# VivoSense®

## User Manual – Galvanic Skin Response (GSR)
## Analysis Module

VivoSense® GSR Analysis Module Version 3.1

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VivoSense® software is not a medical diagnostic tool. It is for research and investigational purposes only and is not intended to be, or to replace, medical advice or review by a physician.

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# Table of Contents

# 1. Introduction

## 1.1.     Galvanic Skin Response Analysis Module for VivoSense®

This manual describes the Galvanic Skin Response (GSR) analysis module for VivoSense®. This module may be used to analyze and visualize several GSR metrics. The manual includes a background to the analysis of GSR, a description of the artifact editing capabilities included in the module and a description of the various indices and methods of calculation and visualization. The module is delivered with several layouts that facilitate the use of the GSR analysis. The module also allows for the export of GSR parameters in a variety of possible configurations.

Familiarity with the core VivoSense® module is a prerequisite for use with the GSR analysis module.

VivoSense® GSR allows a user to visualize GSR metrics of sympathetic nervous system activation, synchronized with relevant data channels from other sensors to provide a contextual significance to any research study. Further automated and graphical artifact management capabilities allow for precise and accurate calculations of sympathetic system responses in a variety of application domains.

## 1.2.     System Requirements

This module is an add-on analysis module to VivoSense® and requires VivoSense® Core with a sensor import module that supports a Galvanic Skin Resistance (GSR) sensor. This is also sometimes referred to as an Electro-dermal Activation (EDA) sensor.

# 2. GSR Background

## 2.1. Anatomical and Physiological Basis

The autonomic nervous system (ANS) is the portion of the nervous system operating below the level of consciousness. It acts as a control system for the body's visceral functions, including perspiration, heart rate, respiration rate, movement of the gastrointestinal tract, salivation and many other vital activities. As the ANS is not directly under conscious control, it is affected by mental and emotional states.

The ANS consists of two main branches: The sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS is best known as the "fight or flight" system, although it has many additional roles. While most organs of the body are innervated by both the SNS and the PNS, the skin is mainly innervated by the SNS, making it an ideal place to measure sympathetic arousal.

The skin is an organ with many vital and dynamic functions and thus the skin constantly receives signals from control centers in the brain. It was noted many years ago that we can essentially "listen in" to these signals as their arrival at the skin results in measurable electrical changes. This is called "electrodermal activity".

The primary function of endocrine sweat glands in the human body is thermoregulation. However, the sweat glands located on the hands and soles of the feet are particularly more responsive to emotional stimuli than to thermal stimuli. Thus emotion evoked sweating is most evident at these sites due to the high gland density.

As stated, human sweat glands have predominantly SNS innervation and as the degree of SNS activation increases, more sweat glands become activated, resulting in a more conductive path through the relatively resistant skin epidermis. Thus measurement of the skin resistance offers us a non-invasive window into psychologically induced changes in the sympathetic nervous system.

## 2.2. GSR Analysis Background

Changes in mental or emotional state leads to SNS changes, which in turn results in changes to the skin resistance. The goal of GSR analysis is thus to work in reverse and investigate a subjects affective state by making inferences from the measured skin resistance waveform.

A GSR sensor creates a very small current across the surface of the skin and measures the voltage across the applied electrodes. From this it is possible to generate a resistance waveform that is sensitive to the subtle electrical changes arising from the activity of the sweat glands. The output of the GSR sensor is the skin's conductance represented in units called microSiemens (µS).

A typical GSR waveform is displayed in Figure 1.
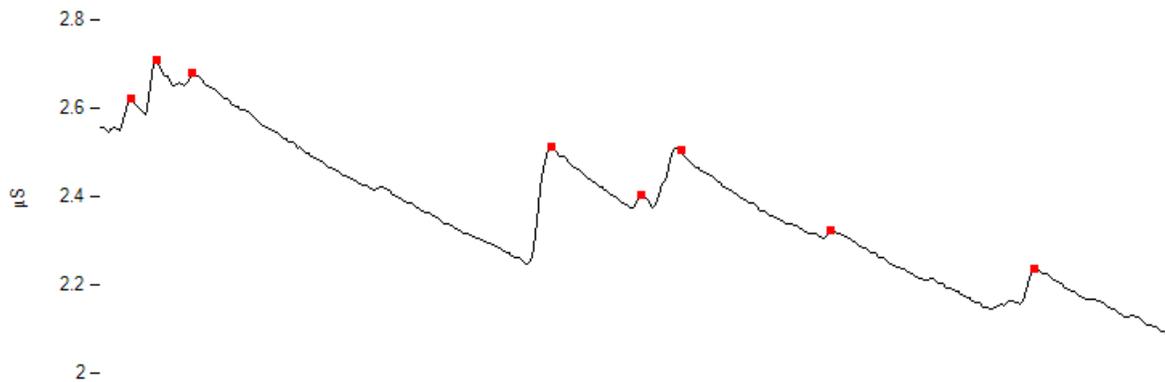
**Figure 1. GSR waveform with response peaks identified in red.**

The GSR waveform is characterized by two important components: A fast component called 'phasic' and a slow component called 'tonic'. Both tonic and phasic components contain information associated with specific psychophysiological aspects of brain states. The tonic component is the baseline level of skin conductance in the absence of any particular environmental event and it varies over time in individuals depending on psychological state and autonomic regulation.

The tonic component changes very slowly and represents the background of the signal called the skin conductance level (SCL).

The phasic component is associated with fast changes (peaks) that occur in response to a single stimulus and is a called a (specific) skin conductance response (SCR).

In contrast to a specific SCR, non-specific fluctuations also frequently occur spontaneously without any external stimulus. The most widely used measure of SNS activity or psychophysiological activation is the frequency (rate per minute) of these non-specific SCRs.

VivoSense® GSR analysis module may be used to accurately identify and quantify non-specific SCR's and SCL's. Responses to specific stimulus may be visualized in VivoSense® software, but no specific analyses are available for these types of responses.

The analysis of SCRs requires accurate identification and marking of response peaks.

# 3. Artifact Marking for GSR

GSR waveform data channels markings will often contain artifact. There are several possible sources of artifact that may arise. Artifact will contaminate the raw measured signal which may in turn result in erroneous measurement of tonic of phasic responses.

The most commonly encountered GSR artifact is motion artifact. Other forms of artifact include electrode movement with respect to the skin interface (disrupting electrochemical equilibrium); signal saturation; spike transients or jumps and signal drift. Some forms of artifact may be eliminated through the use of advanced filtering techniques and design considerations such as shielded cables. Despite this however, artifact may still occur when recording GSR waveforms.

Errors in the location of the SCR peaks will result in errors in the calculation of the non-specific SCR event rate. Therefore, to ensure accurate results, it is critical to manage artifact appropriately prior to performing any GSR analyses.

VivoSense® provides several mechanisms for the management of artifact and the appropriate selection will depend on the nature of the artifact. These different mechanisms and their recommended usage are described below. The GSR Analysis module includes a GSR Artifact Editing layout in the "Modules > GSR Analysis" folder.

## 3.1.      Editing GSR Markings

VivoSense® calculates non-specific fluctuation (NSF) peaks from a GSR waveform. If the sensors were poorly applied, the subject moves a lot, or the waveform is noisy, these markings may be erroneously calculated. The GSR analysis module provides a mechanism to edit the location of NSF peak markings.

NSF peak marking editing must be performed from the NSF peak channel. This channel is located in "GSR > Markers". It is recommended that the SCR (EDA) waveform channel be used to visually locate erroneous markings and to correctly place new markings. This channel may be present on the same chart.

Manually editing NSF peak markings is recommended for portions of the data where the NSF peak detection algorithm may have failed, and the correct markings are clearly visible via visual inspection. This may occur in the presence of noise. This is the most accurate form of artifact management prior to GSR analysis and should be performed if possible.

### *Deleting NSF Peak Markings*

To delete a NSF peak marking, the cursor must be located on a chart that includes a plot of the NSF peak marking. It is recommended to use the appropriate GSR Artifact Editing layout, which will identify deleted NSF u press the D Hotkey. This will delete the NSF peak marking closest to the cursor. VivoSense® will search for an NSF peak marking within a range of 2 seconds around the cursor. By default, a NSF peak must be marked within a range of 2 seconds centered on the cursor for the menu item to appear. This distance is editable in the NSF peak channel's *Search Duration* property. In addition, an annotation will be added to the annotation bar designating the deleted NSF peak marking. The annotation will be centered on the NSF peak with default duration of 1 second, and all NSF peak markings within the range of this annotation will be deleted. The default duration may be modified with the NSF peak channel's *Annotation Duration* property. To undo this operation, right click the mouse as close as possible to the deleted NSF peak marking and select *Artifact Management>Edit NSF peak>Undo Delete,* or by pressing the D Hotkey again.

## *Inserting NSF Peak Markings*

To insert a NSF peak marking, the cursor must be located on a chart that includes a plot of the NSF peak marking. It is recommended to use the appropriate GSR Artifact Editing layout, which will identify inserted NSF peak markings without the blue outline. Position the cursor as close to the location where the NSF peak marking should be, right click the mouse and select *Artifact Management>Edit NSF peak>Insert*, or press the I Hotkey. A NSF peak marking will be inserted at the nearest peak within 50ms of the time at the cursor. In addition, an annotation will be added to the annotation bar designating the inserted NSF peak marking. To undo this operation, right click the mouse as close as possible to the deleted NSF peak marking and select *Artifact Management>Edit NSF peak>Undo Insert*, or press the I Hotkey. NSF peak insertion uses the same *Search Duration* and *Annotation Duration* properties as NSF peak insertion.

## *Un-doing NSF Peak Editing*

Editing an NSF peak marking does not alter the original NSF peak channel, but rather modifies it in the areas denoted by annotations. To undo multiple edits select a range on the NSF peak channel including the edits to delete and select *Artifact Management>Edit NSF peak>Undo Insert Annotations*, or *Artifact Management>Edit NSF peak>Undo Delete Annotations*, or press the U Hotkey to undo all NSF peak editing within the selected range. Alternatively you may use the Annotation Manager to navigate, sort, select and delete the annotations directly which will return those areas to the original NSF peak channel.

## *Moving and Sizing NSF Peak Edits*

Sometimes it is desirable to have even more control over where the NSF peak edit is placed. This can be done by moving the Insert or Delete annotation by dragging and releasing the annotation itself on the annotation bar. The annotation duration can be changed in the Annotation Properties window in Duration. The result of the change will visible as you move or size the annotation. Delete edits may delete multiple markings. Insert edits will always insert a single marking at the maximum value within the annotation range. Delete edits always override insert edits.
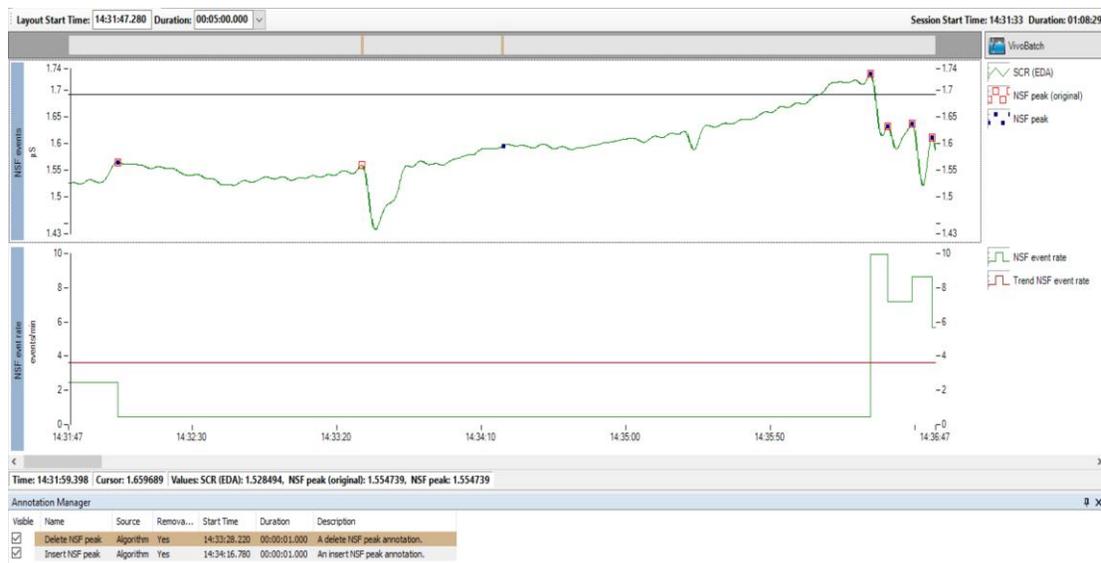


**Figure 2. NSF peak editing with one insertion and one deletion.**

## 3.2.     GSR Waveform Interpolation

If the GSR signal is too noisy to accurately determine the correct peak markings it may be possible to interpolate over regions to smooth the signal. This may be more efficient than editing individual peaks.

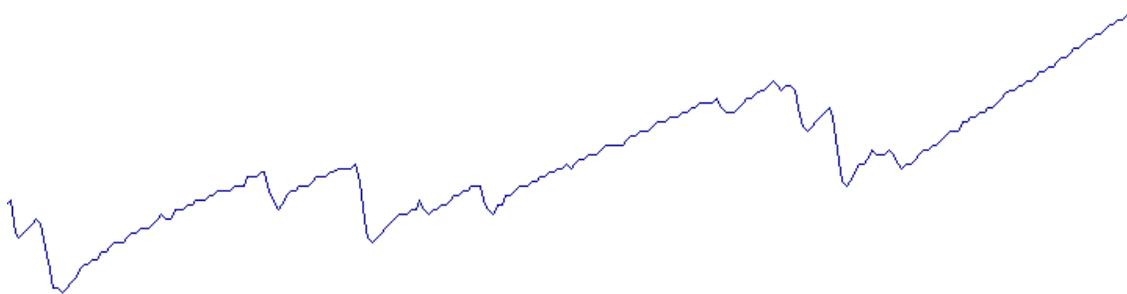### *Performing GSR Waveform Interpolation*

GSR waveform interpolation must be performed on any chart containing a plot of the raw GSR channel. This will be located in the data explorer under *Raw > GSR > Waveforms*. Using the time range and minimum and maximum values selected, the interpolation algorithm will adjust the raw waveform shape. This will be smoothed out in the filtered waveform.

- Select the region and acceptable range (select the left hand corner, left-click and drag the mouse to the right hand corner and release).
- Select *Artifact Management > Interpolate > Interpolate over region*

*OR*

- Select the region and acceptable range and press the N Hotkey.

This will automatically apply an interpolation to GSR values that fall between the selected rectangle. Interpolated areas will be marked by an annotation that appears only on charts containing the Raw GSR waveform channel.  See Figure 3 and Figure 4 for a visual demonstration of the interpolation process.



**Figure 3. Raw GSR waveform before interpolation.**
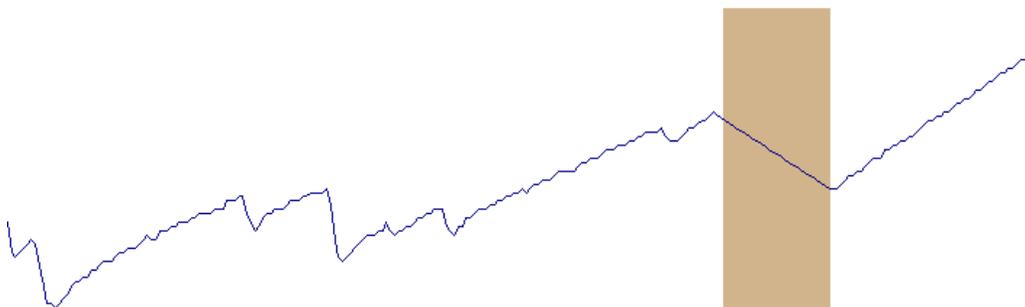


**Figure 4. Interpolated Raw GSR waveform smoothing out noise in a section to make marking of peaks easier.**

## *Removing Interpolations*

### *Removing Interpolations using the Annotation Manager*

Interpolations may be removed by deleting the annotation associated with the interpolation in the annotation manager.  Note that it is possible to select and delete a group of interpolations.

### *Removing Interpolations using the Context Menu*

It is possible to right click on a raw GSR waveform interpolation annotation and select "*Artifact Management > Interpolate > Remove interpolation*" from the context menu. This will remove the annotation and undo the interpolation, reverting to the original state prior to application of the interpolation. Alternatively, place the crosshair cursor over an interpolation annotation and press the U Hotkey.

It is also possible to select a range of data containing at least one interpolation using a rectangle and upon releasing the mouse select "*Artifact Management > Interpolate > Remove interpolations*". This will undo all interpolations in the range.

# 3.3.    Excluding Regions of GSR Data as Artifact

If large sections of data are contaminated by significant noise with poor NSF peak identification, these artifacts will significantly bias GSR analyses and must be managed appropriately. Interpolating over large regions will cause unwanted bias and it may not be possible to visually correct NSF peak markings. In this instance, it will be necessary to exclude these regions from any further calculations.

## *Performing Artifact Exclusion*

To exclude a region as artifact, select a range with the mouse on any chart containing the raw GSR waveform. Upon releasing the mouse a context menu will appear. Select "*Artifact Management > Exclude > Exclude as artifact*" to add an annotation and exclude this region from all calculations. Alternatively, you may select the range and press the X Hotkey.
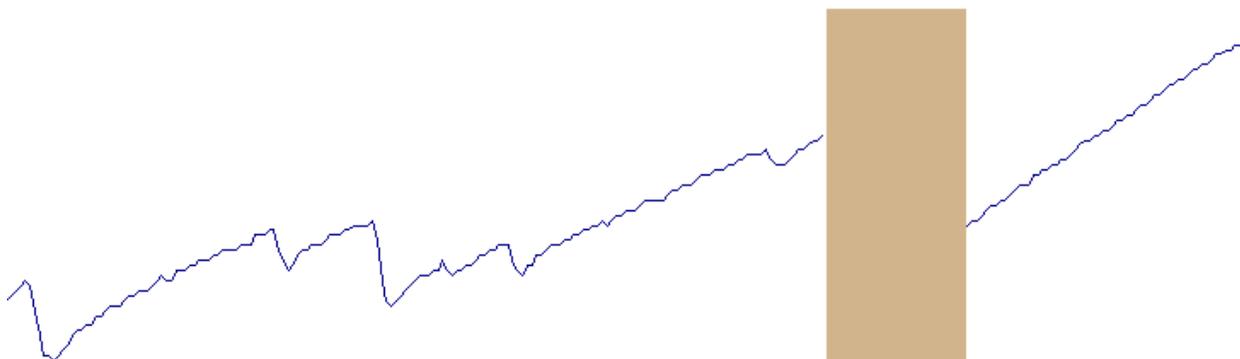


**Figure 5. A region of GSR waveform data is excluded.**

## Removing Artifact Exclusions

### Removing Artifact Exclusions using the Annotation Manager

Exclusions may be removed by deleting the annotation associated with the exclusion in the annotation manager. Please note that it is possible to select and delete a group of exclusions.

### Removing Artifact Exclusions using the Context Menu

It is possible to right click on an artifact exclusion annotation and select "*Artifact Management > Exclude > Remove exclusion*" from the context menu. This will remove the annotation and undo the exclusion, reverting to the original state prior to application of the exclusion. Alternatively, place the crosshair cursor over an interpolation annotation and press the U Hotkey.

It is also possible to select a range of data containing at least one exclusion using a rectangle and upon releasing the mouse select "*Artifact Management > Exclude > Remove exclusions*". In this way it is possible to undo all exclusions in the range.

## 3.4.    Artifact Thresholds

Artifact marking is a complicated and time-intensive process that for now requires human intervention to achieve the best results. In some cases, the signal quality is very poor and either saturates or is below physiologically normal ranges. In these cases, one can set thresholds for automated exclusions to assist with artifact markings.

## Setting Artifact Thresholds

The SCR (EDA) channel is the channel that is used for NSF peak detection. The properties for this channel contains a set of thresholds that can assist with artifact management. See Figure 6.

The Threshold 'Lower Limit' indicates the lowest acceptable range that is physiologically appropriate. The default for this is 0.2 µS. Anything below this threshold this will be set to the value in the 'Lower Value' field. NaN (not a number) is used in VivoSense® to display a blank and thus exclude or remove the data.

Similarly the Threshold 'Upper Limit' is used to set a maximum range useful for efficiently excluding sensor saturations. The defaults are an arbitrary very large number such that this would not have any noticeable effect.
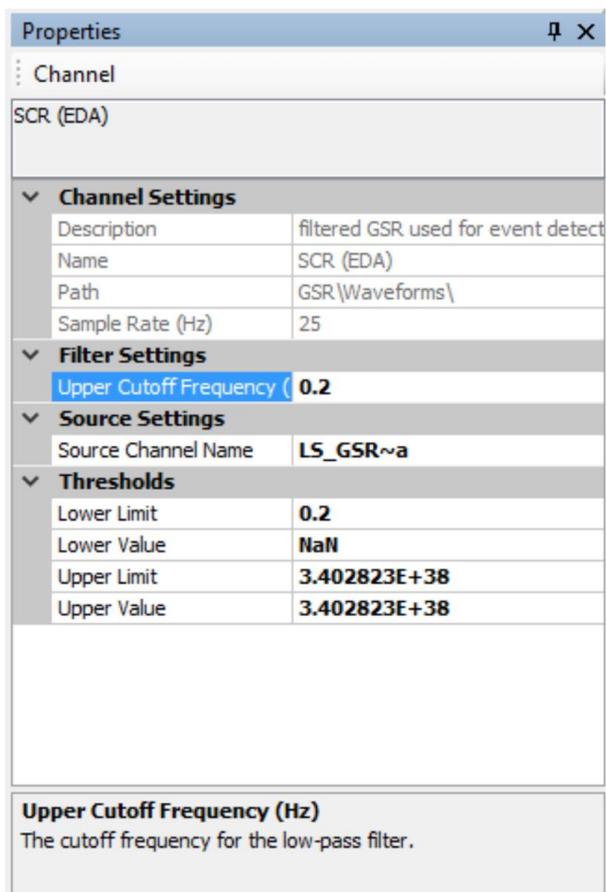
**Figure 6. Properties for the SCR (EDA) channel.**

## 3.5.    Artifact Editing Layouts

Artifact editing layouts are included in the GSR Analysis module to help streamline the artifact management process. VivoSense® contains a single basic artifact editing layout.

To begin using a layout, open a file with GSR data and then select the GSR Artifact Editing layout from the GSR Analysis folder in the Layout Manager. Two charts will be placed on the screen – the first shows the desired SCR (EDA) plot and its associated NSF peak markings. The second chart displays the NSF event rate, along with the Trend NSF even rate. See Figure 7.

One special plot that shows the original state of the data has been added to the first chart. As edits are made to the NSF peak, the user will be able to visualize exactly what changes have been made and how these affect the data. In the first chart, the original NSF peak markings made by the NSF peak picker are shown as a blue square with a surrounding red box. User inserted markings will just show the blue square and user deleted NSF peaks will just show the red outline.
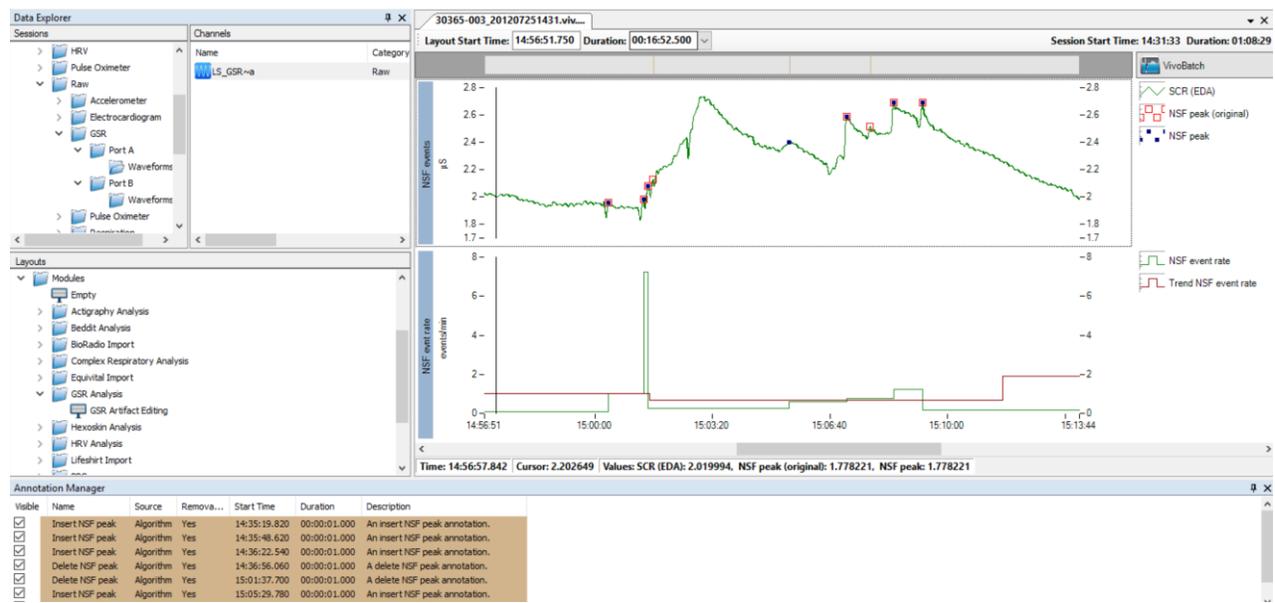
**Figure 7. GSR Artifact Editing Layout**

# 4. GSR Data Processing

## 4.1. Waveform Channels

### GSR

This is a scaled version of the raw GSR waveform channel with units in µS. The raw waveform may be inverted as required depending on the sensor used.

### SCL

This is a filtered version of the GSR waveform. A low pass filter is used to smooth out rapid transients to leave only the slowly changing (tonic) level of the skin conductance. The default filter cut-off frequency is 0.0555Hz or 18s. This may be changed in the filter settings in the SCL channel properties.

### SCR

This is a filtered version of the GSR waveform. A high pass filter is used to remove the slowly changing portion of the signal to leave only the rapid transients (phasic response). The default filter cut-off frequency is 0.0555Hz or 18s. This may be changed in the filter settings in the SCL channel properties.

### SCR (EDA)

This is a filtered version of the GSR waveform. A low pass filter is used to smooth out very rapid noisy transients or low amplitude responses. This leaves a smoothed waveform that still displays peaks and non-specific fluctuations. This waveform is then used to perform the NSF peak detection. The default filter cut-off frequency is 0.2Hz or 5s. This may be changed in the filter settings in the SCL channel properties

## 4.2. Marker Channels

### NSF peak

These markings note the peaks of detected non-specific skin conductance responses. The channel has several properties that may be changed to modify the detection algorithm. These properties are:

**Blockout duration**: After the occurrence of a peak, it is less likely that another true response peak occurs until the response has settled. This setting determines the minimum time between responses and the default is 6s.

**Minimum Threshold**: This is an important setting which determines the minimum amplitude of a response. The default is 0.05 µS. Increasing this may help in the presence of a noisy signal or if the user only wants to search for responses exceeding a minimum amplitude.

**Rise time**: This setting determines maximum time from the start of a response to the peak. In other words this is the allowable time the signal has to rise over the minimum threshold. Responses are typically sharp and do not rise very slowly. The default is 3s.

## 4.3.　　Measures Channels

_NSF event rate_

The NSF event rate is the number of non-specific responses per minute. This is a measure of SNS activity or psychophysiological activation.

# 5. GSR Layouts

VivoSense® includes a GSR Artifact Editing layout in the "Modules > GSR Analysis" folder. This may be used to assist with visualization and editing of detected NSF peaks, as well as the associated event rate together with a trend of this event rate.