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Introduction

The goal of Autonomate is to provide researchers an automated method of analyzing electrodermal data in a fashion similar to manual scoring. While there are multiple software packages available for scoring electrodermal data, the procedures employed deviate from traditional manual scoring methods. The primary focus of Autonomate is the analysis of event-related skin conductance responses, although tools for scoring non-specific responses and tonic skin conductance levels have been incorporated.

This manual is divided into two sections: one describing the general procedures implemented for analyzing electrodermal data, and another specifying the steps required to perform analysis with Autonomate.

Analysis of electrodermal data

Event-related skin conductance responses (SCR)

Preprocessing

Before analysis of electrodermal data, raw data are downsampled to speed computation and remove high frequency artifacts. Following downsampling, event onsets are used to segment the electrodermal data event-related windows. The following analysis steps are repeated for each window (default duration of 9 seconds), producing an estimate of SCR amplitude for each event.

Identifying responses

The first step in scoring SCR amplitude is locating rises in the electrodermal data which constitute the onset of an SCR. Within each window of downsampled data these points are identified when a sufficient number of continuous points (default of 5 samples) have slope above a predefined threshold (default of 0.0002 µS per second). The trough and peak of candidate SCRs are identified by locating zero crossings in the first-order temporal derivative of the downsampled data. To exclude particularly noisy segments of data (in which an implausible number of candidate SCRs are present) events can be excluded from analysis if more than a specified number of responses are found (default of 8 responses).

Isolating overlapping responses

To determine if candidate SCRs are likely to contain multiple overlapping responses, inflection points are identified in the downsampled data by identifying zero crossings in the second-order temporal derivative. If the slope cycles from increasing to decreasing twice within one candidate SCR, then the overlapping responses are segmented at the inflection point where the slope changes from decreasing to increasing (in the middle of the rise).

Next, candidate SCRs are filtered on the basis of response criteria established from manual scoring. These parameters include: the latency of the SCR relative to the eliciting stimulus (default range of 0.8 to 4.2 seconds); and the maximum time between the onset of the SCR and its peak (default of 5 seconds)..

Scoring amplitude

Once plausible SCRs are identified, the amplitude of each response is calculated by identifying the *minimum* value of the raw electrodermal data within a small buffer (default of 25 samples) centered on the *onset* identified in the downsampled data. Similarly, the *peak* is identified as the

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maximum value of the raw data within a buffer centered at the *end* of the SCR. If multiple SCRs fall within the same window, the largest response is scored (this can be changed to the first response in each event window via a radial button option in the analysis set-up GUI).

Non-specific responses (NSR)
Scoring of NSRs is similar to that for event-related SCRs, with the exception that they are not tied to any particular time-point within the data. The method for scoring responses proceeds in the same way as scoring SCRs, with two exceptions: in identifying responses the criteria for SCR latency are omitted, and all responses are scored rather than taking the largest response when scoring amplitude.

Setting up the NSR analysis requires an event data channel with an event marker at the time in the data after which Autonomate should begin analyzing the electrodermal data (see *Specify Channels* and *Specify Conditions* below).

The NSR analysis can be set up using an event channel with an event marker at the time in the data after which Autonomate should begin analyzing the electrodermal data (see *Specify Channels* and *Specify Conditions* below). Alternatively, the "NSR with no Input Event Data" button can be pressed to generate a "fake" event channel with a single marker at the beginning of the data time-course. This second option does not require an event marker channel in the input data.

Skin conductance level (SCL)
Scoring of SCL is performed by taking the mean of electrodermal data within an event-related window. The "SCL Window Start" and "SCL Window End" analysis parameters can be used to specify the time window of interest following each event.

Using Autonomate

System requirements
The Autonomate software was developed under Windows XP using MATLAB R2009b. It has been tested in Windows Server 2008 R2, Windows 7, and more recent versions on MATLAB (2013b, 2014b). Basic functionality for analyzing data is provided for older versions of MATLAB, although the GUI for viewing the data is compatible with releases as of 2008a.

Input Data Formats
Autonomate can import data saved either in BIOPAC Acqknowledge (BIOPAC Systems Inc., CA, USA) format or two-column ASCII text files. For ASCII files, both columns should have the same number of entries corresponding to the number of samples recorded. The first column should contain the electrodermal data. The second column indicates the onset of events with codes unique to trial types of interest.

Installation
To install Autonomate, unzip the contents of the distribution and add the folder named 'Autonomate' to the MATLAB path (or simply work within the directory, if preferred). A shortcut which automatically sets the MATLAB path and calls the function is included for convenience.

Analyzing Data
Once installed, the Autonomate GUI can be called by executing the command `Autonomate` in MATLAB.

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Load data
There are two ways to load data using the interface: browsing for an individual file or performing a batch analysis. Selecting the 'Browse for File' button permits the selection of a single file for analysis. Checking the 'Batch Analysis' box allows the user to load multiple files at once, either by manually selecting the files one at a time using the 'Add File' button or by pointing to an ASCII text file listing the full file path of all data to be anaylzed, with one file per line. Once all the desired files have been selected, the 'Load Files' button can be used to load data into memory. This process will take an amount of time dependent on the size of the input data set to be read in, CPU speed, etc. Short files should take only a few seconds to load while longer files or files with higher sampling rates will take more time.

Specify channels
After the data are loaded, the channels containing electrodermal and event data must be specified.

The drop-down menu can be used to select the channel containing electrodermal data. The data associated with the selected channel are plotted to aid in selection. Similarly, the channel with codes for events of interest should be selected using the second drop-down menu. Finally, pressing the 'Extract Data' button will extract data from the relevant channels for further analysis.

Specify conditions
Next, the conditions to be analyzed are selected. The listbox on the left displays the unique codes in the channel containing event data. Any combination of these codes can be selected and integrated to a single condition for analysis by pressing the '→' button, entering a name for the condition, and pressing the 'Add Condition' button. *(To highlight multiple code entries, hold down the "Ctrl" button (Windows) or the "command" button (Mac) while clicking on them.)*

The selected events are displayed in the listbox on the right of the panel. If conditions are created in error, they can be removed from analysis using the 'Remove Conditions' button. Pressing the 'Analyze Conditions' button prompts the final steps for data analysis.
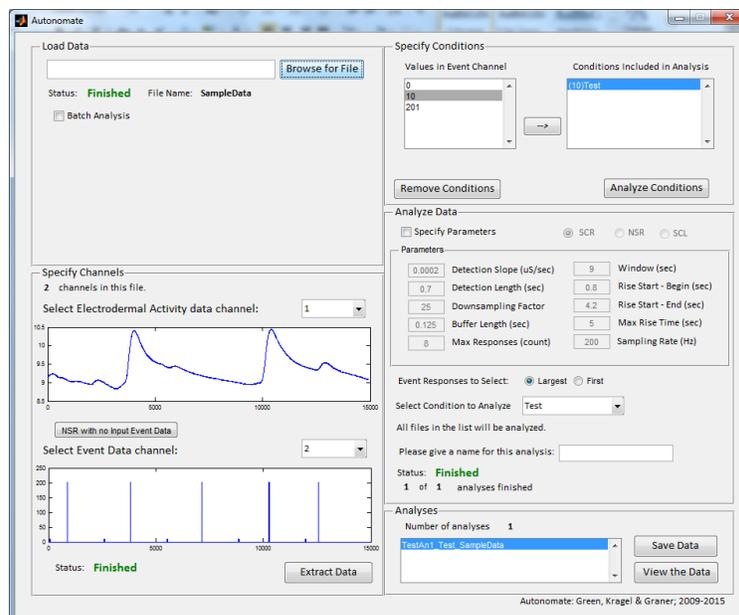

Figure 1. Autonomate GUI for loading and analyzing data.

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Specify parameters and run analysis
The type of analysis to be performed and analysis parameters are specified in the 'Analyze Data' panel. Selecting the 'SCR', 'NSR', or 'SCL' radio button indicates which type of analysis will be conducted. Upon checking one of these radio buttons the parameter panel will format itself to the specific needs of the selected analysis; irrelevant parameters will be greyed out and, in the case of SCL analysis, certain parameter names will change to more accurately convey the parameters' roles in the analysis.

Checking the 'Specify Parameters' box permits manual adjustment of default parameters. This is particularly important for specifying the sampling rate of the input file. Note: although multiple analyses can be run at once, currently all analyses must be of the same type (SCR, NSR, or SCL) within the session. Thus, once the 'Analyze Data' button has been pressed, the data type radio buttons will inactivate until the Autonomate GUI is closed and restarted.

The default values for the SCR and NSR analysis parameters were determined to produce results that most closely matched the results of hand-scoring GSR data. Details of the validation of these values can be found in this reference:

> Green SR, Kragel PA, Fecteau ME, & LaBar KS. Development and validation of an unsupervised scoring system (Autonomate) for skin conductance response analysis. *Int J Psychophysiol*. 2014 Mar;91(3):186-93

Specific descriptions of the analysis parameters are as follows:

Detection Slope: the minimum slope necessary for an increase in the electrodermal data to be considered a possible response to a preceding event (default 0.0002 μS/sec.)

Detection Length: the minimum length of the rising period for a potential response to be considered valid (default 0.7 sec.)

Downsampling Factor: the factor by which the input data are downsampled prior to analysis (default 25; recommended to be 1/8th of the sampling frequency; for *no* downsampling (not recommended) set to 1)

Buffer Length: the size of the search window applied to the beginning and end of valid response periods of the downsampled data when looking for the response trough and peak in the *non*-downsampled data (default 0.125 sec.)

Max Responses: the maximum number of potential responses that can be detected in the time window following an event before the data in that window are considered too noisy to be analyzed (default 8)

Window: the length of time following an event in which Autonomate will look for responses in the electrodermal data (default 9 sec.)

Rise Start-Begin: the closest point in time following an event at which a potential response can start in order for it to be considered valid (default 0.8 sec.)

Rise Start-End: the furthest point in time following an event at which a potential response can start in order for it to be considered valid (default 4.2 sec.)

Max Rise Time: the maximum duration of the rising portion of a potential response for it to be considered valid (default 5 sec.)

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Sampling Rate: the rate at which the input data were sampled (default 200 Hz; *should always be set to match input data!*)

SCL Window Start: (note: only appears for SCL analyses) the time after each event that marks the beginning of the SCL analysis window for that event (default 0 sec.)

SCL Window End: (note: only appears for SCL analyses) the time after each event that marks the end of the SCL analysis window for that event (default 9 sec.)

Event Window Length: (note: only appears for SCL analyses) the time after each event that marks the end of the period associated with that event; this must be larger than the SCL Window End but only affects the display of the data in the plots of the data-view GUI (default 9 sec.)

If the NSR radial button is selected, Max Responses and Window will be set to `Inf` and the parameters will be greyed out, indicating that Autonomate will include results for any number of detected valid rises within the entire time-course following the initial event marker.

Autonomate can also look for non-specific responses across the entire data set without the need for an event marker channel in the input data file. Pressing the "NSR with no Input Event Data" will cause Autonomate to create a "fake" event marker channel with a single marker at the beginning of the time-course. The analysis can then be carried out as usual.

After the analysis parameters have been set the condition to be analyzed can be selected using the dropdown menu and a name for the analysis can be specified in the nearby textbox (this is helpful for indicating the adjustment of parameters or the experiment from which the data originate). The analysis proceeds by pressing the 'Analyze Data' button. As with loading in data, the time necessary to perform the analysis will depend on the length of the data file, the down-sampling rate selected, CPU speed, etc. Short data sets can be analyzed in a matter of seconds while longer files may take on the order of minutes to complete.

Saving results (batch)

Results from the data analysis can be output as a text file by pressing the 'Save Data' button on the interactive GUI. This text file will contain results from all analyses that have been run in the GUI so far, allowing output of all results from a batch data run. *(Note: it is recommended to view the detected responses prior to writing out results!)*

Viewing results

The analyzed data can be viewed in an interactive GUI using the 'View the Data' button. The GUI includes a summary of each analysis, plots for visualizing scored responses, a history of exclusion criteria for individual responses, an interface for manually adjusting scores, and saving new output. Note: even though only the first analysis in the 'Analyses' panel list-box is highlighted, pressing the 'View the Data' button will load all of the analyses in the list into the interactive GUI.

Analysis Summary

The 'Analysis Summary' panel includes a description of each analysis including information about the input data, analysis parameters, and descriptive statistics for SCRs. The 'Back' and 'Forward' buttons at the top of the left panel can be used to cycle through the analyses run in the previous GUI.

The top portion of this panel lists overall details and summary statistics of the selected analysis. *(Note: 'Identified Responses' reports the number of non-zero skin conductance responses*

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detected in the selected analysis. Events with no valid detected responses contribute zeros to the statistic calculations for the analysis.) The 'Analysis Parameters' sub-panel lists the parameter values used in the selected analysis.
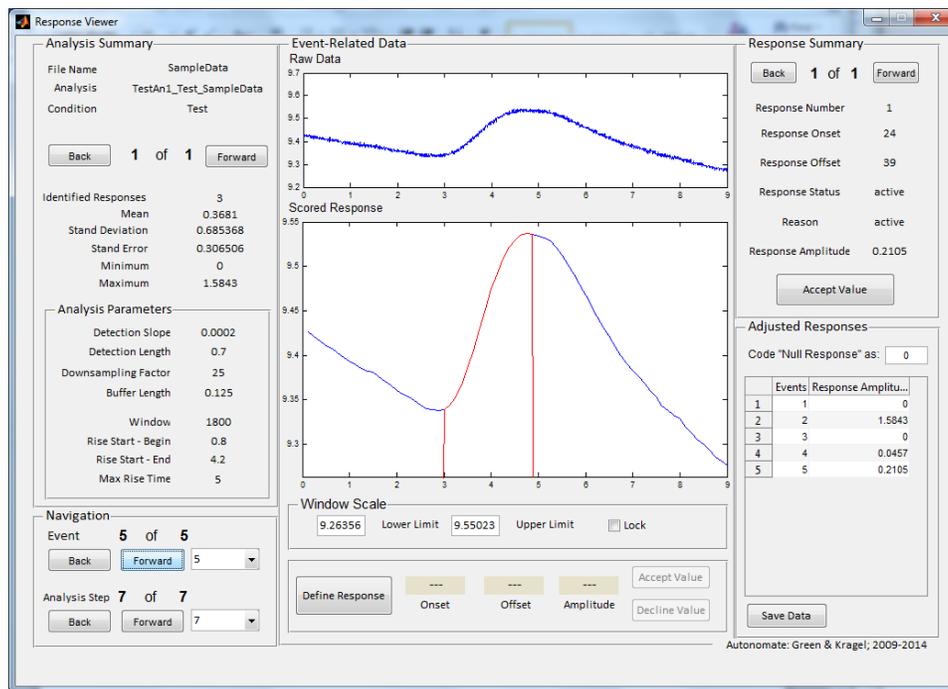

Figure 2. Response Viewer GUI for visualization of event-related data and manual scoring.

Navigation

The interface provides flexible visualization of scoring using the 'Navigation' panel. This interface permits the viewing of different events at various stages of analysis. The 'Back' and 'Forward' buttons may be used to navigate through events or analysis stages. Specific events or analysis stages can also be selected using the dropdown menus.

The seven analysis steps referenced in the Navigation panel represent the application of various criteria to the detected potential skin responses within the event window. These initial potential responses are identified as the time-points in the downsampled electrodermal data where the slope is greater than or equal to the value of the Detection Slope. The following steps are then applied to the potential responses in each event window:

1) Check to see if the number of potential responses in an event window is greater than the value of Max Responses. If so, the section of data is marked as noisy and no responses are reported for that event.

2) Check to make sure the rising portion of each potential response is longer than the value of Detection Length. If not, the potential response is not valid.

3) Check each potential response for inflection points. If any are found, split the potential response into smaller sections at each inflection point.

4) Check to make sure the rising portion of each of the new, shorter potential responses is longer than the value of Detection Length. If not, the potential response is not valid.

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5) Check to make sure the rising portion of each potential response starts at a time greater than the value of Rise Start-Begin after the event but less than the value of Rise Start-End after the event. If the beginning of the rise falls outside of this time range, the potential response is not valid.

6) Find the time points in the non-downsampled skin conductance data that correspond to the beginning and end of the remaining responses. Search for the minimum skin conductance value within a range around the beginning time point and search for the maximum skin conductance value within a range around the ending time point. Each of these ranges has a length of twice the value of Buffer Length.

7) Keep response amplitudes for only the largest response in each event window or the first response in each event window (depending on analysis settings).

Event-Related Data
The 'Event-Related Data' panel displays the raw input data and the downsampled version of the data used to detect valid skin conductance responses. Both plots show the section of electrodermal data within the detection window following the event currently selected in the 'Navigation' panel. Valid response regions are highlighted in red in the bottom ('Scored Responses') plot.

Changing the event in the 'Navigation' panel will automatically adjust the scale of the electrodermal data plots. However, the lower and upper limits can be manually specified and locked in place using the 'Window Scale' sub-panel.

The 'Define Response' button can be used to manually adjust the output of individual trials. Pressing this button changes the cursor to a crosshair, prompting the user to press once to locate the trough of the desired SCR and a second time to select the peak. The onset, offset, and amplitude of the defined response are displayed, and the score can be accepted or declined using the corresponding buttons.

Response Summary
The 'Response Summary' panel displays information for individual responses detected for the currently selected event and analysis step. Before the final analysis step (or when using the NSR analysis) two or more responses may be 'active' at the same time. The 'Back' and 'Forward' buttons navigate through these responses. The information displayed for each response includes the response amplitude, the response onset and offset (in number of time-points of the downsampled data), the status of the response (active or inactive), and, if the response is inactive, why it was determined to be an invalid response.

If desired, scores from different analysis stages (e.g. prior to segmenting a response) can be accepted in lieu of the default scoring using the 'Accept Value' button in the 'Response Summary' panel. In this case, the value for the selected event in the 'Adjusted Responses' table will be replaced with the Response Value currently shown in the 'Response Summary'.

Adjusted Responses
The 'Adjusted Responses' panel contains a table listing the amplitudes of all responses in the currently selected analysis. Values should represent any adjustments the user has made via manual response identification or selection of response amplitudes from intermediate analysis steps. The adjusted responses for the currently selected analysis may be saved to a text file using

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the 'Save Data' button. The text file will be written to the current Matlab directory and have a file name of the form:

"`Autonomate_Output_[ANALYSIS]_[CONDITION]_[INPUT_FILE]_YYYYMMDD_HHmm.txt`"

Here `[ANALYSIS]` and `[CONDITION]` are the analysis and condition names entered by the user in the analysis set-up GUI, `[INPUT_FILE]` is the name of the electrodermal data input file, "`YYYYMMDD`" is the current date in month, day, and year, and "`HHmm`" is the current time in hours and minutes.

Batch Analysis

The batch analysis option can be used to apply an analysis to several data files at once. Autonomate assumes the files all have the same general format; the channel numbers of their electrodermal activity data and event data are identical, as are the event codes in the event data channel.

After clicking the 'Batch Analysis' check box, files can be added to the batch analysis list in two ways: one at a time using the 'Add File' button, or as a group using the 'Use Text File' button. When using the 'Use Text File' button, Autonomate will prompt the user to find a previously made .txt file containing the names of all the data files to be loaded. This file should contain only the file paths and names of the data files, with one file per line.

Once all desired files have been added to the list, the 'Load Files' button will read in the files and continue the analysis setup process. Setting up a batch analysis is identical to that for setting up single file analyses. The channel plots and event marker code values displayed in the GUI are those read from the first file in the batch list. Each file is analyzed separately using the parameters set in the GUI and will appear as a unique analysis in the 'Analyses' list-box. Results from all analyses can then be written out using the 'Save Data' button or viewed in the GUI with the 'View the Data' button (the 'Forward' and 'Back' buttons in the 'Analysis Summary' panel can be used to move between each file's analysis results).

Citing Autonomate

If you use Autonomate for your research, please cite the following reference:

Green SR, Kragel PA, Fecteau ME, & LaBar KS. Development and validation of an unsupervised scoring system (Autonomate) for skin conductance response analysis. *Int J Psychophysiol*. 2014 Mar;91(3):186-93

Support

For questions and concerns, please send inquiries to labarlab@duke.edu

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