Toolbox 4.5

Additional Tools for Scan Software

Table of Contents

1   Toolbox

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Toolbox^{TM}

(for SCAN Version 4.5)

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 **1-877-717-3975**. International callers should use **1-704-749-3200**.

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

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1.2   Introduction

The Toolbox programs are ancillary "plug-in" programs that interface with the SCAN software. The programs extend the functionality of SCAN, and are available for users who have need for the extra capabilities. The information contained in this manual is consistent with the **V4.5** version of SCAN. There are currently five features in the Toolbox.

- **EKG Noise Reduction (offline)**
- **Blink Artifact Reduction**
- **Export to MS Excel**
- **Interface with MATLAB**
- **PCA/ICA** (Principle and Independent Component Analyses)

To access the programs, it may be necessary for you to first reprogram your dongle (software lock connected to your computer's parallel or USB port). 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** → **Neuroscan** → **Scan4.5** → **License Manager**), and the serial number is displayed.

Then go to the Neuroscan web site http://www.neuroscan.com/ (or contact licenses@neuroscan.com), and go to **Support** → **Resources**.
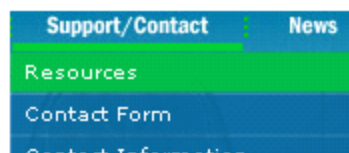
Enter your **Username** and **Password**. If you do not have these, click the access request form link, and the information will be e-mailed to you. Then enter the information and click Log In to Access Resources .

Click REQUEST SCAN PASSWORD , and enter all of the required information. The Lock Number is the Serial Number. Then click REQUEST SCAN PASSWORD .

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 process was successful. Then click Done .

License Number

Password

You can now access the software.

2   EKG Noise Reduction - Offline

The offline EKG Noise Reduction transform (CNT files only) has been revised with the V4.4 release. It is intended for removal of ballistocardiogram (BCG) from recordings made in the MR bore, but may be used for routine heart beat removal also. It may have application for other types of artifact, as well. Briefly stated, the EKG Noise Reduction transform identifies and averages artifact sweeps, and then subtracts 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 correlation correction can be performed to align waveforms rather than single point triggers, and a correlation test can be performed to exclude atypical sweeps from the average. An amplitude correction is also available. The average artifact is created in a rolling fashion, where the most recently identified and accepted artifacts are averaged. The average is based on the N most recent artifacts (N is the value entered for **Averages**).
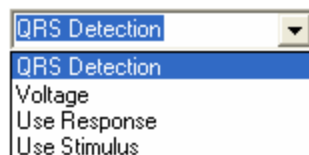
Select **Transforms** → **EKG Noise Reduction**. There are three sets of parameters: Triggering, Epoch Interval, and Advanced, plus three Preview displays.

Triggering. There are four ways to initiate an artifact sweep: QRS Detection, a Voltage threshold, and Stimulus or Response event codes.

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

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 this method tends to place the events not at the R wave peak, but rather between the R and S waves.
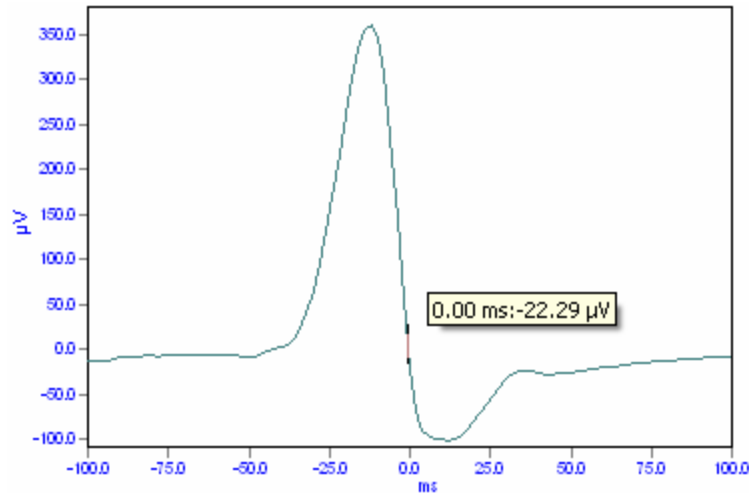
There is a "warm up" period at the beginning of the CNT file where no events are placed (8 beats), then you should see events inserted for each detected QRS complex.

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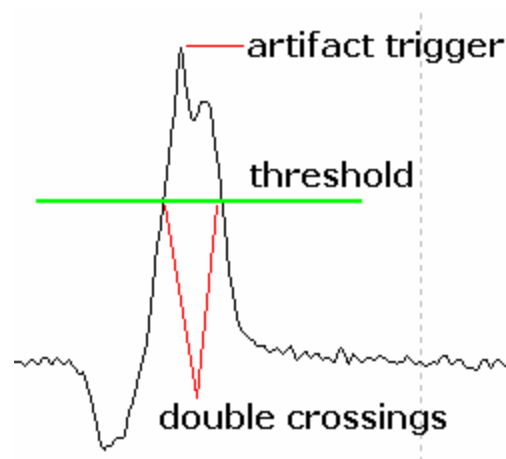
Use Stimulus/Use Response. The final methods use stimulus or response trigger events from an external device, such as an EKG monitoring instrument. TTL pulses are sent and interpreted by the program as either red response events or blue stimulus events, based on which pins are used in the connector on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

Trigger Code. Enter the Stimulus or Response trigger code to be used for detecting the EKG artifact (Use Response/Use Stimulus modes only).

Refractory Period. The Refractory Period is an interval that may be set immediately after an artifact trigger has been detected. Any other potential triggers in the refractory period will be ignored. This avoids spurious triggering.

Threshold. Enter the μV value of the Threshold (Voltage method only). The value should be great enough to miss the T wave peaks (and any others), yet small enough to detect the R wave peaks.
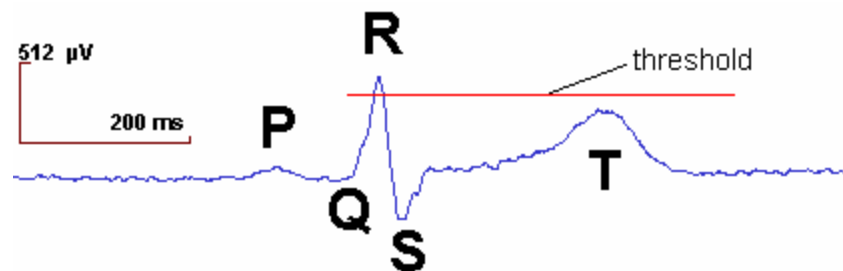
You should inspect the file first to see what threshold value to use. In more difficult files (e.g., BCG), you may need to use the **Refractory Period** and/or the **Filter** to enable accurate peak detection. Use the Trigger Channel preview to see the Threshold position (green line), and adjust the Threshold as needed. If the Threshold is out of range for the display, you will see an up or down arrow indicating its position.
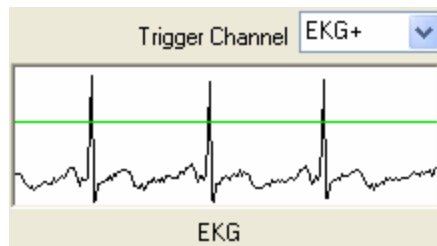
Direction. **Positive** and **Negative** directions are roughly analogous to *greater than* or *less than*. Remember that the peak point is selected with a double-crossing method. *Positive* takes the largest point between crosses; *Negative* takes the smallest point between crosses. Consider the example of BCG to the right. There is a large DC offset, causing the large voltage values. We wanted the smallest peak voltage, even though all measurements are positive voltage. This is a case where you use a *Negative* direction.
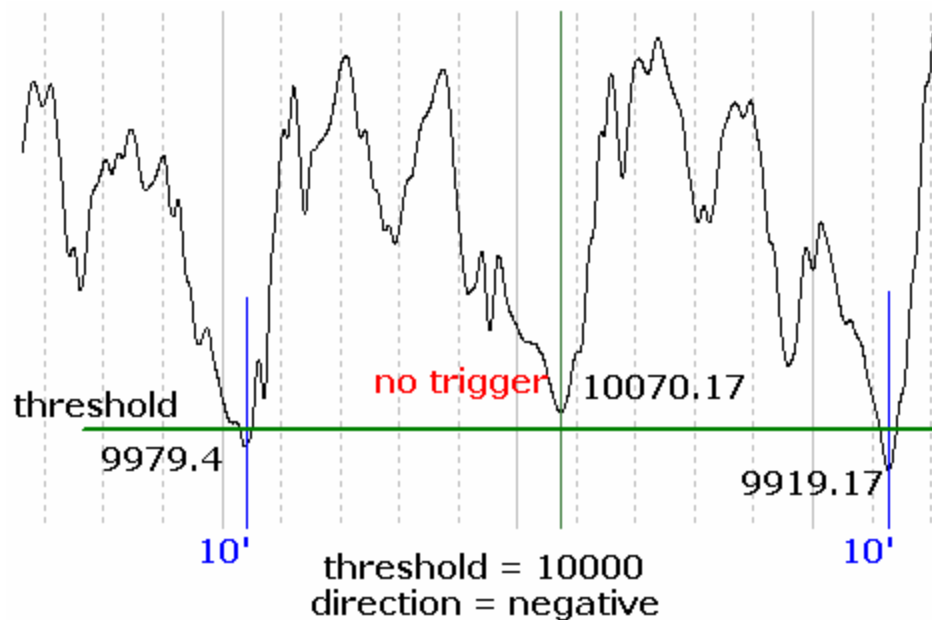
If we had used a *Positive* direction, triggers would have been placed at the greatest voltage between the two threshold crossings at 10000µV. (All settings were the same except Direction was changed to Positive).

threshold = 10000
direction = positive
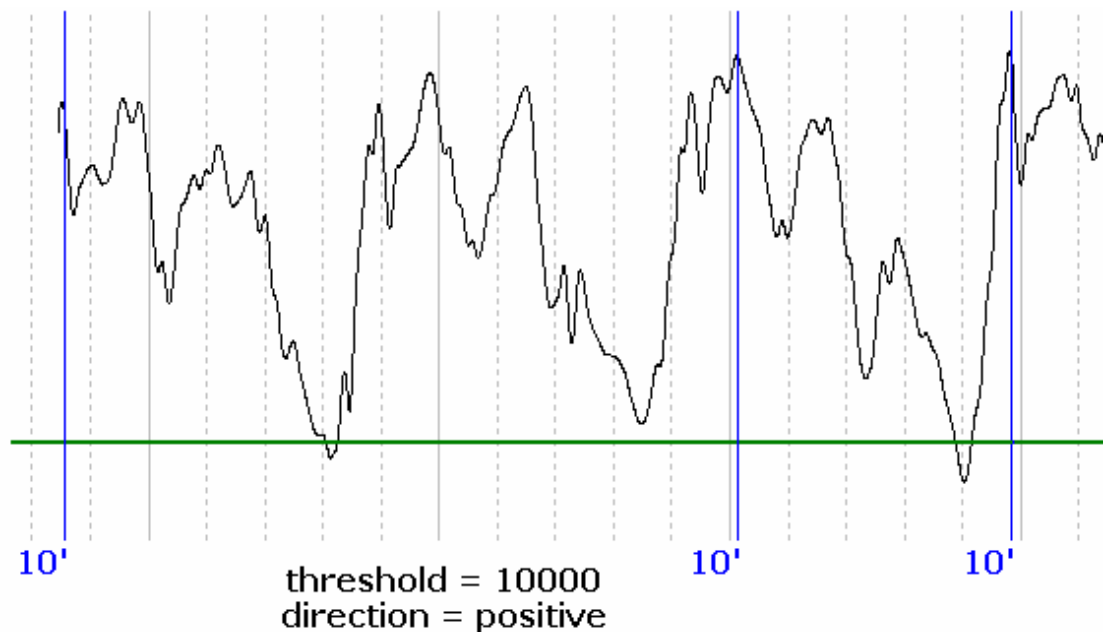
Positive sets the trigger at the greatest voltage point between the two threshold crossings; **Negative** sets the trigger at the least voltage point between the two crossings.

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 Parameters... button to see the Filter dialog screen.
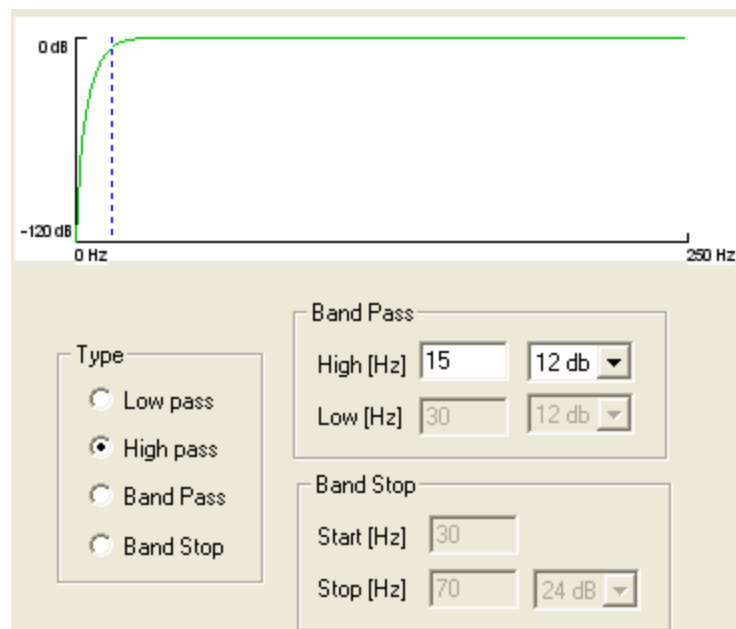
Select the type of filter you want to use (Low pass, High pass, etc.). Enter the cutoff values and rolloffs in either the Band Pass or Band Stop fields (depending on the Type of filter selected). The effects of the filter are seen in the diagram at

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 defines the time limits of the artifact sweeps that are averaged, and is determined by **Start** and **End** times. In the example below, 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*.
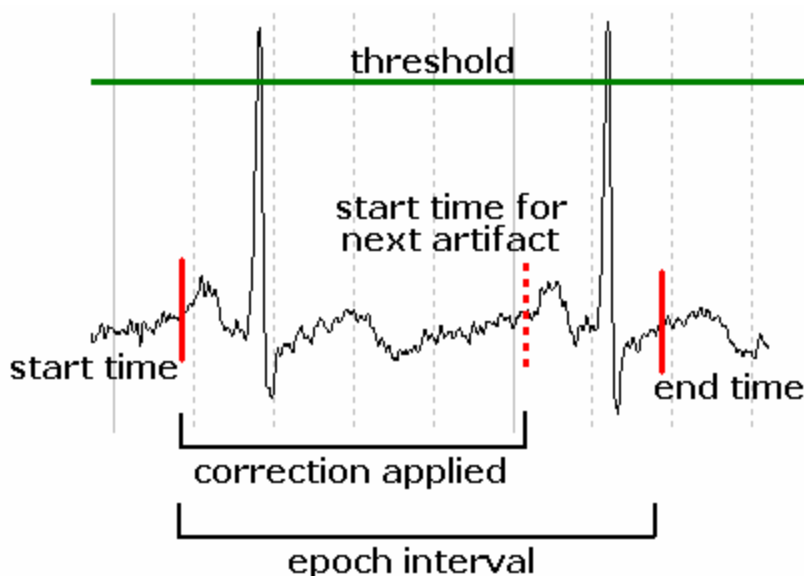
This method minimizes abrupt transitions that can otherwise occur at the edges of the Epoch Interval. It also means you do not need to know what the precise End time should be (that would exclude the next artifact), and works well when the heart rate varies over the recording. The **Refractory Period** can be used, if needed, to block any unwanted triggers between the desired ones. With most EKG files, we have found that Start/End times of -200 to 1200ms will work well.

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.

Trigger Channel. Select the channel that will be used to detect the artifact (typically the EKG channel). The horizontal green line shows the position of the Threshold. If the Threshold is out of range, you will see an up or down arrow.
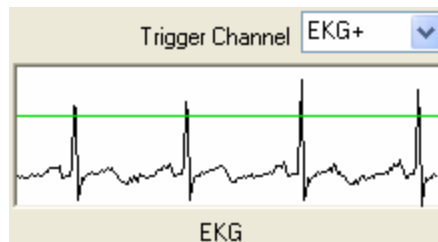
Raw Data. This displays the raw or uncorrected data for the Preview channel you select. You can use the arrow buttons or sliding bar to move through the CNT file. The section you select will be displayed in the other Preview displays as well.
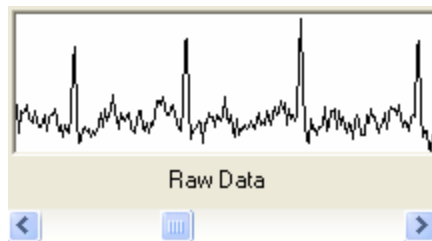
Corrected Data. This shows a preview of the results following application of the correction, for the channel and file section you selected. If the Preview does not show accurate EKG reduction, try changing some of the parameters. Remember to click the button to apply the parameter changes you have made.
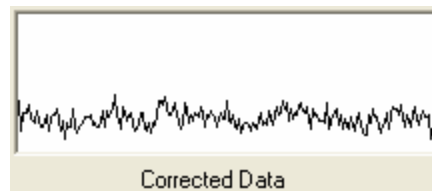
Advanced. The information displays the current settings. Click the button to access the additional parameters.

Correlation. 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.

Correlation

The artifact waveform may shift over time reducing the accuracy of the artifact determination by "shifting" the trigger code. Enable correlation to dynamically relocate the trigger. Epochs not meeting the correlation threshold are excluded from average.

☑ Enable correlation   Channel EKG+ ▼

Start from trigger (ms)   -50   Shift limit   25

Stop from trigger (ms)   50   Threshold (%)   90

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 have been shifted. The average of the two will be affected.
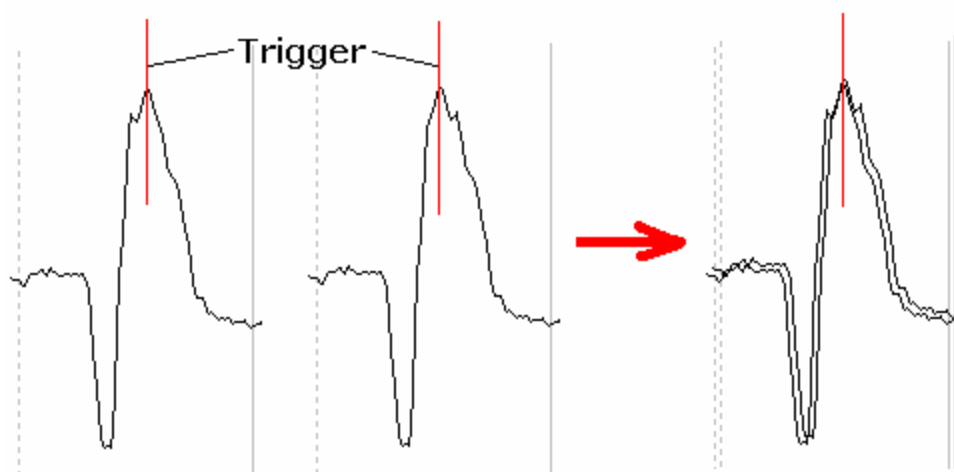
When you enable the **Correlation** option, the program will perform a series of intra-class correlations between the **Correlation Interval** of the current sweep (using the **Correlation Channel** you select) and the same interval in the average artifact (relative to the trigger that has already been defined). The correlation interval is defined by the **Correlation Interval Start** and **End** times. 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 500Hz (one point every 2 ms). Try a Shift Limit of half the R wave span - 10 points (or 20ms).

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.

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.
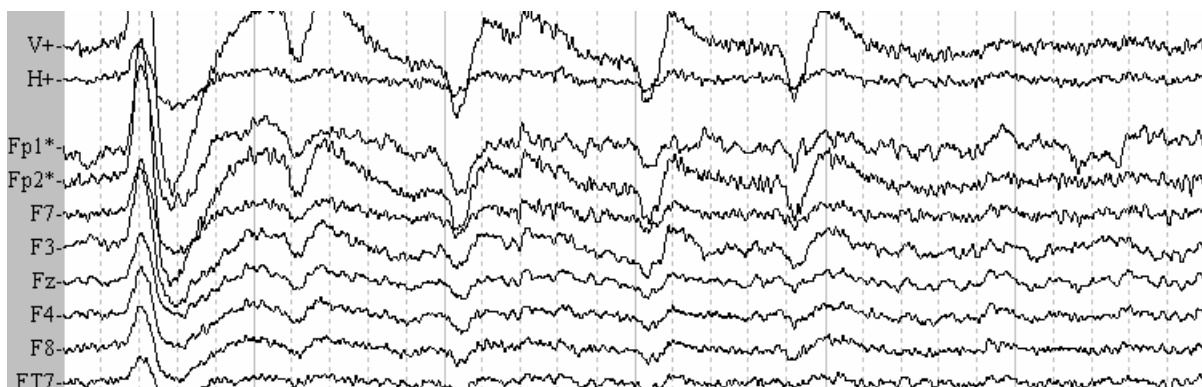
If you instead use the VEOG channel as the Correlation Channel, the artifact sweeps containing VEOG will be rejected from the average artifact, and therefore no VEOG will be added to the EEG channels. You will likely need to reduce the Correlation Threshold in these cases.
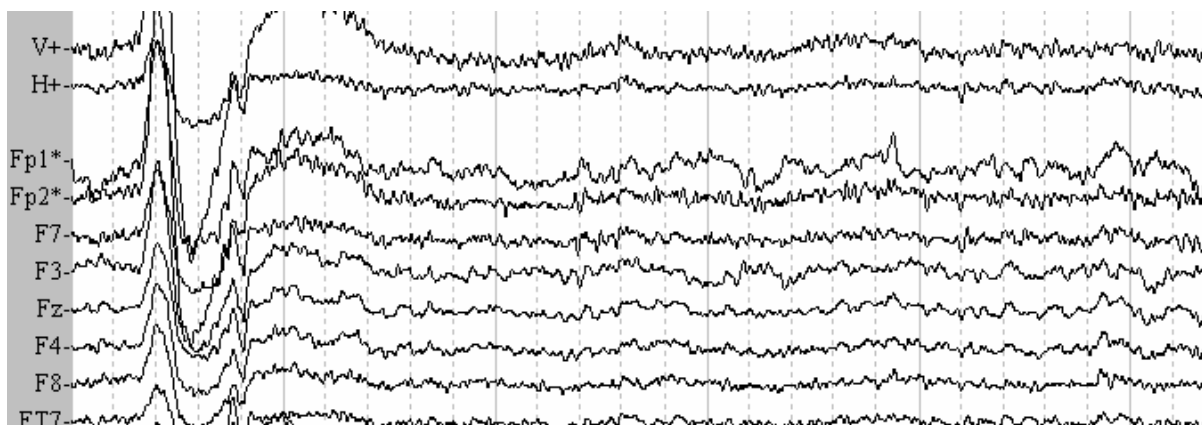
📄 **Note**

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

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 average 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.

> **Dilate**
>
> A given artifact sweep may vary from the average artifact in terms of overall amplitude. The Dilate option will dilate or constrict the average artifact to create a closer match to the current sweep, thus improving the subtraction.
>
> ☑ Dilate

📄 **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). This can be avoided by removing the VEOG prior to removing the EKG/BCG.

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. Enter a value for the type code (do not overlap the trigger event code with stimulus event codes). If the artifact is detected, you will see the event at the peak of the artifact.

The events are seen in the corrected CNT file, thus allowing you to verify that the peaks were detected accurately.
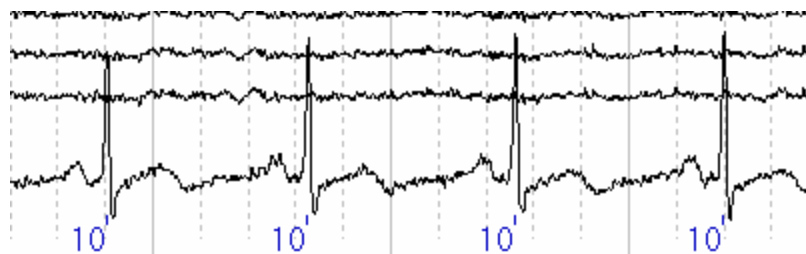
Click OK to return to the initial dialog screen. If you have made any changes, click the Preview button to see the effects on the correction.

📄 **Note**

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

📄 **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**

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.

2.1   Using EKG Noise Reduction

Below is an example for using the EKG Noise Reduction transform.

There is considerable EKG artifact in the sample data file, and it can be seen with varying amplitude in all channels.
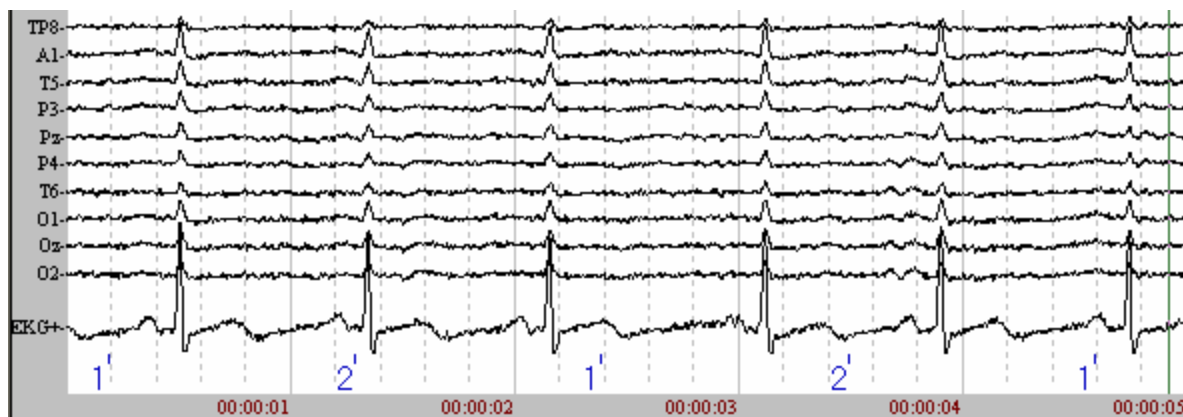
The EKG channel is shown below.
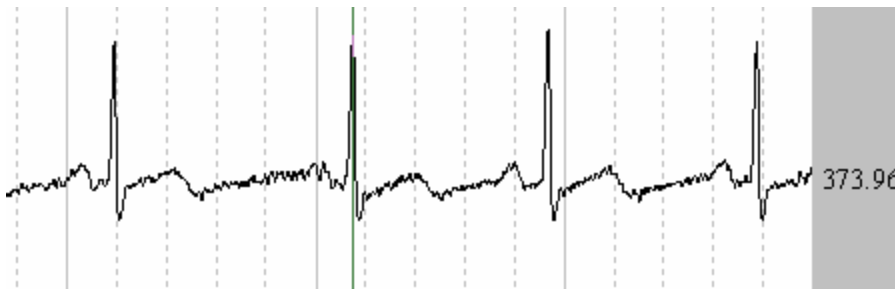
This is an example where EKG removal is straight-forward. There are no Stimulus or Response events to mark the peaks, so we will use the Voltage Threshold method to insert the events. We could also use the QRS Detection method. The R wave peak is easily distinguished (no filtering is needed), and placement of the Threshold can be anywhere in roughly the 150-250μV range (we will use 200 μV). Looking through the file, the inter-beat interval (IBI) is roughly 800 to 1000ms. The width of the R wave pulse is about 40ms. These are measurements you should note prior to selecting the EKG Noise Reduction transform.

We entered the following parameters in the EKG Noise Reduction dialog screen:

We set the **Refractory Period** to 700ms, although it is really not needed in this file. There is no other activity beyond the 200µV **Threshold** that could result in false peak detection, but it does not hurt to use the Refractory Period anyway. 700ms is less than the smallest IBI noted. **Direction** is Positive. No filtering is needed. An **Epoch Interval** from -200 to 1200ms is generally recommended, and that will be adequate with this file. (Recall that it is recommended that you select an end time that overlaps the subsequent R wave).

Advanced Settings. The Correlation option was enabled. We will use the same channel for the **Correlation Channel** as for the Trigger Channel. In this case, the width of the R wave is about 40ms, and the AD rate was 500. We set the **Correlation Interval** to be from -25 to 25ms (to include the full peak span), with a Shift Limit of 10 points (20ms). 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 Correlation Interval. 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. 10 sweeps will be averaged to create the rolling average artifact, and a Stimulus type of 10 will be inserted to allow us to verify that the peaks were detected correctly. The Preview displays indicate that the correction will be effective.

The corrected file appears as follows (right side). We recommend that you look through your files and verify that the events were inserted at the proper positions, and the artifact removal is accurate throughout. In this case, the EKG was greatly reduced (and

the events were correctly placed). (The top two channels were Skip channels, and not corrected).
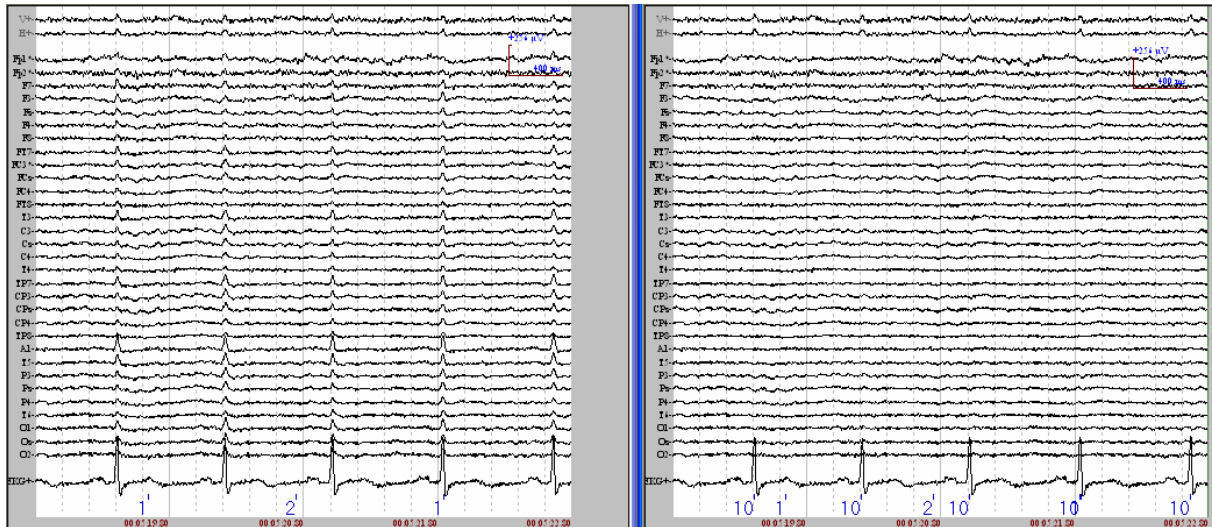
With the new transforms in SCAN V4.4 (QRS Detection, Correlate Peaks, Subtract Average), you may also perform the correction manually, step-by-step, if desired (this was designed for BCG, although there may cases where it is needed with EKG, or other artifacts).

The **QRS Detection** method is also very effective (the same Advanced parameters were used as above).
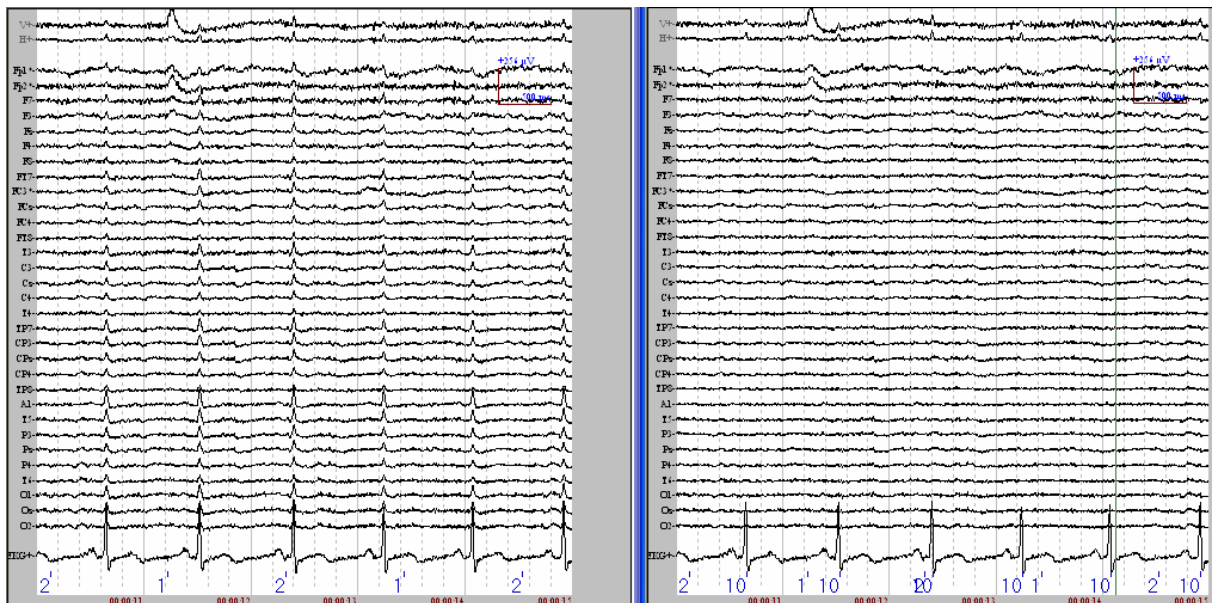
2.2   EKG Noise Reduction Batch Command

The EKG Noise Reduction transform can be used within a batch file. The batch command for V4.4 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 returning to the original EKGNOISEREDUCTION command. 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 V4.4 (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 $\pm$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.

3 Blink Artifact Reduction

The Blink Reduction routine provides a method for the online reduction of VEOG artifact. (Online and offline reduction of gradient artifact in the MR and online reduction EKG and ballistocardiogram artifact are included with the MagLink RT System, and are described in the *MagLink RT User Guide*). An offline version of Blink Reduction was added to EDIT to complement the online version. This is in addition to the **Ocular Artifact Reduction** transform, and the use of the **Spatial SVD** and **Spatial Filter** transforms for VEOG artifact reduction.

3.1 Online Blink Artifact Reduction (in ACQUIRE)

The online Blink Reduction computation is similar to the offline **Ocular Artifact Reduction** transform. One difference is that online Blink Reduction uses a rolling average of N sweeps, where N is the number entered for **Averages**. Based on those sweeps, an internal LDR file is computed and applied to all channels except the trigger channel (the coefficient is 1.0 for the trigger channel, therefore the corrected channel would be a flat line), and any *Skipped* channels. Linear transmission coefficients are computed, and there is a point-by-point proportional subtraction, based on the averaged artifact in the trigger channel. The data are buffered in the correction process, so you may notice a slight delay (about 40ms). The online transform functions basically the same way that the offline Ocular Artifact Reduction transform works (see that section in the EDIT manual for more details). Unlike the offline Ocular Artifact Reduction transform, the online Blink Reduction routine lets you reject sweeps using Artifact Rejection criteria. Additionally, you must be using **Continuous** acquisition mode (single window display) to apply the transform.

📄 Note
The correction is applied to the displayed data only. To apply the correction permanently, use the Blink Noise Reduction transform in EDIT.

Select the transform from **Edit → Overall Parameters → Blink Reduction**.

Blink Reduction is divided into three sets of parameters: Trigger, Interval, and Artifact

Rejection.

Trigger. These parameters are all related to the type of trigger, trigger parameters, and methods for enhancing the trigger channel waveform.

Voltage. An artifact sweep is initiated when the voltage in a designated channel exceeds a criterion you set. Select the **Positive** or **Negative** direction, according to the direction of the artifact. Select the **Channel** that you want to be monitored. Enter the **Threshold** value. This value should be sufficiently large to differentiate the blink 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.

Bipolar Derivation/Reference Channel. In some situations you may want to create a derived *bipolar* trigger channel that displays the blinks more clearly, and allows them to be detected more accurately. Enable the option, and select a channel to be used for the **Reference**. The reference channel will then be subtracted from the trigger channel.

High Pass Filtering. This option lets you apply a high pass filter to the artifact channel. This can be helpful if you are having difficulty setting the Threshold due to increased slow activity. Enable the option, enter a **High Filter (Hz)** value, and frequencies below that value will be attenuated.

External Trigger Code. With the External option, an artifact sweep is initiated when a selected stimulus type code is received. Enable the option, and enter a desired trigger code. The event may come from STIM or from another external device that sends TTL pulses.

📄 **Note**
If you are not using STIM, please see the "Triggering SCAN from an external device" section, in Appendix B of the SCAN Vol. 1 manual - Installation and Orientation manual (or the Overview.pdf) - as well as the pinout diagrams at the beginning of the appendix (specifically the "Back of SCAN connector" diagram).

Interval. The interval is the section before and after the point at which the Threshold is met. This should be long enough to encompass a stable, consistently appearing section of the artifact. It is not necessary to capture the entire artifact. For blinks, you want to capture the section from the peak (point where the threshold is met), or maybe a little before it, through the section after the blink. You do not want the duration (the Stop time) to be so short that you get a second trigger within the same blink. At the same time, if you make the duration too long, you will be including more variability in the average, which could reduce the transmission coefficients, and thereby reduce the effectiveness of the reduction. You should experiment a little with **Start** and **Stop** times to get the best settings for your data. Settings of approximately -100 (Start) to 300ms (Stop) should be close.

The **Averages** field determines how many artifact intervals are collected before

the correction process begins.

Artifact Rejection. The Artifact Rejection criteria are used to monitor voltages in the designated Artifact Rejection channels. When enabled, artifact detected by the Threshold criteria is NOT included in the average blink artifact if the **Y Min** or **Y Max** criterion is exceeded within the interval specified for the trigger. This prevents artifacts in the designated artifact rejection channels from being included in the averaged blink artifact.

📄 **Note**

If the artifact is present with nearly equal amplitudes in the designated artifact rejection channels, you should use caution when enabling the Artifact Rejection criteria. Blink artifacts in these channels could result in the rejection of perfectly acceptable sweeps.

3.2   Using Blink Reduction - Online

Begin acquiring the EEG data. Click the 👁 icon from the Toolbar to see the Blink Reduction control box. The **Trigger** light will blink briefly when the threshold is met. The **Reject** light will blink when an artifact interval is being rejected. The **Correcting** light will come on when number of **Averages** has been reached (indicating that the correction is being applied).
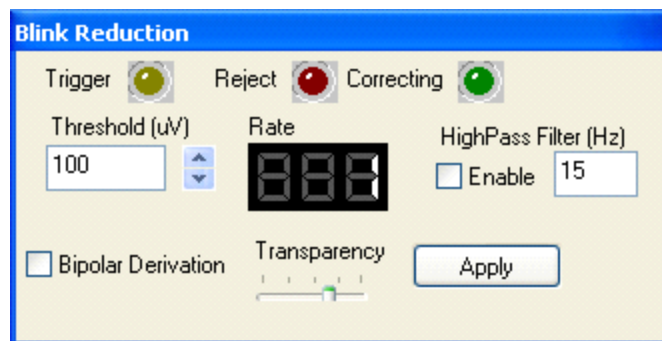
The Threshold level can be changed during acquisition (you will see a line displaying the threshold in the Single Window display). If you set the Threshold level by entering a number from the keyboard, you must click the **Apply** button to register the change. If you use the up and down arrows to adjust the Threshold, you do not need to click the Apply button. The **Rate** counter displays the moment-to-moment blink rate. If you wish to apply a **High Pass Filter**, enable the option, enter a value, and click Apply. You may toggle the **Bipolar Derivation** on and off. If you enable the Bipolar Derivation option, but did not select a reference channel from the Blink Reduction dialog screen, the program will select the first channel in the list as the reference (if you are using the bipolar reference option, be sure to select the reference from the Blink Reduction dialog screen first). **Transparency** refers to the transparency of the Blink Reduction control box itself. Slide the bar to the left to make the control box more Transparent, allowing you to see the waveforms through it. Slide it all the way to the right to make it opaque. The options all function even though the box is transparent.

The Blink Reduction transform can be applied offline in the EDIT program, as well, and can be applied in BATCH files.

📄 **Note**

Be sure to SAVE your setup files when have completed the settings. Then click OK to apply the current changes you have made if you wish to begin immediate acquisition. Clicking CANCEL will exit the Edit section without saving any changes you have made.

3.3   Offline Blink Artifact Reduction (in EDIT)

The offline Blink Reduction computation is similar to the Ocular Artifact Reduction transform.

One difference is that online Blink Reduction uses a rolling average of N sweeps, where N is the number entered for Averages. Based on those sweeps, an internal LDR file is computed and applied to all channels except the trigger channel (the coefficient is 1.0 for the trigger channel, therefore the corrected channel would be a flat line), and any

Skipped channels. Linear transmission coefficients are computed, and there is a point-by-point proportional subtraction, based on the averaged artifact in the trigger channel. Unlike the offline Ocular Artifact Reduction transform, the online Blink Reduction routine lets you reject sweeps using Artifact Rejection criteria. Retrieve a CNT file (only), and select **Transforms** → **Blink Noise Reduction** to access the transform.

Trigger. The artifact sweeps are initiated by triggers, and triggers are based upon a voltage threshold (**Voltage**) or a stimulus type code (**External**).

Voltage. With the Voltage option, an artifact sweep is initiated when the voltage in a designated channel exceeds a criterion you set. Select the **Positive** or **Negative** direction, according to the direction of the artifact. Select the **Channel** that you want to be monitored. Enter the **Threshold** value. This value should be sufficiently large to differentiate the blink 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 whether you selected **Positive** or **Negative**) value during that interval is used for the placement of the trigger.

Insert Event at Triggers. Enable the option if you want to insert event marks at the trigger points. Enter the type code to be inserted in the **Event Code** field.

Bipolar Trigger channel derivation. In some situations you may want to create a derived *bipolar* trigger channel that displays the blinks more clearly and permits more accurate peak detection. Enable the option, and select a channel to be used for the reference. The reference channel will then be subtracted from the trigger channel.

High Pass Filtering. This option lets you apply a high pass filter to the artifact channel. This can be helpful if you are having difficulty setting the Threshold due to increased slow activity. Enable the option, enter a filter value, and frequencies below that value will be attenuated.

External. With the External option, an artifact sweep is initiated when a selected stimulus type code is received. Enable the option, and enter a desired type code. The event may come from STIM or from another external device that sends TTL pulses.

Interval. The interval is the section before and after the point at which the Threshold is met. This should be long enough to encompass a stable, consistently appearing section of the artifact. It is not necessary to capture the entire artifact. For blinks, you want to capture the section from the peak (point where the threshold is met), or maybe a little before it, through the section after the blink. You do not want the duration (the Stop time) to be so short that you get a second trigger within the same blink. At the same time, if you make the duration too long, you will be including more variability in the average, which could reduce the transmission coefficients, and thereby reduce the effectiveness of the reduction. You should experiment a little with **Start** and **Stop** times to get the best settings for your data. Settings of approximately -100 (Start) to 300ms (Stop) should be close.

The **Averages** field determines how many artifact intervals are collected before the correction process begins.

Artifact Rejection. The Artifact Rejection criteria are used to monitor voltages in the designated Artifact Rejection channels. When enabled, artifact detected by the Threshold criteria is NOT included in the average blink artifact if the Min or Max criterion is exceeded within the interval specified for the trigger. This prevents artifacts in the designated artifact rejection channels from being included in the averaged blink artifact.

Care

If the artifact is present with nearly equal amplitudes in the designated artifact rejection channels, you should use caution when enabling the Artifact Rejection criteria. Blink artifacts in these channels could result in the rejection of perfectly acceptable sweeps.

Output file. Click the Browse button to access the standard Save As utility window to save the CNT file.

3.4 Using Blink Reduction - Offline

With blinks, ideally, you should record a long enough section at the beginning of the CNT file to create the averaged artifact. If, however, you don't have that blink section, you can append the CNT file to a copy of itself, if necessary, then use part of the first half of the created to compute the average artifact, and the correction will be applied throughout the rest of the file (original and copy). Then retrieve the corrected CNT file, and use **Mark Block → Save Block** to save only the last half of the file (from the SS event on). Or, you can reject the blocks containing the initial uncorrected blinks using **Mark Block → Reject Block**, or you reject those sweeps from the epoched file.

In the example below, we used a 250μV threshold, from -100 to 300ms, with 5 sweeps averaged. The blink reduction routine did a good job of removing the blinks. Artifact Rejection was set for +/-250μVs.
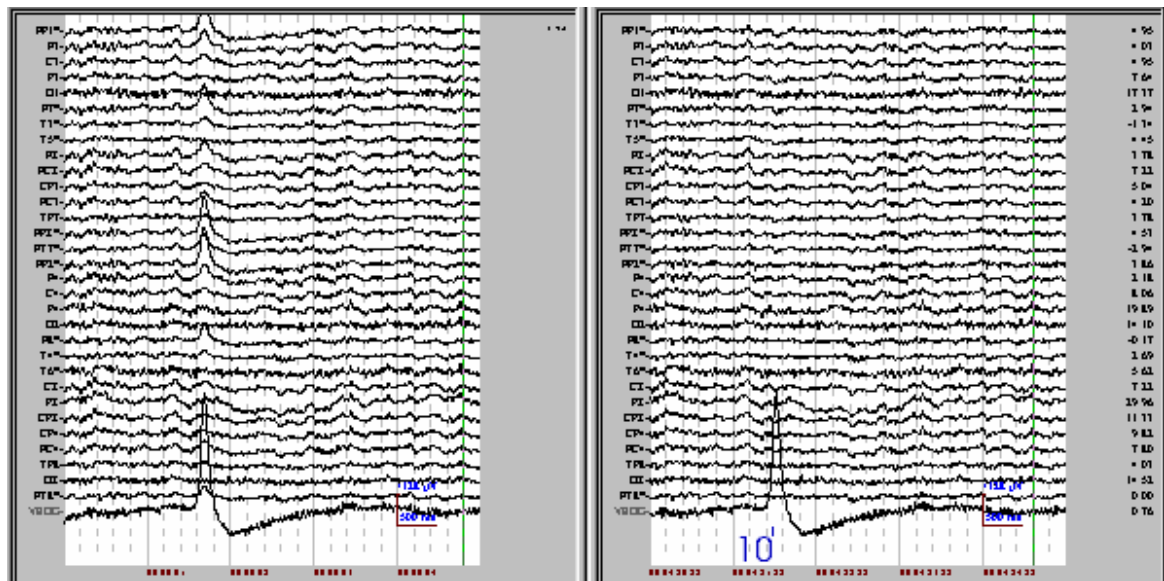
Does this routine work better than the Ocular Artifact Reduction (OAR) transform? We analyzed the same original file using the OAR transform, and used the Voltage Threshold transform to insert events at the 250μV point (from the VEOG channel). This allowed us to compare the averaged blink results between methods.
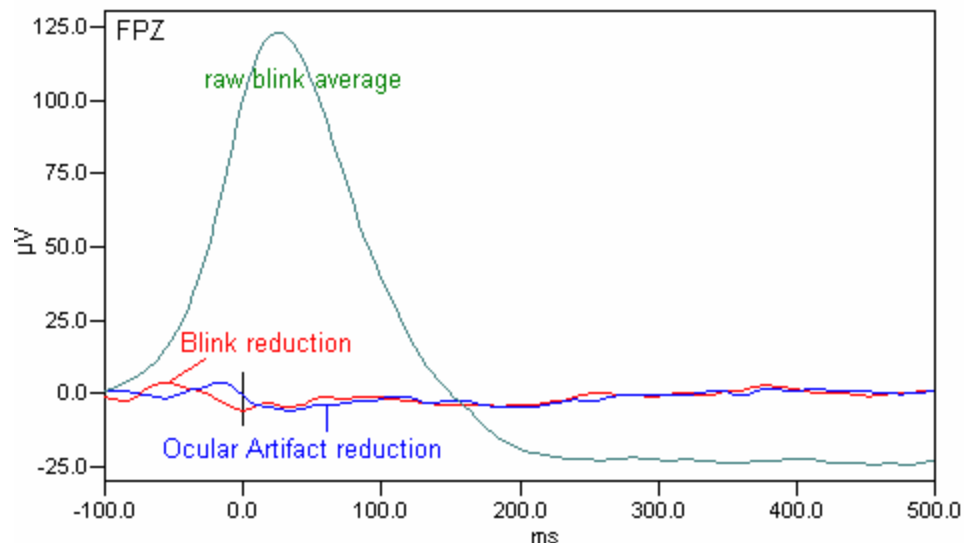
The results (from FPZ) show very little difference between methods, as expected, and both methods were very effective in removing the blinks. This may or may not be representative of any file. OAR uses all blinks in the file to create the average, and it allows you to review the Maximum voltage as well as all individual blinks. That may be advantageous in some circumstances. OAR also creates an LDR file that can be used in other files from the same subject (assuming the blink artifact is the same). There is another blink reduction method that uses Singular Value Decomposition and a Spatial Filter (see those sections below). We have found all methods to be fairly comparable, but we encourage you to try different methods and determine which works best with your data files.

3.5 Blink Noise Reduction Batch Command

The BLINKNOISEREDUCTION command provides a method for removing blinks that is the same as the online Blink Reduction correction. See also the ARTCOR command for an alternate (but similar) way to remove blink artifact.

1	string	Output file
2	double	Epoch start time (ms)
3	double	Epoch stop time (ms)
4	integer	Number of averages
5	Boolean	Use external trigger
6	double	Voltage threshold (μVs; ignored if #5 is true)
7	defined value	Trigger direction (Positive, Negative; ignored if #5 is true)
8	string	Artifact channel label (REQUIRED even if #5 is true)
9	int	Trigger code (ignored if #5 is false)
10	Boolean	Enable artifact rejection
11	double	Artifact min (μV)
12	double	Artifact max (μV)
13	Boolean	Insert events
14	int	Event code
15	Boolean	Enable bipolar reference
16	string	Bipolar reference channel label
17	Boolean	Enable high pass filter
18	double	High pass filter value

Example. BLINKNOISEREDUCTION "c:\\Scan Data\\Demo Files\\corrected file.cnt" -50 300 15 N 250 P "VEOG" X Y -100 100 Y 100 N "" N x. The output file is specified. The interval start and stop times create sweeps around the triggers from the VEOG channel where the positive voltage meets the 250μV criterion. Artifact Rejection is enabled, using +/- 100μV thresholds. Events with type codes of 100 are placed at the trigger points. The bipolar reference and high pass filter options are not enabled.

4 Export to MS Excel

This option is used to open the Excel program, and export data files directly to it. For the file transfer function to operate, you must have 1) Excel installed, and 2) a license for the Toolbox. To transfer a CNT or AVG file, open the file, *right click* between electrode displays, and then select the **Export Data To** option.

MS Excel	▶	Export Data To...

You will then see the data in Excel, with a column for each electrode.

Then you can, for example, click the lettered column header to highlight an entire column. Select **Insert**, then **Chart**. Select **line** (without dots on it) as a chart type, and click **Next** twice. Now switch to the Axes tab, and disable **Category (X) axis**. Click **Next** and then **Finish**. You will see the data displayed as a waveform in Excel.
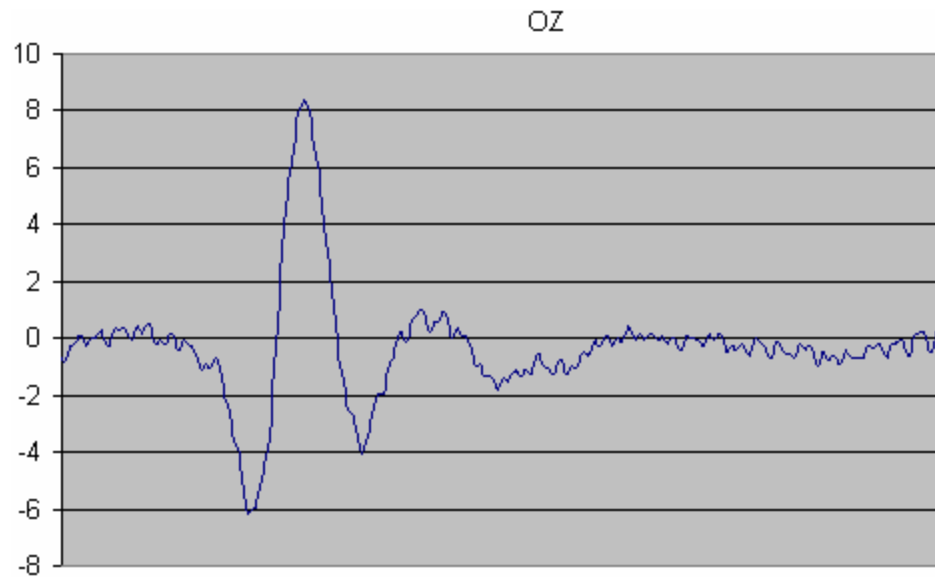
You might then, for example, want to invert the polarity of the file waveform. *Right click* on the text for the y-axis (a Tooltip will display **Value Axis**). Select **Format Axis**, then the **Scale** tab. Enable the **Values in reverse order** option, and click OK. The waveform will be inverted.

Use the full range of options in Excel with the data file. Note that you should not completely close and then reopen Excel in the same session. If you are sending multiple files, leave Excel open while doing so (a limitation of OCX technology).

5   Interface with MATLAB

If the MATLAB software package is installed on your computer, SCAN allows you to export data to MATLAB and import them back to EDIT. You should use MATLAB 6; MATLAB 5 will work, but some of the functionality related to the graphics windows is not supported. Note that trigger information is *not* exported along with the EEG data in the CNT files. The basic steps are as follows:

1. Load, for example, the *Closed.cnt* file in EDIT.

2. From the popup-menu, select the **MATLAB → Export Data To** menu item.
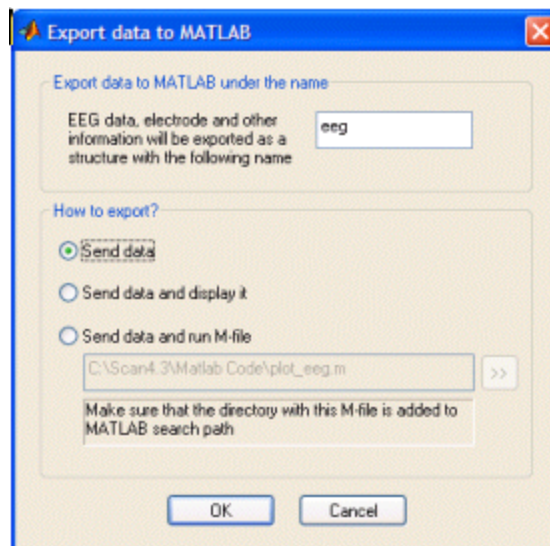

3. If you have not already activated MATLAB within EDIT, the displayed message appears.
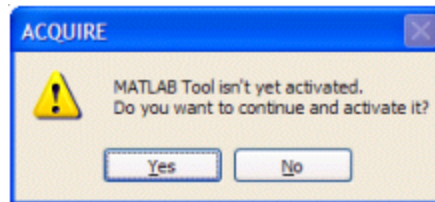
4. Press Yes to activate it. Because MATLAB consists of many modules, it may take several seconds to activate. Typically, it takes 10-15 seconds, and during that loading EDIT warns:
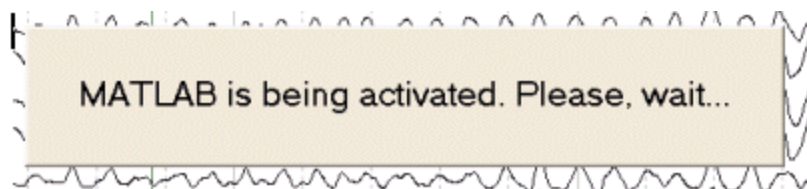
5. After loading, the following dialog screen appears:

Two types of data will be exported to MATLAB:
- Description structure: its default name is "eeg". You can change this name through the dialog box.
- Matrix with EEG data: with the name "eeg_data". You cannot change the name.

EDIT allows three methods of operation:
- Simply send data.
- Send and display them as a "butterfly" plot.
- Send and run M-file to perform some calculations and/or customize the display.

6. For now, use the default setting **Send data** and press the OK button. Then click "MATLAB command window" at the Windows taskbar (because MATLAB is activated as a separate application, it shows its own button on the taskbar). Type the command **whos** and you will see the following information:
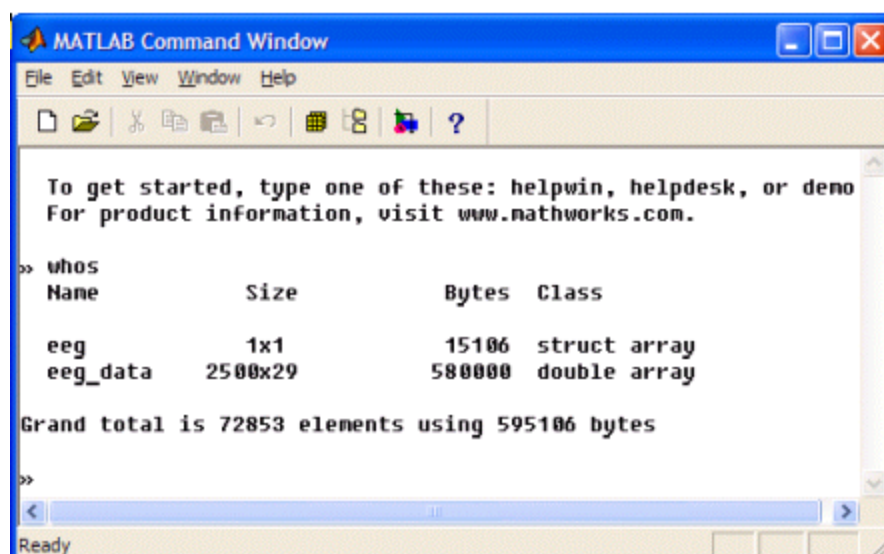
7. It shows that you have structure **eeg** and matrix **eeg_data**. Type **eeg** and

MATLAB will show you contents of the structure:

It includes the name of the file, type (EEG for continuous recording from CNT files and EP for averaged and epoched files), vertical scale in EDIT (usually in μV), and another structure that describes the electrodes. Type **eeg.elec(1)** to see information about the electrodes. SCAN sends only electrode names and positions as set in the Channel Layout dialog.

```
>> eeg
eeg =
      path:     'Closed.cnt'
      type:     'EEG'
    vscale:     128
      elec:     [1x29 struct]
```

8. Before we continue, you need to configure the MATLAB software as described in the "Export data to MATLAB" dialog:

Make sure that the directory with this M-file is added to MATLAB search path.

To accomplish that step, select from the "MATLAB Command window" menu "File → Set Path…". Then click on the "Add Folder…" button, navigate to the SCAN installation directory (usually *C:\Program Files\Neuroscan\SCAN4.x*), and select the subfolder "MATLAB Code". Click OK and then Save.

9. Now return to EDIT, again select "Export Data to…", but this time select "Send data and run M-file" option. If you did everything correctly in the previous step, MATLAB will produce the following display:
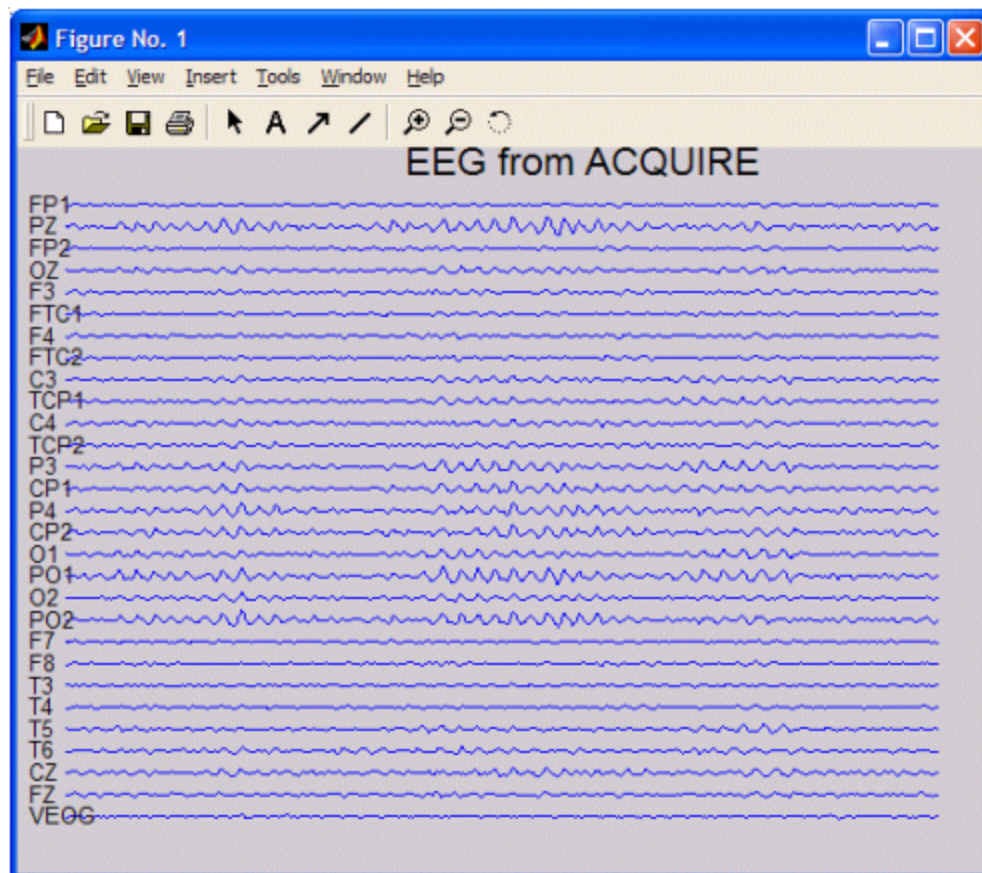
It shows the electrode names and waveforms.

10. Now we will perform a simple EEG data manipulation. Enter the following commands in the MATLAB command window:

```
>> eeg_data(:,3)=0;
>> t=(0:2499)/500;
>> eeg_data(:,4)=100*sin(2*pi*10*t');
>> plot_eeg(eeg_data,eeg);
```

The first line nullifies the signal for the third channel, the following line creates a vector with time information (500 is equal to the sampling rate, and 2499 comes from the fact that we loaded 5 seconds of data 5x500=2500. If you loaded a different file, you will need to make the necessary changes in this code). The third line of this code assigns 10Hz, 100µV signal to fourth channel. The final line of code replots the data as shown in the following display:
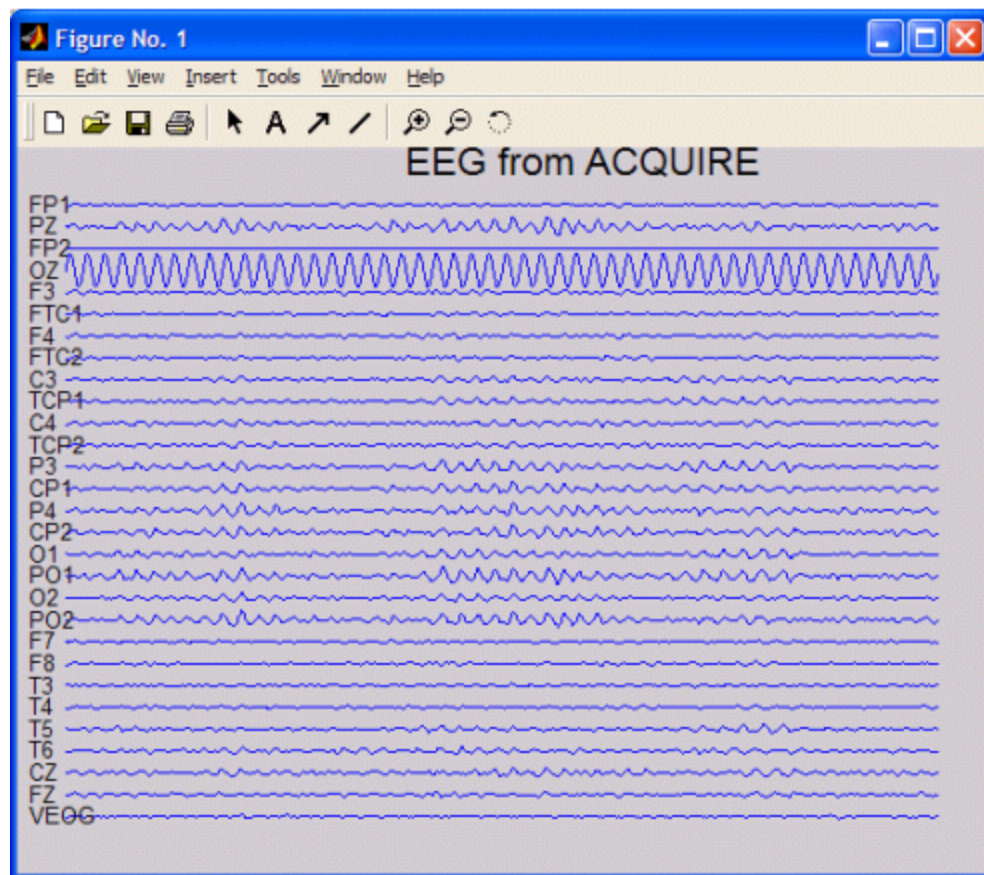
11. Next, we will import that data back into EDIT. Select the **Import Data From...** option from the pop-up menu in EDIT.
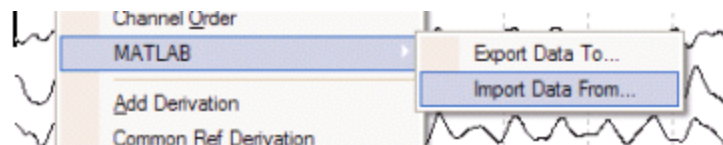
12. In the following display, uncheck **Update data in file as well** (otherwise the data will be changed in the CNT file), and click the OK button.
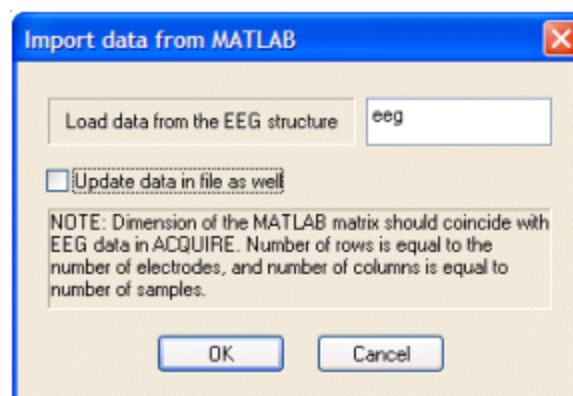
13. The EDIT screen will be updated accordingly.

14. Now load the *vep.avg* file and export it to MATLAB in a similar fashion. Select **Send data and display it**. The Butterfly plot will appear.
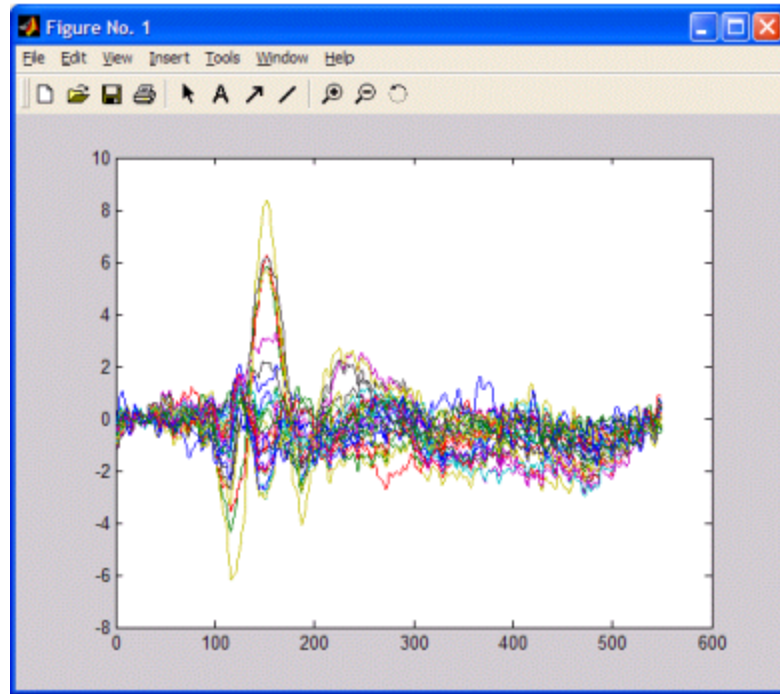
15. Return to EDIT and export the data again, but this time select the **Send data and run M-file** option. The Topographic plot will appear:

16. Now modify the data as we did in step 10, and import the data back into EDIT. For AVG and EEG files, the option to **Update data in file as well** is hidden.

17. In the MATLAB command window, select "File → Open...". Navigate to the "MATLAB code" folder installed by SCAN, and open the file **plot_eeg.m**. From this file you can see how the EEG and EP data are plotted.

Further suggestions:

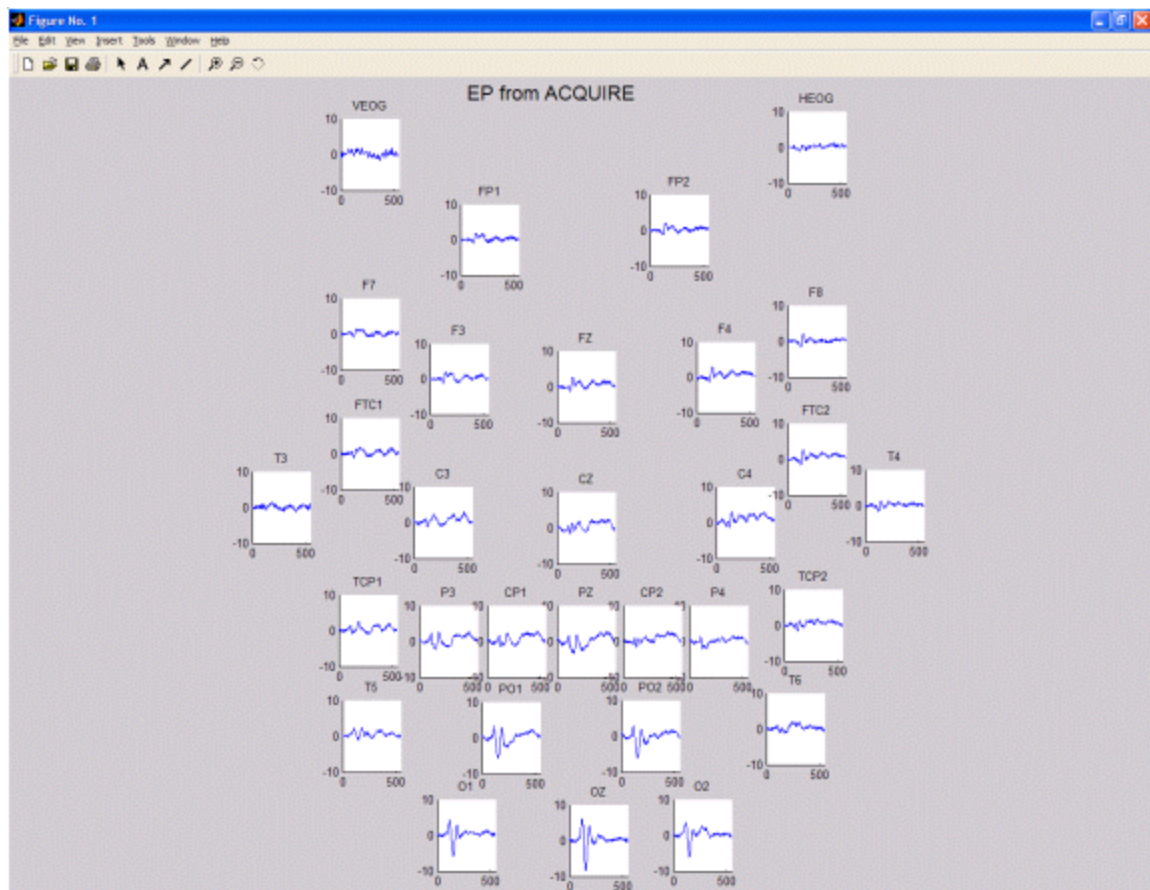1. Activate MATLAB the first time by selecting **Tools → MATLAB...**. The warning displayed in step 4 will appear.

2. This activation of MATLAB needs to be performed once each time you start EDIT.

3. While working with MATLAB from within EDIT, do not close the "MATLAB command window". EDIT will close it automatically after you exit. If you close the MATLAB command window, then any attempt to export/import data warns:
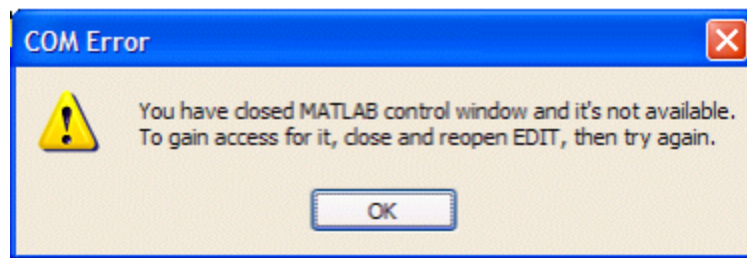
Perform the steps described above again to reactivate MATLAB. There is no way to reactivate MATLAB until you close and reopen EDIT.

6   PCA/ICA

Introduction to PCA/ICA

Principle Component Analysis (PCA) and Independent Component Analysis (ICA) are statistical techniques akin to factor analysis that are used to (1) to reduce the number of variables and (2) to detect structure in the relationships among variables.

PCA generates patterns and loadings that are orthogonal to each other. After the first factor is extracted (by fitting a regression line to a scatter plot), the second factor is extracted from the remaining variability, and so on until there is essentially no variance left. The resulting components are orthogonal to, or uncorrelated with each other (first order decorrelation). It has been argued that PCA may not be the most appropriate method for use with physiological data.

ICA generates patterns and loadings using a stricter criteria for statistical independence (requires that all second order and higher correlations are zero). The generality of ICA lies in the simple principle that different physical processes tend to generate statistically independent signals. Given that scalp-recorded EEG is the summation of signals from multiple sources, ICA computes individual signals that are statistically independent, and which are therefore likely to have been generated by different physiological processes. ICA has been asserted by some to be the preferred method for use with physiological signals. Some advantages with ICA and a further discussion of the differences between ICA and PCA are found in the Using Filtering in PCA/ICA section below.

It is beyond the intent of this manual to present a thorough discussion of PCA and ICA analyses, and the justifications, rationales, and advantages of each. Instead, we urge you to consult the increasing number of original research articles in which PCA and especially ICA are the subject.

6.1   Operating PCA/ICA

Online and offline. The PCA/ICA program can be used during online acquisition in ACQUIRE and in offline analysis in EDIT. The functioning is essentially the same, although there is one restriction during the online calculations: the Filter option is not available during acquisition.

Load 3DD electrode positions. Once you have the PCA/ICA program installed, you will see a new icon on the Toolbar . The PCA/ICA program requires 3D electrode positions. It is always preferable to use the actual electrode position data. If you have the 3DD file from 3DSpaceDx that was measured from the particular subject, simply retrieve the data file, and *right click* between the electrode displays. Select the **Load 3D Electrode positions** option.
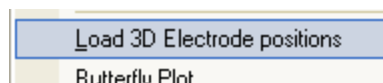
This will display the Open File utility, from which you may select the appropriate 3DD file. Now when you click the PCA/ICA icon, the program will open immediately. If the 3DD electrode positions have not been merged into the data file, you will see the following message after you retrieve your data file and click the icon.
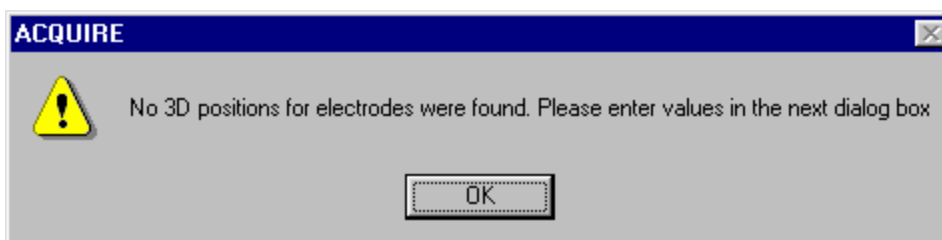
Click OK, and the "radar" display will appear, with no electrode positions. Click the

Match Labels button to place the electrodes automatically according to the 10-20 system. This step presupposes that the electrode labels you have used are standard 10-20 system labels. If not, you will need to relabel them accordingly. You must have either the 3DD file or standard electrode labels to use the PCA/ICA program.

In the steps below, we are using the *EpiSpike.avg* demo file found in the *\ScanData\Demo Files\EEG Spikes* folder. This is a single epileptic spike (filtered). Retrieve the file. Select an electrode display (T7) and enlarge it to mid-size.

The 3DD file is included in the same folder. If you have not already loaded the 3DD file with the data file, *right click* between the electrode displays, select the **Load 3D**

Electrode positions options, and select the *EpiSpike.3dd* file. Then click the icon.

If you have already loaded the 3DD file, then just click the icon.

You will see two vertical lines appear in the electrode display.

In the PCA/ICA window, the column on the left with the contours is referred to as the patterns column. On the right is the loadings column.

Use the mouse to position the vertical cursors in the waveform display to select an interval of interest (-20 to 400ms). You can also position the cursors using the arrow keys from the keyboard. The left and right arrows alone will move the left cursor one data point at a time. Using the *Shift+arrow* key combination will move the right cursor. The *Ctrl+arrow* combination will move both cursors together, maintaining the width between them.
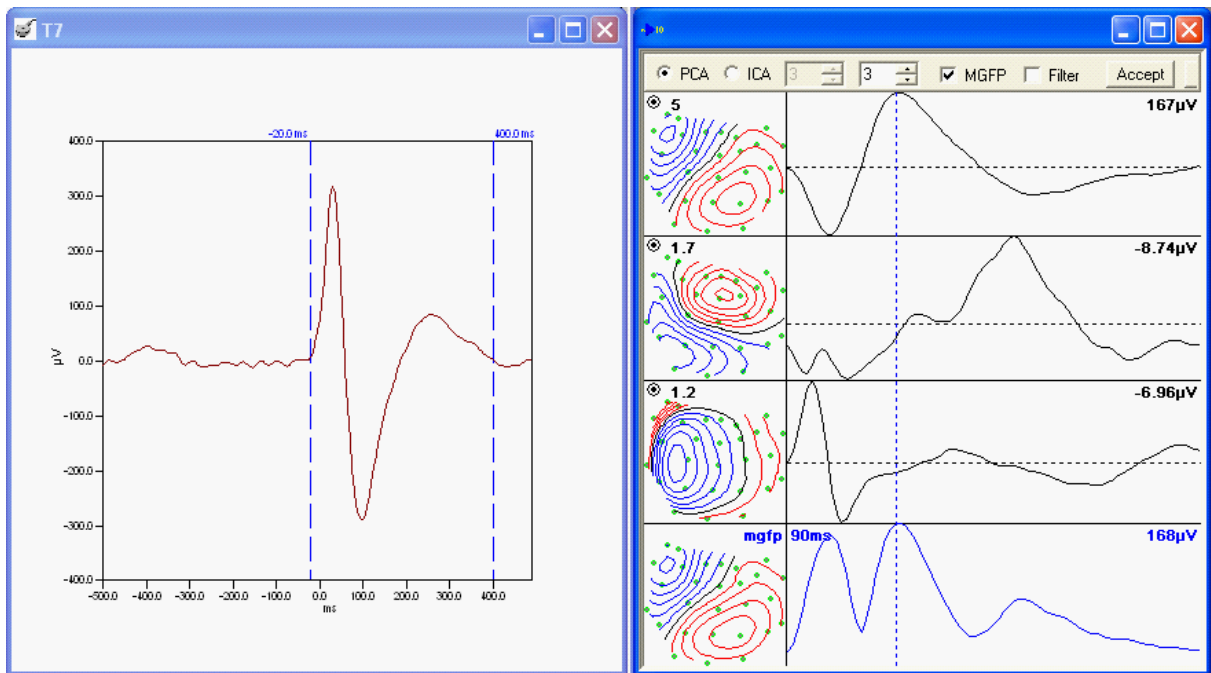
You will see the loadings in the PCA/ICA display. The components may appear inverted at times. In fact, the valence is arbitrary and not relevant. The PCA/ICA program takes whatever loading is largest, and makes it positive for the display. The pattern contours are correct regardless of whether the loadings are positive or negative.

Enable the Mean Global Field Power display (MGFP). This is a composite variance measure across all channels. Peaks in it generally denote potential dipoles. Note that you can move a vertical cursor with the PCA/ICA display, and see the MGFP distribution for each time point.

Select to display 3 loadings, if needed. In fact, up to 10 patterns are available for display (rarely are more than 5-7 patterns significant). There cannot be more patterns than the number of electrodes or time points.

Now let's look at the display in more detail.

> **Option selection fields**. The following options are accessed from the command bar at the top of the display.

a. Click this field to display the patterns and loadings from the PCA analyses.

b. Click this field to display the patterns and loadings from the ICA analyses.

c. This field is active only when you select ICA, and it is used to select the number of ICA loadings to be computed and displayed. In the example below, note that 3 loadings are displayed, and that 2 of them are ICA components. The 3rd (and all additional ones not displayed) is a PCA component. The ICA loadings will always be

indicated by "ICA" in the pattern display area.
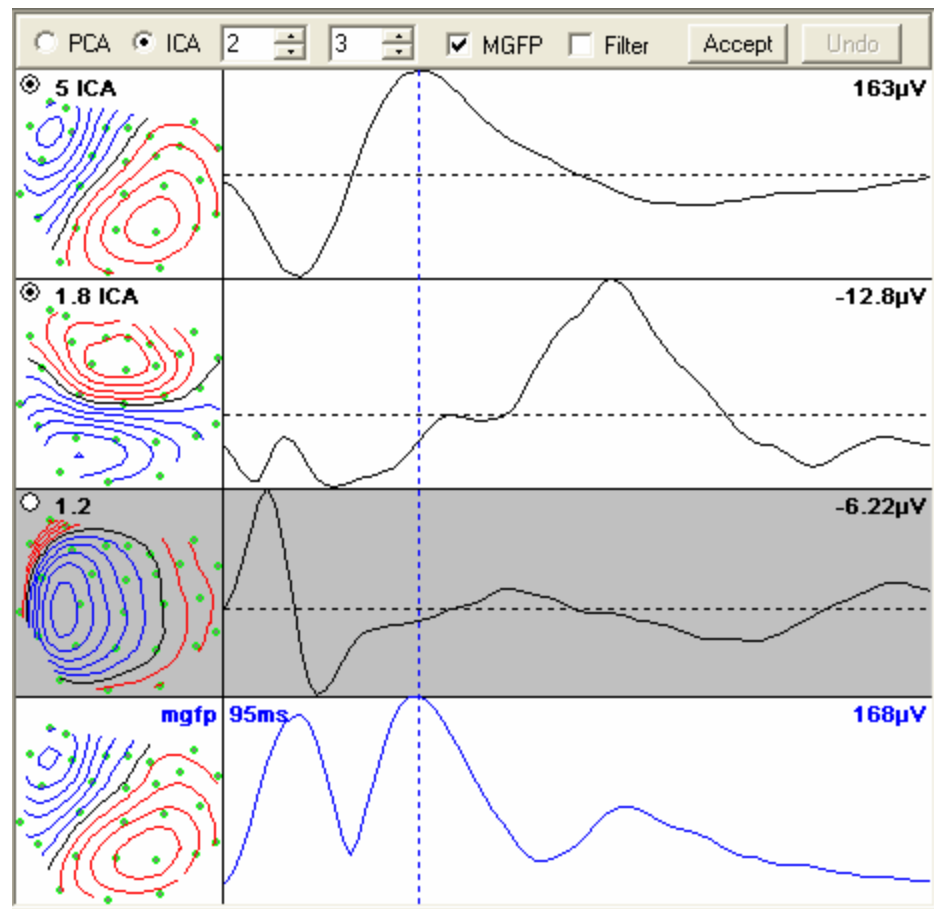
d. This field is used to select the number of loadings to be displayed (all PCA loadings are calculated, and up to the first 10 can be displayed). Loadings beyond the 10th one are assumed to be statistical noise, and are disregarded.

e. This field is used to display the Mean Global Field Power waveform at the bottom of the display. This is a composite waveform based on all EEG channels, and is useful for determining where the power peaks occur. The cursor position (the dashed vertical line) is shown in ms's (to the right of the MGFP label). Use the left and right arrow keys to move the cursor from the keyboard (hold either key down to see the contour pattern change throughout the selected interval).
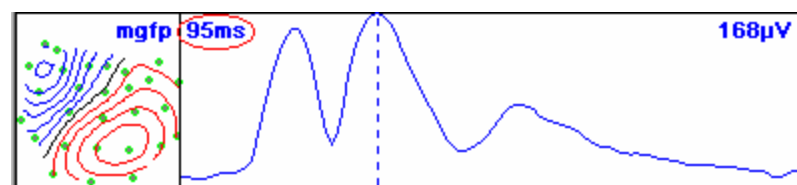
f., g., and h. The ☑ Filter toggle and Accept button are used in conjunction with selecting components to remove/retain them in the selected interval in the waveforms. Click the Undo to undo the filtering. Use of these features is

described in more detail in the Using Filtering in PCA/ICA section below.

Display features. The following information is displayed in the patterns and loadings fields.
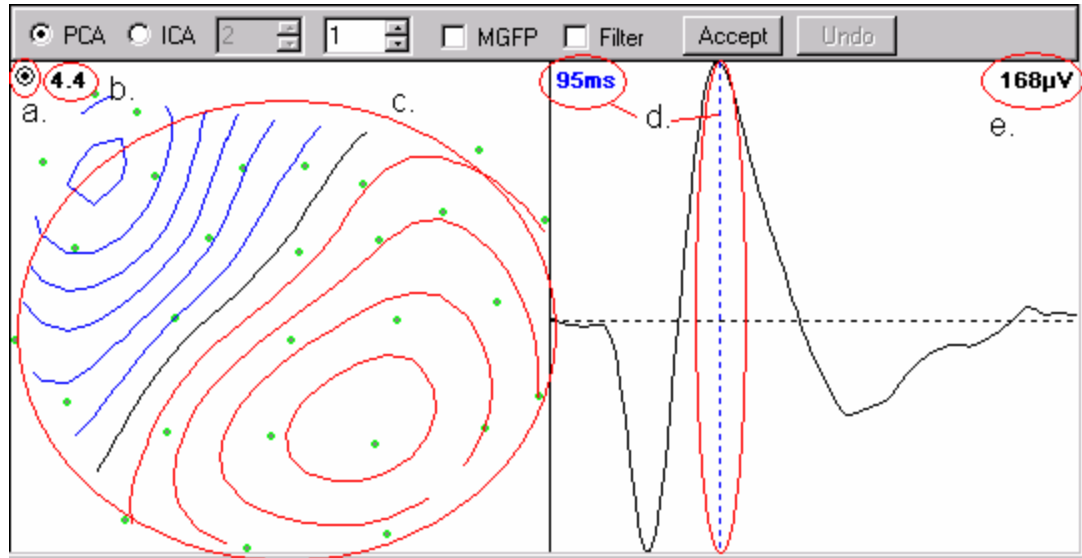
a. The radio buttons are used to select or deselect the corresponding pattern/loading. These and other options can also accessed by clicking the *right mouse* button within the PCA/ICA display.

You may select/deselect each pattern, or you can select or deselect all patterns. (With PCA, if you deselect a component, all trailing components will be deselected automatically). Note that if you Deselect All Patterns, all 10 patterns will be deselected. If you have, for example, 5 patterns displayed, and you manually deselect them, the remaining 5 patterns may still be selected (and you will see activity in the Filtered MGFP display). If all 10 patterns are deselected, you will see nothing in the Filtered MGFP display. It is a good idea to display all 10 components to be sure you are including only the ones you want (especially when using ICA).

The remaining options on the list are as follows. You have the option of displaying the SNR values (default) or the variance percentages in the patterns fields. The results can be saved to either a .pca or .ica file, depending on which analysis was selected. This is a text file that contains the number of electrodes, the numbers of

samples in the selected interval, the XYZ coordinates of the electrode positions, the number of selected patterns, the number of weights, the number of normalized patterns and the number of normalized loadings. The display can be copied to the Windows Clipboard, saved as a BMP or EMF file, or Printed.

b. This number is either the SNR value (signal-to-noise ratio), or the percentage of explained variance. *Right click* in the display and select or deselect **Show SNR values** to display one or the other. Generally, patterns with SNR's greater than 1.0 are the potentially valid ones. Deselect Show SNR values to see the percent of variance explained.

c. The contour pattern shows the distribution of the loading. Blue contour lines show the negative values distribution; red contours show the positive values distribution. Each loading will have its own distribution. The contour line distance is autoscaled. You can change the number of contour lines using the Up and Down arrows on the keyboard, or with the mouse wheel.

d. The vertical cursor is used in association with the MGFP display, and may be "grabbed" and repositioned with the mouse, it may be repositioned by simply clicking at the point where you wish it to be positioned, or use the left and right arrow keys on the keyboard to move it. (The contour pattern for the MGFP display will change with each new position). The ms indicator is shown on the lowest component displayed, or with the MGFP display if MGFP is selected.

e. The pattern amplitude (in μVs) is displayed. Move the cursor to measure different time points.

6.2   PCA versus ICA Loadings

As you use PCA and ICA, you will notice several differences between their operations. When you select PCA and set an interval in the data waveforms, all loadings are computed (there cannot be more loadings than there are electrodes or data points), and your only choice is how many to display (up to 10). Rarely do more than about 5-7 loadings, at most, represent anything other than noise, and these later ones can be disregarded.

When you select ICA, the program attempts to determine a transformation for the subspace of the PCA results (in a mathematical sense, or, in other words, the number of components you select), such that the components are as independent from each other as possible. If you could select only one ICA component, there is nothing for ICA to do, so the result is the same as the first PCA loading. Therefore, you do not have the option to select only one ICA component - you must select at least two.

The question arises: how do you know how many loadings to compute? As a general rule, you should use PCA to determine the number of components. If the SNR value is greater than 1.0, the components are potentially valid (1.0 is the noise level). The program will impose this automatically. For example, if there are 3 PCA patterns with SNRs greater than 1.0, ICA will be set automatically to 3 components. (You can manually change the number of ICA components to a larger number, although this is not recommended in general use).

In this example, the PCA results showed three patterns with SNRs >1.0, and we therefore perform the ICA analyses with 3 components.
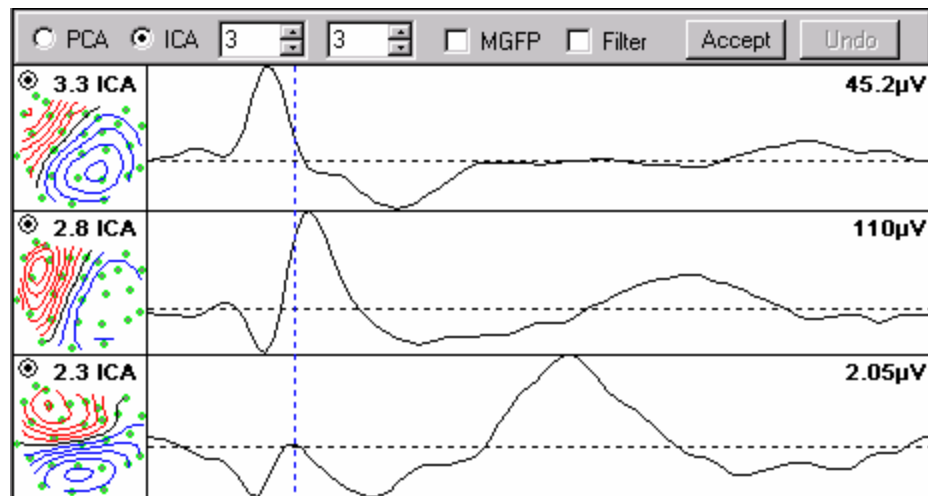
The next section describes how to filter the loadings selectively, and how to see the effects of filtering one or more of them out of the waveform data.

6.3   Using Filtering in PCA/ICA

One of the fundamental applications of the PCA and especially ICA techniques involves the removal and retention of the various components that are computed from your original EEG waveform data. The Filter option, along with Selecting/Deselecting Patterns, and the [Accept] and [Undo] buttons are used in this process. Filtering is possible in the EDIT program only, not during online acquisition in ACQUIRE.

There are some initial considerations to bear in mind when deciding whether to apply filtering based on PCA versus ICA analyses. With PCA, since the extracted field patterns are orthogonal to each other, it is generally not appropriate to remove the leading or distinct non-noise components because this will have no effect on the trailing components. It is appropriate, however, to remove the trailing noise components. In fact, you will find that the program does not let you selectively filter leading PCA components. Whenever you deselect a PCA component, all trailing components are also deselected.
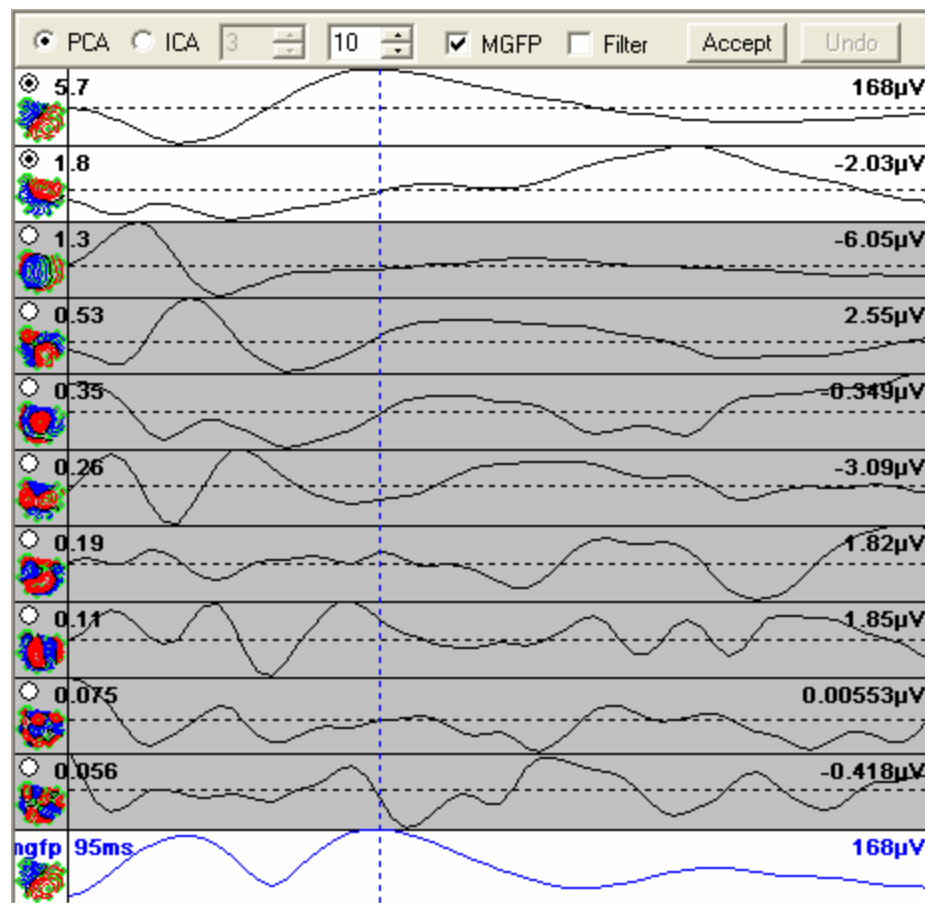
With ICA, the extracted field patterns are not orthogonal and may overlap. You may therefore extract artifact or distinct noise patterns from their temporal independence. In this case, it is appropriate to filter the data by omitting selected patterns.

To elaborate further on this point, PCA is a unique decomposition of the data without any additional parameters other than the time range and the number of sensors. It gives you MIN (NumSamples, NumSensors) components (= field patterns, sorted by their mean amplitude / field strength), and their corresponding loadings (time courses). All patterns are orthogonal to each other (scalar product = 0: no overlap), and all loadings are orthogonal to each other (scalar product = 0: no overlap). Thus, in a mathematical sense, the PCA gives you a unique basis of the data space.

If one has an estimate of the noise in the data, one can omit all trailing patterns that have an amplitude smaller than this noise level. The remaining leading components make up new filtered data. The number of the leading components gives a hint for the number of spatially fixed dipole configurations that are responsible for the signals in the analyzed data range (since spatially fixed dipole configurations lead to fixed field patterns = components). The simplest approach of a fixed dipole configuration is a single fixed dipole; however, the dipoles would not necessarily produce orthogonal field patterns (only in very rare cases like SEPs: tangential N20, radial P23). The PCA patterns, however, span the whole data space since they form a (orthogonal) basis, which means that the dipole patterns are linear combinations of PCA patterns having overlap to these PCA patterns

(scalar product = 0).

From this you can see that, with PCA, one must not filter any non-trailing signal components, since otherwise one would damage (skip) the projections of the dipole patterns to these components. If one would filter the data in this way, one would have to remove the PCA pattern from the computed leadfield of the dipoles as well. This is called projection of the patterns from the data and the leadfield. Only the trailing noise components can be filtered without leadfield projection, since they are assumed to be orthogonal to the remaining signal space. The main information from the PCA is thus the number of relevant components in the analyzed time range!

The ICA implementation uses this information (number of relevant components in the data time range) for speeding up the otherwise slow computation of the ICA decomposition. The number of ICA components is adjusted manually in the PCA/ICA program. If you could select "1" ICA pattern, nothing would happen as compared to the PCA, since one ICA component cannot be independent (independent to what?). An ICA with one component is the same as the PCA first component. Therefore, the program will not allow you to compute a single ICA component; you must select a minimum of two ICA components. With more than one ICA component, one decomposes the data into a signal space (selected ICA components) and a noise space (remaining PCA components). With ICA, you can extract artifact or distinct noise patterns from their temporal independence, and it is appropriate to filter the data by omitting selected patterns.

The number of ICA components is NOT a "free" parameter. It has to be determined from the noise properties of the data in the analyzed time range. If the data are composed of independent enough components, the ICA can separate these. These sources in general have overlapping field patterns, and ICA thus gives a non-orthogonal basis of the data space. In this situation, filtering (rejection) of artifact components is possible by synthesizing the data without projection of these components from the leadfield, since the source patterns survive in the remaining components (there is no projection of the artifact patterns from the data).

It is also true that filtering the first x PCA loadings from the data file will create a file that is identical to the file created by filtering the first x ICA loadings (using the same original data file and interval). Even though the selected PCA SNRs, contour patterns, loadings, and loading amplitudes are different from the ICA ones, you will obtain the identical effects when you filter all but the selected loadings. Consider:
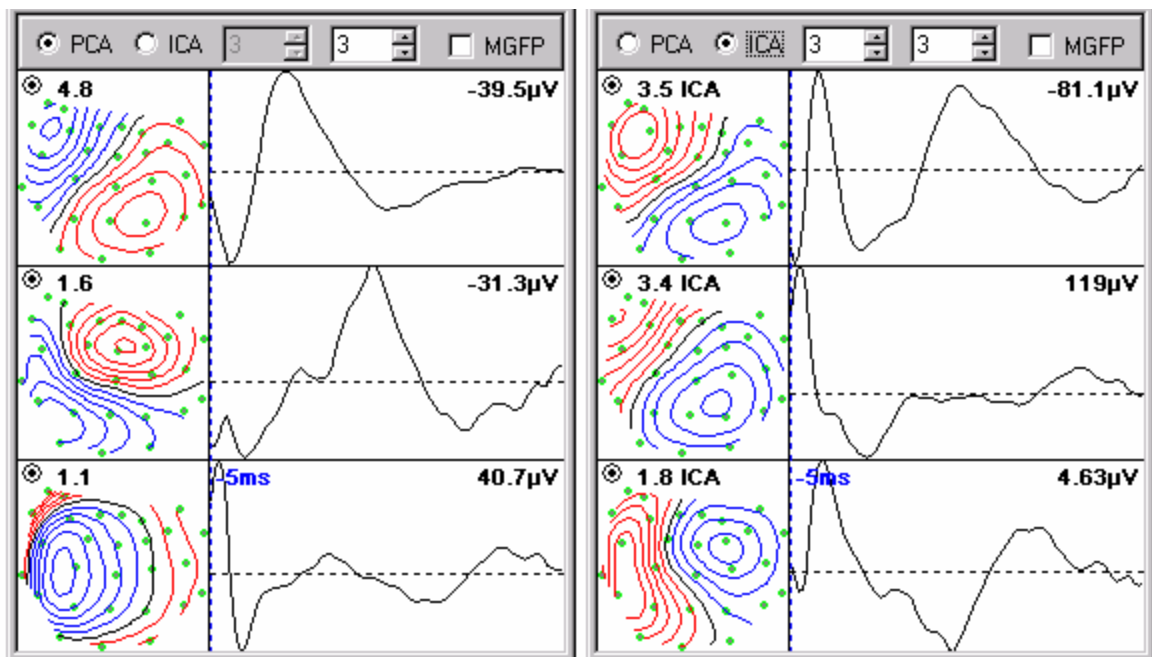
The contours, SNRs, loadings, etc. are fairly different for PCA and ICA. Yet if you filter all but these three loadings from the data files, the resulting waveforms will be identical between files. Why is that? Think of signal subspace and noise subspace. The deselected components (all of them are PCA components in this example) comprise the noise subspace. Therefore, the noise subspace is the same in both cases. The noise subspace plus the signal subspace equals the total subspace, which is the same for both files. Therefore, the signal subspace must be equal for both PCA and ICA loadings. The "size" of the signal subspace is the same; it is merely subdivided into components differently using PCA versus ICA. When the noise subspace is removed from the waveforms, you must be left with the same signal subspace, and therefore the output files will be identical.

This leads to the advantage inherent with ICA. That is, with ICA you may select leading and trailing components independently. With ICA, you may, for example, deselect components as shown.
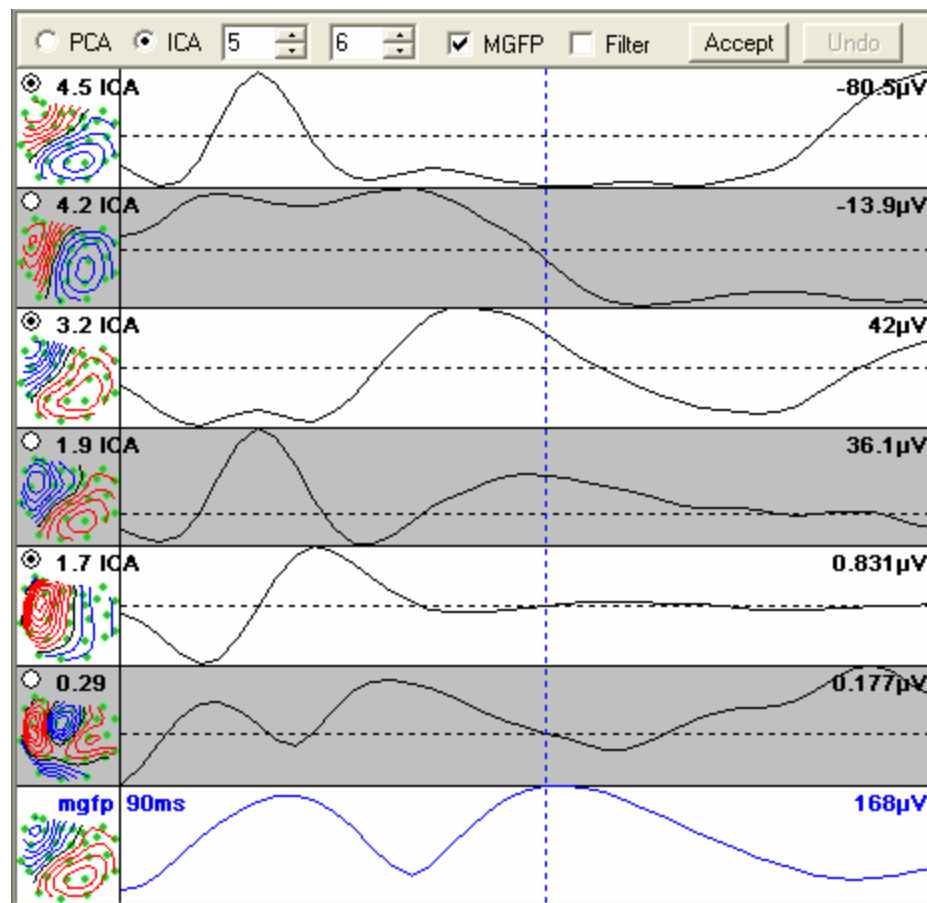
You cannot do that with PCA - all trailing components are always deselected. In this case, the filtered data file with selected ICA components will be different from the PCA filtered data file. That is the advantage with ICA. This will be demonstrated below in an example where the first loading is an artifact that we wish to remove in order to obtain more accurate source localization of the remaining P300 component.

As mentioned above, all PCA loadings are computed, even though only the first 10 can be displayed. The default selection of all components after 10 is "deselected", and they are never displayed nor retained in the filtered data (they are assumed to be noise, and are disregarded). The important point to understand is that, when selecting and deselecting loadings, you should display all 10 of them to be sure you are including/excluding the ones you want.

The key to understanding Filtering is: loadings in gray (deselected) will be removed; loadings in white (selected) will be retained. In other words, you are filtering the data to RETAIN the SELECTED loadings, and REMOVE the DESELECTED loadings.

6.4   Using PCA/ICA in Source Analysis

The components used in dipole source analyses, like all scalp recorded EEG, are potentially influenced by various background or artifactual activities. If these distorting influences can be removed prior to the source analyses, then the dipole

localizations should be more accurate. ICA will allow you to select components to retain and to remove any other ones. PCA is used primarily to help determine how many components are valid ones. There are no absolute rules regarding the process to follow; it is part art and part science, with occasional trial and error.

Example 1. In this example we will demonstrate the basic analysis process we recommend. We wish to determine the most accurate dipole source localization for an epileptic spike. Retrieve the *EpiSpike.avg* file, set the interval for the entire sweep range, and display all 10 PCA loadings. Display the MGFP and filtered MGFP results.
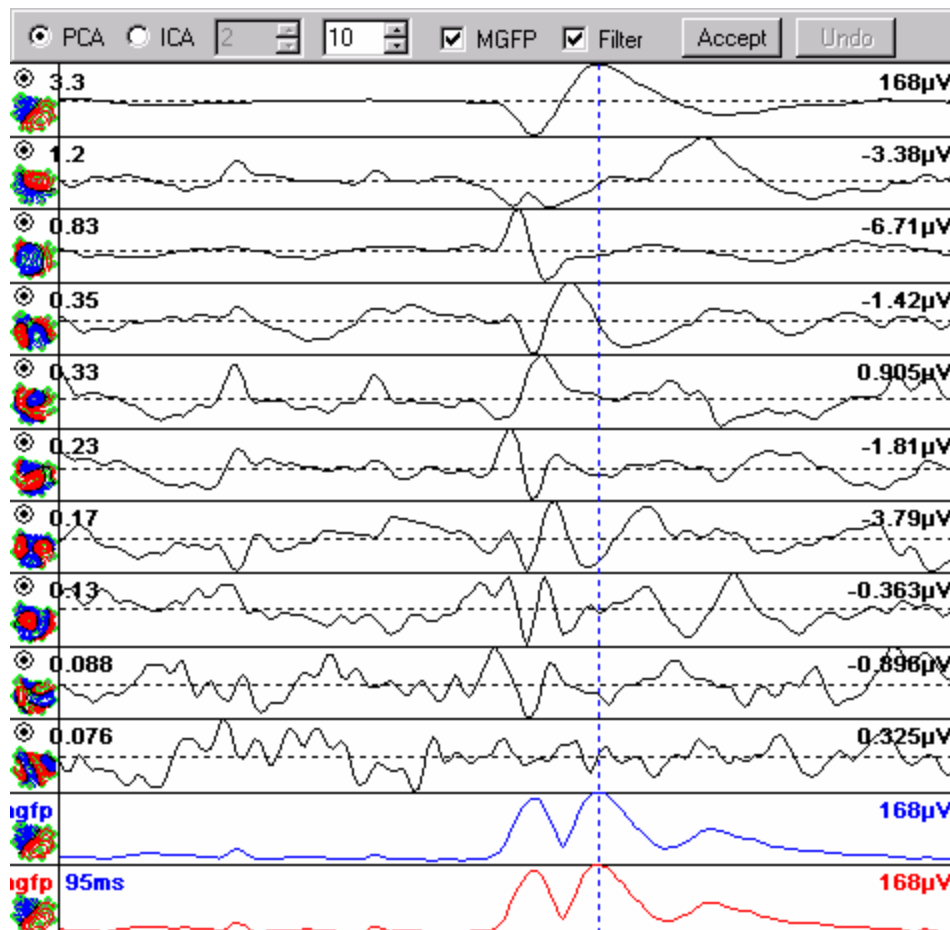

Looking at the relative field strengths, we see that there are 2 valid components (where the SNR > 1.0).

Switch to ICA, compute as many components as possible (10). Select ALL components, and note that the MGFP and filtered MGFP results are identical - nothing has been filtered out. Deselect ALL loadings, and note that the filtered MGFP power is a flat line at zero - everything has been filtered out.

Start selecting any of the ICA components, one at a time, and see the effect each has on the filtered MGFP. The MGFP and filtered MGFP results are autoscaled, so move the vertical cursor to measure the amplitude. Recall, with ICA, the components are statistically independent, and are assumed to have different sources for each.

52   **Toolbox 4.5**

Now change the number of ICA loadings from 10 to 2. The two remaining components change somewhat. You are telling the program to find either two, or more, independent components, and it matters whether you select two or some other number. This is where the PCA part of the program is most useful. From it (from the distribution of relative field strengths), we found there were two valid loadings, so we would use two ICA loadings.

We decide to use a Moving dipole model (in SOURCE), where the two ICA components are computed. In the first figure below, we are using the unfiltered *EpiSpike.avg* file, an interval of -25 to 65ms, with a Moving dipole model, 80% threshold, and the standard BEM. The results trace a path around the tip of the left anterior temporal lobe.
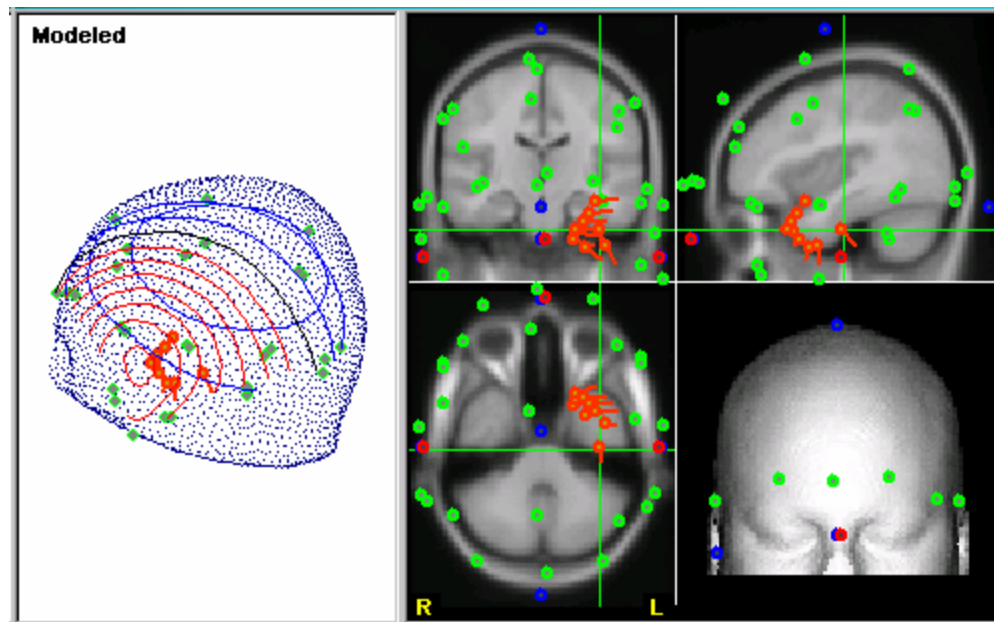
After removing all but the first two components, the source appears to be more in the vicinity of the medial surface of the left anterior temporal lobe. This could be a significant difference if surgery were involved. Which is correct? Evidence from other sources was consistent with the two loading results above, as suggested by the PCA results.

<%COPYRIGHT - 2008%>
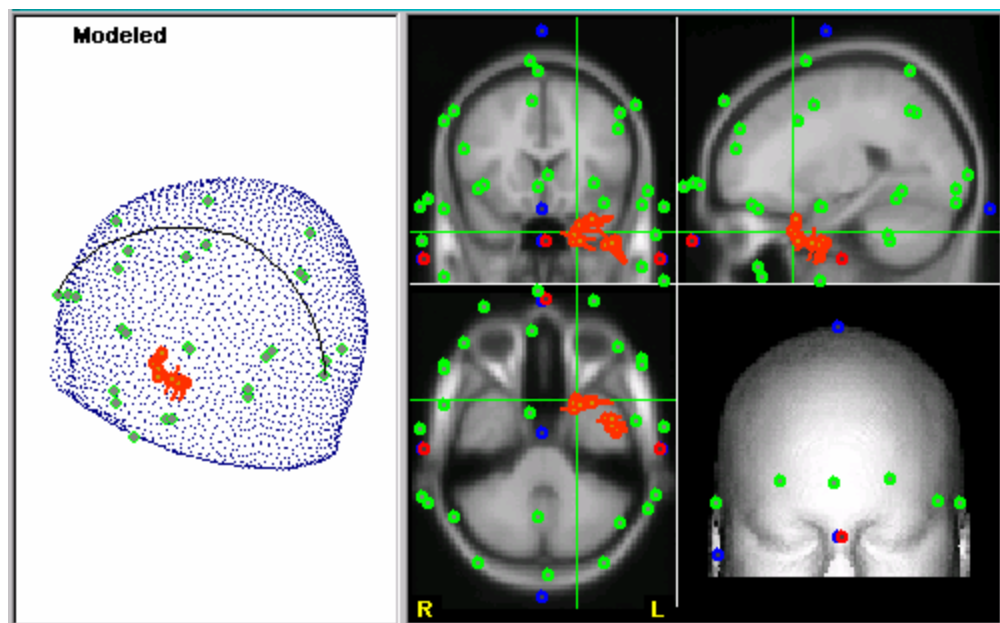
You might want to experiment with different dipole and volume conductor models, as well as number of dipoles computed.

Example 2. In this example, we will use the *p300.eeg* demo file to demonstrate how to remove blink artifact. Responses to the "oddball" stimuli (type 2) were averaged, without any attempt to remove the blink artifact that is in the file. The result is an AVG file that contains anterior blink artifact and the posterior P300 component. We want to calculate the dipole source localization of the P300 component, without any VEOG artifact. Looking at a 2D map and the VEOG channel, we find the peak blink artifact around 700ms, primarily from anterior frontal sites.

The P300 component peaks at midline posterior sites at about 388ms, with what appears to be blink artifact in the latter part of the waveforms.

We will use PCA/ICA to remove the blink artifact while preserving the P300 component. Start the PCA/ICA program. (If you are following along with the example, you will need to add the electrode position information by clicking the Match Labels button on the "radar" screen when it appears, and then OK and OK).

Select the interval from 280ms to 996ms. Display all 10 PCA components, as well as the MGFP and Filtered MGFP results. Looking at the relative field strengths, there are three valid loadings.
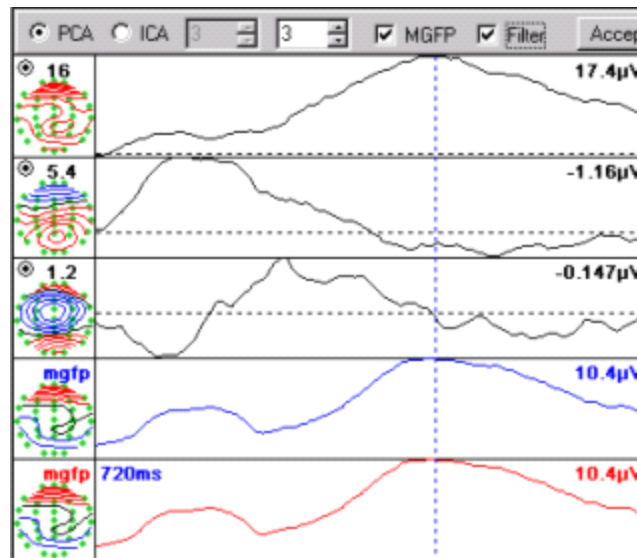
Note that the first one is clearly the blink component. The distribution is frontal, and it peaks around 700ms. The second loading is the P300 component - the distribution is mid-posterior, and it peaks at about 388ms. The third loading is less clear.

Now switch to ICA, and it will be set for three loadings automatically. Here it is less clear what each loading represents, although the first is probably the blink, and the second is probably the P300 component.
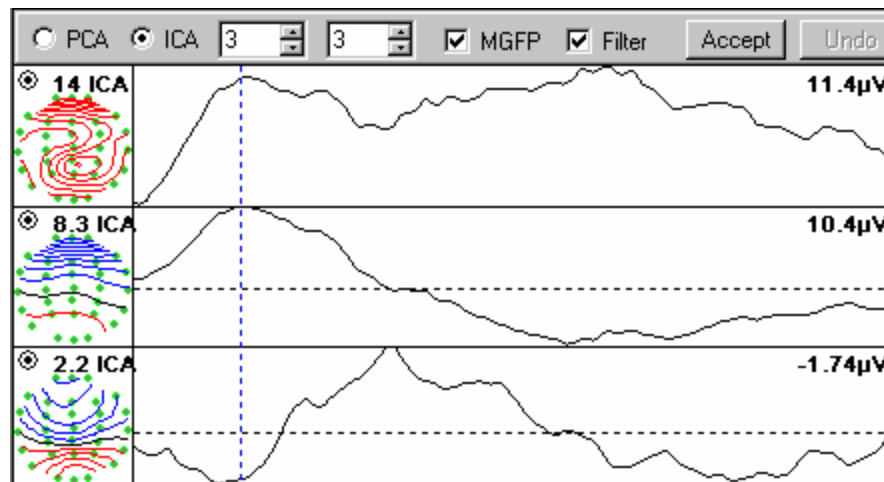
The next step is to try retaining different combinations of loadings to see what effects there are on the waveforms. For example, deselect all but the first two loadings. Click Accept and look at the waveforms. Click Undo to restore the originals. Filtering all but the first two components has a small effect.
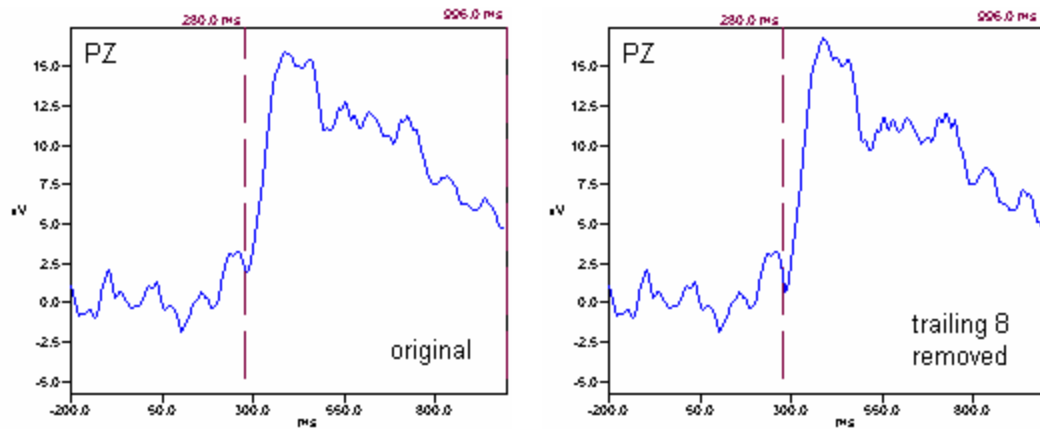
Now deselect all but the second loading. The blink component has been removed, leaving the P300 component intact.
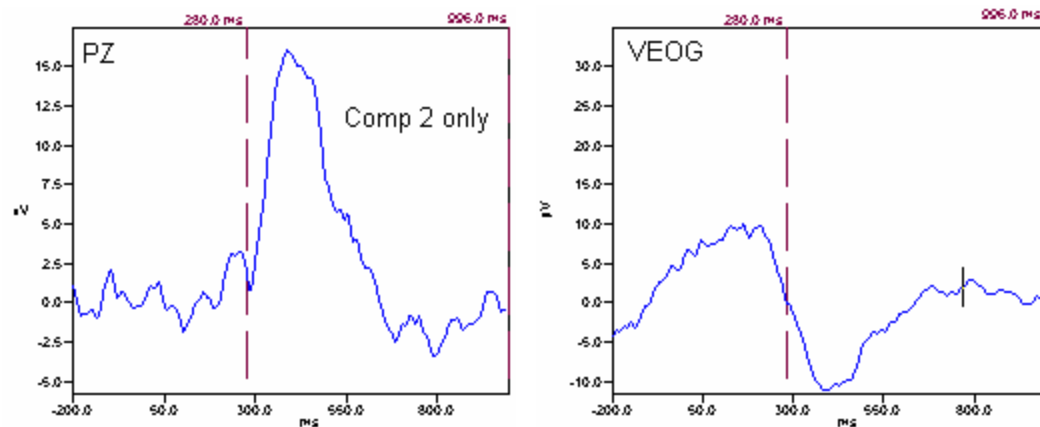

At this point you might try Undoing the filtering, and selecting loadings 2-3 only. There is minimal effect on the P300 component. Save the file with all but the second and third loadings filtered (for use in SOURCE). The reason for including the third component will be explained shortly.

Now, we will see what effect - if any - removing the blink component made on the dipole source solution of the P300 component. First, we retrieve the original data file, and compute the P300 source solution using the 300-500ms interval, a Moving dipole model, 70% threshold, and the standard BEM. An interesting albeit somewhat dubious progression is computed. The progression goes from lower left (vicinity of the anterior part of the corpus callosum) to upper right (vertex), in the sagittal view, across the interval.
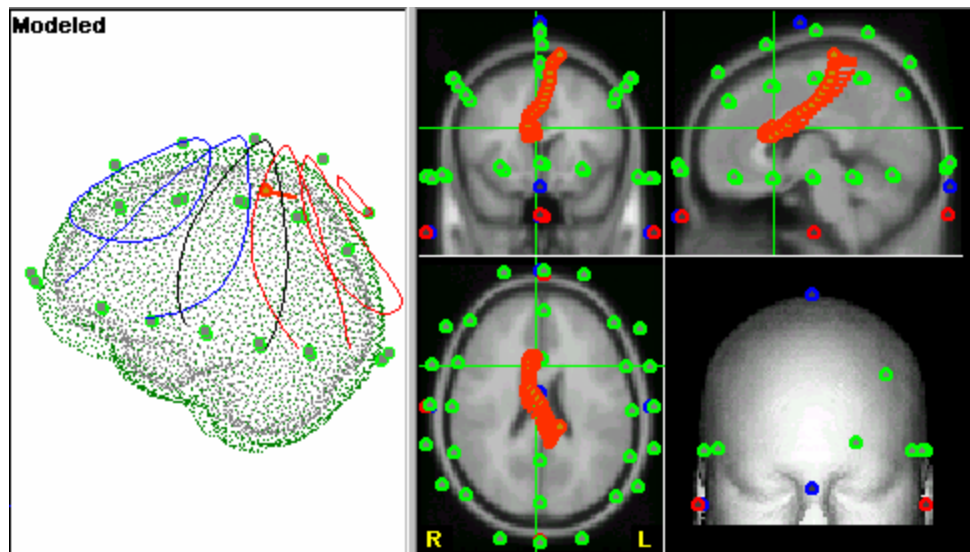
Next, we take the filtered file, leaving only the second and third components (removing the blink and trailing loadings), and use the same parameters to plot the moving dipole.
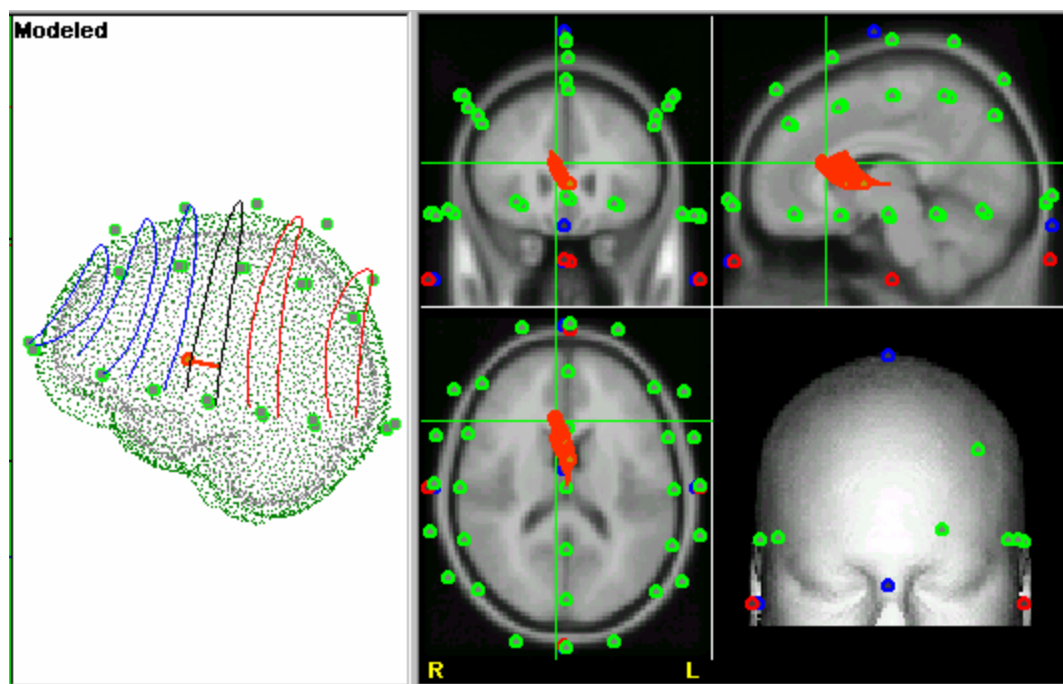
Now, we find that the dipole solutions cluster in the vicinity of the anterior part of the corpus callosum. The later drifting toward the vertex is likely due to VEOG artifact. This demonstrates how important it is to remove loadings that may adversely affect the dipole source solutions.

Why did we include the third component as well as the second one? Any time you use only a single component from PCA/ICA, you will obtain dipole solutions in SOURCE that are the same. Moving dipoles will have all dipoles in the same position, and appear not

to move. The various dipole models will all give the same results. With only a single component retained, the created data file will have a stable pattern scaled by a multiplicative factor from sample to sample (the ICA loading). Therefore all fits account for the same pattern, giving the same result, and the source strength changes to account for the multiplicative factor. For that reason, we included the third ICA component in the example above (since we were removing the first one).

The examples above illustrate some of the possible applications of PCA and ICA. We encourage you to try a variety of applications with different data sets. We welcome your feedback regarding successful and less successful applications. Please send any comments to techsup@neuroscan.com.

6.5   Summary of Keystrokes

Single and combination keystrokes can be used in place of the mouse for some operations.
When the data display has the focus:

The **left** and **right arrows** move the left vertical interval marker (the start of the interval).

Shift+left or **right arrow** moves the right interval marker (the end of the interval).

Ctrl+left or **right arrow** moves both markers, keeping the interval between them constant.

When the PCA/ICA display has the focus:

The **left** and **right arrow** keys move the cursor in the loadings displays (after clicking the focus there).

The **arrows** and **Tab** keys position the mouse on the Command line (after clicking the focus there).

Shift+arrow and **Ctrl+arrow** have the same function as when the data display has the focus.

The **mouse wheel**, or the **up** and **down** keyboard **arrows**, are used to change the number of lines in the contour map (after clicking inside the patterns/loadings area).