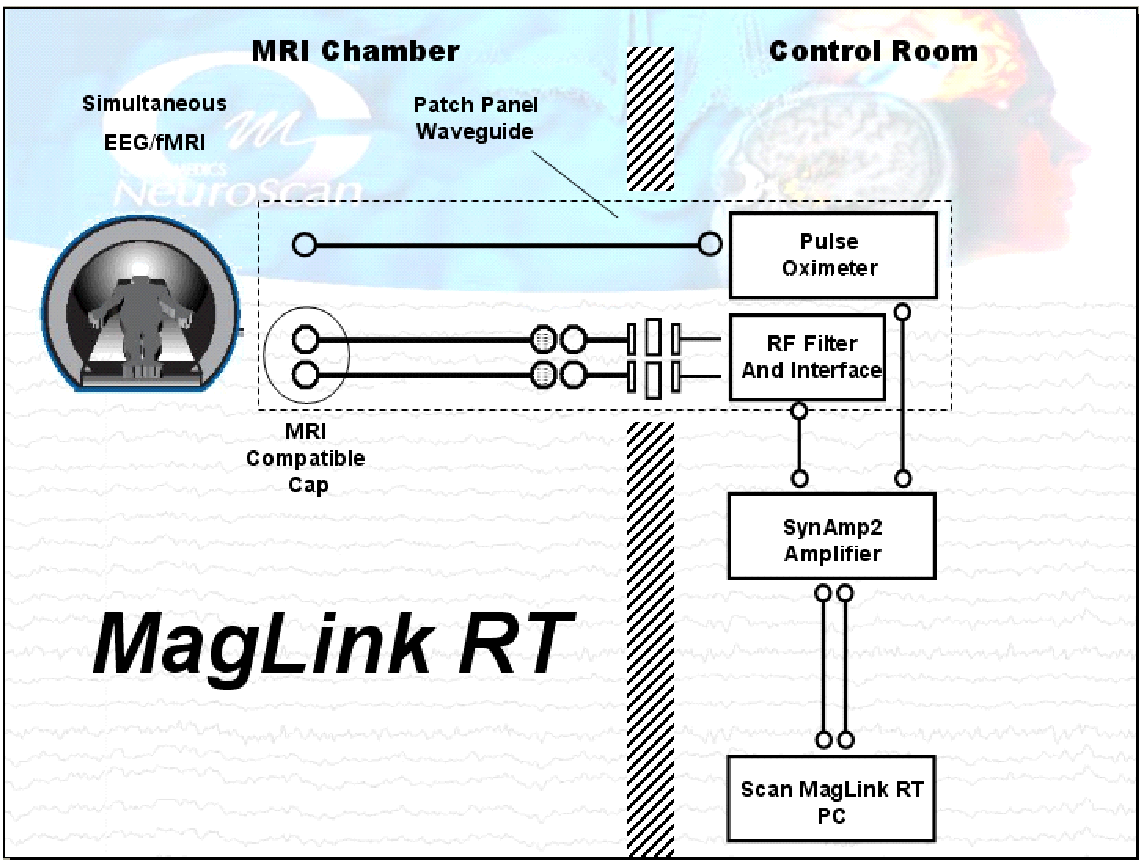
MagLink 4.5



Acquiring and Analyzing Data from
Within the Magnet

COMPUMEDICS NeuroScan

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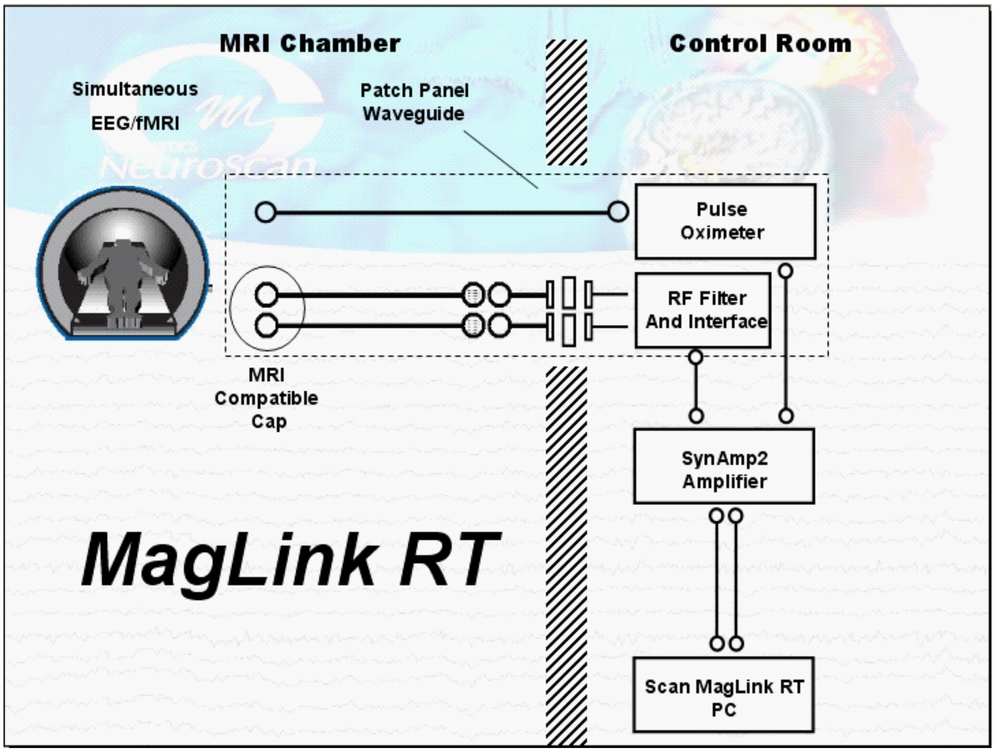
MagLink RT (Real Time)
EEG Recording System™
User Manual



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1.1 Contact Information

For Technical Support...

If you have any questions or problems, please contact Technical Support through any of the following routes.

If you live outside the USA or Canada, and purchased your system through one of our international distributors, please contact the **distributor** first, especially if your system is under warranty.

In all other cases, please use **techsup@neuroscan.com**, or see the other Support options on our web site (*http://www.neuroscan.com*).

Or, if you live in the USA or Canada, please call **1-800 474-7875**. International callers should use **877-717-3975**.

For Sales related questions, please contact your local distributor, or contact us at **sales@neuroscan.com**.

MAGLINK RT IS INTENDED FOR RESEARCH AND CLINICAL USE. READ THE INSTRUCTIONS CAREFULLY BEFORE USE.

7322A MagLink RT45

2 MagLink RT System

Intended Use

The MagLink RT (Real Time) EEG recording system is designed specifically for recording and analyzing EEG data from the MR chamber.

It includes:

- **Non-ferrous cabling and in-line filters,**
- **The *SynAmps2* or *SynAmps RT* amplifier and MRI Trigger Interface,**
- **A specially designed electrode cap (Compumedics Neuroscan MagLink RT Cap™),**
- **Pulse oximeter, and**
- **Real time and offline artifact reduction software designed to minimize ballistocardiogram (BCG) and gradient sequencing artifact.**

WARNING: *The MagLink System must be installed as described in this manual. <u>Only those components shown to be installed in the MRI chamber are to be taken into the MRI chamber.</u> Other components installed in the control room may contain magnetic materials that could act as projectiles in the presence of a high magnetic field and may result in injury. Further, failure to install the MagLink RT system as described in this manual may degrade the quality of data obtained from your MRI and from the MagLink system. If you have any questions or concerns regarding the installation of your system please contact your Compumedics representative.*

WARNING: Because of the special design of the MagLink RT electrode cap, DO NOT USE QUIK-CAPS OR ANY OTHER CAPS IN PLACE OF MAGLINK RT CAPS. USE OF ANY OTHER ELECTRODE CAP, OR INDIVIDUAL MRI ELECTRODES NOT SUPPLIED BY COMPUMEDICS, POSES A POTENTIAL SAFETY RISK TO THE SUBJECT AND INVALIDATES ANY SERVICE AGREEMENTS / WARRANTIES WITH COMPUMEDICS/ NEUROSCAN. For the same reason, do not attempt to service the cap yourself; DAMAGED CAPS MUST BE RETURNED TO COMPUMEDICS/NEUROSCAN FOR REPAIRS.

2.1 SECTION 1: Components of MagLink RT System

The following are brief descriptions of the MagLink RT System components. More detailed descriptions are presented throughout this manual.

Cabling System. MagLink RT includes a non-ferrous based, passive cabling and cap system that is designed to record spontaneous and evoked brain activity in MRI environments. The MagLink RT System is designed to have a minimal impact on the quality of the MR data, while providing the ability to record EEG continuously through structural and functional imaging sequences in magnet strengths up to and including 3 Tesla. Technologies are incorporated into the design, based on independently conducted tests, which maintain magnetically-induced loop currents at levels below those allowed by IEC601 regulations.

The MagLink RT cabling system was engineered to be a simple solution to a complex problem. This is achieved by using a non-ferrous fiber system that is essentially insensitive to high-strength static magnetic fields. Therefore, for recordings obtained within the static field (in the bore of the magnet), EEG activity appears very similar to that recorded outside the field, with one difference: all leads will contain BCG artifact (described in detail later in this manual). This artifact is generated by the micro-movements of the body generated by cardiac activity. These movements cause the body and the electrodes attached to the scalp to cut the (static) lines of force in the magnetic field. This is manifested as a prolonged artifact in all electrodes associated with every heartbeat.

Although the MagLink RT System is designed to be as robust as possible, extra care should be taken when handling and using the components, including the MagLink RT caps. In general-use MR facilities not dedicated to combined MRI/EEG research, it is strongly recommended that the MagLink RT System be removed and stored in a safe location when not in use. Avoid stepping on the cables. Do not pull on the cables to disconnect the MagLink RT from an interface cable - apply force to the connector itself, not to the cables.

MagLink RT Electrode Cap. The MagLink RT System was designed to be used with the MagLink RT Electrode Cap (please see its user manual for more information). Materials and construction of the MagLink RT cap are designed to maximize subject/patient comfort during extended MRI/EEG recording sessions.

***SynAmps^2 or SynAmps RT* Amplifiers**. The *SynAmps^2* or *SynAmps RT* amplifiers are uniquely suited for simultaneously acquiring EEG data and fMRI data from MRI systems with field strengths at least as high as 3 Tesla. Unlike some other systems, the amplifiers from the MagLink RT are placed in the control room. This allows complete use of the fully featured *SynAmps^2/RT* amplifiers, with their high sampling rates and dedicated per channel sigma/delta A/D converters that provide simultaneous sampling across all EEG channels. No sample and hold technology is used and no multiplexing is required. An AD rate up to 10kHz for all channels is required to provide adequate synchronization with the scanner. Even slight amounts of "jitter" in the trigger pulse detection can affect the accuracy of the artifact reduction. The fast AD Rates are also needed to capture the fast frequency gradient sequencing artifact. The correction procedures involve averaging and subtracting MR artifacts. Under-sampling the trigger pulse, or the artifact itself, will adversely affect the correction procedure, and it will not be possible to remove the artifact accurately. The amplifiers use 24 bit

AD converters that allow each amplifier to maintain accuracy (voltage resolution) while at the same time having a very broad dynamic range (400mVs). The broad dynamic range is essential to avoid clipping the very high amplitude gradient sequencing artifact, and the genuine EEG that is riding on it. It is not possible to obtain accurate EEG recordings without these amplifier capabilities.

We do not recommend using *NuAmps* or the original *SynAmps* with the MagLink RT System (the sampling rate for *NuAmps* is too slow, and the dynamic range of the original *SynAmps* is too narrow).

A **MRI Trigger Interface** is provided. This is used in cases where it is necessary to convert the trigger output from the scanner to a recognizable form.

Pulse Oximeter. The pulse oximeter is an EKG recording device that attaches to the finger. It is used to provide a more reliable measure of EKG inside the bore, and thus a preferred measure of EKG for use in BCG artifact reduction. It connects to a High Level Input channel on the *SynAmps*^{2} headbox.

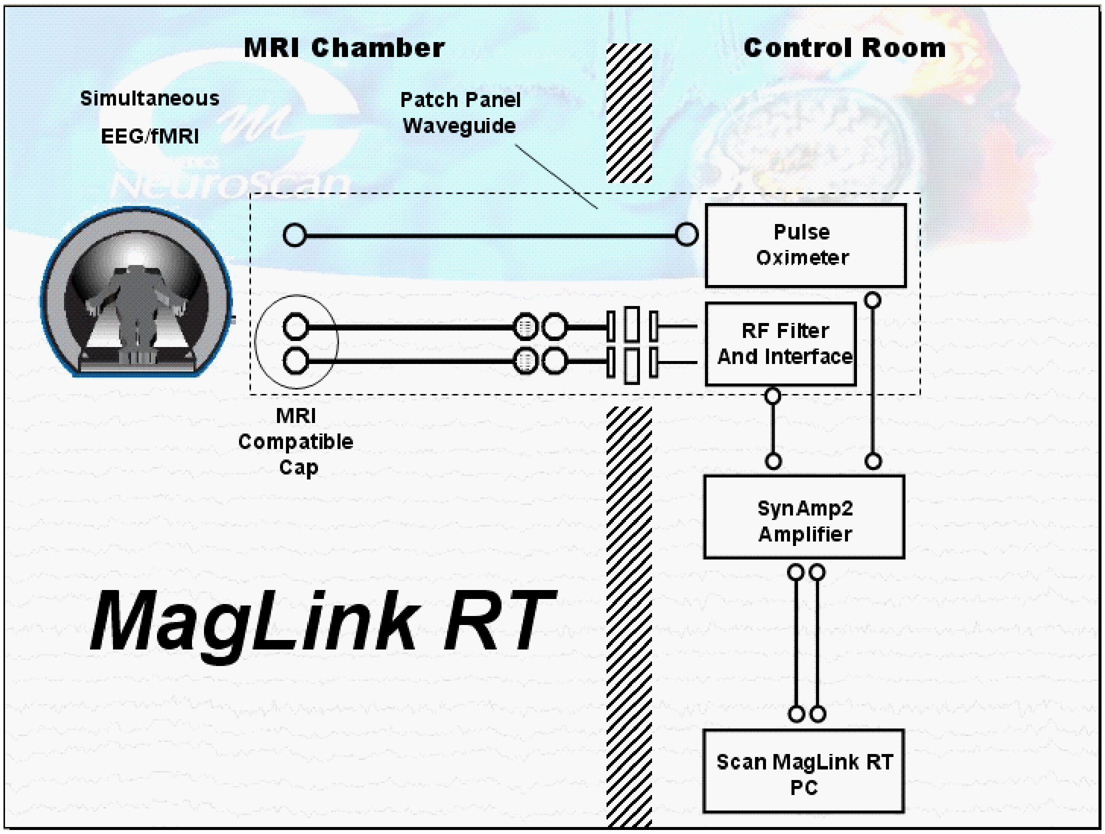
Software Artifact Reduction. Specially created software procedures for significantly reducing BCG and MR artifact are part of the MagLink RT System, and are included in the MagLink RT version of the Scan software. These can be applied online during acquisition, or offline during analysis. If applied online, you can save the corrected and uncorrected data. Offline, the transforms can be applied manually or in batch files. The transforms are described in detail below.

PC Requirements. With the faster AD rates required for recording in the magnet, the PC requirements are more stringent. The SCAN PC should be purchased from Neuroscan to ensure that it will function properly.

The complete MagLink RT system - *cabling*, *electrode cap*, *amplifiers*, and special purpose *software* - permits the accurate recording of EEG in the harshest of environments.

MagLink RT System Components

The figure displays the components of the MagLink RT System. Each component of the system is described in more detail below.



MagLink RT Cabling System

The components of the cabling system are shown in the figure below. The MagLInk RT Electrode Cap connects to a Y-connector, and then to the **Passive Adapter Assembly**. That connects to the **14 meter MagLink RT cable**, and from there, through the waveguide to the **RF Filter Enclosure**, which then connects to the SynAmps headbox. In a real setup, the RF filter is outside of the MR chamber, and the cable runs through a shielded tube, not shown below. Every attempt has been made to make the cable bundles as flexible yet as resilient as possible. However, care should be taken so that the cables are not placed in a location where they may be stepped on or crimped by a closing door.

RF Enclosure Assembly. This assembly is located in the Control Room and couples directly to the control panel through the shielded, flexible conduit that maintains the RF shielded integrity of the control panel all the way to the inside components of the RF Enclosure Assembly. The RF Enclosure Assembly has specialized RF filters that further ensure that the RF signals in the control room cannot get coupled into the MR bore. This helps preserve the high levels of MRI image integrity.

Maglink RT Cable. The MagLink RT Cable (14 meters) is built from all non-magnetic components, and provides shielding for the EEG signals. It has been specifically designed to maintain the high Common Mode Rejection that the *SynAmps^2* headbox provides.

Passive Adapter. The Passive Adapter is an all non-magnetic component that allows a variety of items to be connected to the cable. This is currently used to connect existing MagLink Caps (using the adapter shown), as well as the MagLink RT caps.

SynAmps^2 and *SynAmps RT* Amplifiers

Please refer to the *SynAmps^2 (or SynAmps RT) User Manual* for installation instructions.

The amplifiers are programmed in the ACQUIRE software (see the *ACQUIRE manual* for setup file examples and details regarding the software control of the amplifiers). The features that are exclusively part of the MagLink RT System, including the **MRI Trigger Interface**, are described below.

Pulse Oximeter

The pulse oximeter (currently, Nonin 8600FO) is used to detect the precise moment of the EKG pulse peak, which is essential for reducing ballistocardiogram. There are other ways to detect the pulse without it, but any increased variability makes the BCG reduction that much more difficult.

MagLink RT Artifact Reduction Software

The specially designed software for MagLink RT includes transforms that are not available in the regular SCAN software; they are found in the MagLink RT version of the Scan software. These include online and offline EKG/BCG Artifact Reduction, and online and offline fMRI Artifact Reduction. These and additional transforms that are especially relevant to artifact reduction are described below.

2.2 SECTION 2: Installation of MagLink RT System

Software Installation

Maglink RT

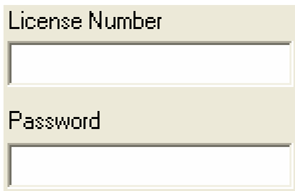
The MagLink RT System includes the SCAN 4.5 software, supplied on CD (or web download). If after inserting the CD, the installation does not begin automatically, go to the CD drive and run *setup.exe*. The installation is largely automatic; just follow the directions on the install screens.

Access to the MagLink RT software is dongle protected, and a MagLink RT license is required. If you bought your MagLink RT System new, it will come with a dongle (the small USB port plug-in device) that has already been programmed for MagLink RT. There are no further steps to complete. If you already have a SCAN or older MagLink system and dongle, and are upgrading to the MagLink RT System, you will need to reprogram your dongle.

To obtain the License Number and Password needed to reprogram your dongle, you first need to find the serial number of the dongle. In either ACQUIRE or EDIT, select **Help** → **About ACQUIRE** (or **About EDIT**). The serial number is displayed. Or, run the *License Manager* program (**Start** → **All Programs** → **Scan4.5** → **License Manager**), and the serial number is displayed.

Then contact techsup@neuroscan.com with your request.

You will receive a License Number and Password in return. Run the *License Manager* program as described above, and enter the new information.



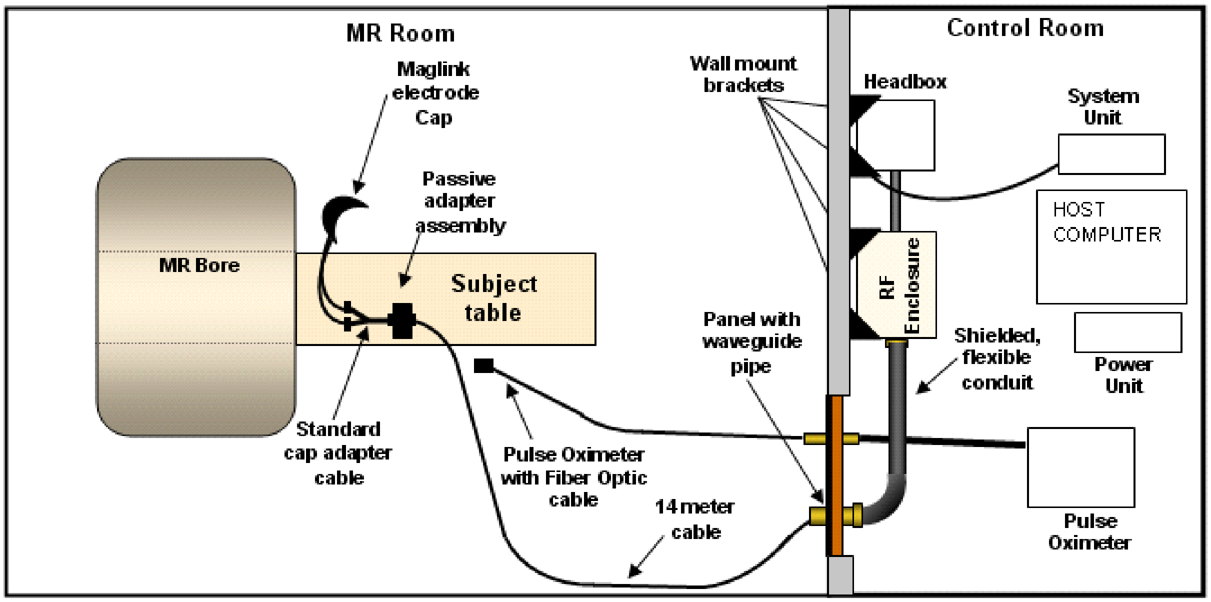
Then click Add License. You should see a message saying the writing process was successful. Then click Done. You can now access the software.

Note
The **Toolbox** programs are included with the MagLink RT System software (otherwise, a separate license is required to access them). These include online and offline Blink Reduction, Principle and Independent Component Analyses (PCA/ICA), Interface with MATLAB, and export to Excel. These are described in the Toolbox manual.

Hardware Installation

Installation of the MagLink RT system is relatively straightforward. Like any other EEG/ERP recording environment, special care should be taken to ensure that all cabling is located as far as possible from noise sources such as transformers and computer monitors. All components that will be placed in the MR bore are built with non-magnetic materials.

WARNING: *The MagLink System must be installed as described in this manual. Only those components shown to be installed in the MRI chamber are to be taken into the MRI chamber. Other components installed in the control room may contain magnetic materials that could act as projectiles in the presence of a high magnetic field and may result in injury. Further, failure to install the MagLink RT system as described in this manual may degrade the quality of data obtained from your MRI and from the MagLink system. If you have any questions or concerns regarding the installation of your system please contact your Compumedics representative.*

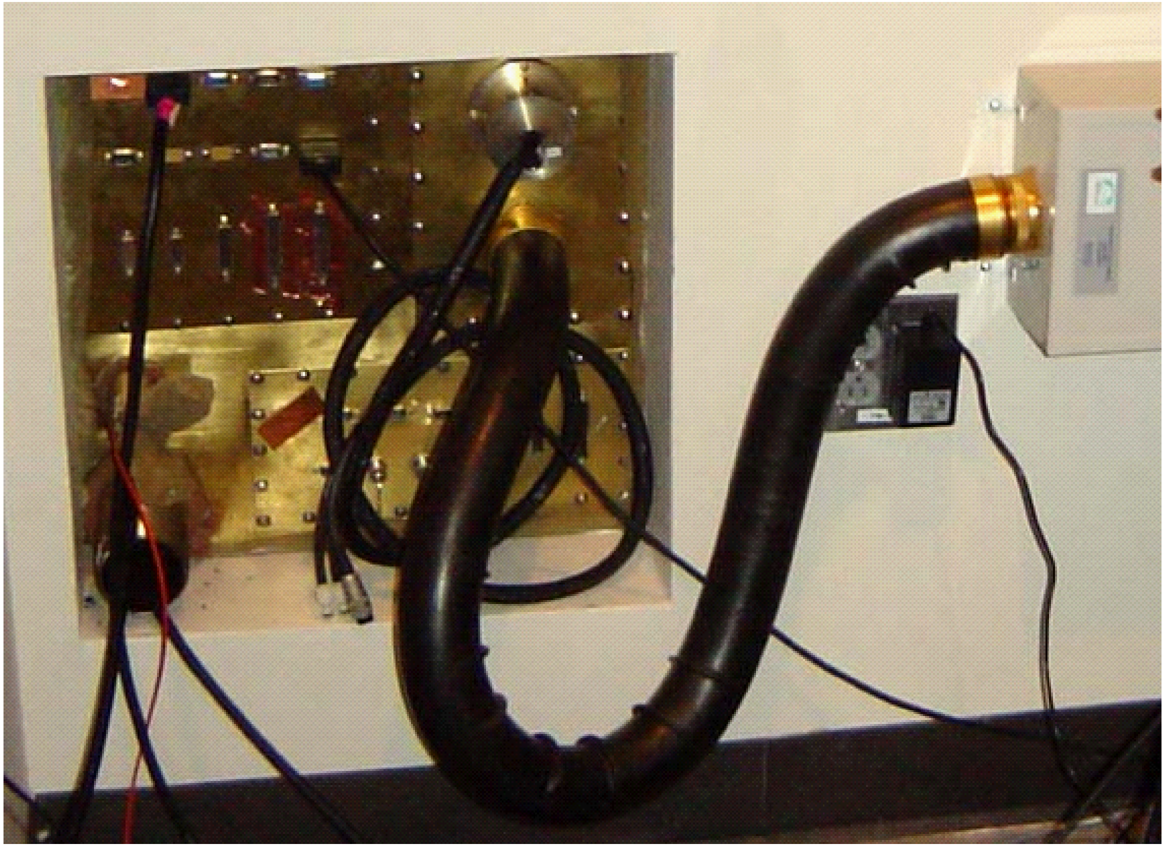


1. **Set up SynAmps² or SynAmps RT amplifiers**. Starting in the control room, set up the *SynAmps RT* system, as described in the *SynAmps RT* manual.

2. **Connect RF Enclosure**. Connect the **RF Enclosure** to the *SynAmps RT* headbox 80 pin cap connector using the short connection cable.

3. **Attach cable and conduit**. The RF Enclosure has an integral 14 meter cable that must pass from the control room waveguide through the wave guide and into the MR bore. In order to maintain low noise performance and maintain the waveguide RF integrity, a special shielded, flexible conduit is placed over the 14 meter cable and threaded onto the RF connection on the RF Enclosure. The RF Enclosure is not constructed for nor intended to be placed in the MRI chamber. Therefore, a complete installation requires that the RF Enclosure must be mounted in a fixed location outside the MRI chamber, preferably on a wall in the control room (see the next figure below for how it appears following installation).

4. **Connect the conduit to the waveguide.** The 14 meter cable is passed through the waveguide to the MR bore first and then the shielded, flexible conduit (which was already slipped over the 14 meter cable) is threaded onto the special waveguide as shown below:



The shielded, flexible conduit is threaded on both ends so that it is solidly and tightly connected both to the RF Filter assembly and to the patch panel. This flexible conduit allows RF assembly enclosure to be placed in a variety of positions in the control room.

5. **Connect Passive Adapter Assembly**. The 14 meter cable then connects to the **Passive Adapter Assembly**, near the subject, as shown below:

6. **Connect cap adapter** (if needed). If you are using the standard MagLink Cap you will need adapter cable (P/N 00036960), which connects between the Passive Adapter Assembly and the cap as shown below:

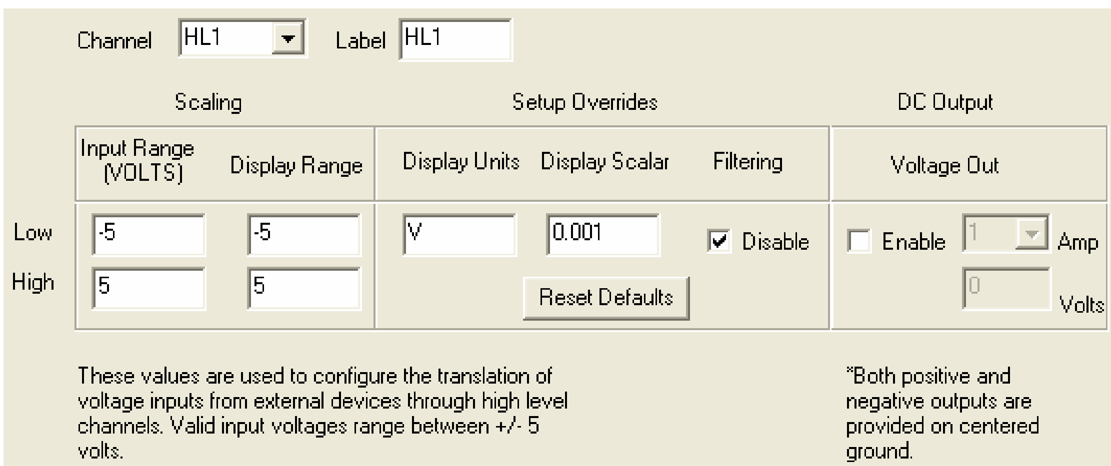
The adapter cable is not needed when using the MagLink RT 64 channel cap.

Note
When laying out the cables used in the MR chamber, do not allow loops to form by the cable crossing over itself. If the size of the MR chamber does not allow for the cables to be fully extended, they can be snaked along the floor.

7. The pulse oximeter finger attachment is MRI-Conditional. The cable from it is run through the waveguide, out to the control room. The outputs from the pulse oximeter - the pulse wave and the oxygen saturation level - are input into the *SynAmps RT* using the High Level Inputs connection. We recommend that you use the MagLink RT setup file which has the HLIs already configured for the pulse oximeter. If you create your own setup file, please refer to the *SynAmps RT* user manual for instructions for configuring the HLI channels.

14 pin Redel connector
for High Level Inputs

Briefly, both HLI channels should be set up using parameters as shown below (channel HL2 is labeled HL2). A different Display Scalar may be preferred, depending on the desired amplitude of the HLI channels in the CNT file. If the HLI amplitude is too low, increase to Display Scalar. If it is too large, decrease the value. Do ***not*** enable Filtering or the DC Output.



Impedance Adapter Cable (optional)

The Impedance Adapter Cable is an optional cable that is used for testing impedances from subjects outside of the bore. ***The cable itself has magnetic components and CANNOT be taken into the bore***.

There are two ways to test impedance during subject prep without being situated in the MR bore area.

1. **No adapter cable**. With the subject in the control room, bring the 14 meter maglink cable from the bore out the door and into the control room, connect to the passive adapter "Y" cable and cap. When the subject is prepped and impedance is good, move them into the bore area and proceed. The advantage is that there is no connection and disconnection of cables, so good readings while in the control room that lead to bad readings in the bore would mean something has been disconnected or disturbed. The disadvantage is you cannot prep a subject in the control room while someone else is running a scan in the bore.

2. **With adapter cable**. With the impedance adapter cable, the subject can be in the control room. Disconnect the Maglink system cable from the RF Enclosure to the headbox (at the headbox). Connect the impedance adapter cable to the headbox. The other end of the impedance adapter goes to the passive adapter "Y" cable and cap. Since the 14 meter cable is left in the MR bore area, the door can be closed and other scans can be run while the subject is prepped. When ready to scan, remove the impedance adapter from the headbox and passive adapter, and CAREFULLY reconnect the RF Enclosure cable to the headbox. ***NOTE the warning on the impedance adapter cable - it contains magnetic components and CANNOT be taken into the MR bore area***. With the subject cap, "Y" adapter cable, and passive adapter, move to the MR bore area, connect to the 14 meter cable, and continue.

System Noise Levels

The ability to capture valid EEG data is very dependant on the system noise levels. Noise level becomes even more critical with EEG recorded in an MR bore, because of the tremendous level of artifact created by the scanning field. The MagLink RT System has been carefully designed to minimize noise induced on the signal lines, and maintain the high common mode rejection capabilities of the *SynAmps RT* headbox.

Most MR rooms have the Faraday cage tied to an anchor/ground system at the point where the floor meets the walls. It is recommended that the 14 meter cable be run along the floor to wall junction. This places the cable over the best grounding plane, as well as positioning the cable away from traffic areas.

The MagLink RT has multiple redundant RF noise reduction components. These components bring the level of RF signal that could get coupled from the control room to the MR bore to an absolute minimum. This preserves high MR image quality. The MagLink RT System specifically avoids any kind of multiplexing or clocking within the MR room components to eliminate the possibility of any image degradation that these type of elements will induce.

Avoidable Noise Sources

Another contributor to system noise is electronic equipment, AC transformers, and AC building wiring. Careful positioning of the Power Unit, System Unit and headbox with regard to these Control Room noise sources will reduce overall noise.

The Power Unit contains a large AC powered Toroid coil. While this Unit has a metal case to help shield the magnetic field, there are still levels in excess of 60 to 100 mGauss emanating from the sides of the Power Unit. Placing the System Unit, the headbox, the headbox cables, or MagLink RT cables near the Power Unit sides will increase the amount of line or 50/60 Hz noise coupled into the system.

It is best to position the Power Unit away from the System Unit and headbox. Some control rooms are notably problematic in providing a consistent 50/60Hz ground to the Power Unit, via the normal mains wall cord. If there is a persistent 50/60Hz problem, and other sources have been eliminated, it may be beneficial to connect a ground wire (the green with yellow stripe that indicate earth ground is an appropriate wire size) from the Faraday earth ground to the Power Unit (via a wire lug connected to the Power Unit case using one of the case screws) and then to the System Unit (also connected via a lug and case screw). This will insure a solid connection to the Faraday ground for both the Power and System Unit.

The System Unit communicates with the host PC running the application via a USB 2.0 cable. Even though this cable is shielded, it can act as an antenna. It is always best to use the shortest USB 2.0 cable possible when connecting between the System Unit and the host PC. Using USB 2.0 cables with molded on ferrites (these will appear as a large cylinder around the cable near both ends) can also help reduce emissions.

Since the headbox, System Unit and MagLink RT RF Enclosure must be placed in the control room, it is important to look at the kinds of control room equipment that may be placed too near the these components. Large power transformers can easily become a noise source problem. Using an Electromagnetic Field Radiation meter to scan around the Control Room can be a valuable way to identify possible noise sources. In some cases, such as building AC wiring, it is not clear that there is a noise source present unless you use the meter to locate the wiring position. This can help indicate the best location for the *SynAmps RT* and MagLink RT systems to be positioned for installation.

Severe Noise Sources

Under no circumstance is it recommended to run any cable near the MR gradient switching equipment. The gradient switching system involves rapidly switching levels of high current and any MagLink RT equipment or cable that runs near this housing will pick up excessive noise.

In some facilities there are other system signal cables that may run near the *SynAmps RT* or MagLink RT components. Any system with high current switching circuitry or high speed TTL signals should be positioned well away from the *SynAmps RT* and MagLink RT equipment and cables.

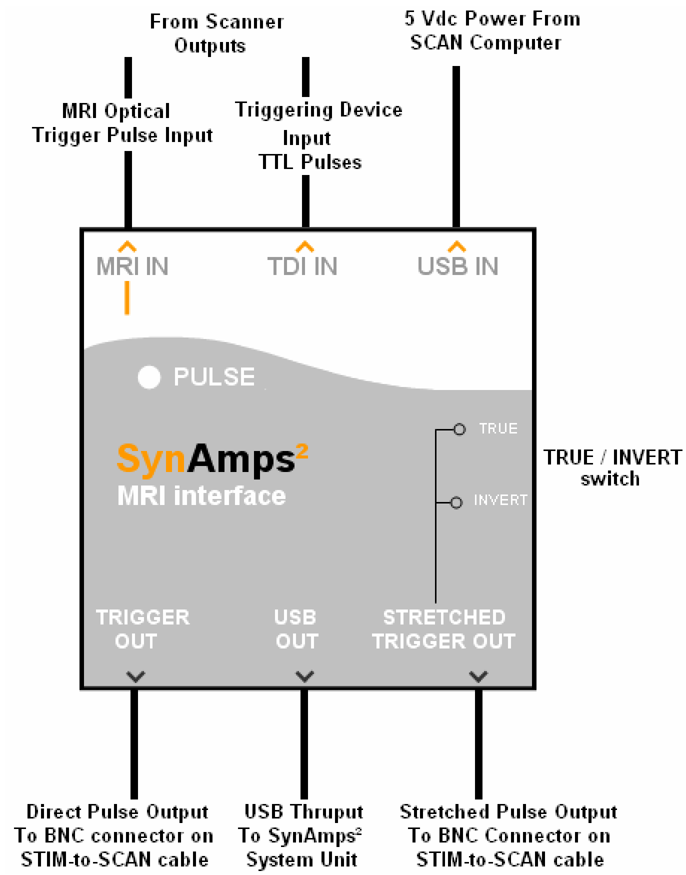
Interfacing the Scanner with the MagLink RT System

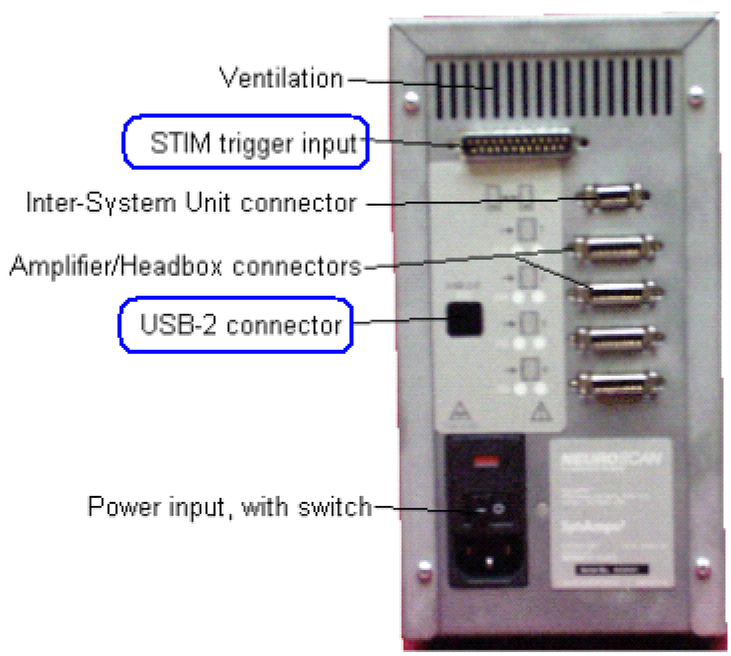
If you are planning to use the fMRI Artifact Reduction transform to minimize gradient sequencing artifact, the preferred option is to have your scanner send an optical or TTL (voltage) signal to the acquisition software to indicate the beginning of each TR Block or TR Slice. The ***SynAmpsRT* Trigger Interface** provides the interface between the MR scanner trigger output and the *SynAmps RT* amplifiers. (Please refer to the *SynAmps RT Trigger Interface User's Guide* for installation and operation details).

Briefly, the scanner output - optical or TTL - is connected to the MRI Trigger Interface - **MRI In** or **TDI In**. The trigger output from the MRI Trigger Interface is either the **Trigger Out** or **Stretched Trigger Out** (recommended) connection. That connects to the BNC connector on the SCAN end of the stim-to-scan cable, which is connected to the **STIM Trigger Input** on the back of the *SynAmps RT* System Unit (see figures below).

The MRI Trigger Interface is powered by a USB cable from the *Scan computer*. Connect the longer USB cable from a USB port on the computer to the **USB IN** input on the Interface.

Connect the short USB cable from the **USB OUT** port on the Interface to the **USB-2** port on the back of the *SynAmps RT* System Unit.





Back of System Unit

When the scanner initiates a TR, a red '5' will be observed in the CNT recording. If you do not have a Stim2 system, you will have received the same or equivalent cable with a BNC connection. You will need to provide the trigger cable from the scanner (type of connection varies) to the BNC connection into the *SynAmps*^{2}.

General Notes on Triggering from the MR
Triggering in the STIM and SCAN systems functions in the following way. Stimulus triggers (from STIM or any other source) must be positive logic TTL pulses. That is, the resting state is 0V and the high, or "on" state is 5V (at least 3.5V). The duration of the pulse is typically 1ms, but may vary under some circumstances. It should never be longer than the interval between stimuli. Prolonged stimulus triggers will block other events occurring at the same time.

The MR scanner trigger is input into an otherwise unused response line (the 64 bit line). The software converts that into a "5" in ACQUIRE, although you will see "64" in Test Trigger Port). Since it is a response line input, the signal from the scanner *must follow the negative logic rule*. If the scanner output uses positive logic, the signal must be inverted (using, for example, the MRI Trigger Interface, where the **Invert** option on the side is selected).

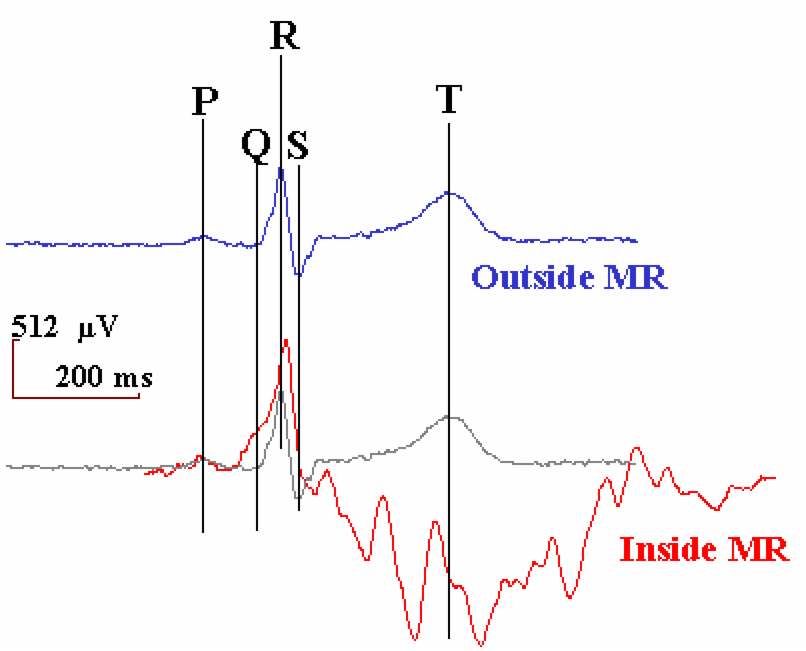
2.3 SECTION 3: Initial Recordings with the MagLink RT System

Prior to initiating a formal set of experimental sessions, it is critically important to set aside the first few test sessions for pilot recordings. These sessions should involve the MR physicist or technician. The following sequence is recommended.

(1) **Record a Reference Set of Data Outside the MR**. Perform an initial series of recordings outside the MR. For example, recordings can be made in the control room with the MagLink RT cables in place and extended from the MRI room. These recordings should include:

a. *Continuous EEG with eyes open and eyes closed*. Check for the detectability of and changes in the EEG spectra, specifically alpha activity. Note the simple and distinct structure of the EKG response and its restricted appearance in the EKG recording channels (this will change profoundly once the subject enters the MR).

b. *Reference recordings*. Record data for your experimental paradigm to act as a reference for data recorded in the MR. These data may also be used to generate reconstruction LDRs for data recorded within the MR environment.



(2) **Repeat Series Inside Static Field**. Repeat the series of tests described above with the subject in the bore of the magnet within the presence of the static field. It should be possible to clearly identify EEG activity. The major change will be the presence of a very large ballistocardiogram artifact. Examine the data recorded from EKG leads. You will observe that the very simple EKG signature obtained outside the MR becomes much more complex within the bore of the magnet.

(3) **Obtain a Structural Scan**. Prepare for a structural scan. Shimming procedures may require some adjustment to reestablish the homogeneity of the field with the added presence of the electrodes, cabling and electrode paste. Obtain structural MR data from the subject. The structural scans will show localized shadowing that should be restricted to within a small distance (2-4 mm) of the recording electrodes. Note that if initial tests are performed on a phantom, the artifact will appear greater with the phantom than that obtained with the cap on a subject.

(4) **Obtain a Functional Scan**. The signal-to-noise ratio of functional MR scans is much poorer than that needed to obtain a quality structural scan. In your pilot investigations, record functional scans with and without the MagLink RT cap and cabling system. This is critically important when interpreting ambiguous fMRI data, as there will be a tendency to attribute poor quality MR data to the presence of the EEG recording system, until such recordings become routine.

2.4 SECTION 4: General EEG Data Acquisition for Optimal fMRI Recordings

Recording electrical signals within a powerful magnetic field is a challenging problem, and one that has yet to see the final solution for dealing with the various artifacts that occur. The information below is based on our recording experiences in several MRI facilities, up to and including 3T magnets. These steps and techniques summarize what we have found to be most effective thus far. We have also found that there can be considerable variation in the artifacts among different facilities. Those techniques that work well for one facility may not be optimal for all labs. We present the information as a useful guideline; you may need to fine tune parts of it for your lab.

There are two major experimental design paradigms used in most fMRI experiments; so-called boxcar or block designs and event-related or sparse stimulation designs. A number of excellent reviews have been written describing the benefits and drawbacks of these techniques. The reader is encouraged to consult references on MR experimental design for the details of these procedures. Briefly, however, boxcar designs are experimental sequences in which stimulation is simultaneous with (occurs at the same time as) the imaging sequence. According to Horowitz et al. (2000), there are advantages and disadvantages to each of the techniques.

Advantages and Disadvantages of Boxcar Designs. Some of the advantages of the boxcar design experiments are higher levels of cortical activation resulting in greater statistical power. This in turn leads to faster fMRI acquisition times. Since the inter-stimulus interval is shorter than the hemodynamic response function for each stimulus item, data collected with boxcar designs are interpreted as a brain-state (task induced) dependent measure. The disadvantage of boxcar designs is that the acoustic noise of the imaging sequence is concurrent with the fMRI stimulation, which may have a significant impact on the arousal and attention. In addition, the acoustic noise of the imaging sequence will act as mask for experiments using auditory stimulation. The reader should review articles on the effects of broadband masking on psychophysiological performance. A number of similar articles describing the effects of noise on evoked potentials (including lateralization of activity related to speech processing) should also be considered. Electrophysiologically, it is more difficult to extract evoked responses from the EEG due to the high amplitude artifact induced into the data by the imaging sequence.

Advantages and Disadvantages of Event-Related Designs. In an event-related paradigm, stimulus presentation is asynchronous with fMRI acquisition sequences. That is, stimulus presentation precedes the acquisition of the fMRI data by an interval equivalent to the buildup time of the hemodynamic response. Some of the disadvantages of the event-related design experiments are somewhat lower levels of cortical activation (compared to boxcar designs) thus resulting in lower statistical power. Lower levels of cortical activation leads to longer fMRI acquisition times. One advantage of event-related or sparse designs is that responses to a single stimulus type can be characterized by averaging activation across multiple stimulus presentations. The data are more easily interpretable relative to specific types of stimulus events. As such, the fMRI data recorded during event-related sequences are much more comparable to evoked (or event-related) potentials. Another major advantage of event-related paradigms is that since stimulus presentation precedes each scanning sequence, the arousal and attentional effects produced by the high noise levels of the imaging sequence are not superimposed on cortical activations produced by the stimulus events. Moreover, artifact removal from the EEG data is simplified since the only artifact that needs to be extracted is the ballistocardiogram.

Recommendation: From the point of view of optimizing the quality of the electrophysiological data and minimizing the interaction of scanner noise with experimental stimulation (especially acoustic), we strongly recommend the use of event-related experimental paradigms whenever possible.

Acquisition Rates: High sampling rates (e.g., 10kHz) are necessary to adequately capture the high frequency components of artifact encountered recording EEG in the MR. The fMRI Artifact Reduction transform may then be used to remove the artifact and the data may be decimated to a lower sampling rate for ease of processing and reduced file size.

Software Versions: It is necessary to have at a minimum SCAN version 4.3.3 or newer software, and that you have the new artifact reduction features (described below). Once you determine the processing steps you will use in most instances, you can create a BATCH file to do the routine steps. Automating the steps will save you time as well as insure that the same steps, in the same order, with the same settings, are used in each case.

I. General Recording Strategies

In general we recommend some variation on the following design when recording fMRI data. The recordings outside the magnet, in an artifact-free environment, are especially important to substantiate the validity of the findings within the bore. This includes "resting" as well as EP stimulation recordings (if you are recording Eps). The resting recording will allow you to compare EEG power spectra inside and outside the MR, providing further evidence that the findings in the bore are not due to MR related artifact.

		Inside the magnet	
	Outside the magnet	During MR	Between MR sequences
"Resting"			
Stimulation for EPs			

Inside the magnet, record resting and stimulation sections between sequences of MR sampling, as well as during MR sampling if you are interested in recording at the same times that the MRI is obtained.

II. Specific Recording Tips for Acquiring Optimal Data

A. **Reference**. For *SynAmps²*, the reference electrode is hardwired in the cap at CPz, and cannot be changed. The use of a midline electrode as the reference may help to minimize BCG artifact. After acquisition, the data may then be re-referenced offline to a linked mastoid, or another scheme of your choice. If re-referencing offline, we recommend that you use a reference scheme most appropriate for your paradigm (for example, if you are doing source localization or coherence analyses, you should use a reference consistent with that recommended in the literature).

B. **Record EEG data in continuous mode**. All EEGs should normally be acquired in continuous mode, but it is especially important for fMRI recordings. The new artifact reduction routines and other transforms require continuous files. Continuously acquired EEG provides the flexibility that is needed for many of the analyses; these are not available with epoched or averaged files.

C. **Record an EKG and a VEOG channel.** VEOG and EKG channels are required for the new artifact reduction routines, and are a good idea in any case.

D. **Get the lowest electrode impedances possible**. This may be the most important factor in obtaining good recordings in the MR. Electrodes with high impedances are especially susceptible to radiant artifact in the MR. Impedances above about 15 to 20kOhms will almost certainly result in unusable data for those channels. Get the impedances as low as possible (<10kOhms, and balanced).

E. **Positioning the patient and cables**. Ballistocardiogram (BCG) results from micro-movements of the subject or the electrode wires due to cardiac activity. You can generally minimize BCG by securely taping down the electrode wires, by immobilizing the subject's head, or any other technique that will minimize the micro-movements. Using the stretchable netting that we provide for the electrode caps will also help hold the wires in place and minimize their movements.

The main transmission cable from the cap must be placed to run down along the side of the body on the bed of the MRI, and out of the front of the bore. Do not lay the cables across the subject. Laying the cables across the body of subject, particularly the chest and the stomach, induces additional ballistocardiogram-like artifact. When positioned across the body, the cable bundle will cut magnetic lines of force with each respiration. There are often several devices in the rear opening of the bore that can introduce artifact into the signal, making the correction that much more difficult. Most head coils provide a tight fit, including the padding and cap, so there is some constraint on the placement of cables coming out of it. It is always good to start recording without saving (once the subject is placed inside), and apply a lowpass filter at 30Hz. This will let you observe baseline EEG along with the BCG as you reposition the cables.

F. **Minimizing RF artifact in the MR images**. It is critical to ensure that the RF Enclosure Assembly is positioned as close to the waveguide as possible. In recordings we have made with the MagLink RT electrode cap, there are minimal distortions of the MR images as a result of the connection to the external EEG equipment when the RF filter enclosure assembly is properly positioned.

When the RF Enclosure Assembly is properly positioned, there should be little effect on the quality of the MR images. With electrode caps containing up to 128 electrodes, shimming the magnet sufficiently restores the homogeneity of the MR field to obtain quality images. Shadowing by the electrodes and gel should be very local, without interference at the depth of the cortex. The scalp electrodes may be seen at the skin level in the MR images. Successful recordings and quality MR data have been obtained with MagLink RT Systems containing from 37 to 128 electrodes.

G. **Recording parameters.** Record **Continuous** data in **DC** mode, with an AD rate of **10kHz**, and filters at **DC-2000Hz** (Never use the 50/60Hz notch filter). Currently, online suppression of gradient artifact and BCG artifact is not supported due to speed of processing limitations of the current generation of PCs.

2.5 SECTION 5: General Analysis Strategies for Data Recorded in the MR

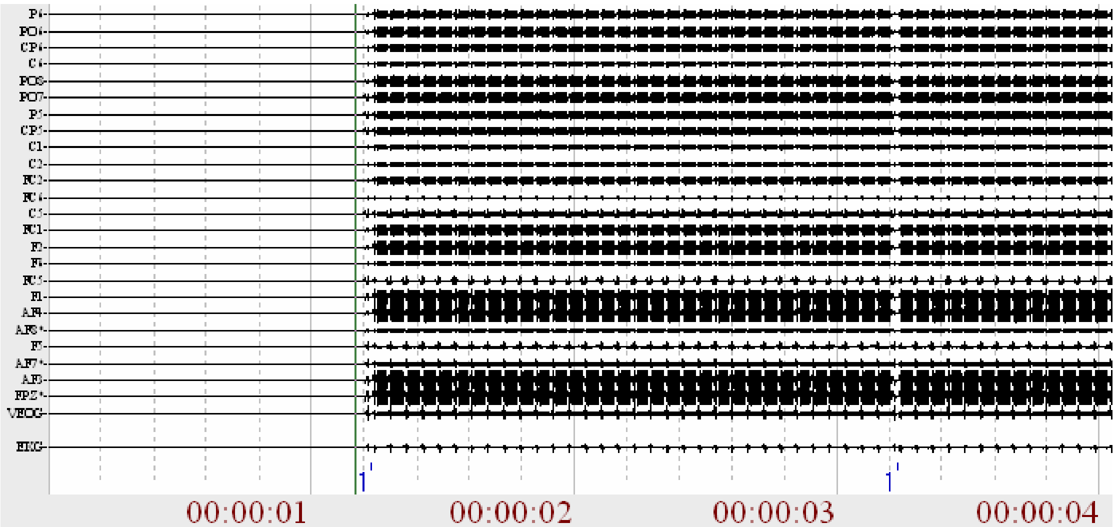
As mentioned above, there is no absolute sequence of steps that will always result in artifact-free data. Below are steps that we have found to be effective in removing or minimizing the artifact in the data files we have acquired. You may find that these steps work for you, or that you may need to vary the order, or use different approaches for the optimal effectiveness in your setting.

The transforms that are most relevant for recordings in the magnet include fMRI Artifact Reduction and EKG/BCG Artifact Reduction. These are described in the next section.

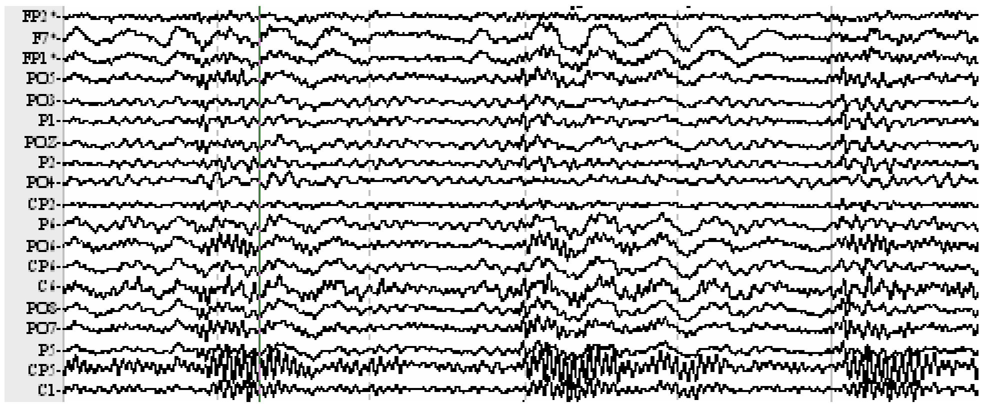
One of the first decisions you should make is whether you will be using the artifact reduction procedures *online* during acquisition, or *offline*. You can apply the corrections online, and then save the corrected data file or not (the raw data file is always saved). The advantage of applying the correction online is that it lets you verify that you are obtaining genuine data. The advantage for saving the raw data file is that you have more options offline for analysis and re-analysis. Ideally, it is best to do both: apply the correction online while saving the raw data. Saving both the corrected and uncorrected data is possible, assuming your computer can keep up. We recommend a 10kHz AD rate, which allows online artifact suppression, but still generates very large date files if you have many channels (>32) and are recording over long periods of time. Storage for the files, therefore, may or may not be an issue, depending on your computer's capacity. The best results are generally obtained by analyzing the raw data offline.

We strongly encourage you to make several test recordings prior to actual data acquisition with subjects/patients. This will help you fine tune acquisition parameters, and ensure that the recordings will yield valid data.

In the raw data example below, gradient sequencing was performed in a series of blocks, with 32 slices per block. The MR artifact is extremely high in voltage.



If we rescale the beginning of the data file, we also see there is BCG artifact, with a high noise background.



Generally, the best approach is to remove the MR artifact first. In the process, the file will be decimated and filtered, and that will make subsequent removal of BCG and VEOG easier. Always look through your data file initially to get a feel for what artifact it contains. If there are some very bad sections, with likely irretrievable data, use **Mark Block** → **Reject Block** to reject those sections first.

1. Use the fMRI Artifact Reduction transform to minimize the scanner artifact (as described in the next section). You have the option to decimate (down-sample) the raw data file. The data files are recorded with high sampling rates in order to capture the trigger and scanner artifact accurately. Once the scanner artifact is removed, there is no need for the very fast sampling rate, so decimation is recommended since the subsequent steps will run faster with a smaller data file. The decimation process requires low pass filtering (to avoid aliasing). This has the added benefit of filtering out the faster artifact in the recording.

2. Once the scanner artifact is minimized, you should then use the EKG Noise Reduction transform to reduce the BCG artifact. If need be, you can apply the components of that transform individually (QRS Detection, Correlate Peaks, Subtract Average). If there is significant VEOG artifact as well, you should remove it before removing the BCG. A general rule-of-thumb is to remove the more serious artifact first, and the least serious artifact last.

If you are recording evoked responses, and you find that there is a minimal amount of residual artifact in the recordings following artifact reduction, this may or may not be a serious concern. In cases we have examined, the residual artifact tends to cancel out when the sweeps are averaged.

3. Once all the scanner related artifacts are reduced, you should then precede with the next analysis steps (epoching, averaging, etc.). Ideally, you may want to compare the EEG (power spectra) and/or evoked potentials between recordings made outside the bore versus inside, or inside the bore between scans versus during scans.

One important consideration is the number of sweeps that are acquired. When you record in the magnet, where there is a higher background noise content, it is generally necessary to acquire more sweeps that you would normally obtain outside the magnet, or in fMRI paradigms. Too few sweeps produces a very modest Signal-to-Noise Ratio (SNR). SNRs of 2-3 at most electrode locations are sufficient for visual identification of the ERP, but not of value for anything else. SNRs in that range are significantly lower than what is necessary for co-registering the MRI, fMRI, and the ERP data together.

The quality of the evoked potential is based on a number of factors, the most critical of which are (1) the magnitude of the response and (2) the background noise in the data. The magnitude of the response is primarily determined by stimulus characteristics. The background EEG noise is determined by a number of factors including electrode impedance, subject state of arousal, comfort level etc. If the signal level is constant, then in order to improve SNR, the noise level has to be reduced. Assuming that electrode application is optimized to produce the best possible impedances (and thereby minimize radiated noise pickup), and that the subject has been made physically and psychologically comfortable (which will reduce the level of background spontaneous EEG noise), then the only variable left to manipulate SNR is to increase the number of
stimulus presentations so that the non-stimulus locked background electrical activity in the recording will cancel more effectively. Since this is a 1/SQRT(N) function, more data are better, at least to start with until one can determine the number of stimulus presentations that are typically require to generate an acceptable SNR (approaching 10).

2.6 SECTION 6: Advanced Artifact Reduction

Recordings in the magnet require specialized software for minimizing the extreme artifact that is generally present. The MagLink RT System includes options for reduction of ballistocardiogram (BCG) and gradient sequencing artifact.

Note
You should always work with a copy of your data files, leaving the original data files intact. Store a protected copy on an external device, so you can always retrieve the original data.

The initial section provides an introduction to the artifact reduction software. Presented first is a series of questions designed to elicit information that will describe how the corrections function. We strongly encourage you to read that section first. The artifact reduction transforms are more complicated and less transparent than many of the other transforms in SCAN. Following that are more detailed descriptions for each of the corrections, online and offline, including the relevant batch commands. The artifact reduction techniques are described in the following order:

- **Online EKG/BCG Reduction**
- **Offline EKG Noise Reduction**
- **New Transforms in V4.4 and V4.5**
- **Online fMRI Reduction**
- **Offline fMRI Artifact Reduction**

In the V4.4 and V4.5 releases, there are several new transforms that were designed specifically for reducing BCG artifact. Basically, the steps in the EKG Noise Reduction transform were split out and formed into separate transforms. These provide more flexibility, control, and review opportunities that are needed in cases where the BCG artifact is not adequately removed with the integrated EKG Noise Reduction transform. New peak detection and automated methods are included as well.

2.6.1 Fundamental Concepts in EKG/BCG and fMRI Reduction

There are a number of similarities among the artifact reduction algorithms for EKG/BCG and fMRI, online and offline. It is important to understand how the routines function in order to maximize their effectiveness.

Briefly stated, the algorithms in the EKG/BCG and fMRI artifact reduction techniques identify and average artifact sweeps, and then subtract the average artifact sweep from each subsequent artifact. An average artifact is created for each channel and subtracted from subsequent artifacts in each channel. The subtraction is as effective as the artifacts are stable. That is, the correction will be most effective when there is little variation among the artifact sweeps. A cross-correlation correction can be performed to align components rather than single point triggers, and a correlation threshold test can be performed to exclude atypical sweeps from the average. The average artifact can be dilated or constricted in amplitude to better fit the current artifact sweep. The average artifact is dynamically created/updated in most cases in a rolling fashion, where the most recently identified and accepted artifacts are averaged.

In a given EEG channel and within any section of the data recorded during scanning, that section of data consists of three parts: the gradient artifact, the BCG riding on it, and the EEG riding on both. All three are present, and the idea is to remove the gradient artifact first, while not affecting the BCG and EEG, and then remove the BCG while preserving the EEG.

The gradient artifact is remarkably constant, and changes little if at all. When sweeps that are time locked to the gradient artifact are averaged together, that averaged gradient artifact will be identical to any given single incidence of artifact, assuming that the AD rate is fast enough to capture the artifact accurately and that the timing of the scanner events is set up properly. Under those conditions, it is not difficult to remove the gradient artifact completely using the "average and subtract" method.

BCG, on the other hand, is not as consistent as gradient artifact. It will change somewhat from moment to moment, and may change considerably across the entire recording. For example, there are rhythmic changes in the position of the head due to neck flexion associated with respiration. These subtle changes in head position relative to the static magnetic field and to the gradient field produce substantial and scalp-location specific changes in the BCG artifact. Such changes can substantially impact the effectiveness of the BCG artifact removal or suppression. EEG, of course, is in a constant state of flux. Therefore, the idea for averaging the artifacts and then subtracting the average requires that the average artifact be a true representation of the subsequently encountered artifact, and that the BCG and/or EEG riding on the artifact be reduced as nearly as possible to zero in the averaged artifact. The extent to which BCG and EEG remain in the averaged artifact (not fully canceled out) is the degree to which the genuine EEG will be affected following subtraction.

If the artifact for the average is captured accurately, and if the BCG and/or EEG riding on it cancel to nearly zero, then the artifact will be subtracted and the BCG and/or EEG will remain unaffected. The way to accomplish this is to average enough sweeps so that the non-artifact activity being subtracted cancels out. For example, it takes very few sweeps in the average to capture the gradient artifact accurately and subtract it from the data. But with very few sweeps, there will likely not be complete cancellation of the BCG and EEG. The artifact will be removed, and the remaining data may look like EEG, but it may be altered EEG (literally, EEG subtracted from EEG). Similarly, it may take very few sweeps to capture the BCG average artifact and subtract it out, but the EEG will be affected if the EEG riding on the BCG does not cancel out in the averaged artifact.

How many sweeps should go into the average artifact? There is no simple answer to that. If the EEG is recorded in an eyes open condition, where there is predominately low voltage activity, you may get good cancellation after a few sweeps. If you are recording with eyes closed, and have a subject with high amplitude alpha activity, it may take quite a few sweeps for alpha to cancel out. If it so happens that the EEG activity is somewhat in phase with the scanner or BCG artifact, it may take many sweeps for it to cancel out. We recommend that at least 10 "averages" (TR Blocks, Slices, or BCG sweeps) be used to create the averaged artifact. In some cases fewer will work, and in other cases you may need to use more. The drawback with BCG, of course, is that, since it changes over time, the more sweeps you include, the less likely the average artifact will be the same as the next BCG artifact that is detected (and subtraction will therefore be less than perfect). With gradient artifact, it may take about 10 TR Bocks to get a good average, and there may be only 30 or so blocks. There are compromises, and trial and error may be required to find the best parameters to use. BCG is especially difficult to remove completely, and in some cases the best result is a reduction in BCG, rather than a complete removal.

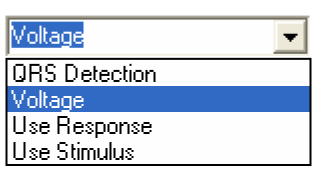
If you are recording evoked responses, there is more tolerance for residual EEG that may remain in the averaged artifact. Averaging the corrected responses should "correct" for minor changes to the EEG that may have occurred during the gradient and BCG corrections, although, as stated above, you may need to record more responses than usual in order to obtain acceptable SNR levels. If you are looking for activity in the raw EEG, such as instances of epileptic spike activity, that activity will be more affected by any residual EEG in the averaged artifact (gradient and BCG averaged artifacts). Particular care should be exercised in determining the optimal parameters to use.

One final point to realize is that the correction begins after the first artifact sweep, even though the user-selected number of averages has not been reached. This means that the accuracy of the correction will improve as you go further into the file - the first sections will be corrected with fewer than the user-selected number of "averages". Whether you include the early "partially corrected" sections in further analyses is left up to the user.

The following information answers basic questions regarding the underlying concepts and operations of the correction algorithms.

2.6.1.1 How are artifacts identified?

There are several methods for detecting the artifacts, and these differ slightly between EKG/BCG and fMRI Artifact Reduction. With **EKG/BCG Artifact Reduction**, there are four methods: QRS Detection (*added in V4.4*), Voltage threshold, and external Stimulus or Response event codes. fMRI Artifact Reduction uses a slightly different voltage threshold detection procedure, as well as stimulus or response event codes (described below).



QRS Detection. The **QRS Detection** method uses an automated QRS Detection routine, based on a public domain algorithm for QRS detection (Open Source ECG Analysis Software Documentation; Copyright © 2002 Patrick S. Hamilton).

The algorithm is used for peak detection and trigger placement. With it, there is no need for the **Refractory Period**, **Threshold**, and **Direction** parameters. The remaining parameters are still used, including the Advanced Settings (described below).

Briefly, beats are detected in two phases: Filters and Detection Rules.

Filters. The signals are filtered to generate a windowed (time limited) estimate of the energy in the QRS frequency band. This is accomplished by:

1. Low pass filtering,
2. High pass filtering,
3. Taking the derivative,
4. Taking the absolute value of the signal, and
5. Averaging the absolute value over an 80 ms window.

The final filter output produces what might be called a "lump" every time a QRS complex occurs. T-waves generally produce smaller lumps than QRS complexes.

Detection Rules. After the signal has been filtered, peaks are detected in the signal. Each time a peak is detected, it is classified as either a QRS complex or noise, or it is saved for later classification. The algorithm uses the peak height, peak location (relative to the last QRS peak), and maximum derivative to classify peaks. The following is an outline of the basic detection rules for the algorithm.

1. Ignore all peaks that precede or follow larger peaks by less than 200 ms.
2. If a peak occurs, check to see whether the raw signal contained both positive and negative slopes. If not, the peak represents a baseline shift.
3. If the peak is larger than the detection threshold it is called a QRS complex, otherwise it is called noise.
4. If no QRS has been detected within 1.5 R-to-R intervals, there was a peak that was larger than half the detection threshold, and the peak followed the preceding detection by at least 360 ms, that peak is classified as a QRS complex.

Threshold Estimation. The detection threshold used in 3 and 4 above is calculated using estimates of the QRS peak and noise peak heights. Every time a peak is classified as a QRS complex, it is added to a buffer containing the eight most recent QRS peaks. Every time a peak occurs that is not classified as a QRS complex, it is added to a buffer containing the eight most recent non-QRS peaks (noise peaks). The detection threshold is set between the mean or median of the noise peak and QRS peak buffers according to the formula:

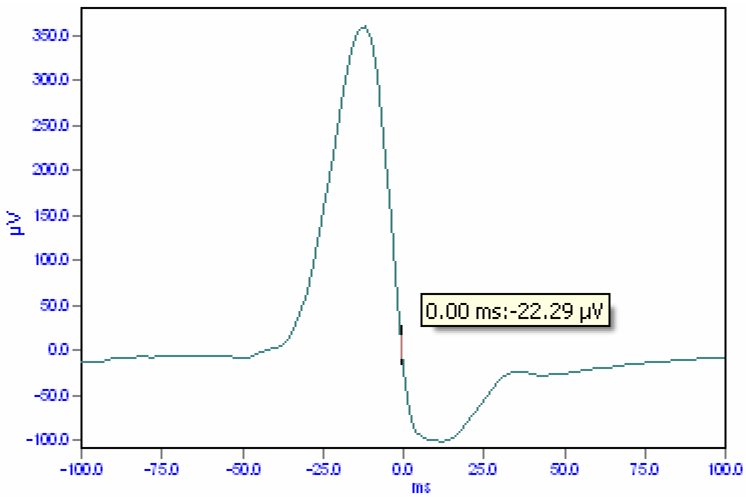
Detection_Threshold = Average_Noise_Peak + TH*(Average_QRS_Peak Average_Noise_Peak)

where TH is the threshold coefficient. Similarly, the R-to-R interval estimate used in 5 is calculated as the median or mean of the last eight R-to-R intervals.

The beat detector must begin with some initial threshold estimate. In order to make an initial estimate, the maximum peaks are detected in eight consecutive

1-second intervals. These eight peaks are used as the initial eight values in the QRS peak buffer, the initial eight noise peaks are set to 0, and the initial threshold is set accordingly. The eight most recent R-to-R intervals are initially set to 1 second.

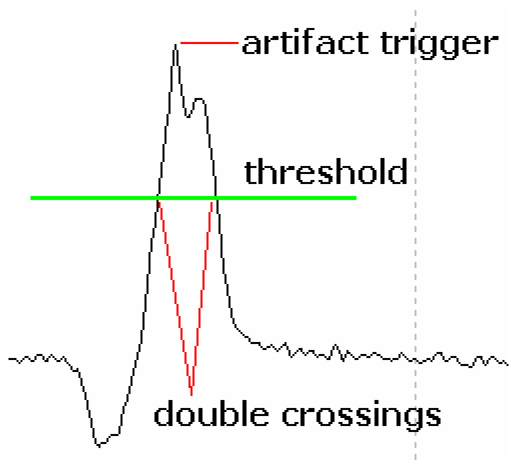
In practice, you will find that it tends to place the events not at the R wave peak, but rather between the R and S waves.



There is a "warm up" period at the beginning of the CNT file where no events are placed (about 8 seconds), then you should see events inserted for each detected QRS complex.

Our experience thus far with the public domain QRS Detection method is that it is very effective in detecting and removing the QRS complex in routine EKG recordings; however, it tends to become less accurate with BCG (which it was not designed to detect).

Voltage. The **Voltage** threshold option uses a double-crossing method to detect a peak from the selected channel (the EKG channel, or the HLI channel if you are using the pulse oximeter). That is, the voltage threshold must be crossed two times, and the greatest or least [absolute] value between the crossings is used as the zero-time point of the artifact sweep. The zero-time point is referred to as the artifact trigger. See also the Correlation and Shift Limit section below.



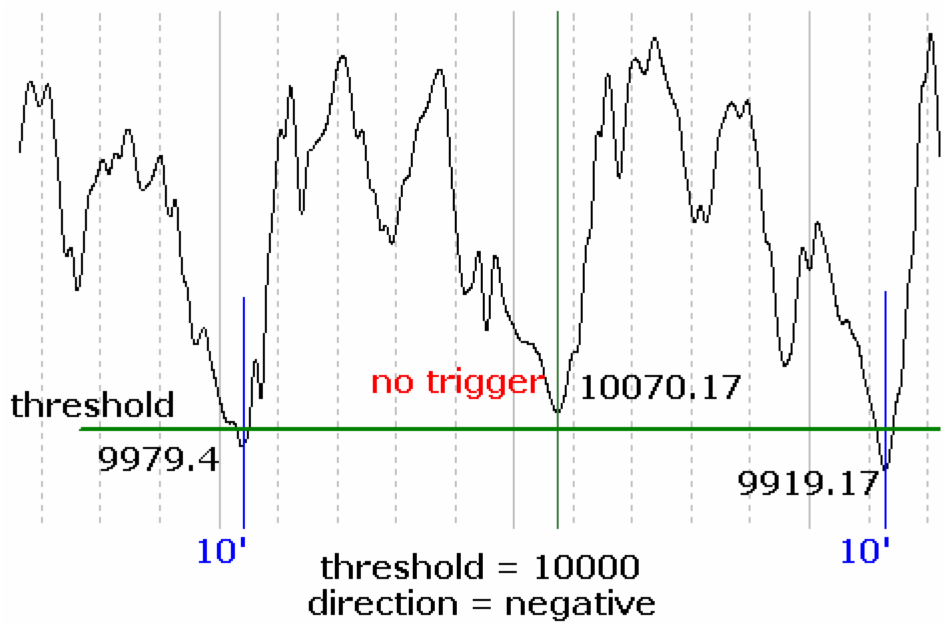
Use Response / Use Stimulus. The final methods (**Use Response**, **Use Stimulus**) use stimulus or response trigger events from an external device, such as an EKG monitoring instrument. TTL pulses are sent and interpreted by the program as either red response events or blue stimulus events, based on which pins are used in the connector on the back of the amplifier.

With the **fMRI Artifact Reduction**, a slightly different method is used for voltage threshold detection. The program scans in 5 data point spans, looking for a voltage transition that exceeds the value you enter for the Voltage Threshold. A trigger event is placed where that occurs, which should be coincident with the beginning of an MR sequencing artifact. The Duration field serves as a Refractory Period.

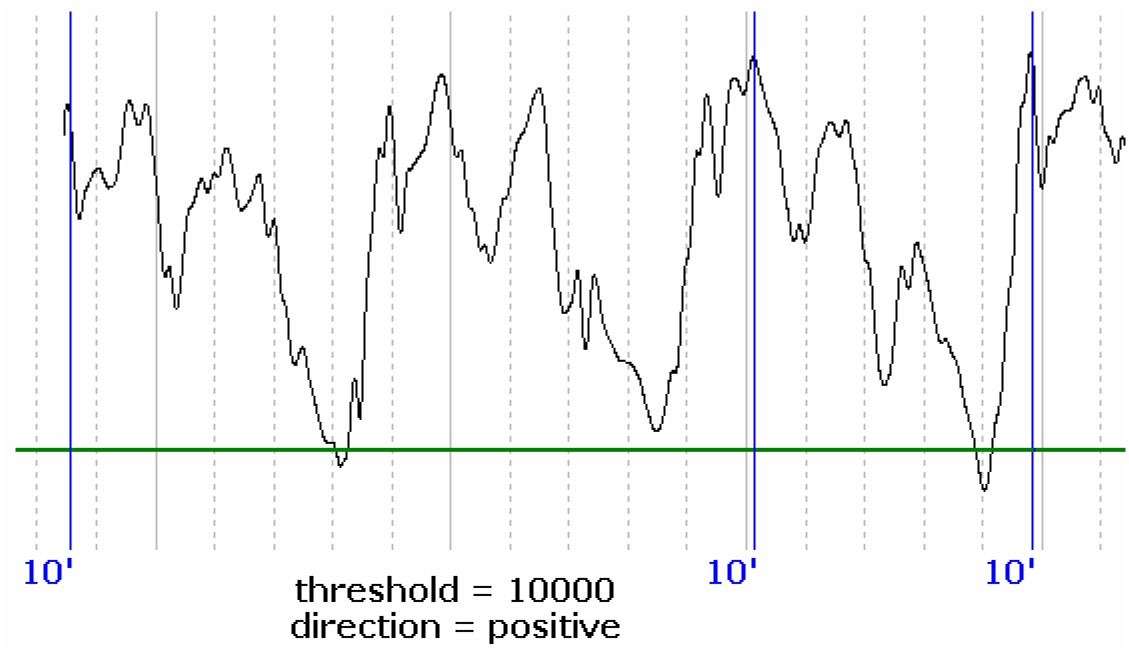
There is also a difference between the Voltage Threshold online versus offline with the fMRI transform. Online, triggers are inserted for each instance in which the threshold criterion is met. Offline, only one trigger is inserted at the first threshold. The Previous and Next buttons are used to tell the program explicitly where the first trigger should be placed (in case there are spurious voltage increase due to "shimming" the scanner).

2.6.1.2 How does the Direction parameter function?

Positive and **Negative** directions are roughly analogous to *greater than* or *less than*. Remember that the peak point is selected with a double-crossing method. *Positive* takes the largest point between crosses; *Negative* takes the smallest point between crosses. Consider the example of BCG to the right. There is a large DC offset, causing the large voltages. We wanted the smallest peak voltage, even though all measurements are positive voltage. This is a case where you use a *Negative* direction.



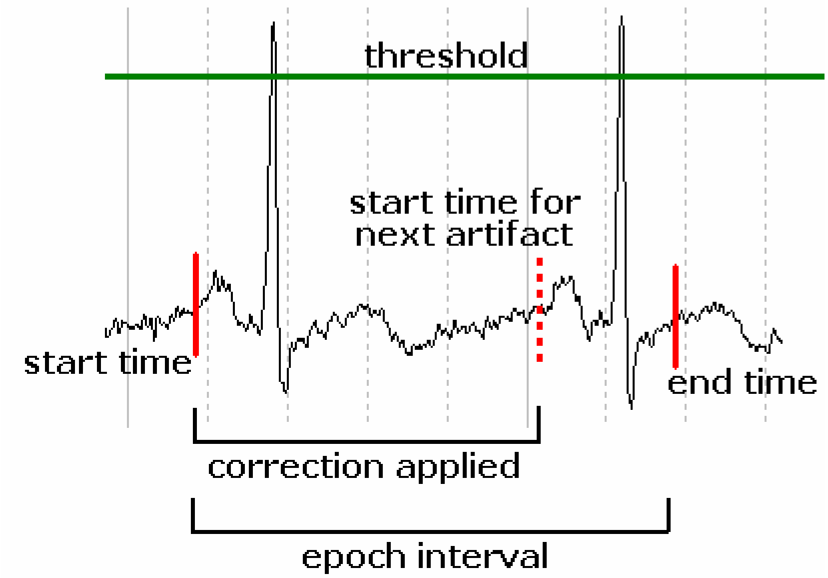
If we had used a *Positive* direction, triggers would have been placed at the greatest voltage between the two threshold crossings at 10000µV. (All settings were the same, except Direction was changed to Positive).



Positive sets the trigger at the greatest voltage point between the two threshold crossings; **Negative** sets the trigger at the least voltage between the two crossings.

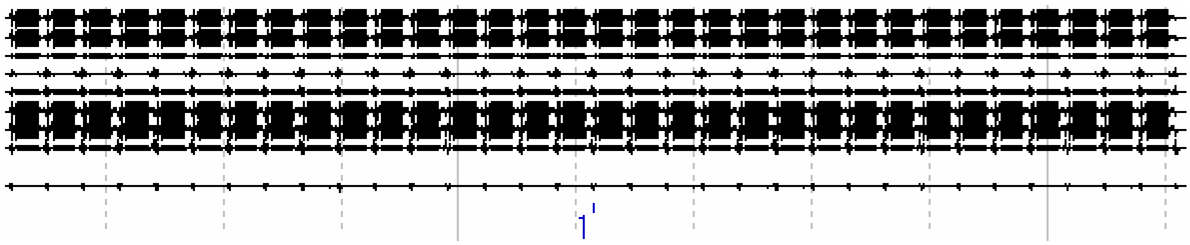
2.6.1.3 How is the span of the artifact sweep determined?

The span of the artifact sweep is determined in slightly different ways for the EKG and fMRI corrections. With EKG Reduction, the **Epoch Interval** is determined by **Start** and **End** times you enter. In the example shown, the Start time was -200ms before the artifact trigger, and the End time was 1000ms after the trigger (the triggers are at the R wave peaks).



While that entire epoch is included in the average artifact, *the correction is applied only up to the subsequent trigger, minus the Start time*. This method minimizes abrupt transitions that can otherwise occur at the edges of the Epoch Interval. It also means you do not need to know what the precise End time should be (that would exclude the next artifact), and works well when the heart rate varies over the recording. The **Refractory Period** can be used, if needed, to block any unwanted triggers between the desired ones. With most files, we have found that Start and End times of -200 to 1200ms will work well for EKG reduction. BCG may require some experimentation.

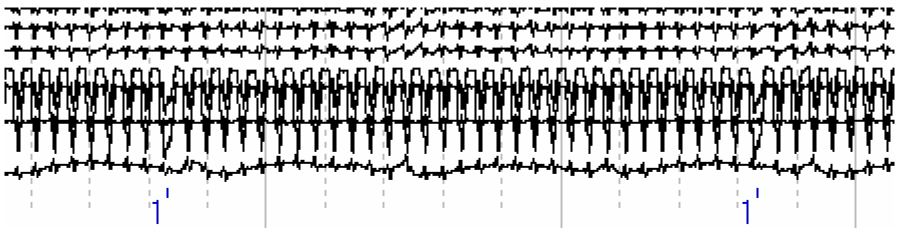
The method for fMRI Reduction is slightly different, and uses the **Duration** of the TR Block or Slice instead of an End time. For example, say the TR Block began 1000ms before the trigger event, and lasted 1000ms after it.



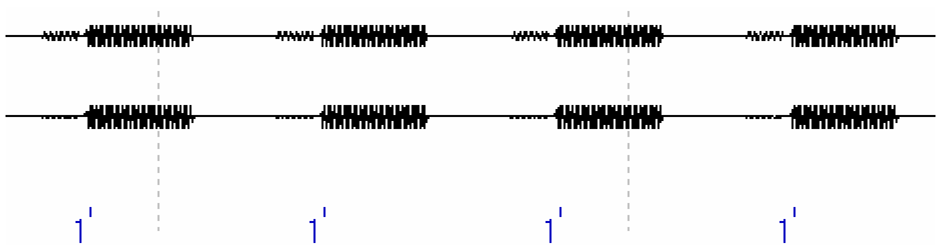
The **TR start from trigger offset** is **-1000**, and the **Duration** is **2000**. It uses the actual duration of the TR Block, rather than the ending time point.

2.6.1.4 In fMRI Reduction, what are TR Blocks, what do the parameters mean, and when should Artifact Removal be performed by TR Block versus Slice?

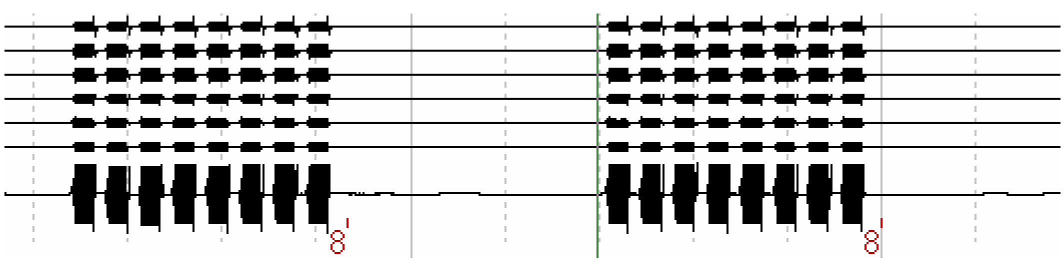
TR (Time Repetition) Blocks are simply blocks of MR slices that are usually designated by a TTL pulse at the beginning of the block. In the example below, there are 32 slices in the TR Block. Each block is designated by a stimulus type code of 1. You would therefore select **Use Stimulus** for the **Triggering Method**, and enter **1** for the **Trigger Code**. The interval between triggers is 2000ms. The **TR start from trigger offset** is **0**, and the **TR Duration** is **2000**. **Artifact Removal** should be set to **TR Block**.



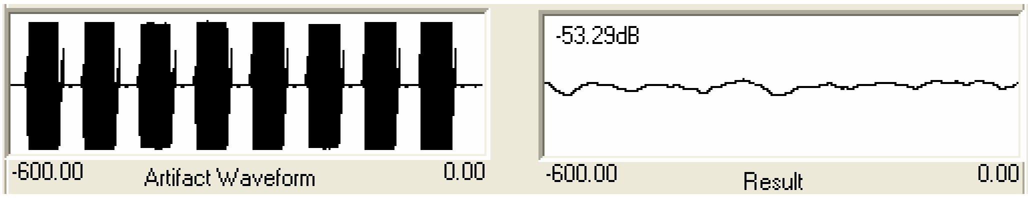
In other cases, depending on your scanner, you may have trigger events for each Slice. In this case, the **TR start from trigger offset** is also **0**ms, and the **TR Duration** is also **2000**ms, in this example. Enter the **Number of slices per TR block** (**32** in this case). **Artifact Removal** should be set to **Slice**.



In the next example, Response codes of 8 appear at the end of a sparsed method of MR sampling, where each TR Block is 600ms containing 8 slices.



In this case, the **Triggering Method** is **Use Response** with a **Trigger Code** of **8**. The **TR Start** time is **-600ms**, and the **TR Duration** is **600ms**. Artifact is removed by **TR Block**. **Continuous removal** is **Off**. The Preview would appear as follows:



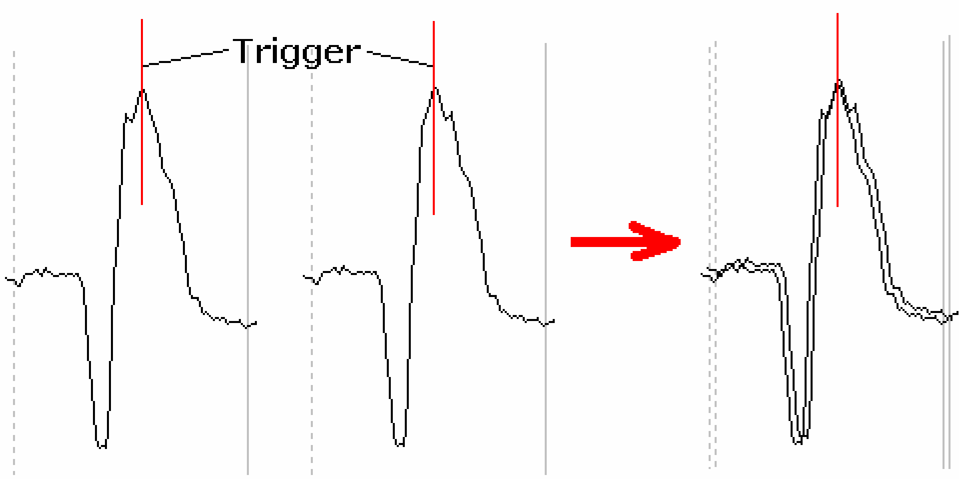
2.6.1.5 What is Continuous Removal, and when should it be used?

Continuous Removal should only be used if the fMRI artifacts occur continuously throughout the data file, with no gaps between TR Blocks. The program will find the first trigger, and use the **End** time for each subsequent trigger. The End time should coincide exactly with the beginning of the next artifact. Any other trigger events in the file will be ignored. The correction will continue throughout the data file.

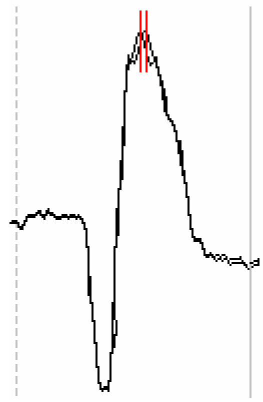
2.6.1.6 What do Correlation and Shift Limit mean?

The Correlation option is used as a means for improving the accuracy of the correction, and we recommend that you use it whenever possible. If disabled, the artifact sweeps are aligned by the voltage threshold method alone. The Correlation option is used in a secondary step to fine tune the average artifact by aligning sections of the waveform rather than triggers. Using the Correlation option will generally improve the effectiveness of the correction.

Recall from above that the **Voltage** threshold method for the artifact trigger determination uses a double crossing procedure. Within that interval, the actual trigger, or zero-point, may vary, depending on where the peak voltage occurs. This can affect the average artifact and result in a less than optimal subtraction of the artifact. To illustrate, the first two EKG sweeps below (left side) are very similar, yet the peak voltage that defines the triggers varies slightly between the two sweeps. Superimposing the two sweeps with the triggers aligned (right side) shows that the waveforms are slightly out of phase. The average of the two will be affected.



When you enable the **Correlation** option, the program will perform a series of cross-correlations between the **Correlation Interval** of the current sweep (using the **Correlation Channel** you select) and the same interval in the average artifact (relative to the trigger that has already been defined). The correlation interval is defined by the **Correlation Interval Start** and **End** times for EKG/BCG Reduction (fMRI Reduction uses a span equal to the duration of the first slice in a TR block, or Duration divided by the Number of slices). The current sweep is shifted by the number of data points necessary to maximize the correlation, then the sweep is averaged in with the previous artifact sweeps. This process can reduce the variability in the average artifact, and thereby improve the subtraction result. The **Shift Limit** option limits the range within which the interval can be shifted. Shift Limit is measured in points rather than ms. If you enter, for example 10 points, the span will be 10 points in either direction. (You will need to know the AD Rate if you want to determine the corresponding ms span). Shift Limit avoids excessive demands on processing time. As a general rule-of-thumb, the Shift Limit should encompass about half of the peak of interest. Say there is an EKG R wave peak with a duration of about 40ms, and an AD rate of 1000Hz (one point every 1 ms). Try a Shift Limit of half the R wave span - 10 points (or 10ms).



If the obtained (maximum) correlation exceeds the **Correlation Threshold** you select, that sweep will be included in the accumulating average artifact. If not, the sweep is excluded. This provides a method for ensuring that only genuine artifact sweeps will be included in the average artifact. The value for the Threshold is the correlation x 100.

You do not necessarily have to include the artifact trigger within the EKG Correlation Interval. In some cases, you may want to use a different section for the correlation. The section might delineate a more stable waveform in the artifact.

With *offline* fMRI artifact reduction, a slightly different procedure is used. There is no user selectable Correlation Channel nor Correlation Threshold. Correlations are computed using the TR epoch across all combinations of channels. The more frequwently occuring shift value is then used.

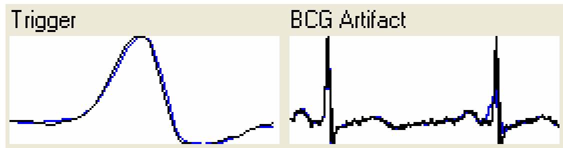
The **Shift** field 

, seen when you click the  button during acquisition, displays the number of points that the most recent artifact sweep was shifted.

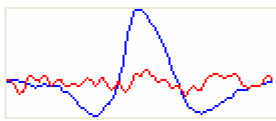
The **Correlation** field 

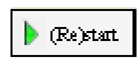
displays the most recently computed (maximum) correlation value. In many cases with EKG, the Correlation will be quite large, near 100%. It would not be unusual to use a Threshold of 90%, or greater, for EKG.

During acquisition, you will see the ongoing Trigger and Artifact waveforms (the average as well as the most recent sweep, in blue). The interval displayed for the **Trigger** is the Correlation Interval, and the interval displayed for the **BCG Artifact** is the Epoch Interval.



Rejected sweeps - those that to not meet the Correlation Threshold - will be seen in red.

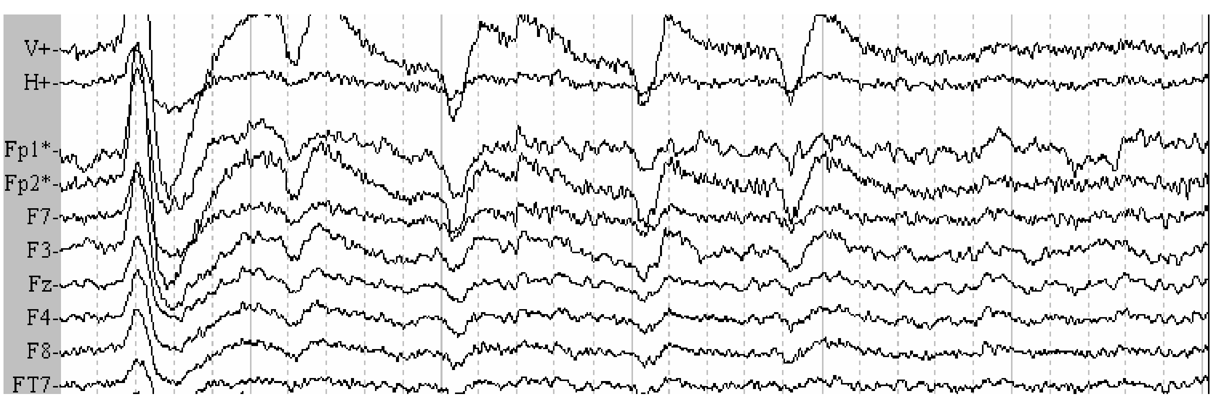


On occasion, it may happen that the initial artifact sweep is not a genuine artifact. Each subsequent genuine artifact will therefore be rejected when the correlation threshold is not met. Should that happen, just click the 

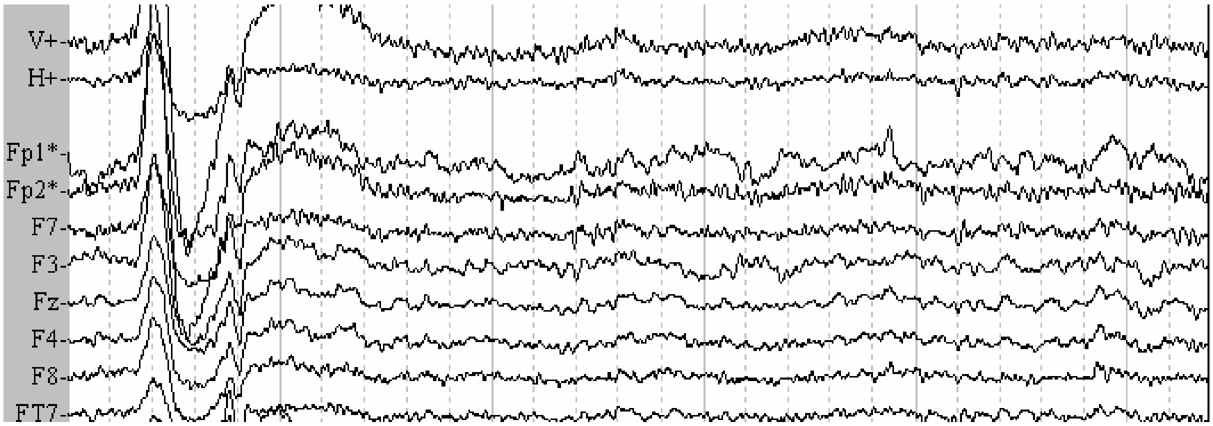
button to restart the averaging.

2.6.1.7 When should you use a different channel for the Correlation Channel?

In the EKG Noise Reduction transform, you have the option to select the channel you want to use for the **Correlation Channel**. In many cases this will be the same channel as the Trigger Channel. However, if you have, for example, coincident VEOG (blinks coinciding with the EKG artifact) in the recording, and the blinks do not appear in the EKG channel, you may want to use the VEOG channel as the Correlation Channel. If the blinks also appear in the EKG channel, then the correlation correction, using the EKG channel, will likely exclude those sweeps from the average artifact. If the blinks do not appear in the EKG channel, then the coincident blinks will be included in the average artifact. When it is subtracted from subsequent artifact sweeps, VEOG can be introduced into the EEG channels (there was only the single blink in the file shown below).

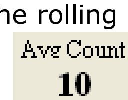


If you instead use the VEOG channel as the Correlation Channel, the artifact sweeps containing VEOG will be rejected from the average artifact, and therefore no VEOG will be added to the EEG channels. You will likely need to reduce the Correlation Threshold in these cases (use the online correction to determine the threshold from the Artifact Suppression waveform displays).



Note
You can avoid this problem by removing the VEOG prior to removing the EKG/BCG.

2.6.1.8 What is the number of Averages?

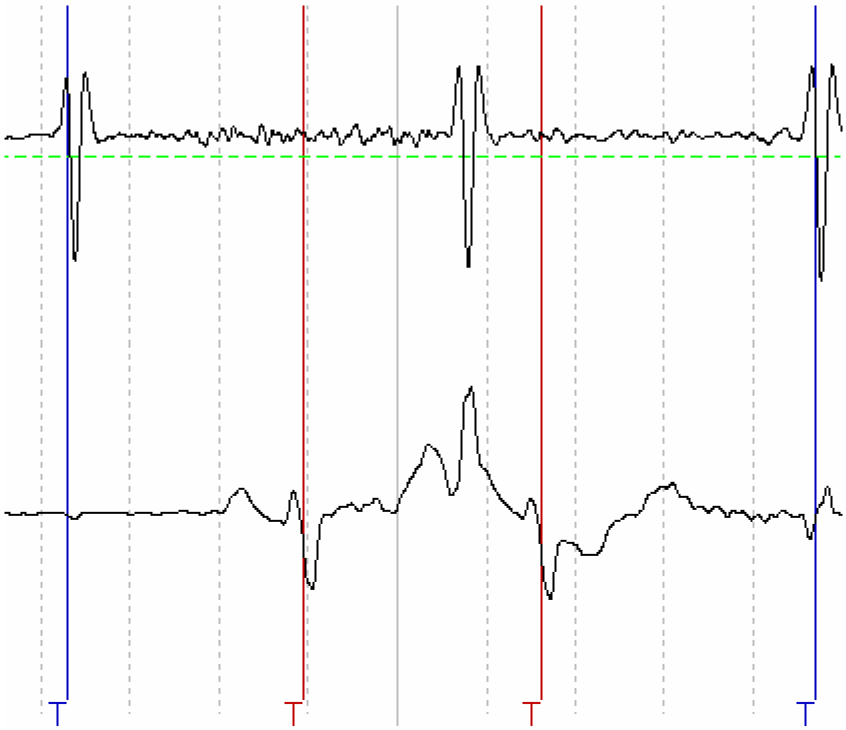
The maximum number of artifact sweeps included in the rolling average is set in the **Averages** field. It is displayed in the **Avg Count** field 

, seen when you click the  button from the Toolbar during acquisition.

We recommend that you use at least 10 averages. With fewer sweeps, the artifact may be corrected, but you also risk altering the EEG data. Whatever EEG data are contained in the average artifact will be subtracted from the subsequent sweep. Therefore, as a minimum, we recommend 10 sweeps for adequate cancellation of the EEG in the average artifact.

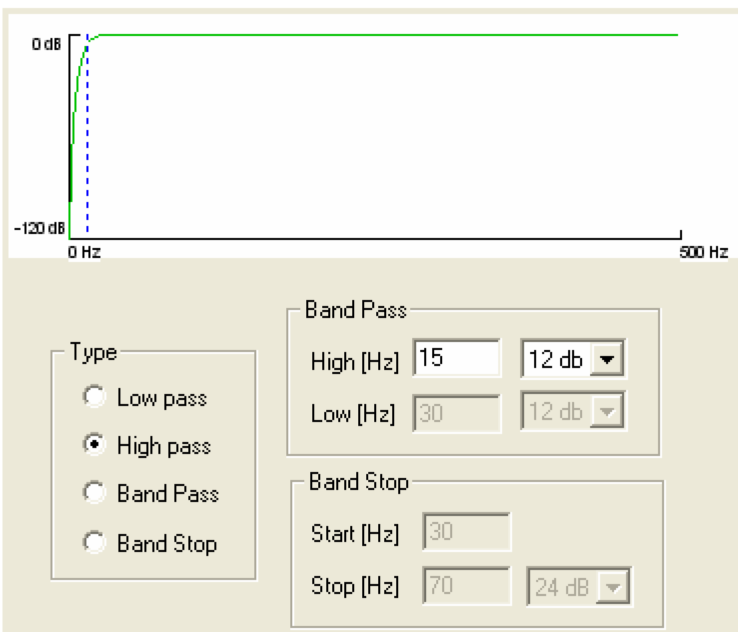
2.6.1.9 What does the Insert Events option do?

The **Insert Events** option will display events in the data file to indicate genuine triggers (blue) and rejected triggers (red) during acquisition.



2.6.1.10 At what point in the process is the Filter applied?

Both the EKG/BCG and fMRI Reduction methods include a filter option; however, the effects of the filtering differ between them. They are alike in that the filter is applied to the display only; it does not affect the data that are stored during acquisition.



For EKG/BCG Reduction, enabling the filter option activates the Parameters button. Clicking it displays the Filter option screen shown to the right. You may select the type of filter (Low Pass, High Pass, etc.) and select the cutoffs and rolloffs. These settings take precedence over any other Display Filter parameters you may have set (by *right clicking* in the display and selecting **Add Display Filter**). The Filter is applied to the *Trigger Channel only*. It is applied *before* the voltage threshold is determined, and is, in fact, used primarily to facilitate peak detection when using the Voltage threshold. In some cases, especially with BCG, you may need to filter the artifact to allow precise detection of a reliable peak (this is not necessary if you have a pulse oximeter).

fMRI filtering has a low pass filter only, with a fixed rolloff (48dB/oct). The filter is applied to *all* channels, *after* the correction has been performed. Offline, if you are decimating (down-sampling) the file, you must use the filter to avoid aliasing.

2.6.1.11 What is the Refractory Period?

The Refractory Period (EKG/BCG only) is an interval that may be set immediately after an artifact trigger has been detected. Any other potential trigger in the refractory period will be ignored. This avoids spurious triggering. With fMRI Reduction, Duration of the TR Block is its refractory period. No additional triggers will be recognized during that span.

2.6.1.12 Is the fMRI or EKG/BCG correction applied to Bad and Skipped channels?

No. Neither correction is applied, online nor offline, to channels designated as Bad or Skipped channels.

2.6.1.13 Why do I see different parameters at different times in the artifact reduction dialog screens in EDIT?

When you save the data file in ACQUIRE, the parameters that are saved in the setup file are included with the data file. If you change the parameters "on the fly" during a recording, the most recent settings will be stored with the data file. Whenever you open a data file in EDIT, those are the parameters you see in the artifact reduction dialog screens. If you change the parameters in EDIT, apply the correction, and return to the artifact reduction dialog screen, you will see the most recent parameters you entered. If you close and reopen the data file, you will again see the original parameters from ACQUIRE.

Note

If you have used the **Delete Bad Channels** transform to remove channels from the original data file, you may find that the **Trigger Channel** and **Correlation Channel**, as seen when you initially open the new data file, differ from what was seen with the original data file when it was initially opened. (The channel numbers have changed, and these fields use the channel numbers). Be sure to check these fields to confirm that the correct channels have been selected.

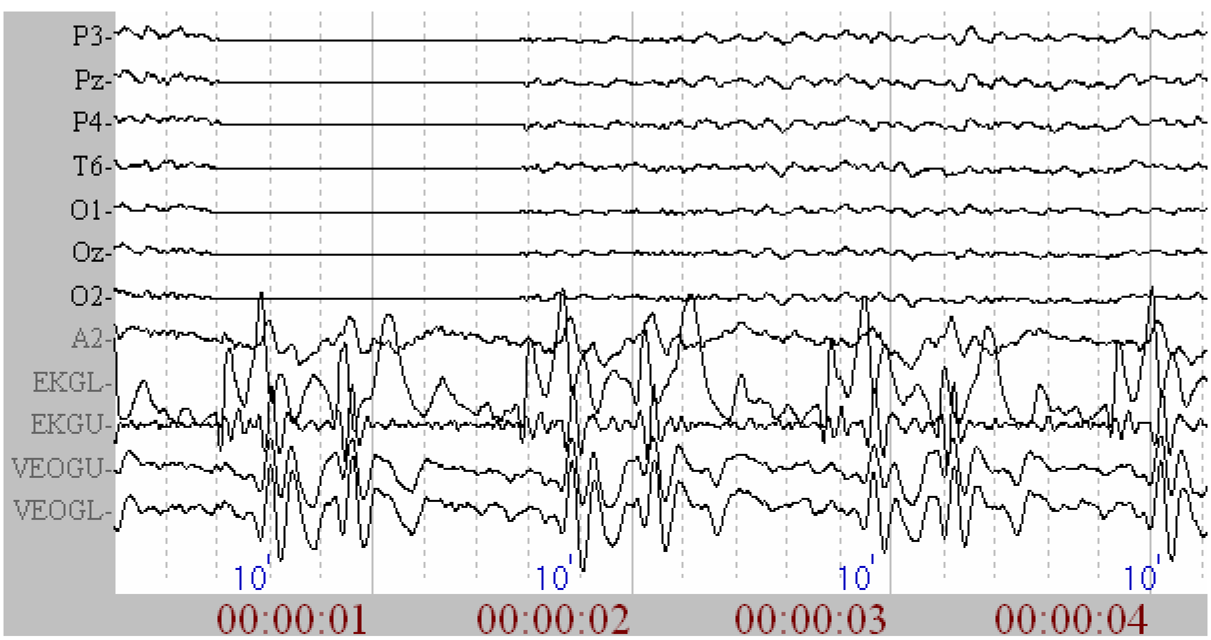
2.6.1.14 Why are the options sometimes grayed out when I click the Artifact Reduction icon in ACQUIRE?

There are two ways to enable the reduction routines. From the **Startup** screen, accessed by **Edit** → **Overall Parameters**, there are options to enable each correction.

These have the same effect as clicking  or  from the EKG/BCG Reduction or fMRI Reduction tabs. When enabled, the options will not be grayed out when you first click the  button. If the options are grayed out, click the  button to activate them. Clicking the  button will gray out the options.

2.6.1.15 Why is there a blank space near the beginning of the corrected file?

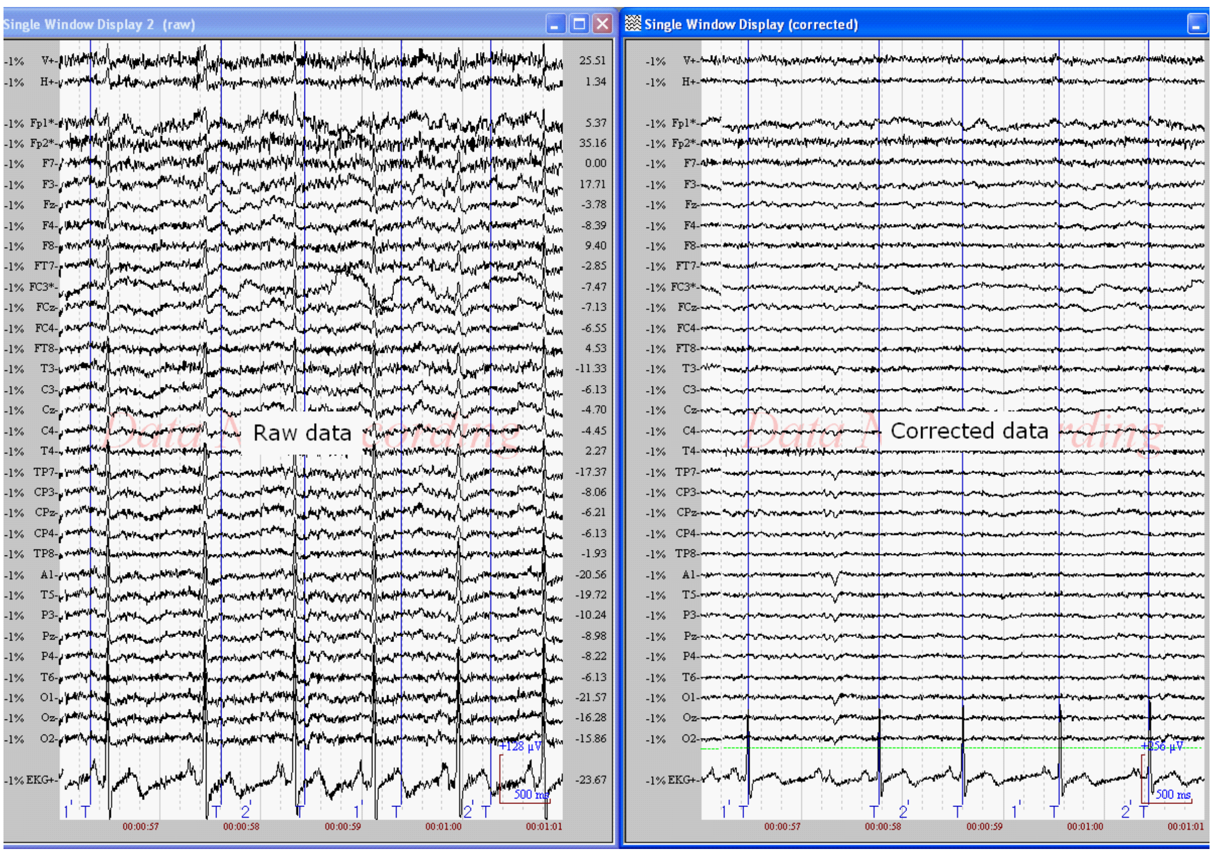
Artifact sweeps are averaged and then subtracted from the current artifact sweep. Offline, in the case of the initial sweep, the artifact sweep is subtracted from itself, thus the flat line at the beginning. When the second sweep is detected, artifact sweeps 1 and 2 are averaged together and subtracted from sweep 2, and so on, up to the number of **Averages**. The duration of the flat line is the corrected span (as described above). That is, the **Epoch start from trigger offset** to one data point before the subsequent trigger, minus the Epoch start span. It follows then, that the correction will become more stable as you move past the first few sweeps, as the average artifact is based on an increasing number of artifact sweeps, up to the number you enter.



Online, you will see a blank space (flat lines) at the beginning of the corrected file. This is required for buffering. The amount of buffering is a function of the size of the intervals and the Shift Limit. If you are displaying the uncorrected and corrected data files at the same time, the uncorrected data will appear before the corrected data for that reason.

2.6.1.16 Is it possible to store the corrected data?

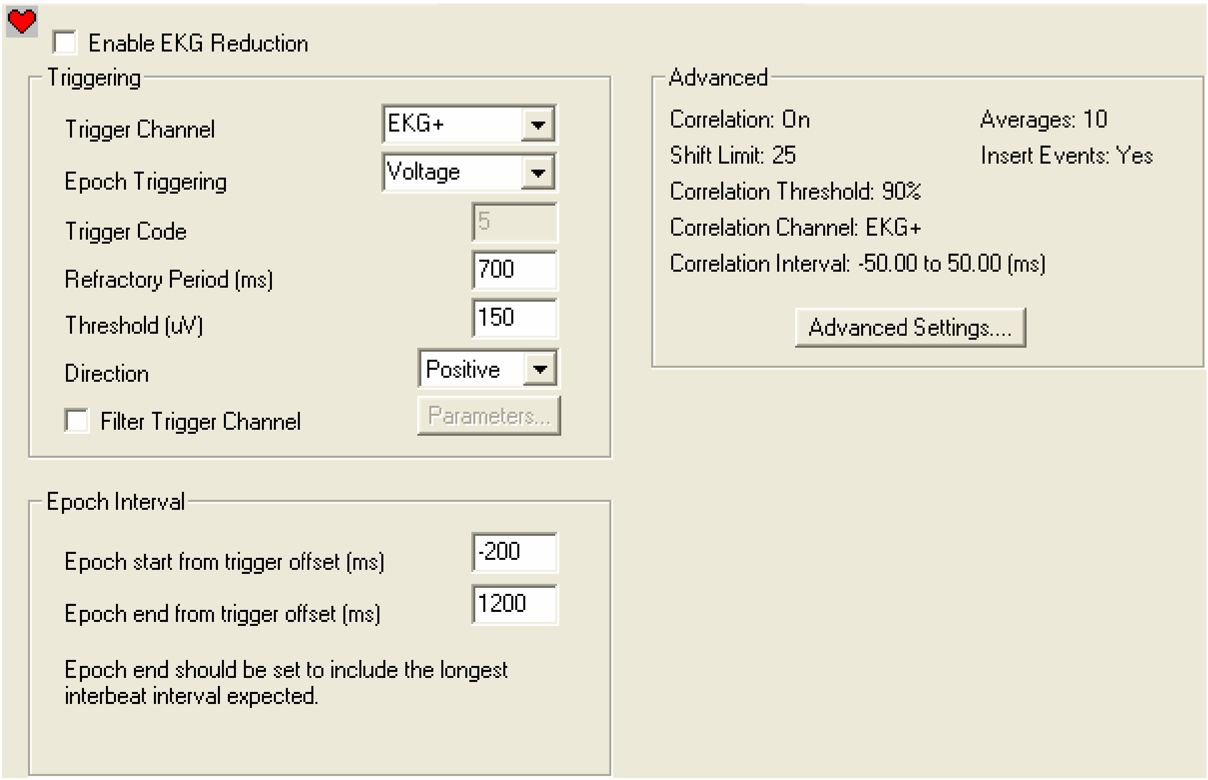
Yes. Go to the **Edit** → **Overall Parameters** → **Startup** tab. You will see an option near the bottom to ☑ Save Corrected Data. This gives you the option to save either the raw or the corrected data (not both). On the same screen, notice also that there is a new option for the **Single Window Display No. 2**. If you enable ☑ Show uncorrected data, you can see both the corrected and uncorrected (from **Single Window No. 1**) data during acquisition.



2.6.2 Online EKG/BCG Reduction

The EKG/BCG Reduction routine (CNT files only) is intended for removal of ballistocardiogram (BCG) from recordings made in the MR bore, but may be used for routine heart beat removal also. The EKG/BCG Reduction procedure uses a voltage threshold, external event codes, or automatic QRS Detection methods to identify artifacts. You select how many artifact intervals you want to be averaged, and an averaged artifact is created for each channel. The averaged artifacts are subtracted per channel from each subsequent instance where the threshold is met. A correlation test can be performed to exclude sweeps that are too dissimilar from the average artifact. A rolling average is used to accommodate any changes in the artifact throughout the data file. The average will always be based on the N most recent artifacts (where N is the number you enter for Averages).

Click **Edit** → **Overall Parameters** → **EKG/BCG Reduction** tab. There are three sets of parameters: Triggering, Epoch Interval, and Advanced.



Triggering. There are several ways to initiate an artifact sweep: QRS Detection, a voltage threshold, and stimulus or response event codes.

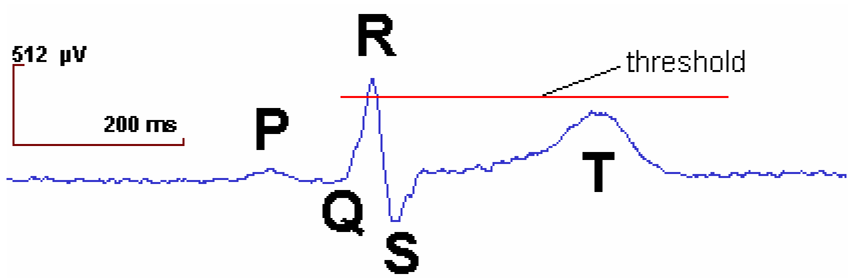
Trigger Channel. If you are using a Voltage threshold, select the channel that will be monitored (typically the EKG channel, or an HLI channel if you are using the pulse oximeter).

Epoch Triggering. The options are **QRS Detection**, **Voltage** or **Use Response / Use Stimulus**.

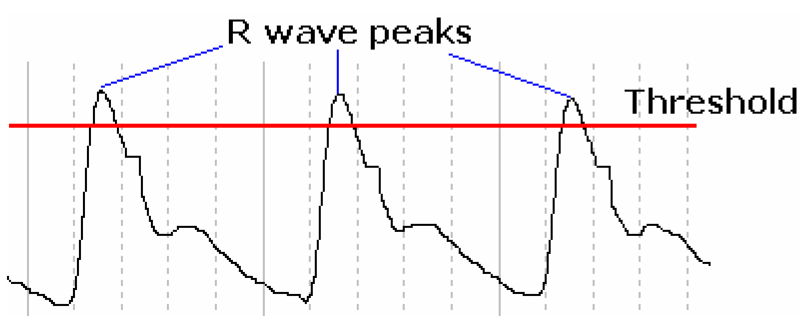
QRS. The **QRS Detection** option is new to V4.4, and is described above in the **Fundamental Concepts** 28 section. Briefly, the QRS Detection method uses an automated QRS Detection routine, based on a public domain algorithm for QRS detection (Open Source ECG Analysis Software Documentation; Copyright © 2002 Patrick S. Hamilton). There is a "warm up" period at the beginning of the CNT recording before the correction begins (about 10 beats), then you should see the EKG artifact become markedly reduced (after a brief flat line).

Our experience thus far with the public domain QRS Detection method is that it is very effective in detecting and removing the QRS complex in routine EKG recordings; however, it tends to become less accurate with BCG (which it was not designed to detect).

Voltage. With the Voltage option, an artifact sweep is initiated when the voltage in the **Trigger Channel** exceeds a criterion you set. Enter the **Threshold** value. This value should be sufficiently large to differentiate the EKG artifact from other activity. The selection of the trigger point uses a peak detection algorithm. The waveform must cross the threshold two times, and the maximum (or minimum, depending on the settings) value during that interval is used for the placement of the trigger. The best Threshold is one that captures the R wave while exceeding the T wave voltage. You may also use the **Refractory Period** to disregard T wave (or other) voltages that exceed the Threshold. Select the **Positive** or **Negative** direction for the EKG artifact.



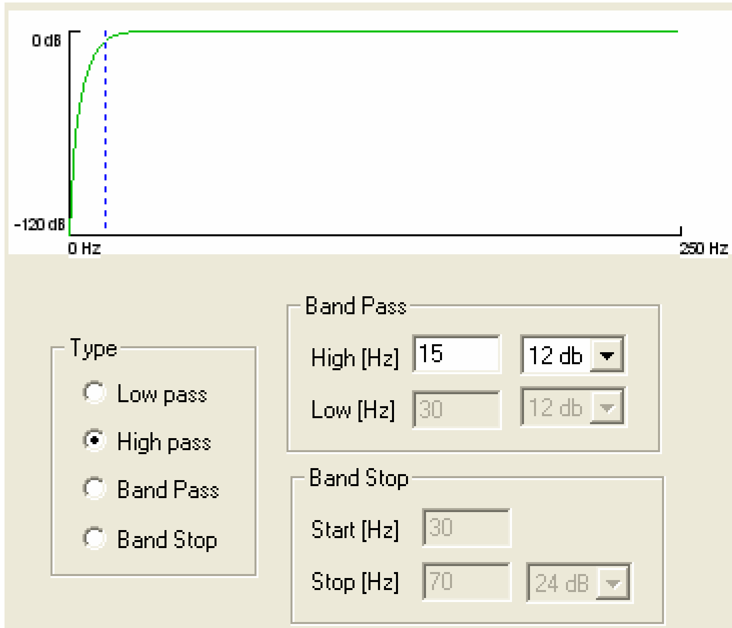
If you are using the pulse oximeter, the HLI pulse channel will appear similar to the following. The pulse may appear extremely large, depending upon the scaling factor you used in the HLI configuration in ACQUIRE (when the data were recorded). There will be a prominent peak, and you should select a Threshold level that captures the peaks (this may be a very large number).



Use Response / Use Stimulus. In some cases, you may have TTLs from a peripheral EKG device. These will be seen as red response events or blue stimulus events, as with STIM. In that case, select either Use Stimulus or Use Response. Enter the event code in the **Trigger Code** field. The Threshold and Direction fields will gray out.

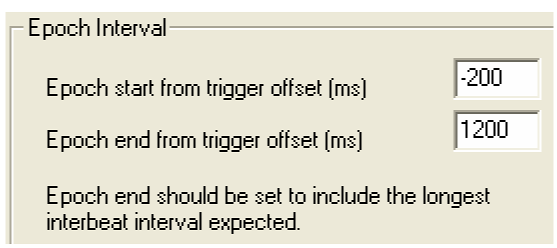
Filter Trigger Channel Filter. This option lets you apply a high pass IIR filter to the artifact channel (Voltage triggering). Enable the option, and click the

button to see the Filter dialog screen.

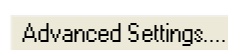


Select the type of filter you want to use (Low pass, High pass, etc.). Enter the cutoff values and rolloffs in either the Band Pass or Band Stop fields (depending on the Type of filter selected). The effects of the filter are seen in the diagram at the top of the display. The filter is applied *before* the correction, and is used to facilitate peak detection. This is especially useful in some instances with BCG artifact, where a consistent peak may be difficult to find.

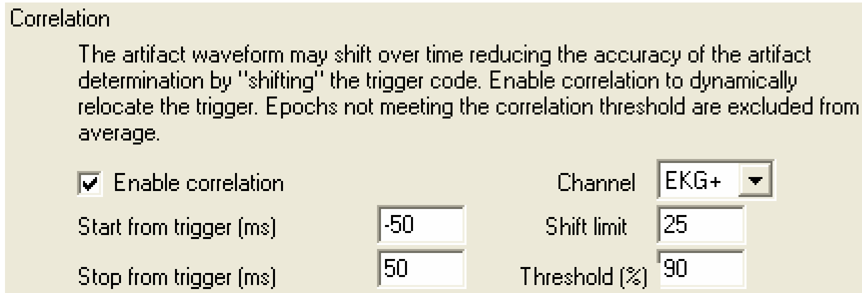
Epoch Interval. The Epoch Interval includes the section before and after the point at which the Trigger is placed. This is the section that will be included in the average artifact. It should be long enough to encompass the entire artifact, and a little more (see the **Fundamental Concepts** 32 section for more information). In contrast to the fMRI Reduction, which uses the complete span of the TR Block for the **Duration** field, EKG Reduction uses the time point for the end of the Epoch Interval.



Advanced. The information displays the current settings. Click the button to access the additional parameters.

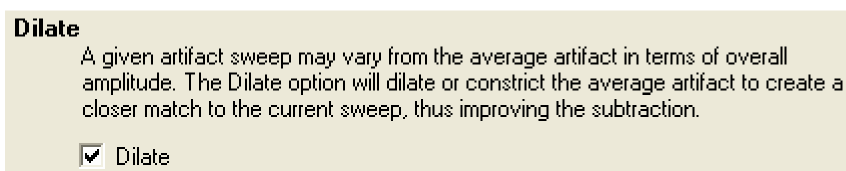


Correlation. The Correlation fields provide a method for aligning the artifacts by similarity between the current sweep and the average artifact, and for excluding artifact sweeps that are too dissimilar from the average artifact (see the **Fundamental Concepts** 35 section for more information). Using the Correlation option will generally improve the effectiveness of the correction.



The Correlation Interval (**Start from trigger**, **Stop from trigger**) defines the span that is correlated with the same span in the average artifact. It may be the same interval that includes the peak used for triggering, or a different interval. **Channel** is typically the same as the Trigger Channel, although you have the option to use a different one (see the **Fundamental Concepts** 37 section for an example). **Shift limit** (in points, not ms) defines the range that the trigger may be shifted. The **Threshold** is the maximum correlation value x 100. (If you want to use a threshold of r = .95, enter 95). Sweeps with a correlation less than the threshold will be excluded from the average artifact.

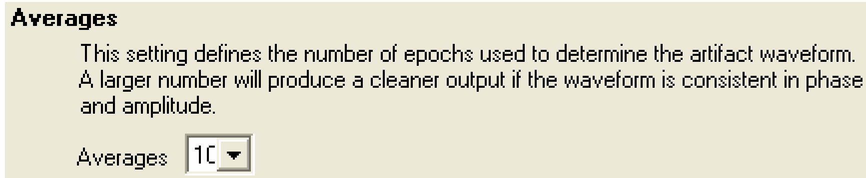
Dilate. A given artifact sweep may vary from the average artifact by overall amplitude - it may be somewhat larger or smaller than the average artifact. Enabling this option will direct the transform to fit the average to the current sweep by using a multiplier to dilate or constrict the waveform until a best fit is obtained. On a per channel and per trigger basis, data points in the average waveform are scaled according to a minimized RMS value. The final subtraction will reduce over- or under-correction that may otherwise occur.



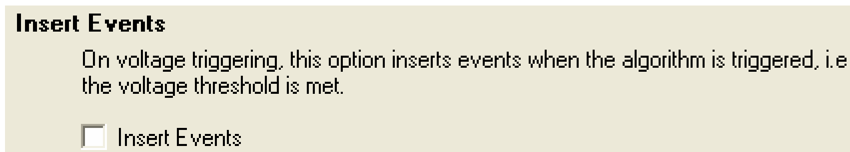
Note

If there are blinks or other large artifacts in the recording, the scaling will be affected by the larger amplitude of the artifacts. The correction just before and after the artifacts may show paradoxical increases of the EKG (due to the larger scaling factor used). In this case, it is recommended that the blinks be removed first.

Averages. This is the number of artifact sweeps that will be averaged to create the average artifact. The average artifact is rolling, based on the N most recently detected sweeps (where N is the number you enter). We recommend that you use at least 10 sweeps in the average. With fewer sweeps, the artifact may be corrected, but you also risk altering the EEG data. Whatever residual EEG data are contained in the average artifact will be subtracted from the subsequent sweep. Therefore, as a minimum, we recommend 10 sweeps for adequate cancellation of the EEG in the average artifact.



Insert Events. Enable this option if you want to have trigger code events inserted where the artifacts are detected. If the sweep is detected, you will see a blue vertical line with a "T" event. If the sweep is rejected, you will see a red line.



In Operation

Click the  icon from the Toolbar to see the fMRI and EKG/BCG Reduction parameters that may be accessed during acquisition. If the parameters for either the fMRI or BCG/EKG sections are grayed out, just click the 

icon on the Toolbar. If you see only the fMRI parameters, click the  button next to the 

button to display the BCG/EKG parameters. To minimize the display during acquisition, click the  at the top of the fMRI side of the display and all parameters will be hidden.

The Trigger light will blink briefly when each threshold is met. The Reject light will blink when an artifact sweep is rejected. The On light will come on when the correction is active. The Rate (BPM) displays the rate of the heart beat per minute.

The parameters are the same as those you set from the Overall Parameters.

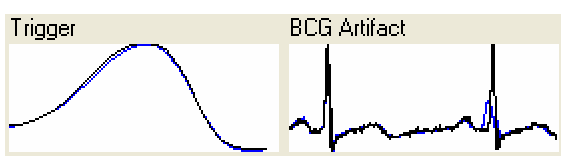
EKG/BCG Parameters

Triggering	
Triggering Method	Voltage
Channel	EKG+
Code	5
Refractory (ms)	700.00
Threshold (uV)	150.00
Direction	Positive
Channel Filter	Disable
Correction Interval	
Start (ms)	-200.00
Stop (ms)	1200.00
Advanced	
Enable Correlation	Enable
Correlation Channel	EKG+
Correlation Start(ms)	-25.00
Correlation Stop(ms)	25.00
Shift Limit (points)	10
Correlation Threshold %	95
Averages	10
Insert Events	Enable

The parameters can all be changed during acquisition. The most recently applied settings will be stored with the data file (and seen when you apply the transform in EDIT). *When you change a parameter, click the* (Re)start *button to apply the changes.* This will reset and restart the artifact reduction procedure. Click the Halt button to stop the correction.

The Filter Parameters button is used to access the Filter parameters, and is active if you have enabled Channel Filter Enable.

During acquisition, you will see the Correlation Interval (Trigger) and the Epoch Interval (BCG Artifact) waveforms. The blue trace is the most recent one, and the black is the average. Rejected sweeps will be seen in red.



The **Avg Count** displays the number of sweeps in the average artifact, the **Shift** field displays the number of points that the more recent trigger was shifted, and the **Correlation** field displays the correlation between the current Correlation Interval and the average artifact.

Avg Count	Shift	Correlation
10	**0**	**99.92**

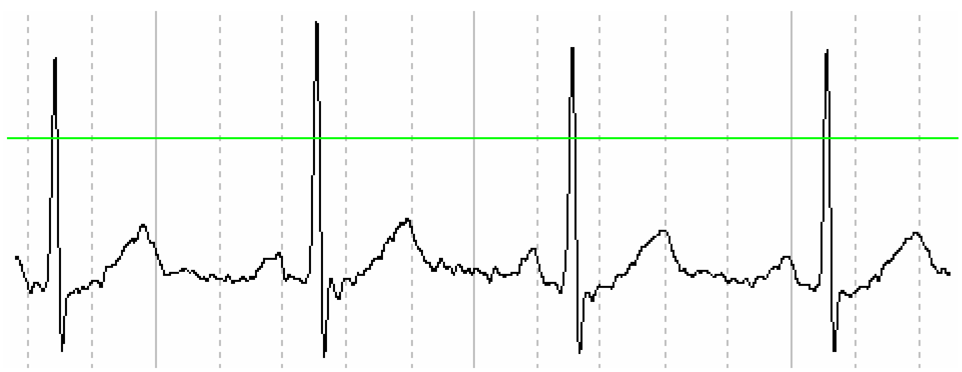
2.6.3 Using EKG/BCG Reduction - Online

Configuring the online EKG/BCG Reduction parameters is fairly straight-forward. The **Voltage** or **QRS Detection** triggering method will be used in most cases. The exception is if you have a peripheral EKG device that sends a TTL trigger pulse with each heart beat (in which case you would use either the **Use Response** or **Use Stimulus** method). EKG and BCG can vary considerably from person to person. There are some parameters that will be the same across recordings, while others should be selected according to the individual subject. You should allow some time at the beginning of the recording session to determine the specific parameters.

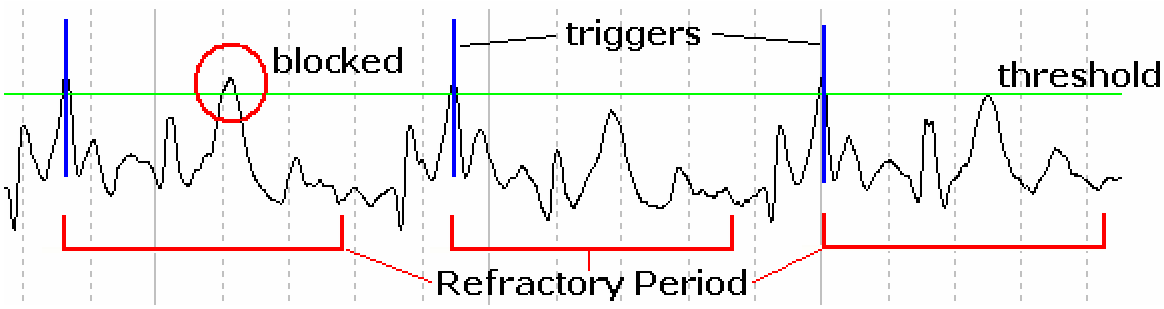
In advance, you will know the Triggering Method, the Triggering Channel, and the Type Code (if you are using one). You will likely have decided how many artifacts you want to be averaged, and whether or not you want to Insert Events. The Correlation Interval and the other Correlation parameters will likely be fairly consistent across subjects. See the **Fundamental Concepts** 35 section if you are not sure how to use these parameters.

The remaining parameters may or may not be used, depending on the Method you selected, and they may be unique for each subject. In a preliminary recording, you should determine the Threshold (unless you are triggering by events). This will be a voltage that differentiates one peak (usually the R peak) from all the others in a single artifact. Verify the Threshold at several points as you monitor the recording.

Refractory Period. You should then determine whether you need to use the Refractory Period. In the first example below, there is no need for a refractory period (minimum time is 100ms). There are no voltages between the R waves that are great enough to be mistaken for the R waves.



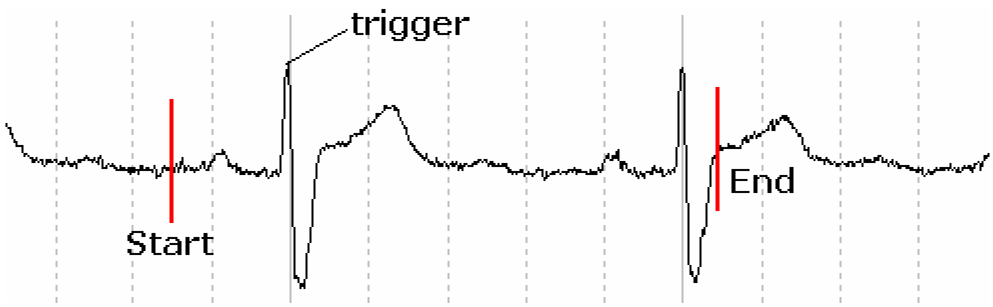
In the next example (BCG), it is less clear which component is which. If we assume that the larger, sharper one is the R wave, then the secondary large one is likely the T wave. In this example, it is not possible to use a threshold alone to differentiate the two. Adding a **Refractory Period** (approx. 800ms), however, will block any T or other waves large enough to cross the Threshold. Triggering will then be reliable.



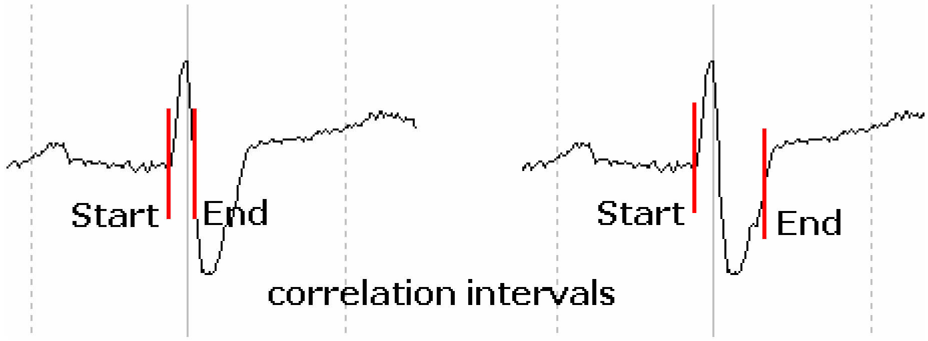
If you are using the pulse oximeter, there will be no doubt or difficulty in determining the peaks using the Voltage threshold method (QRS Detection is not recommended with BCG).

Channel Filter. The Filter may or may not be needed. A High Pass filter is useful if there is DC drifting, or if you need to remove slower components to enhance the peaks to be used for the threshold detection. With BCG especially, it may be helpful to filter the slower frequencies, allowing the faster peak component to become more prominent. With the pulse oximeter you will likely not need to filter the trigger channel.

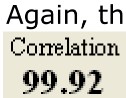
Epoch Interval. The Epoch Interval must be determined for each subject, as it depends on the heart rate (BPM). You need to see some of the EKG/BCG in order to determine the Start and End times. In the example below, we might choose an interval from -300ms to 1100ms about the trigger. Again, the average artifact is based on the entire interval; however, the correction will extend to the next trigger minus the Start time.



Correlation Interval. The Correlation Interval should be selected from a stable part of the artifact. This does not have to be a span around the Trigger; it can be specified elsewhere in the artifact. With EKG, it would typically encompass the R wave, or the R and S waves, as shown below.



Shift Limit (points). Again, this parameter is in data points, not ms. It refers to the jitter of the Trigger within the double-crossing method used to determine the trigger position. Watch the Shift display during acquisition to see how much shifting is being done to align the Correlation Intervals. The Shift Limit setting will limit the correction to the specified range. (Note that the number of points is directly related to the AD rate). Avoid excessive large Shift Limits as this places a large demand on the processor. (See the **Fundamental Concepts** 35 section for more details).

Correlation Threshold. The Correlation Threshold is used to exclude artifact sweeps that are not well correlated with the average artifact. What Threshold should you use? Again, this will depend. When you make a test recording, watch the Correlation field 

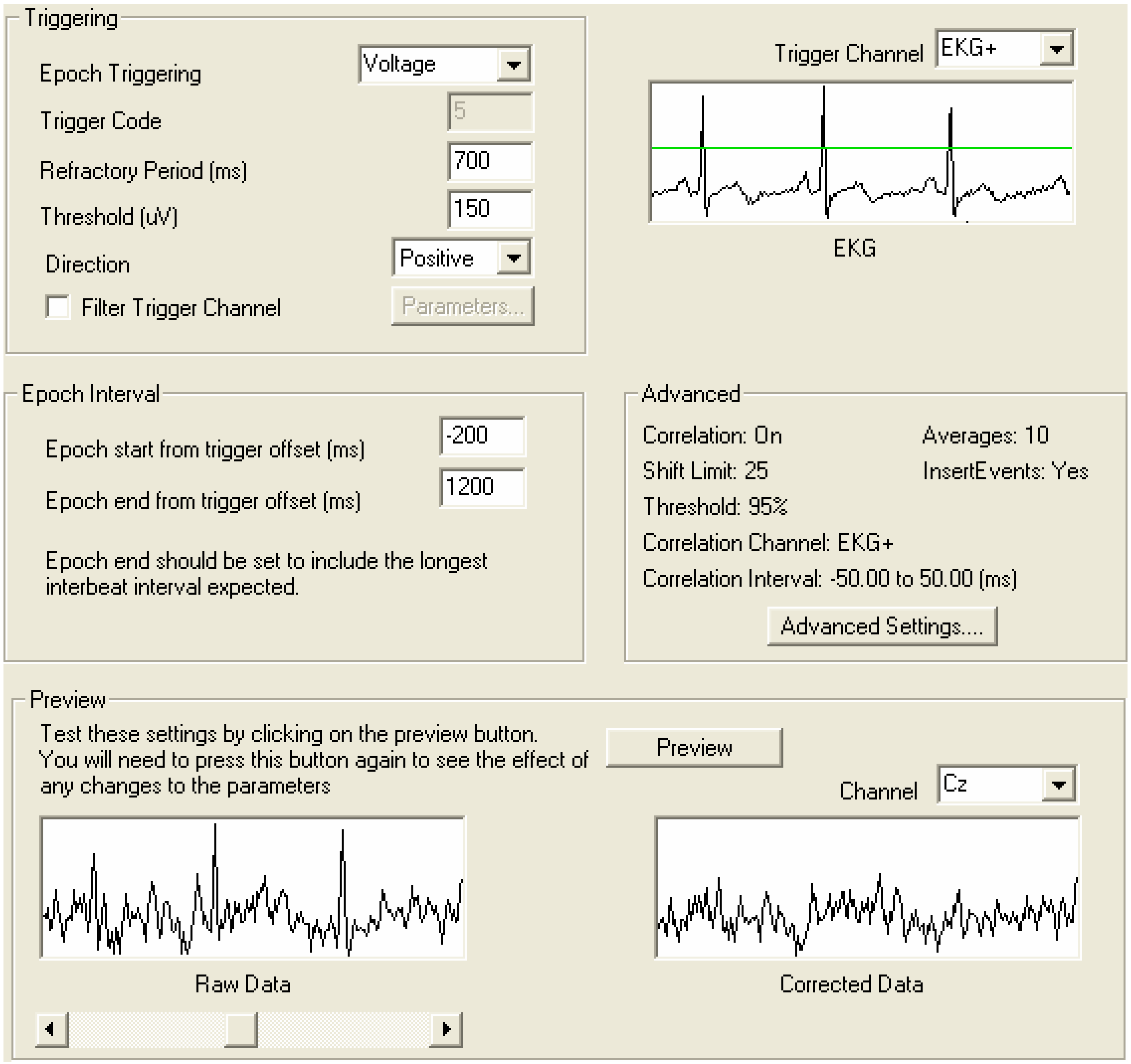
. The artifacts will typically be highly correlated with each other. A Threshold of 95 or greater is not uncommon for EKG. (Note that the Threshold is the maximum correlation value X 100).

2.6.4 EKG/BCG Batch Command - Online

The batch commands for configuring and enabling EKG/BCG Reduction *online* have been discontinued. In practice, the EKG/BCG correction happens "on the fly", depending on the individual subject. The settings that are common across subjects are usually stored with the setup file. Therefore, there is no real need for batch commands online. If you acquire data with a batch file controlling acquisition, you can insert a PAUSE command that will let you configure and apply the correction as needed. The offline batch commands are described below.

2.6.5 Offline EKG/BCG Artifact Reduction

The parameters for the offline EKG Noise Reduction transform are the same as the online ones, as described above, with the addition of the Preview displays.



The Preview displays let you see the position of the Threshold (horizontal green line in upper right display) and the correction for a selected channel (lower displays). *Whenever you change a parameter you need to click the **Preview** button to see the effects.* The Preview displays are very useful in that they allow you to assess the effectiveness of the correction before applying it.

Note

If there are blinks or other large artifacts in the recording, the scaling in the **Dilate** option (Advanced Settings) will be affected by the larger amplitude of the artifacts. The correction just before and after the artifacts may show paradoxical increases of the EKG (due to the larger scaling factor used). This can be avoided by removing the VEOG prior to removing the EKG/BCG.

Note

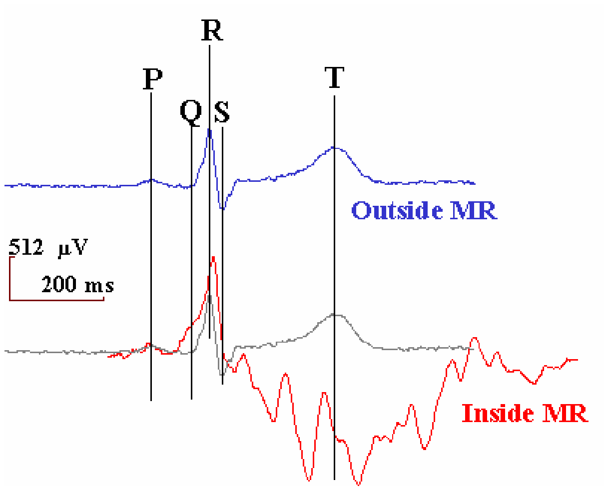
If you have used the Mark Block option (on the Toolbar) to reject blocks of data in a CNT file, the EKG Noise Reduction transform will not correct those sections, nor any adjacent artifact sweeps that include the rejected block.

Note
The correction is not applied to channels designated as *Bad* or *Skipped* channels.

2.6.6 Using EKG Noise Reduction - Offline

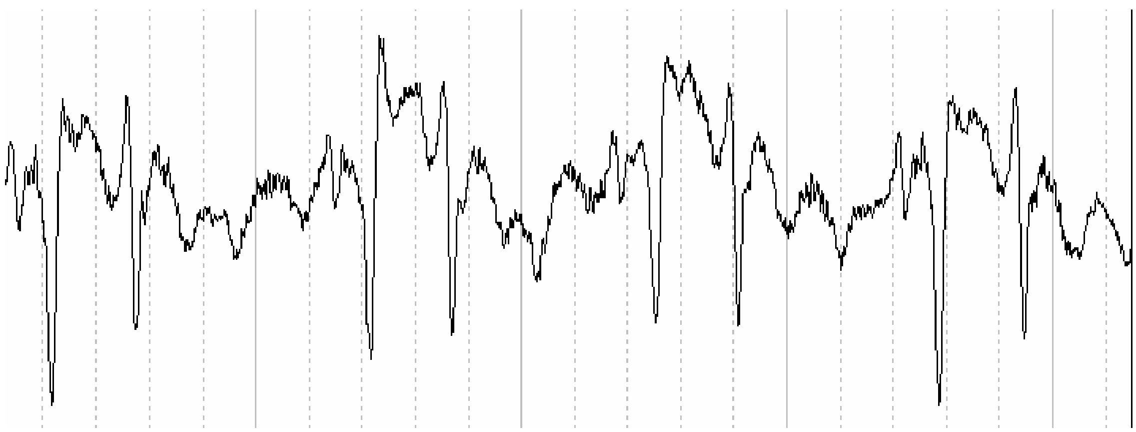
Below is an example for using the EKG Noise Reduction transform. Note that this is one method for reducing EKG and BCG artifact. See also the **New Transforms in Version 4.4** 75 section below.

Removing BCG Artifact. EKG outside the bore is often greatly magnified inside (BCG), and can seriously affect some or all EEG channels. The correction is performed in basically the same way as for EKG reduction.

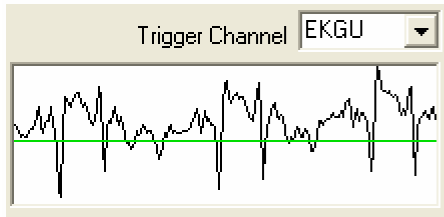


There is considerable ballistocardiogram (BCG) artifact in the sample data file below. It is not uncommon to encounter BCG that is a radical distortion of the EKG that is seen outside the bore. Which method should you use to reduce it? In most cases there will be no events marking the peaks. Our experience so far indicates that QRS Detection is not especially effective with BCG (but it may be worth trying anyway). That leaves the Voltage threshold method and the transforms that were split out from EKG Noise Reduction. We will use the Voltage threshold method. If you are not using a pulse oximeter, it can be challenging to determine the threshold to use.

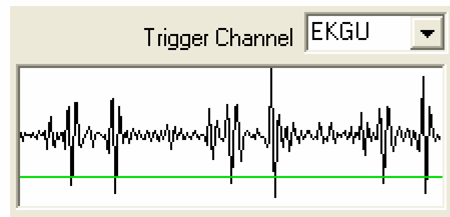
The EKG channel is shown below. You can see that while the artifact repeats, there may not be a simple threshold that will reliably differentiate each primary heart beat.



This is a good example for when to use the **Filter Trigger Channel** and **Refractory** options. First, we will filter the trigger channel to remove the slower components, as well as the faster noise. Removing the fast frequency noise will facilitate trigger placement and reduce jitter. We apply a Band Pass filter, with a High Pass of 15Hz and a Low Pass of 50Hz (24dB for both). The effects are seen in the Trigger Channel preview.

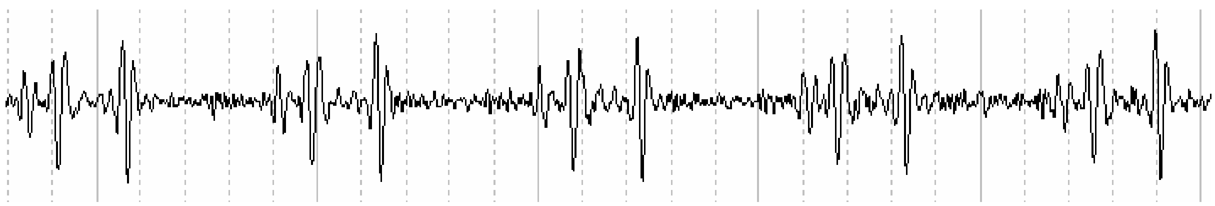


raw data



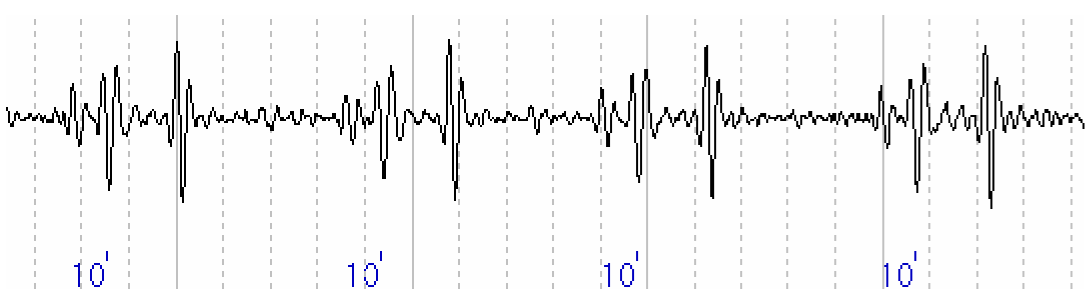
filtered data

In difficult cases, it may be helpful to apply the correction just to see the effects of the filter. In this case, we see the following result for the EKG channel.



We want the voltage trigger to detect the first of each pair of negative peaks, and ignore the second one. This is accomplished easily with the **Refractory Period**. If we use a refractory period of 500ms, we will exclude any other peaks after the R wave that may otherwise exceed the threshold. Looking at the EKG channel throughout the file, we see that the R peak is always less than -300µV (absolute value). Therefore, a threshold of -250µV with a Negative direction should work well. For the **Epoch Interval**, we determine that the **Start** time should be -200ms, and the **Stop** time should be 1400ms (to extend slightly beyond the next trigger).

Running the transform, we see that the triggers were reliably placed throughout the file.

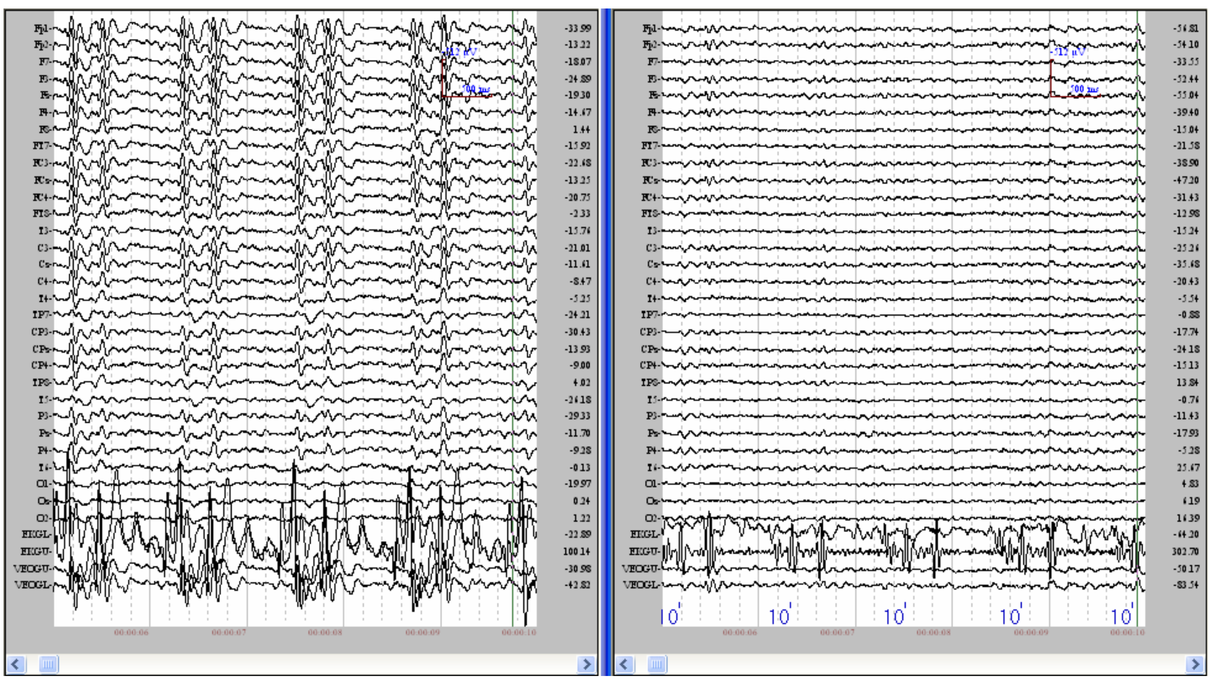


It is generally preferable to use the **Correlation** option. In this case, the width of the R wave is about 50ms, and the AD rate was 500Hz. We set the **Correlation Interval** to be -25 to 25ms (to include the full peak span), with a **Shift Limit** of 5 points (10ms). There should be little shifting since the peaks in this case are sharp, with little opportunity for jittering. We expect a high correlation threshold - a given sweep will likely be highly correlated with the average during the span of the R wave. When you acquire the data file with the EKG/BCG correction, you will see the number of points that the peaks were shifted as well as the correlations. In this case we will use a **Threshold** of 95%. We will use the Dilate option since the EKG artifact may vary in amplitude from sweep to sweep.

Returning to the original data file, we entered the following parameters in the EKG Noise Reduction dialog screen:

Epoch triggering: **Voltage**
Refractory Period: **500**
Threshold: **-250**
Direction: **Negative**
Filter Trigger Channel: **Band Pass, 15Hz (24dB), 50Hz (24dB)**
Trigger Channel: **EKGU**
Epoch start: **-200**
Epoch end: **1400**
Advanced Settings
    Enable Correlation: **On**
    Start time: **-25**
    Stop time: **25**
    Channel: **EKGU**
    Shift Limit: **10**
    Threshold: **95**
    Dilate: **On**
    Averages: **10**
    Insert Events: **On**
    Code: **10**

The corrected file appears as follows. We recommend that you look through your files and verify that the events were inserted at the proper positions. In this case, the BCG was greatly reduced.



The reason we recommend using the **pulse oximeter** is that, regardless of how complex the BCG may be, you will generally have a clean EKG measure.

This greatly simplifies the task of peak detection. Filtering and the Refractory Period are rarely needed, and the correlation will be high.

2.6.7 EKG Noise Reduction Batch Command - Offline

The current batch command is **EKGNOISEREDUCTION**.

The original command was also EKGNOISEREDUCTION. This was modified with the EKGNOISEREDUCTION_EX command, and then again with the EKGNOISEREDUCTION_EX2 command. For the V4.4 release, we are using the original EKGNOISEREDUCTION command *only*. This will include all of the settings used in the V4.4 version of the software. If you have an existing batch file that uses a prior version of the EKGNOISEREDUCTION command (or _EX, or _EX2), you will need to replace it with the V4.4 version of the EKGNOISEREDUCTION command. EKGNOISEREDUCTION_EX and EKGNOISEREDUCTION_EX2 are obsolete and will not be recognized. If you have an existing batch file with the original EKGNOISEREDUCTION command, you will get an error message when you try to run it with V4.5 (incorrect number of parameters). In other words, *you will need to replace any prior batch command for EKG Noise Reduction with the new version of the EKGNOISEREDUCTION command*.

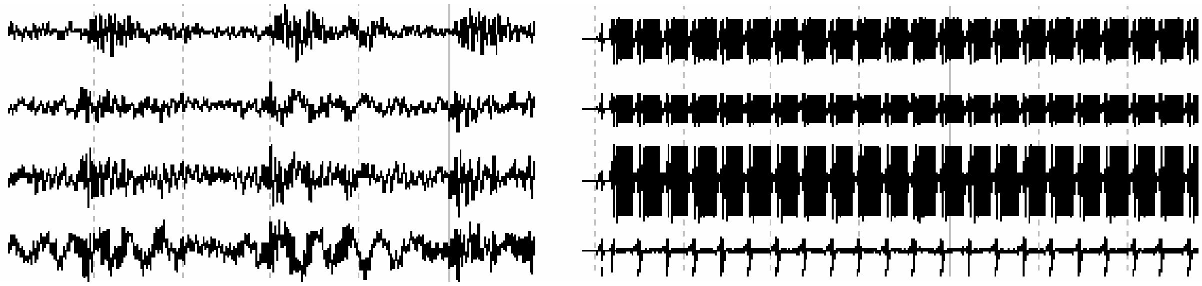
Because of the large number of parameters used with this transform, it is recommended that you set the parameters in point & click mode, apply the transform, then copy and paste the line into the batch file you are creating.

1	string	Output file
2	double	Artifact Epoch Start
3	double	Artifact Epoch Stop
4	integer	Number of averages
5	defined value	Trigger type (QRS, VOLTAGE, RESPONSE, STIMULUS)
6	int	External Trigger Code
7	double	Voltage Threshold (μV) (ignored if not using voltage triggering)
8	defined value	Trigger direction (POSITIVE, NEGATIVE)
9	string	Trigger channel label
10	Boolean	Insert Events
11	int	Insert Code
12	Boolean	Enable Trigger channel Filter
13	defined value	Filter Type (LOWPASS, HIPASS, BANDPASS, BANDSTOP)
14	float	High Pass cutoff
15	int	High Pass attenuation (db)
16	float	Low Pass cutoff
17	int	Low Pass attenuation (db)
18	float	Notch start frequency
19	float	Notch stop frequency
20	int	Notch attenuation (db)
21	double	Refractory period
22	Boolean	Enable Correlation
23	double	Correlation Interval Start
24	double	Correlation Interval Stop
25	int	Shift limit (data points)
26	double	Correlation threshold
27	string	Correlation channel label
28	Boolean	Enable Dilate average

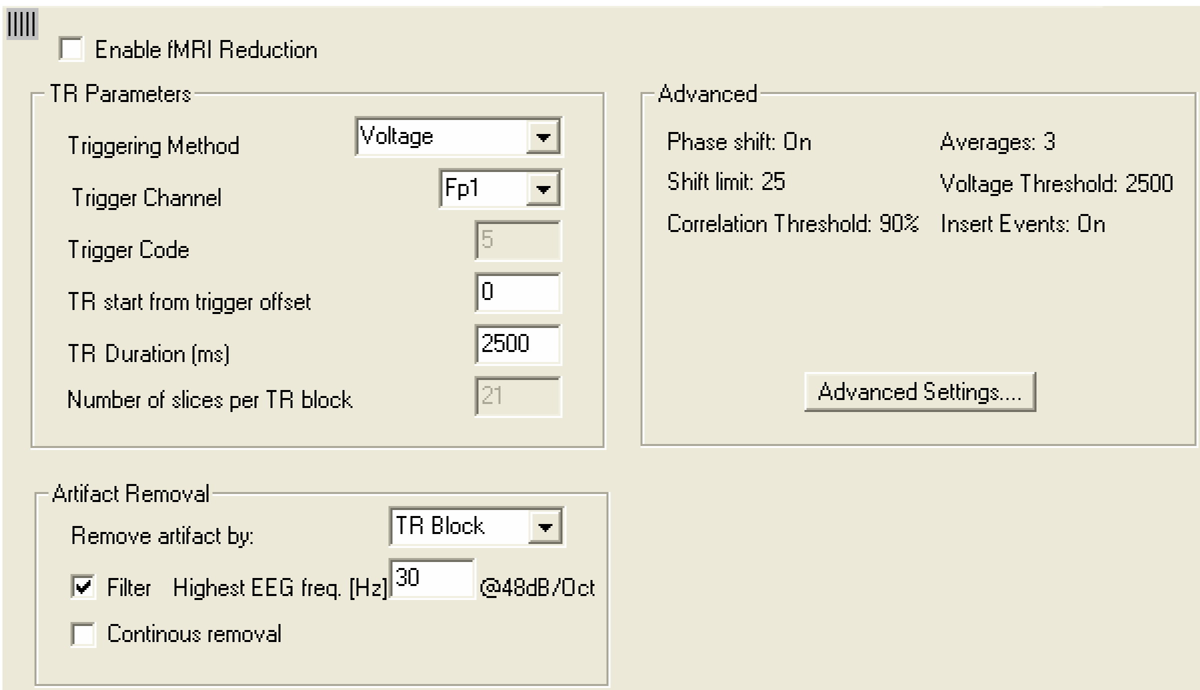
EKGNOISEREDUCTION {D:\Scan data\output.cnt} -200 1200 10 VOLTAGE x 150 POSITIVE EKG+ Y 10 Y HIPASS 15 12 x x x x x 700 Y -50 50 25 95 EKG+ Y. The Epoch Interval was from -200 to 1200ms. 10 artifact sweeps were averaged. A voltage threshold was used for the triggering method, with a threshold of 150μV. The artifact was positive going in direction. EKG+ was the trigger channel. Event codes of 10 were inserted at the trigger points. A high pass filter was applied to the trigger channel, at 15Hz, 12dB. The refractory period was 700ms. Correlation was enabled, with an interval of ±50ms, a Shift Limit of 25 points, and a correlation threshold of 95%, using EKG+ as the correlation channel. The Dilate average option was enabled.

2.6.8 Online fMRI Reduction

The MR environment, particularly during gradient sequencing, is an extremely hostile one for recording EEGs. In addition to ballistocardiogram artifact (BCG), there can also be increased fast frequency noise between MR sequences (left side below), pump noise artifact, and very large artifact during sequencing (right side below, amplitude greatly reduced).



The fMRI Reduction procedure was created to reduce these artifacts.



TR Parameters. These parameters relate to the trigger method and trigger events, as well as the characteristics of the TRs.

Triggering Method. There are three Triggering Methods.

Voltage. The Voltage method is typically used in cases where you have no stimulus or response events to indicate the start of a TR slice or block. In that case, a voltage threshold may be used. The relevant parameters are set in the **Voltage** field accessed from the Advanced Settings.... button (described below).

Use Response. If the triggers from your scanner appear as red response trigger events in the CNT file, select this option.

Use Stimulus. If the triggers from your scanner appear as blue stimulus trigger events in the CNT file, select this option.

Trigger Channel. If you are using the **Voltage** triggering method, select the channel to be monitored. This is also the channel that will be used for the correlation correction (online only).

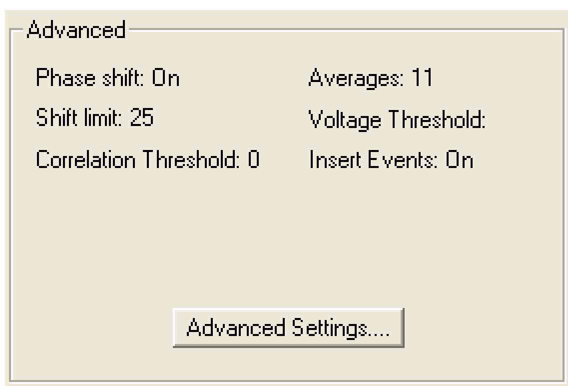
Trigger Code. If you are using the **Response** or **Stimulus** triggering method, enter the trigger type code associated with the scanner's triggers.

TR start from trigger offset. Enter the time (in ms) from the trigger event to the beginning of the artifact. This will often be 0.

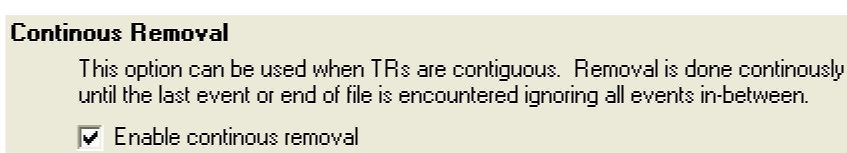
TR Duration (ms). Enter the duration of the TR Block. For example, your scanner might send one trigger at the beginning of each series of slices. The **TR Duration** would be the span of time from the trigger to the end of the series of slices. If your scanner sends a trigger for each slice, the **TR Duration** would still be the duration of the TR Block. Select to remove artifact by Slice, and enter the Number of slices per block. If there are no TR blocks, but rather an uninterrupted series of slices, use the **Continuous removal** option. The Duration time also functions as a refractory period - no triggers will be recognized during the time span of the Duration.

Number of slices per TR block. If you are removing artifact by **Slice**, enter the number of slices per TR block, especially if there is a gap between TR Blocks (sparse sampling). If you are removing artifact by **TR Block**, the option will be grayed out.

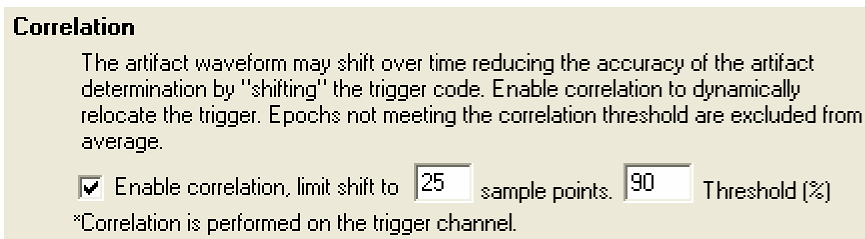
Advanced. The information in the Advanced field displays the current settings that have been chosen. Click the Advanced Settings.... button to access the advanced parameter settings.



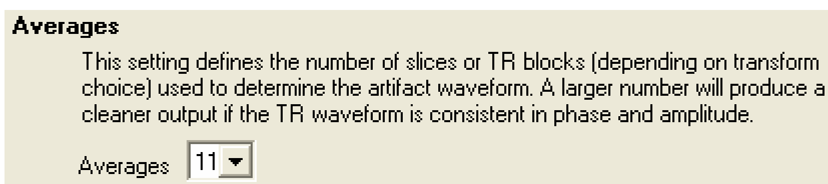
Continuous Removal. This option should only be enabled if you have contiguous TRs throughout the recording. That is, equal spacing between slices throughout, with no extra gaps. When enabled, all events after the initial one will be ignored, and artifact removal will continue through the final event or to the end of the file.



Correlation. Enable the option to align the artifact sweeps based on the correlation of defined intervals, rather than by the triggers alone. This serves as a correction for peak latency shifts that may occur. Enter a number for the Shift Limit (in points). The option is used only if you have selected the Voltage triggering method. See the **Fundamental Concepts** 35 sections for more details. If you are not sure what number to enter, try a large number (but one that does not exceed the Correlation Interval) and watch the **Shift** field on the Artifact Suppression screen during acquisition. It will display the number of points that have been shifted for each sweep. If the average artifact remains stable, you will get a good idea for the Shift Limit to use. Artifact sweeps that do not meet the Correlation Threshold will be excluded from the average. The Trigger Channel is also the Correlation Channel in the online fMRI Reduction. If you are not sure what number to enter, try a small number and watch the **Correlation** field on the Artifact Suppression screen during acquisition. It will display the correlation for each sweep. By watching the sweeps that are included and rejected, you will get a good idea for the Threshold to use.

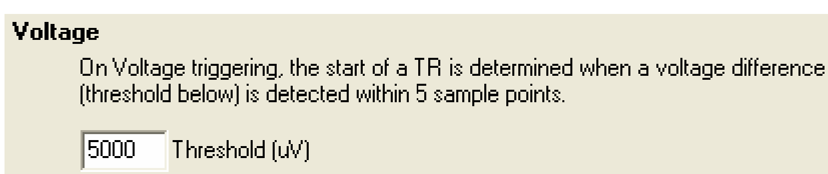


Averages. This parameter determines the number of slices or blocks (depending on whether you selected **Slice** or **TR Block** under **Artifact Removal**) that will be combined to create the average artifact. As a minimum, we recommend 9-11 sweeps for adequate cancellation of the EEG in the average artifact.



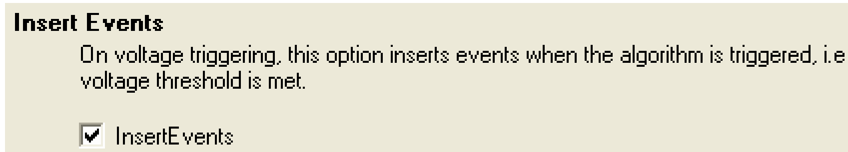
The numbers of Averages in the pull-down list will vary. If you select to remove artifact by **Slice**, the maximum number of averages available is half the number of slices, plus 1. If you select by **TR Block**, the maximum is hard coded at 21.

Voltage. The Voltage settings are used only when you have selected **Voltage** for the **Triggering Method** (under **TR Parameters**). The program will detect the TRs based on the voltage differences that exceed the Threshold (scanning 5 sample point spans). The threshold should be large enough to avoid false triggers, and small enough not to be missed.

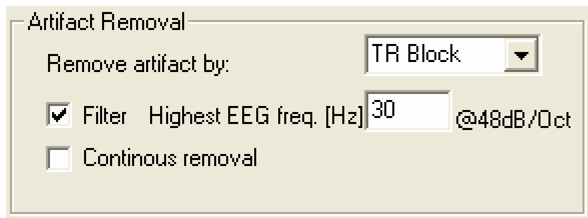


Insert Events. You can have the program insert events when the Voltage

Threshold criterion is met. The event will be a vertical line with a "T" that is either blue or red, indicating accepted or rejected artifact sweeps.



Artifact Removal. You can remove the MR artifact either by **Slice** or by **TR Block**. If you select **Slice**, the individual slice artifacts are combined to create the average artifact that will then be subtracted from subsequent slices. If you select **TR Block**, blocks of slice artifacts are combined to create the average artifact that will then be subtracted from subsequent blocks.

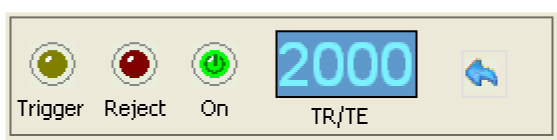


Filter. Enable the option to apply an IIR filter to all channels. This is a low pass filter, filtering all frequencies greater that the Hz value you enter. The slope of the filter is hard coded at 48dB/oct.

Continuous removal. Enabling this option has the same function as enabling **Continuous Removal** in the **Advanced** settings section (described above), and is provided for convenient access.

When you are acquiring data and wish to apply the correction, click the  button on the Toolbar. You will then see the Artifact Suppression Control Box appear. On the left side are three lights. The Trigger light will flash when a trigger event is detected (via either method). The Reject light will flash when a sweep has been rejected (due to an insufficient correlation). The On light will light and remain lit when the correction is active.

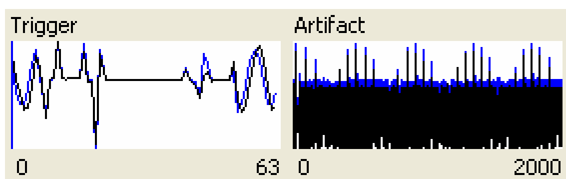
The TR/TE display will show the span of the TR (block) or TE (slice). Click the  button to see the full list of parameters. The toggle is provided as a convenient way to hide most of the display during acquisition.



The parameters are the same as those detailed above, with some additional display fields. The parameters can be changed during acquisition. The most recently applied parameters are stored with the data file (and seen when you select the transform in EDIT). *When you change a setting, click the*  *button at the bottom of the display to apply the new settings.* The button will clear and restart the process.

fMRI Parameters	
TR Parameters	
Triggering Method	Use Stimulus
Trigger/Cor. Channel	FPZ
Trigger Code	1
Start from Trigger (ms)	0.00
Duration (ms)	2000
Number of Slices	21
Artifact Removal	
Remove Artifact by	TR Block
Filter	Enable
Highest EEG Freq. (Hz)	30.00
Continuous Removal	Disable
Advanced	
Correlation	Enable
Shift Limit (points)	25
Correlation Threshold %	50
Averages	3
Voltage Threshold (uV)	100.00
Insert Events	Disable

There are additional display fields for the Trigger and Artifact. The Trigger field displays the first slice in the TR interval - the section that is used for the correlation analysis. The Artifact field displays the Epoch Interval.



There are also three informational fields near the bottom of the display.

Avg Count	Shift	Correlation
3	-7	89.25

The **Avg Count** field displays the number of artifact sweeps that have been accepted thus far. The upper limit will be the value you entered for **Averages**. The **Shift** field displays the number of points that the artifact trigger was shifted. This will be within the range you specified for **Shift Limit**. The **Correlation** field displays the maximum correlation of the most recent sweep with the accumulating average artifact. If the value is below the **Correlation Threshold**, the sweep will be excluded from the average.

Click the  button in the lower left corner to display the EKG/BCG parameters (described below). You may apply either or both fMRI and EKG/BCG reductions online.

The Halt button is used to stop the correction. If you click the (Re)start button, the entire process will be restarted. If you make changes to any of the parameters, you must click the (Re)start button to apply the new settings.

2.6.9 Using fMRI Reduction - Online

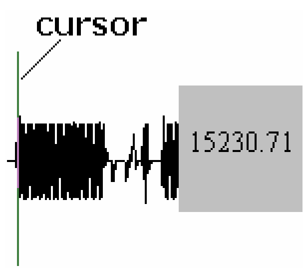
It is not possible to provide the optimal parameters for all possible configurations. There are differences among scanners, and each scanner, or at least each model of scanner, will have its own characteristics. We provide the information you need to configure the program for your particular setting.

There are some parameters that you will know based upon how your scanner operates and how it communicates with SCAN. For example, you should know whether it sends trigger pulses or not. If so, you should know whether it sends them at the beginning of each TR Block, or for each slice. You should know the duration of TR Blocks, and how many slices are in each block. You should know whether the pulses will be seen as stimulus or response type events. Refer also to the **Fundamental Concepts** 27 section above, if you have not already done so.

In the beginning, you should run a test recording. This will verify the above parameters as well as let you see the amplitude of the artifact (if you are using a Voltage threshold). You will see the triggers from the scanner, how often they occur (per TR Block or Slice), what the type code is, and whether they are stimulus (blue) or response (red) events.

The remaining parameters are as follows:

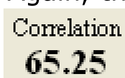
Trigger Channel. Select a channel that has significant artifact. This channel will be used for Voltage triggering and also for the Correlation channel. Typically, you will see the MR artifact in all channels, although the amplitude can vary. Select a channel that has relatively high amplitude.



Voltage Threshold. This option (in the Advanced Settings) will be ignored unless you are using the **Voltage** option. You should use the Voltage option if your scanner cannot send optical or TTL triggers. In the test recording you make, measure the approximate voltage of the artifact at the Channel you select. It is helpful to display a single second on the screen. Position the mouse cursor at the peak of an artifact and read the voltage from the column on the right. You may have significant DC shifts that will result in very large numbers (the amplitude is large in any event). The Threshold (absolute difference) will be autodetected whenever the voltage between any of 5 data points, in a rolling scan, exceeds the value you enter.

Correlation and **Shift Limit**. As described in the **Fundamental Concepts** 35 section above, there can be a sort of "latency jitter" for the Voltage threshold triggers. Enabling the Correlation option will align the Correlation Intervals and result in a more accurate average artifact (and subtraction). The Shift Limit (expressed in the number of data points rather than ms) sets the range within which the triggers will be shifted. You should avoid large values for the Shift Limit, as this unnecessarily increases computation demand. What value should you use? You will get an idea by making a test recording. Watch the Shift field 

during acquisition and see the range of shifts that are detected. Note at the same time whether the appropriate triggers are being detected. You should get an idea what the limit will be. The idea is to avoid aligning aberrant triggers, should they occur. Again, note that the value is points. With the very fast sampling rate you are likely using, the Shift Limit could be several hundred points (for example, with a 10kHz AD rate, 20ms contains 200 points).

Correlation Threshold. The Correlation Threshold is used to exclude artifact sweeps that are not well correlated with the average artifact. What Threshold should you use? Again, this will depend. When you make a test recording, watch the Correlation field 

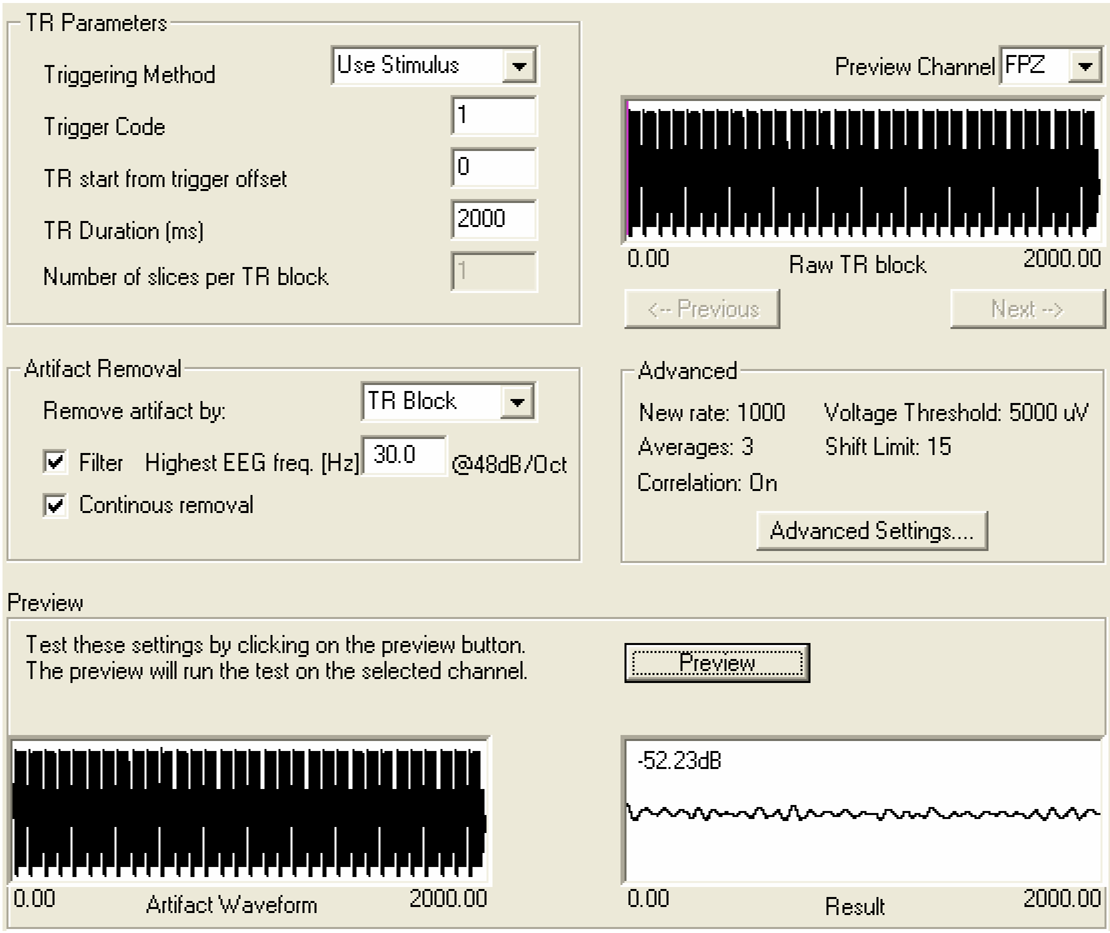
. The artifacts will typically be highly correlated with each other. A Threshold of 80 or greater is not uncommon, although this will vary depending on the stability of the artifact. (Note that the Threshold is the maximum correlation value X 100).

Once you determine the parameters that are most effective, they will likely not change very much from subject to subject. The parameters can be accessed and modified during acquisition, as needed.

2.6.10 Offline fMRI Artifact Reduction

The offline fMRI Artifact Reduction transform is used to reduce the EPI artifact in the CNT data file. As with the online method, the transform averages the MR slice artifacts (creating an average for each channel), and then subtracts the average from those sections containing the slices.

The offline parameters are similar to those seen in the online reduction. The Preview panels allow you to assess the effectiveness of the correction before applying it.

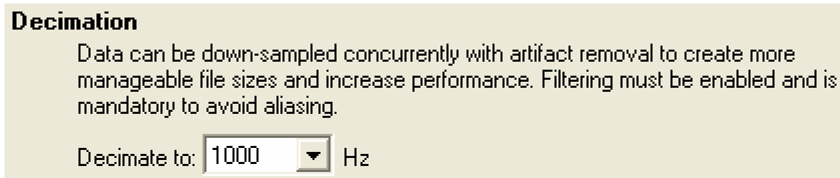


There is a difference, however, in how the correction functions. If you are using a **Voltage** triggering method, a single initial starting point is required. This is determined through a voltage detection procedure, described more below, in which the beginning of the first MR artifact is made by using the **Previous** and **Next** buttons below the Preview Channel display. You need only to select the sweep that shows the beginning of the first MR sequence. You also need to set the **Voltage Threshold** from the Advanced Settings. This is a relative voltage difference (in either direction). The program will scan sets of 5 data points for the point at which that voltage is exceeded. That time point will then become the initial triggering point for the correction.

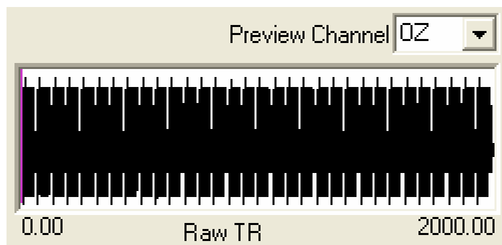
There are no options for the Correlation Channel and Correlation Threshold in the offline fMRI Reduction transform. You can still enable or disable the correlation correction, and it has the same effect as in the EKG and online fMRI transforms. Offline, all channels are selected for the correlation channels (hard coded). If there are known bad channels, these should be designated as Bad or Skip channels so they will be excluded from the analyses. There is no correlation threshold (or sweep rejection) in the offline fMRI transform.

The other differences are the Decimation option and the Preview displays.

Decimation. Data recorded in the MR will have very fast sampling rates to capture the triggers accurately as well as the very fast frequencies in the artifact. Decimation is performed concurrent with artifact removal to create more manageable file sizes and thereby improve performance in subsequent operations. Filtering must be enabled (under **Artifact Removal**) to avoid aliasing. Click the pull-down list to see valid down-sampling options.

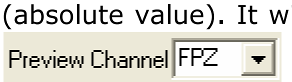


Raw TR/TE Block. The Raw TR/TE display shows the raw signal in the span of the TR or TE depending on whether you have selected to remove artifact by TR Block or Slice. The Preview Channel field lets you select the channel to be displayed for the raw as well as corrected data displays.

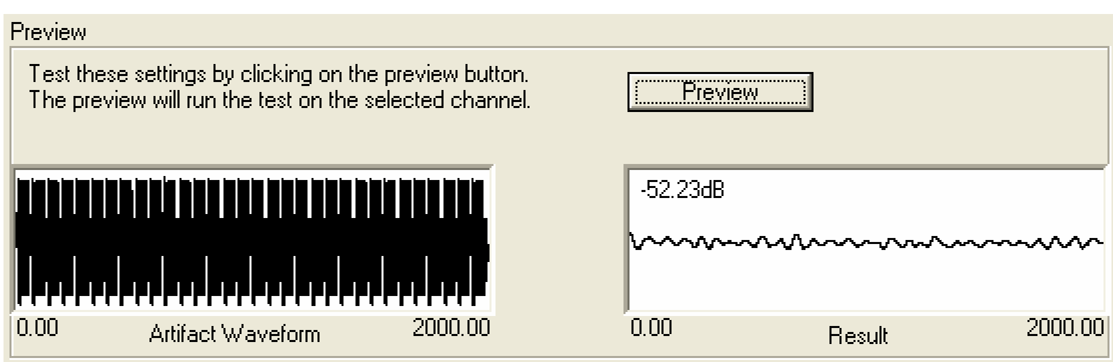


If you are in **Voltage** triggering mode, the Previous and Next buttons will be active, letting you step through the file. In some cases, the scanner is “shimmed” prior to the actual scan, or a pre-scan can be performed. If the shim effects are included in the data file, they could trigger the algorithm falsely. Use the Previous and Next buttons to explicitly tell the algorithm where to start.

When you run the transform, the FMRI batch command is autowritten. It contains a parameter indicating the offset (in points) to the initial Voltage threshold (see the FMRI batch command section below).

Preview. Click the **Preview** button to see the expected result of the transform. The Result section should show genuine EEG with little or no residual MR artifact. The extent of the attenuation can be assessed from the dB value displayed. You want this value to be as large as possible (absolute value), and ideally, it should exceed -50dB (absolute value). It will also vary by channel. Select the preview channel using the 

field.



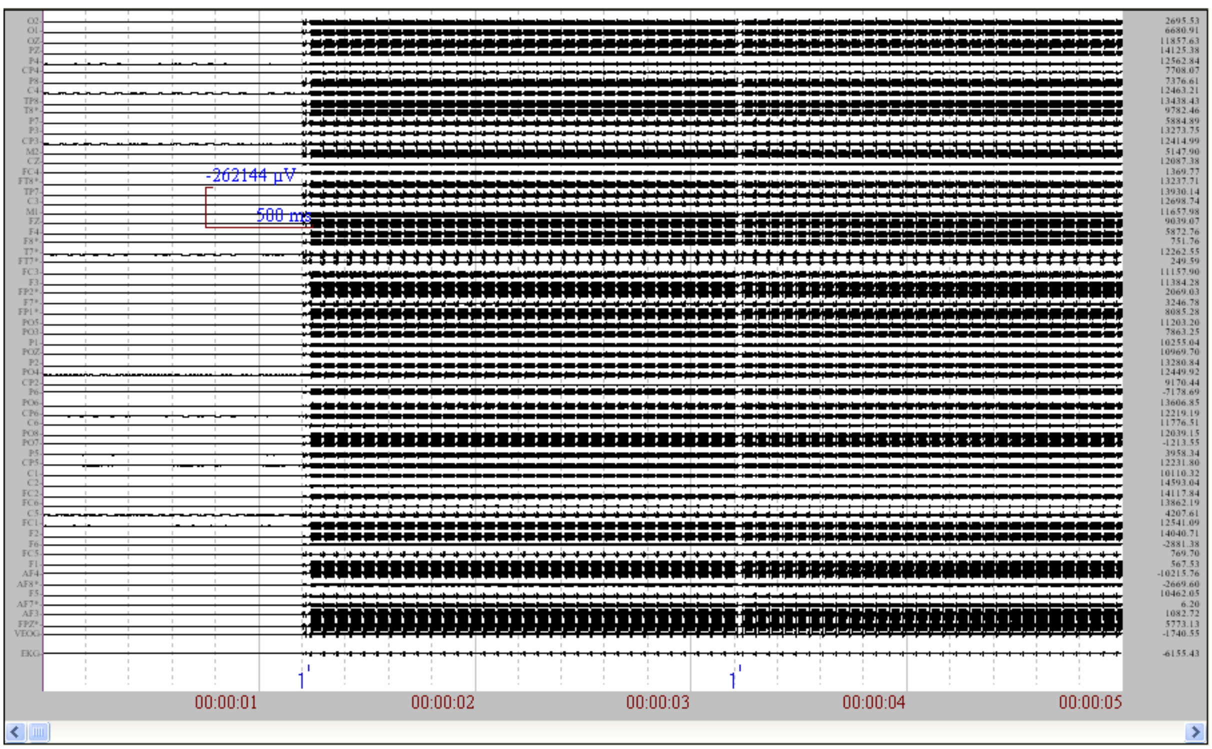
2.6.11 Using fMRI Artifact Reduction - Offline

In this section we will retrieve a data file and apply the fMRI reduction transform. There are stimulus event codes of "1" every 2000ms indicating the beginning of a new TR block. That being the case, we know that we will be using the stimulus codes to designate the beginning of the TR blocks. Since we want to decimate the file, we will need to apply a low pass filter. These are all things we note in the beginning. If we had performed the online fMRI Reduction, these parameters would have been saved with the data file.

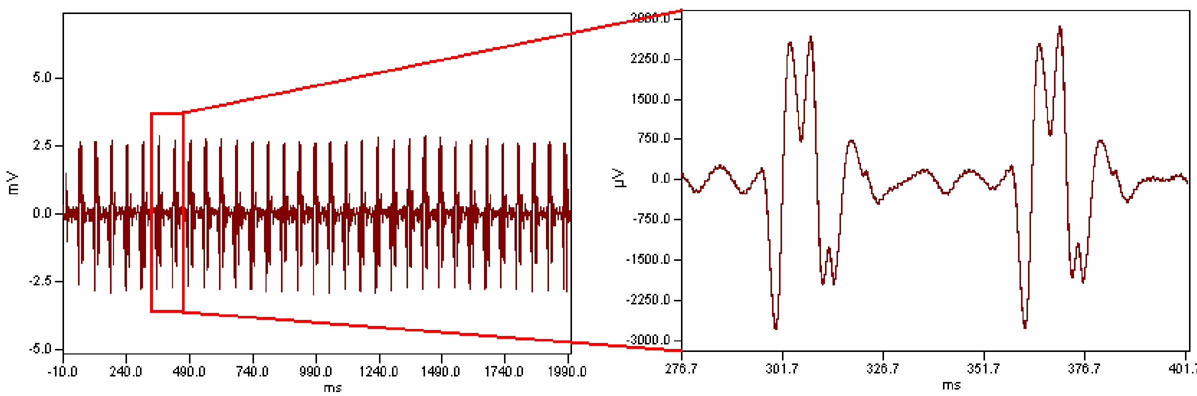
Triggers at the beginning of each TR Block

1. Retrieve the file. You may need to autoscale the data . This file is an approximate 20 second recording of EEG during MR gradient sequencing.

You may notice a slight sluggishness with these files compared to other files (depending somewhat on your computer). Although the recording time was fairly brief in this example, the AD rate was 10,000Hz and there are 64 channels. The file size is in excess of 50MBs.

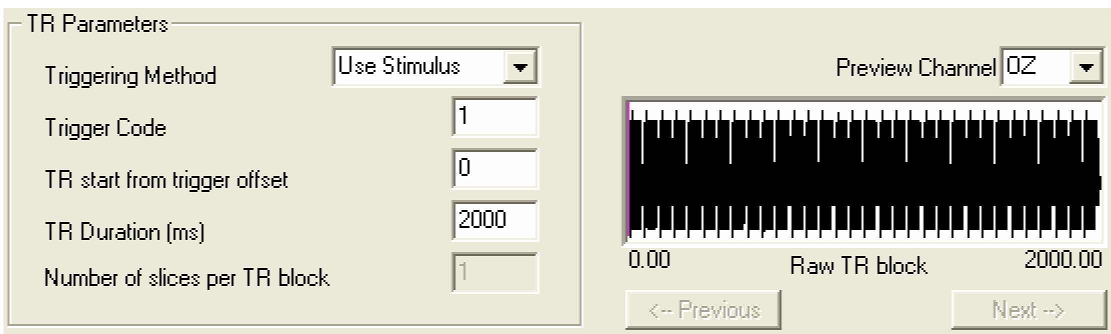


2. For demonstration purposes, we will first epoch the uncorrected file into sweeps using the type codes, and average the sweeps to see what the average gradient artifact looks like before applying the correction. We Epoched the file using -10 to 2000ms, performed a Baseline Correction on the eeg file (Entire Sweep), and then averaged the sweeps.

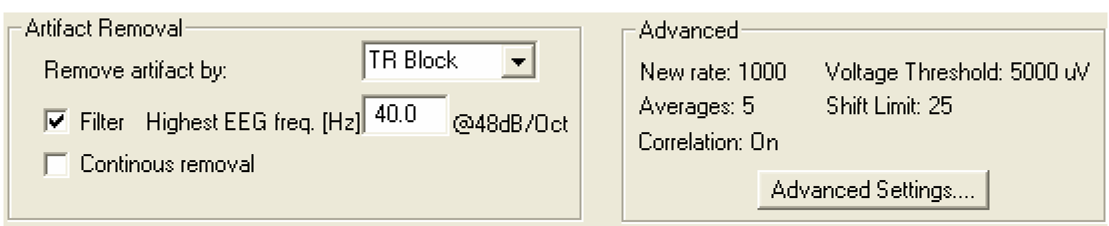


The figure on the left shows the entire sweep for a single channel (CP5). The figure on the right zooms in on a section. The maximum p-t-p voltage is approximately 5mVs.

3. Using the original continuous file, we then selected the **fMRI Artifact Reduction** transform. We selected [Use Stimulus] for the Triggering Method, and entered the **Trigger Code** (1), **TR start from trigger offset** (0), and **TR Duration** (2000). We select a **Preview Channel** (OZ), and then examined the initial raw TR block.



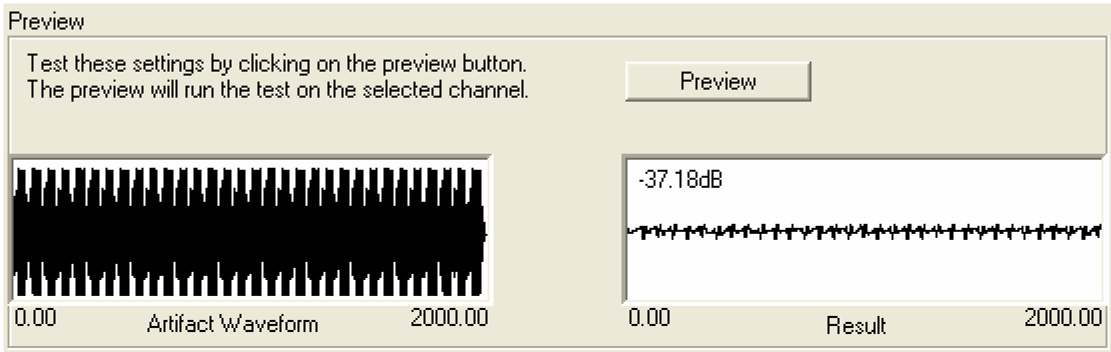
4. We selected **TR Block** under Artifact Removal, and enabled the **Filter** (**40**Hz). **Continuous Removal** was disabled.



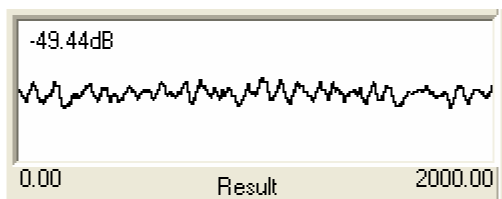
5. For [Advanced Settings....] we enabled the **Correlation** option, and entered **25** points for the **Shift Limit** [Enable correlation, limit shift to 25 sample points].

We set [Averages 5] and [Decimate to: 1000]. The **Voltage** field is not used with Stimulus or Response triggers.

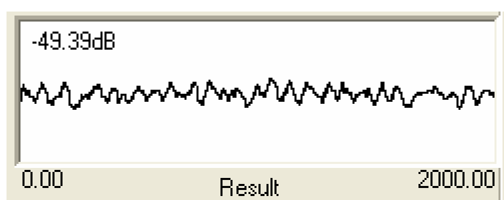
6. Clicking the Preview button, we see that the artifact has been reduced, although the EEG is not clear.



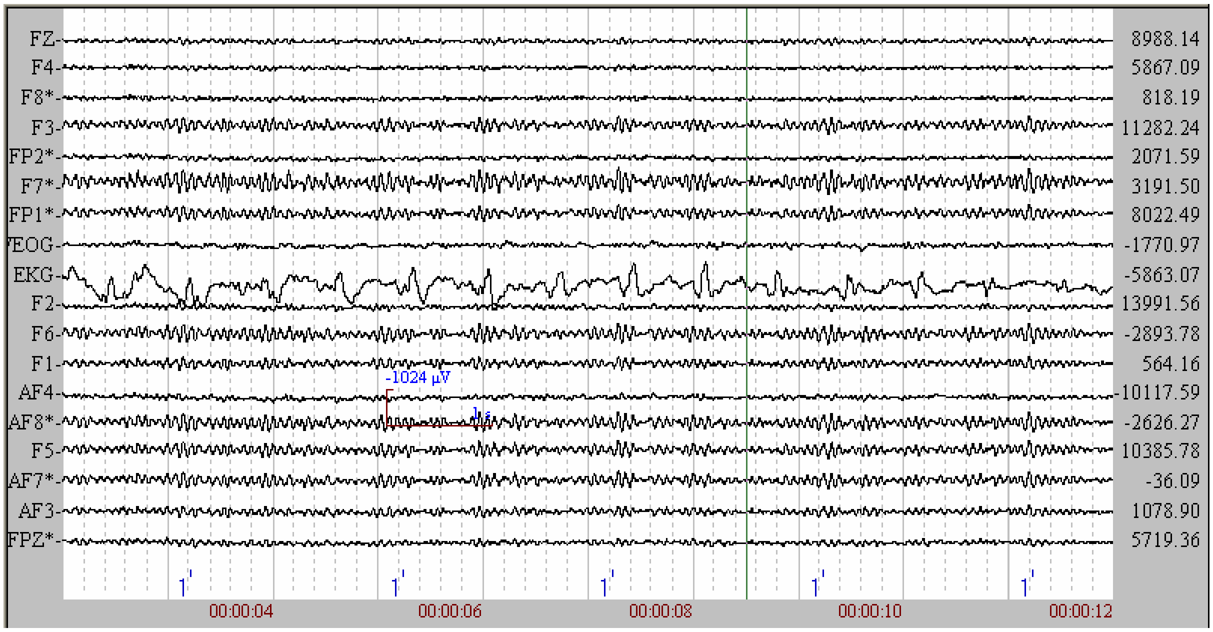
We then select **Continuous Removal**, and again clicked Preview. The correction has been improved. In some files, enabling Continuous Removal may further improve the correction.



Under Advanced Settings.... we set the Voltage **Threshold** to **5000**µV and selected **Voltage** (for the Triggering Method). Clicking Preview again shows that the results are essentially the same as with the initial parameters we set, and, in this example, either method could be used.



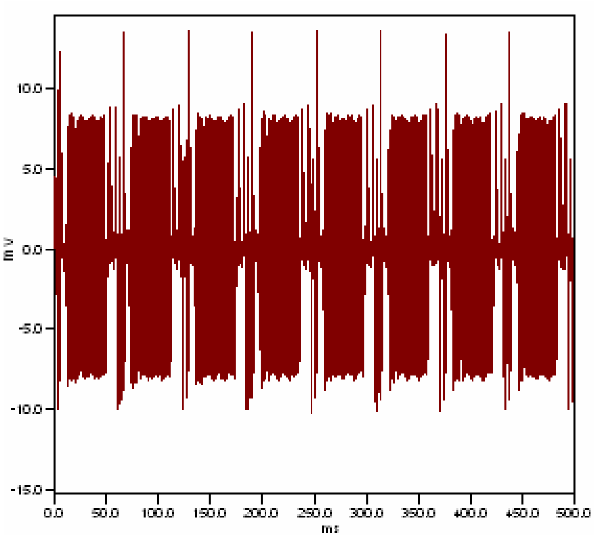
7. Applying the transform displays the corrected file. Additional Display Pages were created to make it easier to see the channels.

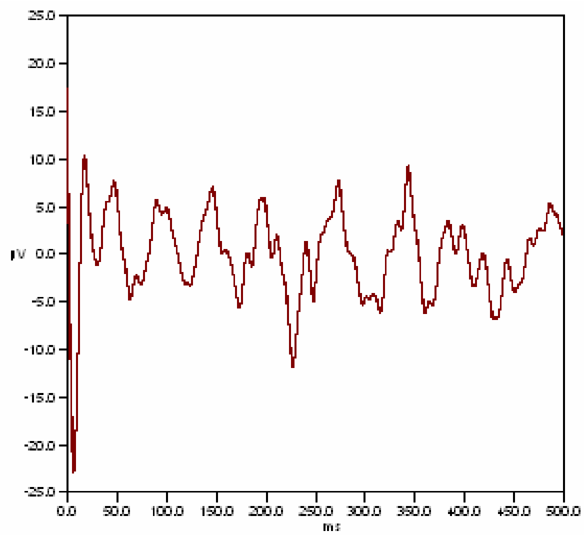


Note
Should you have large DC offsets in the data file, you may measure extreme voltages for the channels. These will be corrected when you Epoch the file and apply the **Baseline Correction**.

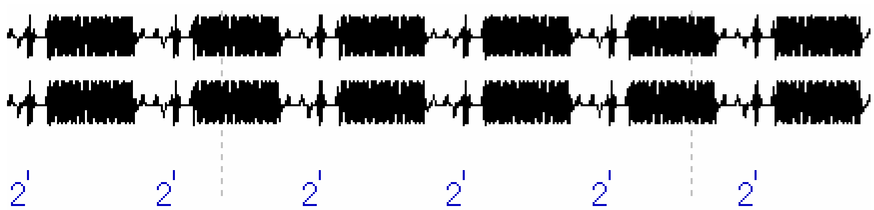
8. While there is some BCG artifact in the EKG channel, it does not appear to be present in the EEG channels. In other files it may be necessary to use the EKG/BCG Noise Reduction routine as well as the fMRI Artifact Reduction.

9. As a final demonstration, we epoched the corrected CNT file using the Type 1 events only, averaged the sweeps, and compared the average to the average based on the original uncorrected data file (0-500ms). The EEG would normally average out, leaving any residual MR artifact. In this file, there were few sweeps and so the EEG did not fully cancel. There is nevertheless no discernible evidence of MR artifact. The figure below shows the CP5 electrode, before and after the correction. Note the display scale for the MR artifact (left) is from approximately $\pm$8**mV**, while the scale for the corrected EEG is approximately $\pm$8µ**Vs**.

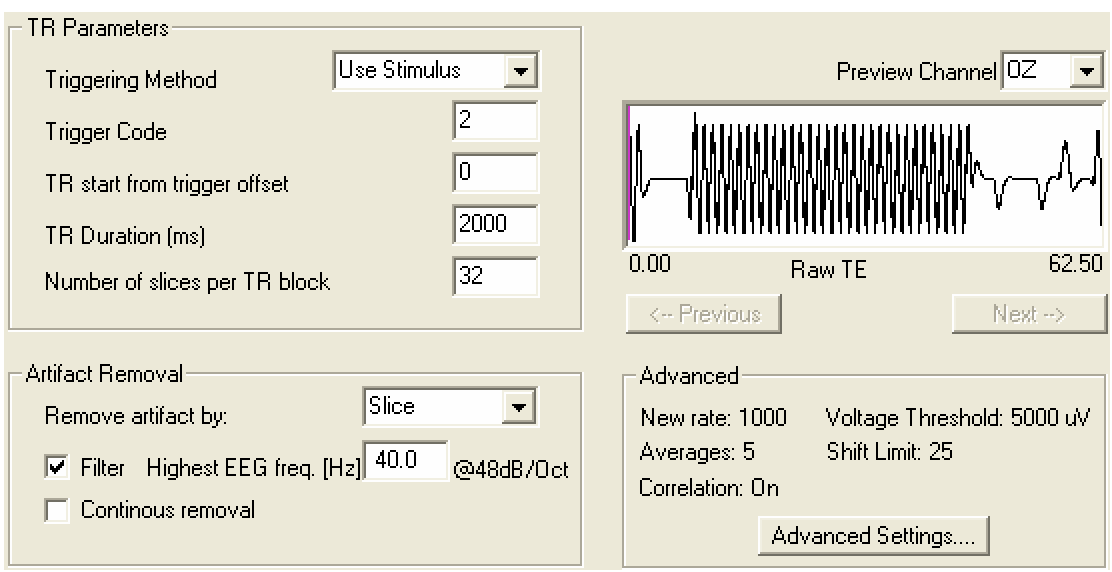




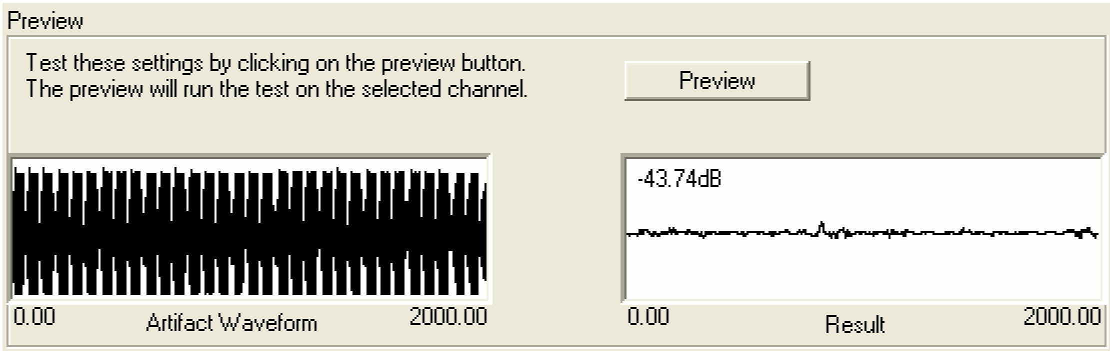
Triggers at Each Slice
Depending on your scanner, you may have trigger events at each slice.



In this case, there were TR blocks with a 2000ms span. There were 32 slices within each block. **Remove artifact by** was set to **Slice**.

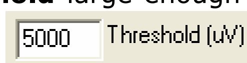


The Preview field shows the anticipated effectiveness of the removal.



Voltage triggering. In most cases you will have stimulus or response events from the scanner to signify the beginning of the sequences. Otherwise, you can use a Voltage Threshold method to identify a single starting point. Select

. Go to the Advanced Settings screen and enter a **Voltage Threshold** large enough to detect the voltage difference at the beginning of the MR artifact



. The **TR Start time** and **TR Duration** are used as usual to specify the beginning and end point of the TR Block. With a single trigger point, you will need to enable the **Continuous removal** option (at least for correction by TR Block).

Use the Preview channel and displays to see the expected effect of the correction. In **Voltage** triggering mode, the **Previous** and **Next** buttons will be active. Use these to step through the file to get to the first genuine threshold. In some cases, the scanner is “shimmed” prior to the actual scan, or a pre-scan can be performed. If the shim effects are included in the data file, they could trigger the algorithm falsely. Use the Previous and Next buttons to explicitly tell the algorithm where to start. The program will look for abrupt voltage differences (relative differences in either direction) that exceed the Voltage Threshold you enter. The point where that occurs becomes the initial starting point of the correction. When you run the transform, the FMRI batch command is autowritten. It contains a parameter indicating the offset (in points) to the initial Voltage threshold (see the FMRI batch command section below).

Different scanners produce different types of artifacts, and it is not possible to predict which parameters will work best in any given situation. In practice, you may need to experiment with different settings to find those that are most effective with your data files. Once you find the optimal parameters for one data file, it is likely that the same settings will work for subsequent data files (all other things being unchanged).

2.6.12 fMRI Batch Command - Offline

The batch command for fMRI reduction is **FMRI**, containing the parameters listed below. The 13th parameter, Offset to Voltage Threshold, is used only with a **Voltage** triggering method; otherwise it should be 0. In some cases the scanner must be "shimmed" and this can cause potentially spurious voltage triggers. The **Next** and **Previous** buttons are used to step past such events. If you use the autowrite feature to create the batch command, the offset to the first voltage threshold is computed for you.

The 14th and 15th parameters are not used in the batch command, and are reserved for later development. Once the transform has been run, the 13th parameter, the offset to the voltage threshold, is the one that determines where the correction begins. Running that command will use whatever the offset is to initiate the correction; it does not recompute the voltage threshold. That is done from the fMRI Reduction screen. The offset will be different in every data file (with rare exceptions, perhaps). It is recommended that you run the transform in point & click mode, at least initially, for each data file. Once you have the offset, you can use the batch command with that same file, but not with another file (since the offset will be different). Therefore, the Voltage Threshold, parameter 14, is not used in the command, and can be ignored. The 15th parameter is the number of the Preview channel that has been selected - it is not used in the batch command and can be ignored.

If you are using Stimulus or Response triggering methods, the 14th and 15th commands are ignored. Triggering is based the event codes, not a voltage threshold.

1	int	TR Trigger code
2	string	Trigger Method (VOLTAGE, STIMULUS, RESPONSE,)
3	double	TR start (ms)
4	double	TR duration (ms)
5	int	Number of slices per block
6	int	Number of Averages
7	defined value	Decimation Frequency (Hz)
8	Boolean	Enable Correlation
9	int	Shift limit (in sample points)
10	Boolean	Enable Continuous Removal
11	Boolean	Enable Filter
12	float	Low pass filter cutoff (Hz)
13	int	Offset (in points) to Voltage Threshold
14	float	Voltage Threshold
15	int	Preview channel number
16	string	Output file

Example. FMRI 1 STIMULUS 0.00 2000.00 32 10 1000 1 25 1 1 30.0 18591 5000.00 14 {D:\Data\output.cnt}. fMRI Reduction is performed using a stimulus event code of 1, TR Block with Start and End times of 0 and 2000ms, 10 averages, and a Decimated sampling rate of 1000Hz. Correlation is enabled, with a Shift limit of 25 points. Continuous Removal is enabled, and a 30Hz filter is applied. The trigger is 18,591 data points into the file. The voltage threshold was 5000, and the 14th channel (zero-based index) was selected as the Preview channel (again, these two parameters are ignored if you run the batch command).

2.6.13 Combined Online Artifact Reduction

With MagLink RT, you have the greatest options for online artifact reduction. If desired, you can apply online corrections for fMRI, EKG/BCG, and Blink Reduction all at the same time (assuming your computer can handle the demand). In that case, the corrections will be applied in the following order: fMRI, then EKG/BCG, then Blink Reduction.

The online fMRI and EKG/BCG corrected data can be saved, but not the Blink corrected data. Blink reduction can be performed permanently offline using Blink Noise Reduction, Ocular Artifact Reduction, or the Spatial SVD and Spatial Filter transforms.

3 New Transforms in V4.4

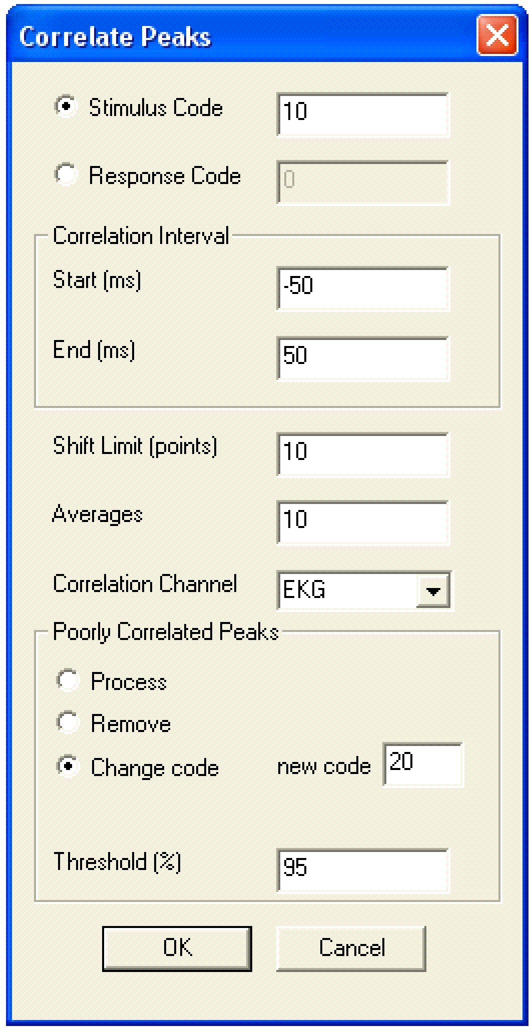
The new Transforms in V4.4 that involve EKG/BCG artifact reduction are used with CNT files only. Be sure to read the **Fundamental Concepts** 27 section above for more complete explanations.

Most of these transforms were split out from the EKG Noise Reduction transform, where they are applied within the transform. Splitting them out allows you to apply them in isolation, which in some cases may be necessary in order to obtain the best BCG reduction.

3.1 Correlate Peaks

The Correlation Peaks transform, unlike the EKG Noise Reduction transform, has no option to use a voltage threshold to identify peaks; you must use either stimulus or response codes positioned at the peaks. In most cases, you will not have those events. They can be added easily using the **Voltage Threshold** or **QRS Detection** transforms (see example below). They can also be added manually using the **Insert Multiple Events** option (described below).

Selecting the transform displays the Correlate Peaks dialog screen.



Stimulus/Response Code. Select either the Stimulus or Response type of code, and enter the type value.

Correlation Interval. This functions the same way as in the EKG Noise Reduction transform. A series of cross-correlations is performed between the **Correlation Interval** of the current sweep (using the **Correlation Channel** you select) and the same interval in the average artifact (relative to the trigger that has already been defined). The correlation interval is defined by the Correlation Interval **Start** and **End** times. The current sweep is shifted by the number of data points necessary to maximize the correlation, then the sweep is averaged in with the previous artifact sweeps. This process can reduce the variability in the average artifact, and thereby improve the subtraction result (using the **Subtract Average** transform). The **Shift Limit** option (measured in data points, not milliseconds) limits the range within which the interval can be shifted. (If you enter, for example 10 points, the span will be 10 points in either direction). It prevents the shifting from extending too far. Avoid excessive Shift Limits as they will place an increasing demand on processing time. As a general rule-of-thumb, the Shift Limit should encompass about half of the peak of interest. Say there is an EKG R wave peak with a duration of about 40ms, with an AD Rate of 500Hz. Try a Shift Limit of half the R wave span - 10 points (20ms).

You do not necessarily have to include the artifact trigger within the EKG Correlation Interval. In some cases, you may want to use a different section for the correlation. The section might delineate a more stable waveform in the artifact.

Averages is the number of artifact sweeps that will be averaged to create the average artifact that is then correlated with each successive artifact sweep. The average is rolling, that is, only the N most recent artifact sweeps are averaged, where N is the value you enter for Averages. You should average at least 10 sweeps - more if possible - for adequate EEG cancellation to occur in the average artifact.

Poorly Correlated Peaks. Poorly correlated is defined as any value less than the Threshold (%) you enter. The Threshold (%) is the correlation x 100. If the obtained (maximum) correlation exceeds the **Threshold** you select, that sweep will be included in the accumulating average artifact. If not, the sweep is excluded. This provides a method for ensuring that only genuine artifact sweeps will be included in the average artifact. (See the **Examples** 84 below).

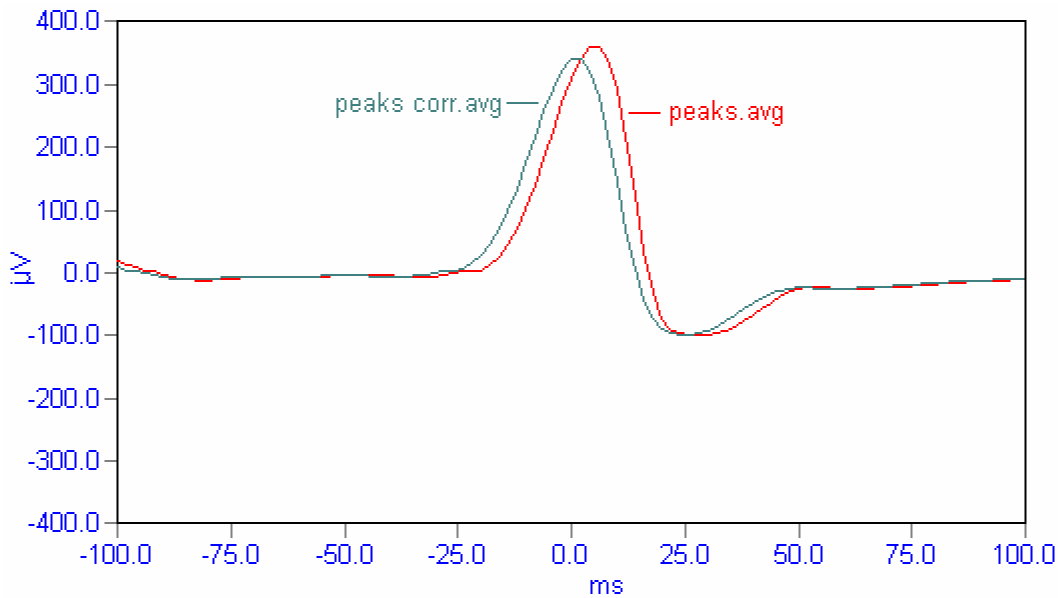
There are three ways to use this option:

Process. If you select this option, no correlation test is performed. The triggers will be positioned as well as possible, regardless of whether the Correlation Intervals are correlated or not.

Remove. If you select Remove, then the type codes will be removed for any sweep having a correlation that does not reach the Threshold you enter.

Change Code. When enabled, any sweep whose correlation does not reach the criterion will be given a new type code (that you select). The idea is to run the transform once, and identify the uncorrelated sweeps. Then run it again specifying that event code, and change the codes of any of those sweeps that do not correlate. Repeat as many times as is needed. In this way, classes of activity that are correlated within themselves - but not correlated with other classes - can be identified. The option was designed for use in files with difficult BCG artifact (where there are classes of BCG artifact that appear through the recording). The EKG Noise Reduction transform can then be used with each stimulus event code. The result is a more effectively corrected file.

When you apply the transform, it may appear as if nothing has happened. In fact, the event marks have been shifted to maximize the correlation. You can see this by creating epochs about the peaks just after using the Voltage Threshold transform to place them, then averaging those sweeps. Then apply the Correlate Peaks transform to the CNT file, and epoch and average the sweeps again. The new average will be based on the aligned peaks, rather than the type codes as they were originally positioned (even then, the difference may be very subtle in some files). In the example below, the original average is the *peaks.avg* file, and the correlated peaks is the *peaks corr.avg* file.



If you have the Change Code option enabled, you will see which event codes have been changed.

Note

The Correlate Peaks transform does not have to be used solely with EKG/BCG Artifact Reduction. It aligns by waveform morphology rather than by event codes. It therefore acts like a Woody filter, and can be used with any waveforms that have event marks for the peaks.

Correlate Peaks Batch Command

The batch command is **CORRELATEPEAKS**.

1	defined value	Trigger type (STIMULUS, RESPONSE)
2	int	Type code
3	double	Correlation interval Start (ms)
4	double	Correlation interval End (ms)
5	double	Shift Limit (points)
6	int	Averages
7	string	Correlation Channel label
8	defined value	Bad peaks (PROCESS, REMOVE, CHANGECODE)
9	double	New event code (ignored if 8 is PROCESS or REMOVE)
10	double	Correlation Threshold (ignored if 8 is PROCESS)

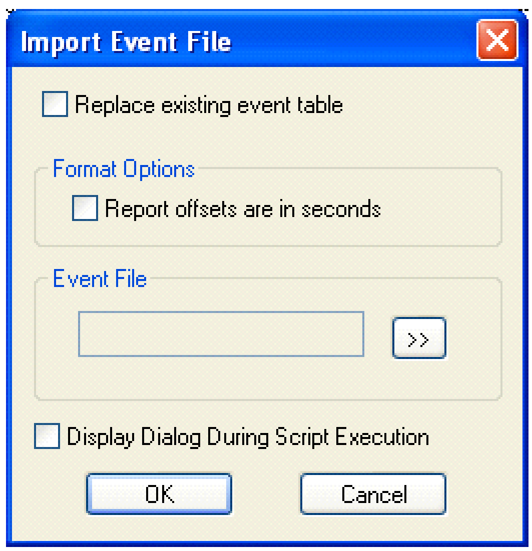
Example. CORRELATEPEAKS STIMULUS 10 -50 50 10 10 EKG CHANGECODE 20 95. A stimulus type code of 10 is used to define the peak of the blinks. The correlation interval is -50 to 50ms, with a Shift Limit of 10 points. 10 sweeps are averaged to create the average artifact. Sweeps with correlations less than 95% are excluded from the average artifact, and given a new type code of 20.

3.2 Import Event File

The Import Event File transform allows you to retrieve and apply an event file to a CNT file. The new event file can replace an existing event table, or be added to it. (The event table is that section at the end of a CNT file that contains the event information for the file). Therefore, if you have an event file that has, for example, stimulus type codes at every 1250ms, you could import the event file to one or more CNT files and thereby place the events automatically. If you are importing a CNT file from ASCII - which does not contain the event information - you can add the events from an event file you have created.

The Import Event File transform also has a use in EKG artifact reduction, when not using the EKG Noise Reduction transform. In some cases (primarily involving BCG), it may be necessary to filter the trigger channel extensively in order for the **Voltage Threshold** transform be able to place events at the R wave peaks accurately. However, you might then want to use the correction with the unfiltered data. Therefore, you can create the event file from the filtered file, and then import the R wave peak events back into the original unfiltered file.

After selecting the Transform, the Import Event File dialog screen appears.



Replace existing event table. Enable this option if you want to replace the existing event table. This means that all previous event information will be deleted. If you do not enable the option, then the new events will be added to the existing event table, and the previous events will be retained.

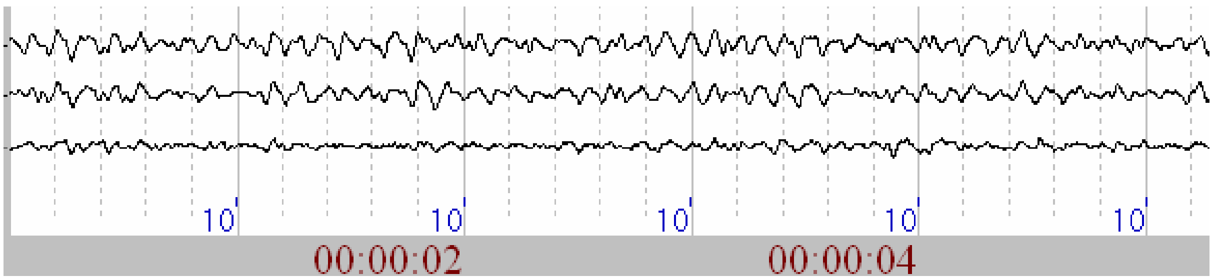
Report offsets are in seconds. When you create the event file (using the **Event File** transform), you have the option to report the point offsets in seconds. The default is bytes. If you selected seconds when you created the event file, then you should enable the **Report offsets are in seconds** option when you import the event file. Similarly, if you have created the event file through some other method, then enable or disable this option, as needed.

Event File. Use the browse button to locate and retrieve the event file (.ev2 or .evt types; see Event File in the EDIT manual for a description of the two file types).

For example, the displayed .ev2 file contains Type 10 events at every 1000ms, for 5000ms, with no response, accuracy or latency information included. The AD rate was 500Hz, so a byte offset of 500 equals 1000ms. The offsets are in bytes, so **Report offsets are in seconds** was left disabled.

1	10	0	0	0.0000	500
2	10	0	0	0.0000	1000
3	10	0	0	0.0000	1500
4	10	0	0	0.0000	2000
5	10	0	0	0.0000	2500

Applying it to a CNT file with no events shows the new events that are added.



Import Event File Batch Command

The batch command is **IMPORTEVENT**.

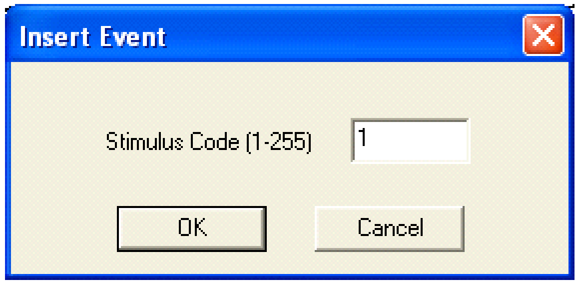
1	Boolean	Replace events
2	Boolean	Use seconds
3	string	Event file name

Example. IMPORTEVENT N N {D:\Scan Data\Demo Files\VisualAttention\event file.ev2}. An event file is imported without replacing the existing event table. The offsets are in bytes, and the selected file is shown.

3.3 Insert Multiple Events

The Insert Multiple Events option provides as easy method for manually inserting Stimulus events into a CNT file. In some rare cases (such as extreme BCG), it may be impossible for the Voltage Threshold or QRS Detection transforms to place events automatically at desired peaks in the CNT file. The Insert Multiple Events option lets you place stimulus events at manually selected locations.

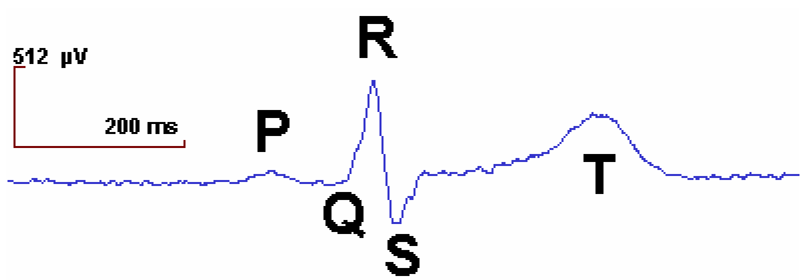
The option is accessed from the  icon on the Toolbar. Clicking it displays the Insert Event dialog screen.



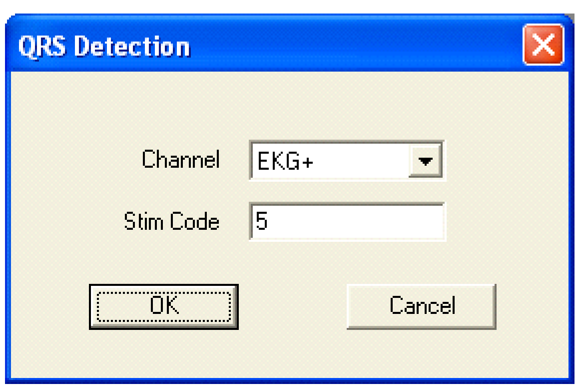
Enter a stimulus type code from 1 to 255. Be sure to use a code that does not overlap with any stimulus types codes (from Stim2, or other system). Then position the mouse where you want the type code to appear and click the left mouse button to add the event at that point. Continue clicking at each desired position. If you want to use more than one type code (to mark more than one type of waveform in the file), click the icon again to deselect it, then click it again to reselect it and enter a new type code. Then place the events as desired. The Correlate Peaks transform can then be used to align by the waveforms, which will correct for minor misplacements of the manually inserted events.

3.4 QRS Detection

The QRS Detection transform is used to automatically detect QRS waveforms in CNT files. Recalling the major components of an EKG beat, the Q, R, and S waves are often the most recognizable and most stable components.



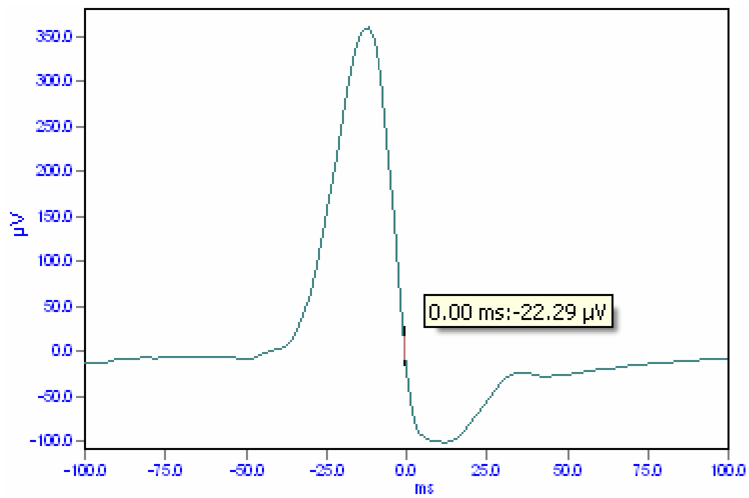
The transform will place events based on the detection of the QRS complex. Selecting the transform displays the QRS Detection dialog screen.



Select the **Channel** that is to be used, which is typically the EKG channel. Enter the event code that you want to use in the Stim Code field. Be sure to use a code that does not overlap with genuine stimulus codes sent from Stim2 (or other system).

The **QRS Detection** method uses a public domain algorithm for QRS detection (Open Source ECG Analysis Software Documentation; Copyright © 2002 Patrick S. Hamilton). See the **Fundamental Concepts** 28 section above for details (*How are artifacts identified?*). It is used here as one method for placing events in the CNT file for each QRS waveform.

In practice, you will find that it tends to place the events not at the R wave peak, but rather between the R and S waves.



There is a "warm up" period at the beginning of the CNT file where no events are placed (about 8 secs), then you should see events inserted for each detected QRS complex.

Our experience thus far with the public domain QRS Detection method is that it is very effective in detecting the QRS complex in routine EKG recordings; however, it tends to become less accurate with BCG (which it was not designed to detect).

QRS Detection Batch Command

The batch command is **QRS**.

1	string	Trigger Channel
2	int	Stim code

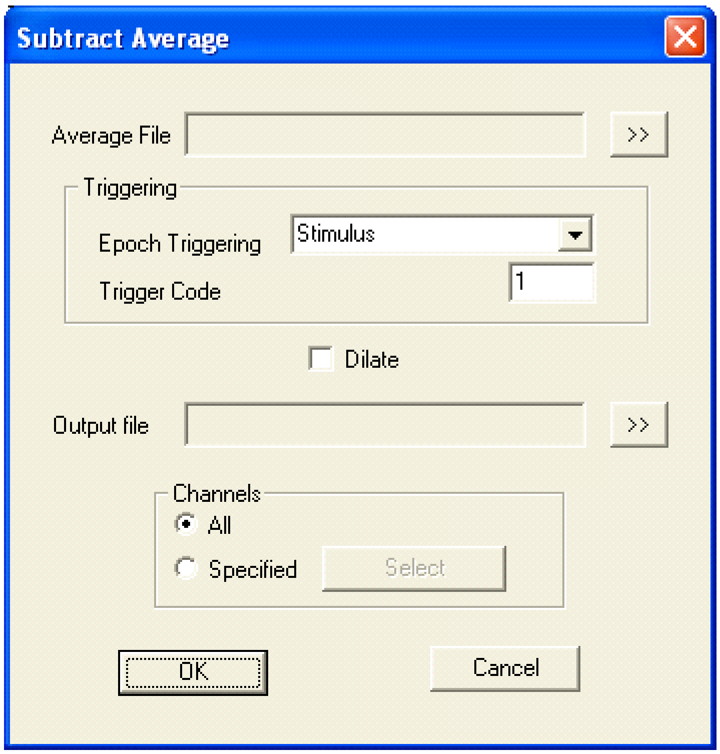
Example. QRS EKG+ 5. QRS detection using the Standard QRS Detection method is performed using the EKG+ channel. A stimulus event code of 5 is inserted for each event.

3.5 Subtract Average

The Subtract Average transform lets you subtract an AVG file from sections in a CNT file. For example, if you have an averaged EKG or BCG artifact, you can subtract that average from detected artifacts in the CNT file. To use the transform, you must first have stimulus or response events placed for the artifact sweeps. The events can be placed using the **Voltage Threshold** transform, the **QRS Detection** transform, or manually using **Insert Multiple Events**.

Subtract Average, as mentioned above, was split out from the EKG Noise Reduction transform to allow you more control in its use. Part of the EKG Noise Reduction transform involved creating a rolling average, and then subtracting that from subsequent artifact sweeps. The Subtract Average transform is similar in that an averaged artifact is subtracted from detected artifact sweeps. The average file, in this case, is not rolling - it is based on whatever sweeps you use to create the average.

Selecting the transform displays the Subtract Average dialog screen.



Average File. Select the AVG file that will be subtracted from each designated event in the CNT file. Generally, the AVG file is one created by Epoching and Averaging sweeps from the CNT file. The events should be place first using the **Voltage Threshold** transform, the **QRS Detection** transform, or manually using **Insert Multiple Events**.

Note
When you epoch the CNT file, you should use Start and End times just as if you were using the EKG Noise Reduction transform. That is, select an End time that overlaps slightly with the next R wave peak. In most cases, Start and End times -200 and 1200ms should work well for EKG (see the **Fundamental Concepts** 32 section above). For BCG, you may need to do some experimentation to find the best Start and End times.

Triggering. Triggering uses either **Stimulus** or **Response** events. There is no Voltage Threshold option, as there is with the EKG Noise Reduction algorithm. Select the type of event, and enter the **Trigger Code**.

Dilate. A given artifact sweep may vary from the average artifact by overall amplitude - it may be somewhat larger or smaller than the average artifact. Enabling this option will direct the transform to fit the average to the current sweep by using a multiplier to dilate or constrict the waveform until a best fit is obtained. On a per channel and per trigger basis, data points in the average waveform are scaled according to a minimized RMS value. The final subtraction will avoid over- or under-correction that may otherwise occur.

Note
If there are blinks or other large artifacts in the recording, the scaling will be affected by the larger amplitude of the artifacts, and the correction just before and after the artifacts may show paradoxical increases of the EKG (due to the larger scaling factor used). This can be avoided by removing the VEOG prior to removing the EKG/BCG.

Output file. Enter a name for the new CNT file that will be created.

Channels. You can have the correction applied to **All** channels, or only **Specified** ones. If you select All, that includes any Bad and Skipped channels. If you select Specified, the selected the channels (green) will be corrected.

Subtract Average Batch Command

The batch command is **SUBTRACTAVG**.

1	string	Output file
2	defined value	Trigger type (RESPONSE, STIMULUS)
3	int	Trigger Code
4	string	Average file name
5	Boolean	Enable Dilate average
6	list	Channels to be modified (or "All")

Example. SUBTRACTAVG {D:\Scan Data\Demo Files\AudioVisual\EKG removed.cnt} STIMULUS 10 {D:\Scan Data\Demo Files\AudioVisual\EKG artifact.avg} Y { ALL }. The *EKG artifact.avg* file is subtracted from each stimulus type 10, from all channels, Dilate is enabled, and the new CNT file is saved.

4 Examples Using the New Transforms

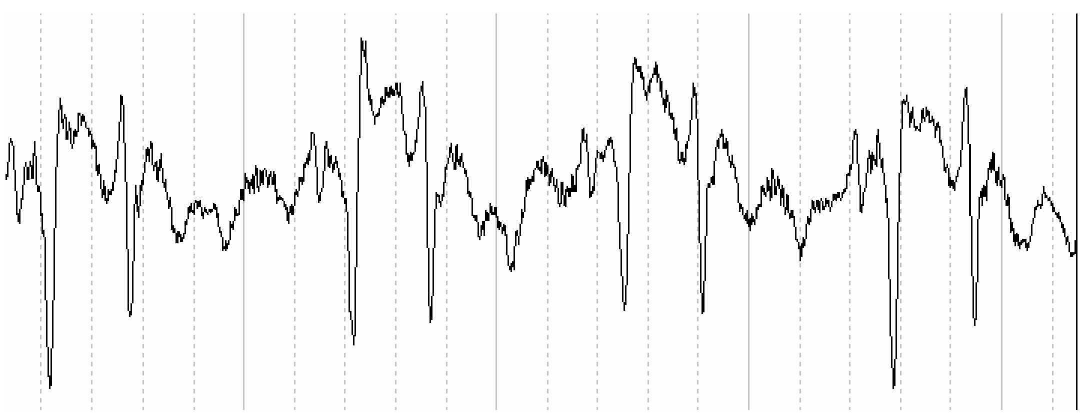
As mentioned, these new EKG/BCG reduction transforms are, for the most part, contained within the EKG Noise Reduction transform. Our experience has been that, in some cases with severe BCG, it is more effective to apply the steps separately, where you have more control over the parameters, and can see better what parts are not effective enough. Also, we have added some additional methods. We will demonstrate with two CNT files: one with considerable BCG artifact, and the second with severe artifact.

4.1 Example 1

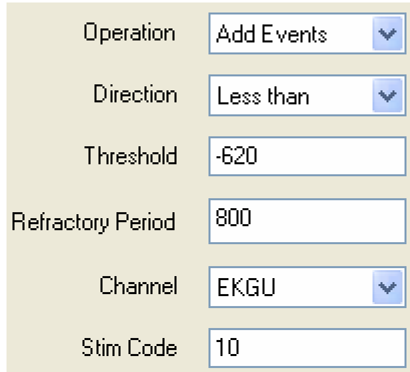
This is a typical case in which the BCG artifact, while prominent, is fairly constant throughout the file.

1. The first thing we need to do is add event marks for the peaks of each artifact. There are at least three ways to do this: the Voltage Threshold transform, the QRS Detection transform, and manually.

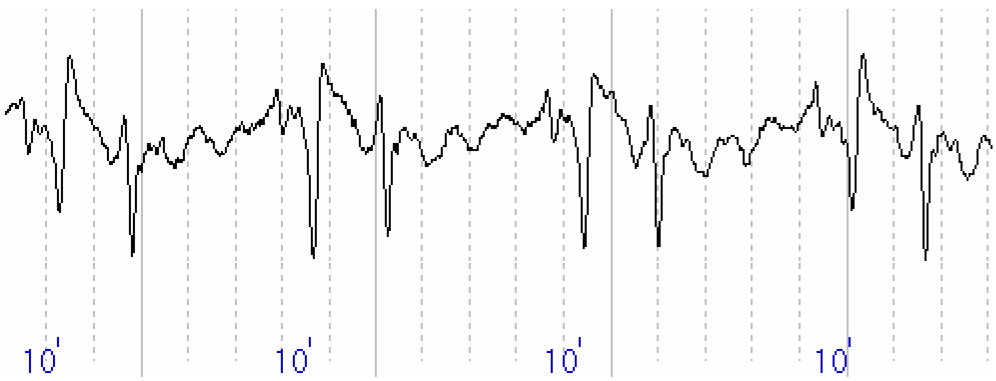
a. **Voltage Threshold**. There is no pulse oximeter channel recorded with this file. If there had been, it would be a relatively simple matter to use the Voltage Threshold to detect the peaks. In this case, if we look more closely at the EKGU channel, we see that there are two peaks for each heartbeat. The first is likely the R wave.



Looking through the file, it appears that a threshold of about -620μV may work. We enter the parameters as displayed to have the Voltage Threshold transform insert the events (type 10). The Refractory Period will block out other peaks that reach the threshold.

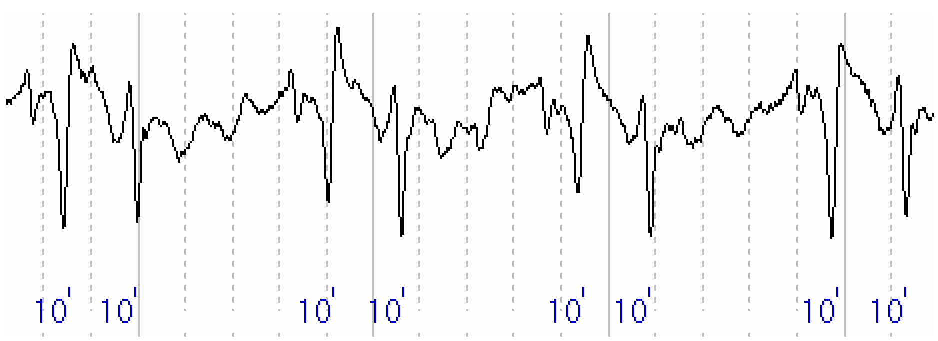


Looking again through the file, the events were placed correctly in all instances, with no false positives or false negatives.



b. **QRS Detection**. Had the Voltage Detection not worked, we might then try QRS Detection to insert the trigger events. You need only select the artifact channel and enter the Type code to insert (plus the Advanced Settings).

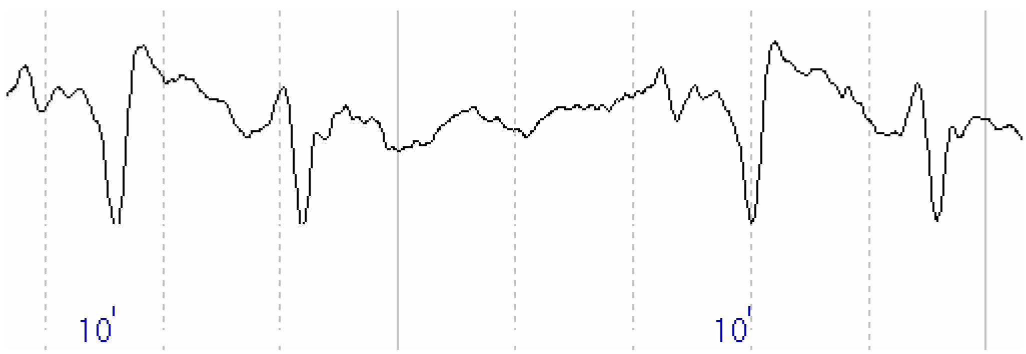
In this file, QRS Detection inaccurately placed events at all peaks. Averaging those sweeps and then subtracting the average would lead to very unacceptable results.



The QRS Detection method is based on an automatic QRS detection algorithm, and works very well for regular EKG recordings. However, with BCG, it is often ineffective.

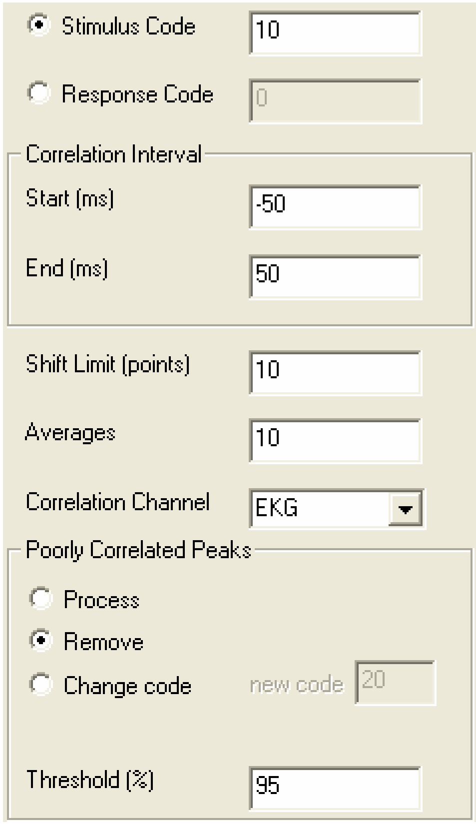
It is also possible - with any of the above methods - to filter the trigger channel first to make the peaks easier to detect. Assume you filter the trigger channel and have placed the events accurately using one of the above methods. Now, if you want to perform the correction using the original data, you will need to transfer the events from the filtered file to the original file. You can do this by selecting the **Event File** transform to create a text file that contains the event types and positions. You can then import that event file using the Import Event File transform (see **Import Event File** 79 above). You will then have the same events in the original file, and you can proceed to the next step.

c. **Manually insert the events**. If no other way will work well enough, you can use the icon to **Insert Multiple Events**. Display a few seconds at a time to facilitate placements at the peaks. The Correlate Peaks transform will correct small errors by aligning by waveform correlation rather than event placement.



Manual placement can be very effective, albeit time-consuming.

2. Once you have placed the events, the next recommended step is to correct the placements based on waveform correlations, rather than by simply aligning the events, using the **Correlate Peaks** transform. Enter the stimulus (or response) code marking the peaks. The Correlation Interval has been described above. It is the actual interval in the most recent artifact sweep that will be correlated with the same interval in the average artifact. It typically encompasses the R wave, although it can be a different interval (-50 to 50ms about the events was used in this example).



The Shift Limit is imposed to bound the cross-correlation function to a limited time range, preventing inadvertent "locking" on inappropriate peaks. The shift limit also restricts the total correlations that will be computed (±10 points was used), thus minimizing computational overhead. Ten sweeps will be averaged to create the average artifact. Sweeps that do not reach a correlation of .95 will be excluded from the average.

You probably will not notice any difference after applying the correction. The events were repositioned as needed to maximize the correlations.

3. The next step is to create the averaged artifact that will be used in the correction. In the EKG Noise Reduction transform, this will be a rolling average. In the current steps, we will use a single average based on the entire recording. **Epoch** the CNT file *only* about the events that were entered (type 10 in this example). For X Minimum and X Maximum, we recommend -200 to 1200ms for EKG. It does not matter that the maximum extends into the next artifact (see **Fundamental Concepts** 32 above). For BCG, the Start and End times may vary. You can use the Previews in the EKG Noise Reduction transform to see the time points that work best, before actually applying the correction.

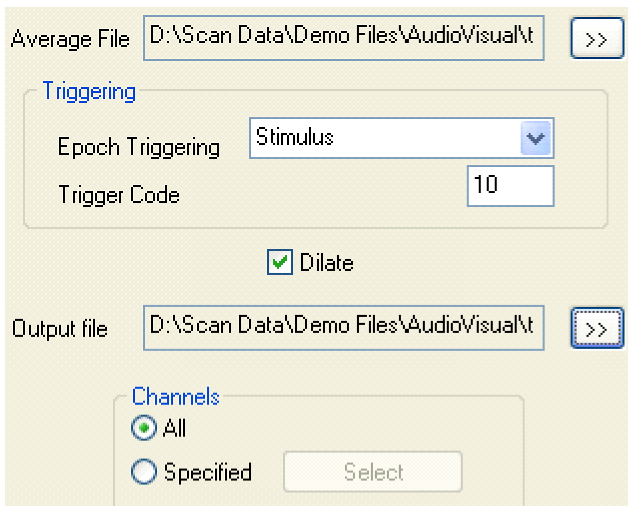
Now that you have the epoched file, you can reject any remaining sweeps that are aberrant, perform baseline correction, detrending, etc. as needed. Filtering is not recommended at this point.

Then average the artifact sweeps.

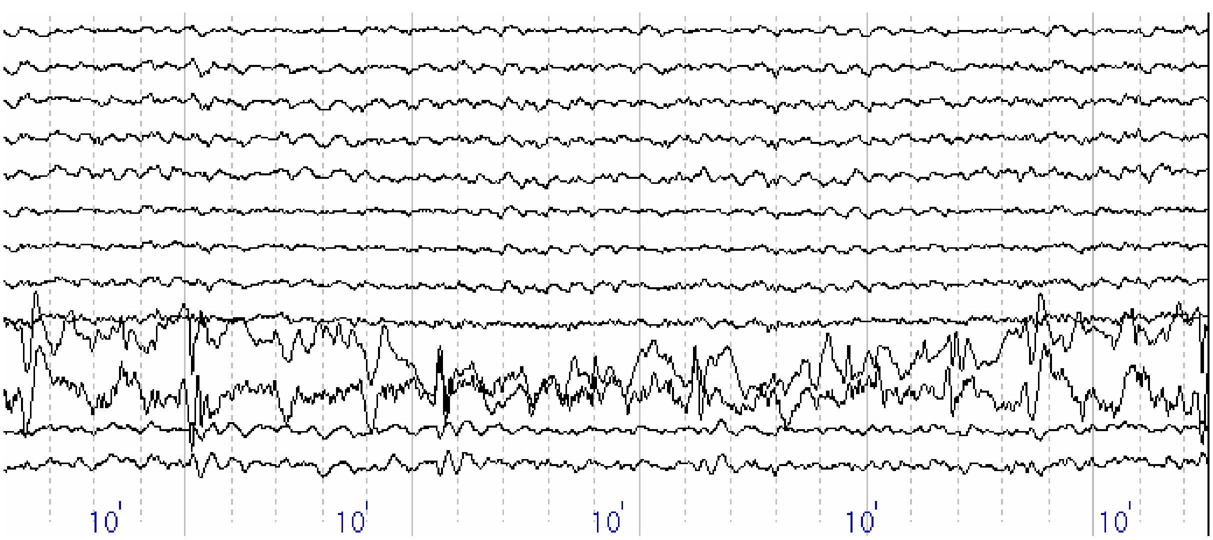
Note

The EKG Noise Reduction transform uses a rolling average. That is to allow for variations in the heart beat that can occur over time. The assumption is that a given EKG pulse will be more similar to the N beats that precede it than to the average of all heart beats in the file. In the preceding step, we averaged all the heart beats in the file, knowing that the subtraction may be less than perfect.

4. Now that we have an average artifact AVG file, the final step is to subtract that waveform from each section about the events in the original CNT file. This is the purpose of the **Subtract Average** transform. Select the file to be subtracted, select whether the CNT file events are stimulus or response types, and enter the type code. The Dilate option was selected to correct for beat to beat amplitude variability. Enter an output file name, and apply the corrections to all or selected channels.



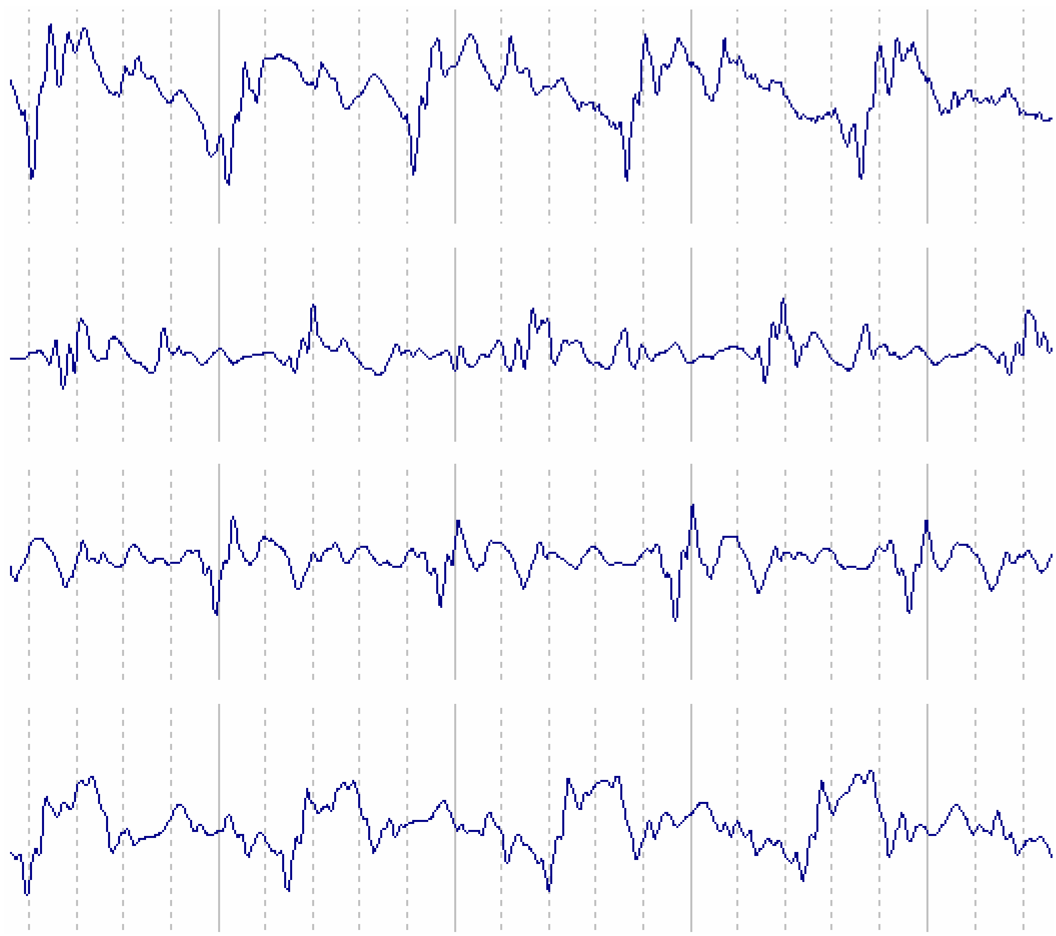
You will then see the corrected CNT file.



The steps have significantly reduced the BCG artifact. In general use, we recommend that you try the EKG Noise Reduction transform first, and then try the individual steps if the results are not satisfactory. The individual steps allow you to observe better what is happening with a difficult file, and thereby suggest parameters or other steps that may be more effective.

4.2 Example 2

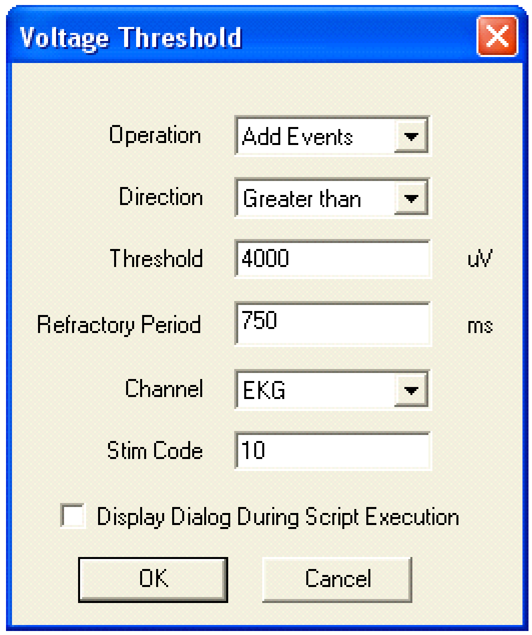
This is a much more challenging example in which the BCG varies considerably through the file, and in some places the R wave peak is too low to be detected by a simple voltage threshold method. The following are examples of the EKG channel taken at various places throughout a single recording. The display scale is the same in all examples.

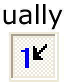


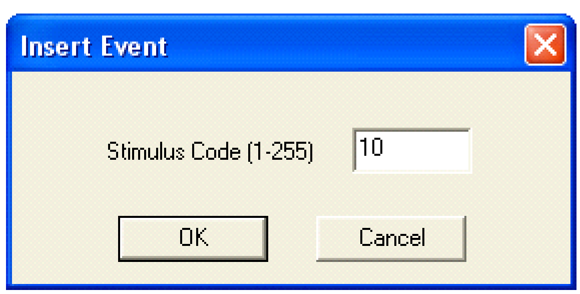
Just from looking, you can see that 1) no single voltage threshold will identify the same peaks in all instances, 2) even if the peaks were identified, many sweeps would be rejected with even a modest Correlation Threshold, and 3) combining these into a single average which is then subtracted would distort all of the sweeps. This is where the Change Code option in the Correlate Peaks transform can be used to create "bins" of correlated sweeps, which can then be removed a bin at a time using EKG Noise Reduction.

The following is one way to approach the problems - you may find different ways depending on the files you have acquired.

1. The Correlate Peaks transform requires that events are already placed to identify the peaks. In an extreme BCG artifact file such as this, we recommend you use the **Voltage Threshold** transform first to place events in as many sweeps as can be reliably detected. If you have a CNT file recorded in DC mode, there may be considerable DC offset, and the Threshold can be a large number. Filtering the trigger channel first may be helpful. High-pass filtering the trigger channel at 1 Hz, for example, will eliminate the DC offset and facilitate threshold setting for EKG detection.

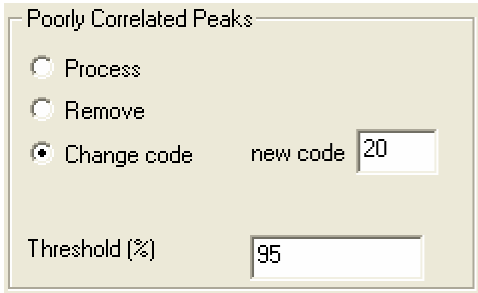


2. While many BCG artifacts will be identified with the voltage threshold, others may be missed (a threshold low enough to capture low voltage peaks can yield false positives, despite the Refractory Period). In these cases, the most reliable solution is to mark the missed peaks manually. That process has been eased considerably with the new Insert Multiple Events  option. Set the event code you want to insert, and then just click on the peaks. It is not necessary to be painstakingly obsessive in placing the events precisely at the appropriate time point - the Correlate Peaks option will make minor corrections.



3. Now that all peaks have been identified, the next step requires several passes with the Correlate Peaks transform. The Change Code option should be enabled, with a different code for the rejected sweeps. In this case, Type 10s were inserted with the Voltage Threshold transform as well as manually. Any sweeps that do not reach the

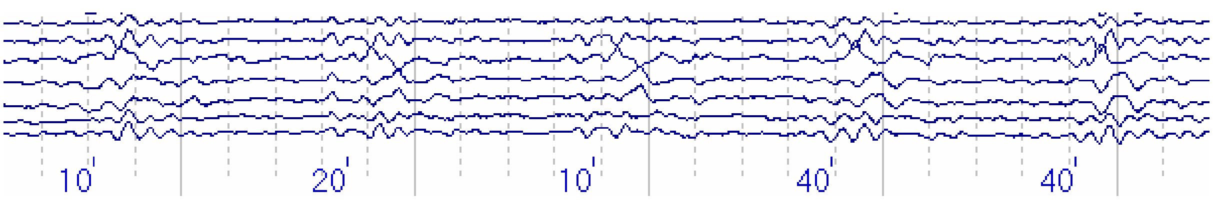
95% Threshold will have their Type 10 codes changed to Type 20 codes. The remaining Type 10s constitute the first bin, or the first class of BCG artifacts.



Then run Correlate Peaks again, selecting the Type 20 events, where the **new code** is, for example, Type 30. The Type 20s that were not rejected constitute the second bin of artifacts.

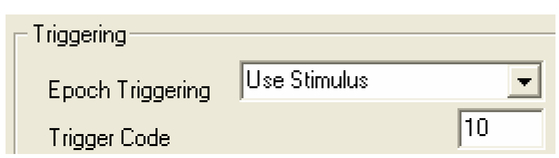
Repeat the procedure as long as there are enough sweeps to be used in the EKG Noise Reduction transform. The number of bins is determined by the number of distinguishable types of artifact in the file. The last bin may be a sort of trash bin, containing sweeps that do not correlate with other bins, and may or may not correlate among themselves.

After running Correlate Peaks several times, you should see the various types of artifacts in the CNT file.



Incidentally, while this procedure was developed for binning BCG artifact, it may well have additional uses. For example, epileptic spike activity may appear in different forms throughout a recording. The same procedure could create bins of spikes that could then be processed separately (for source reconstruction).

4. The last step is to run the **EKG Noise Reduction** transform as many times as needed to correct each class of artifact. In this case, select **Use Stimulus** for the triggering method, and set the **Trigger Code** to the first bin's type code. When the new CNT file is created, run EKG Noise Reduction again with that file, using the second bin's type code. And so on for as many bins as you want to include. It is questionable whether to use the last bin - the trash bin - since the sweeps may or may not be similar to each other (try it both ways).



In the end you will wind up with a CNT file that is corrected for each type of artifact.

Some Tips
We have found some useful tips that may help with BCG artifact reduction in more difficult files. These have been compiled from our experiences with files we have seen. You may find other parameter settings that work better with your files.

1. Extend the **Correlation Interval** specified in the Correlate Peaks transform. In this case, you are not trying to align peaks - you are trying to identify classes of artifact. An extended interval may be more effective (e.g., -200 to 400ms).

2. If you extend the Correlation Interval, you may need to *reduce* the **Correlation Threshold**.

3. Do not be surprised or concerned if you find bins with a single sweep. That is an atypical artifact that occurs early in the file. It does not correlate with any prior sweeps, nor do subsequent sweeps correlate with it.

4. Try combinations of parameters that leave few sweeps in the last bin (the trash bin). These sweeps will not be corrected as well as the other bins.

5. When using the EKG Noise Reduction transform, it is likely not necessary to use the Correlation options. This has been performed already in the Correlate Peaks transforms, and doing it again may cause unexpected problems.

6. The **Dilate** option in the EKG Noise Reduction transform may help or hurt - it depends on the artifact in the file. In some cases, it may result in an overcorrection of the artifact. That is, the residual artifact appears like an inverted version of the original, only with much lower amplitude.

7. Since there are several parameters that may need to be varied, and many repetitive operations that are involved in finding the best settings, it is very useful to create a batch file to assist in the process.

For example, the first part of the batch file might appear as follows.

```
OPENFILE {C:\My Data\My Data file.cnt}
CORRELATEPEAKS STIMULUS 10 -200 400 20 10 EKG CHANGECODE 20 80
CORRELATEPEAKS STIMULUS 20 -200 400 20 10 EKG CHANGECODE 30 80
CORRELATEPEAKS STIMULUS 30 -200 400 20 10 EKG CHANGECODE 40 80
CORRELATEPEAKS STIMULUS 40 -200 400 20 10 EKG CHANGECODE 50 80
SAVEAS_EX {C:\My Data\new events.cnt} N
OPENFILE {C:\My Data\new events.cnt}
CLOSEFILE {My Data file.cnt}
```

Five bins are created with type codes of 10, 20, 30, 40, and 50. You can create further bins, as needed. Changing the Correlation Interval and Threshold can be done easily in the Batch Editor.

The next section could epoch the CNT file for each bin.

```
CREATESORT SORT35
SORT35 -TypeEnabled T
SORT35 -TypeCriteria 10
EPOCH_EX PORT_INTERNAL "" N -200 1200 N Y Y N N SORT35 {C:\My Data\bin10.eeg}
```

```
DELETESORT SORT35
SELECTFILE "new events.cnt"
CREATESORT SORT35
SORT35 -TypeEnabled T
SORT35 -TypeCriteria 20
EPOCH_EX PORT_INTERNAL "" N -200 1200 N Y Y N N SORT35 {C:\My Data\bin20.eeg}
DELETESORT SORT35
SELECTFILE "new events.cnt"
CREATESORT SORT35
SORT35 -TypeEnabled T
SORT35 -TypeCriteria 30
EPOCH_EX PORT_INTERNAL "" N -200 1200 N Y Y N N SORT35 {C:\My Data\bin30.eeg}
DELETESORT SORT35
SELECTFILE "new events.cnt"
CREATESORT SORT35
SORT35 -TypeEnabled T
SORT35 -TypeCriteria 40
EPOCH_EX PORT_INTERNAL "" N -200 1200 N Y Y N N SORT35 {C:\My Data\bin40.eeg}
DELETESORT SORT35
SELECTFILE "new events.cnt"
CREATESORT SORT35
SORT35 -TypeEnabled T
SORT35 -TypeCriteria 50
EPOCH_EX PORT_INTERNAL "" N -200 1200 N Y Y N N SORT35 {C:\My Data\bin50.eeg}
DELETESORT SORT35
```

A section can then be included that displays the number of sweeps for each bin.

```
OPENFILE{C:\My Data\bin10.eeg}
set sweeps [GETNUMSWEEPS -Accept]
set report [format "Type 10 sweeps: %d" $sweeps]
INSTRUCT $report
CLOSEFILE {bin10.eeg}
OPENFILE {C:\My Data\bin20.eeg}
set sweeps [GETNUMSWEEPS -Accept]
set report [format "Type 20 sweeps: %d" $sweeps]
INSTRUCT $report
CLOSEFILE {bin20.eeg}
OPENFILE {C:\My Data\bin30.eeg}
set sweeps [GETNUMSWEEPS -Accept]
set report [format "Type 30 sweeps: %d" $sweeps]
INSTRUCT $report
CLOSEFILE {bin30.eeg}
OPENFILE {C:\My Data\bin40.eeg}
set sweeps [GETNUMSWEEPS -Accept]
set report [format "Type 40 sweeps: %d" $sweeps]
INSTRUCT $report
CLOSEFILE {bin40.eeg}
OPENFILE {C:\My Data\bin50.eeg}
set sweeps [GETNUMSWEEPS -Accept]
set report [format "Type 50 sweeps: %d" $sweeps]
INSTRUCT $report
CLOSEALL
```

The EKG Noise Reduction transform is then applied as many times as desired to remove the artifact bin by bin.

```
OPENFILE {C:\My Data\new events.cnt}
EKGNOISEREDUCTION {C:\My Data\10s corrected.cnt} -200 1200 10 STIMULUS 10 x x x
    x x x x x x x x x x x x 100 N x x x x x N
OPENFILE {C:\My Data\10s corrected.cnt}
EKGNOISEREDUCTION {C:\My Data\1020s corrected.cnt} -200 1200 10 STIMULUS 20 x x
    x x x x x x x x x x x x 100 N x x x x x N
OPENFILE {C:\My Data\1020s corrected.cnt}
EKGNOISEREDUCTION {C:\My Data\102030s corrected.cnt} -200 1200 10 STIMULUS 30 x
    x x x x x x x x x x x x x 100 N x x x x x N
OPENFILE {C:\My Data\102030s corrected.cnt}
EKGNOISEREDUCTION {C:\My Data\10203040s corrected.cnt} -200 1200 10 STIMULUS
    40 x x x x x x x x x x x x x x 100 N x x x x x N
OPENFILE {C:\My Data\10203040s corrected.cnt}
EKGNOISEREDUCTION {C:\My Data\1020304050s corrected.cnt} -200 1200 10 STIMULUS
    50 x x x x x x x x x x x x x x 100 N x x x x x N
OPENFILE {C:\My Data\1020304050s corrected.cnt}
PAUSE
CLOSEALL
```

Again, you can enable the Dilate option and change the Epoch Interval as desired using the Batch Editor. Once you develop a feel for the best parameters to use, the batch files should not be necessary.

If you want to see the effects of the correction for each bin, you could average the raw and corrected sweeps, then retrieve the average files for each bin - raw and corrected - and superimpose them to see whatever residual artifact there may be.

```
OPENFILE {C:\My Data\new events.cnt}
CREATESORT SORT36
SORT36 -TypeEnabled T
SORT36 -TypeCriteria 10
EPOCH_EX PORT_INTERNAL "" N -200 700 N Y Y N N SORT36 {C:\My Data\raw10.eeg}
DELETESORT SORT36
OPENFILE {C:\My Data\raw10.eeg}
AVERAGE_EX TIME Y AMPLITUDE 10 COSINE PRESTIMINTERVALNOISE x x
POSTSTIMINTERVALSIGNAL x x NULL {C:\My Data\raw10.avg}
OPENFILE {C:\My Data\raw10.avg}
BASECOR_EX2 PRESTIMINTERVAL x x N N { ALL } {}
SAVEAS_EX {C:\My Data\raw10.avg} N
OPENFILE {C:\My Data\raw10.avg}
CLOSEFILE {raw10.avg}
CLOSEFILE {raw10.eeg}

SELECTFILE {C:\My Data\new events.cnt }
CREATESORT SORT36
SORT36 -TypeEnabled T
SORT36 -TypeCriteria 20
EPOCH_EX PORT_INTERNAL "" N -200 700 N Y Y N N SORT36 {C:\My Data\raw20.eeg}
```

```
DELETESORT SORT36
OPENFILE {C:\My Data\raw20.eeg}
AVERAGE_EX TIME Y AMPLITUDE 10 COSINE PRESTIMINTERVALNOISE x x
POSTSTIMINTERVALSIGNAL x x NULL {C:\My Data\raw20.avg}
OPENFILE {C:\My Data\raw20.avg}
BASECOR_EX2 PRESTIMINTERVAL x x N N { ALL } {}
SAVEAS_EX {C:\My Data\raw20.avg} N
OPENFILE {C:\My Data\raw20.avg}
CLOSEFILE {raw20.avg}
CLOSEFILE {raw20.eeg}

SELECTFILE {C:\My Data\new events.cnt }
CREATESORT SORT36
SORT36 -TypeEnabled T
SORT36 -TypeCriteria 30
EPOCH_EX PORT_INTERNAL "" N -200 700 N Y Y N N SORT36 {C:\My Data\raw30.eeg}
DELETESORT SORT36
OPENFILE {C:\My Data\raw30.eeg}
AVERAGE_EX TIME Y AMPLITUDE 10 COSINE PRESTIMINTERVALNOISE x x
POSTSTIMINTERVALSIGNAL x x NULL {C:\My Data\raw30.avg}
OPENFILE {C:\My Data\raw30.avg}
BASECOR_EX2 PRESTIMINTERVAL x x N N { ALL } {}
SAVEAS_EX {C:\My Data\raw30.avg} N
OPENFILE {C:\My Data\raw30.avg}
CLOSEFILE {raw30.avg}
CLOSEFILE {raw30.eeg}

SELECTFILE {C:\My Data\new events.cnt }
CREATESORT SORT36
SORT36 -TypeEnabled T
SORT36 -TypeCriteria 40
EPOCH_EX PORT_INTERNAL "" N -200 700 N Y Y N N SORT36 {C:\My Data\raw40.eeg}
DELETESORT SORT36
OPENFILE {C:\My Data\raw40.eeg}
AVERAGE_EX TIME Y AMPLITUDE 10 COSINE PRESTIMINTERVALNOISE x x
POSTSTIMINTERVALSIGNAL x x NULL {C:\My Data\raw40.avg}
OPENFILE {C:\My Data\raw40.avg}
BASECOR_EX2 PRESTIMINTERVAL x x N N { ALL } {}
SAVEAS_EX {C:\My Data\raw40.avg} N
OPENFILE {C:\My Data\raw40.avg}
CLOSEFILE {raw40.avg}
CLOSEFILE {raw40.eeg}

SELECTFILE {C:\My Data\new events.cnt }
CREATESORT SORT36
SORT36 -TypeEnabled T
SORT36 -TypeCriteria 50
EPOCH_EX PORT_INTERNAL "" N -200 700 N Y Y N N SORT36 {C:\My Data\raw50.eeg}
DELETESORT SORT36
OPENFILE {C:\My Data\raw50.eeg}
AVERAGE_EX TIME Y AMPLITUDE 10 COSINE PRESTIMINTERVALNOISE x x
POSTSTIMINTERVALSIGNAL x x NULL {C:\My Data\raw50.avg}
OPENFILE {C:\My Data\raw50.avg}
```

```
BASECOR_EX2 PRESTIMINTERVAL x x N N { ALL } {}
SAVEAS_EX {C:\My Data\raw50.avg} N
OPENFILE {C:\My Data\raw50.avg}
CLOSEFILE {raw50.avg}
CLOSEFILE {raw50.eeg}

PAUSE

OPENFILE {C:\My Data\raw10.avg}
GETCOMP {C:\My Data\corr10.avg}
PAUSE
CLOSEALL
OPENFILE {C:\My Data\raw20.avg}
GETCOMP {C:\My Data\corr20.avg}
PAUSE
CLOSEALL
OPENFILE {C:\My Data\raw30.avg}
GETCOMP {C:\My Data\corr30.avg}
PAUSE
CLOSEALL
OPENFILE {C:\My Data\raw40.avg}
GETCOMP {C:\My Data\corr40.avg}
PAUSE
CLOSEALL
OPENFILE {C:\My Data\raw50.avg}
GETCOMP {C:\My Data\corr50.avg}
PAUSE
CLOSEALL
```

8. Lastly, realize that the more stable the artifact, the better it will be removed. When a given artifact sweep varies from the average of the N sweeps that precede it, the subtraction will not be perfect. If the artifact varies considerably throughout the file, it will not be possible to remove it completely, even with multiple bins. To the extent possible, you should try to avoid acquiring files where the BCG artifact is too variable. You can help keep the artifact stable by keeping the subject as still as possible, and by taping all of the EEG and EKG leads to minimize the movements. Using a pulse oximeter will help with the artifact detection, but again, keep the subject's hand and head as immobile as possible, as well as the electrode cap and pulse oximeter cables.

5 Artifact Reduction in Curry 6

Current changes in the Curry 6 software now include not only a way to perform PCA Projection, an alternate way to remove artifact such as BCG, but also the ability to export PCA corrected CNT data files. If you are encountering difficulties removing BCG, especially, try using PCA Projection in Curry. If the exported CNT file does not contain the correct event information, you may use the Event File transform in Edit to first create a file containing the events. After exporting the corrected data from Curry, use the Import Event File transform in Edit to restore the events.