Biomechanics Analysis and Reporting

Application

User Manual

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# Intent

The creation of this application hopes to establish a generalized framework by which scientists in the biomechanics community conduct their data processing and analysis. The intent is that this will facilitate data analysis and reporting by making the process easier for students with varied backgrounds, and by enhancing the repeatability of analytical procedures. The framework provides a base-level application that others can use as-is or build upon with their own sources and methods.

# Scope

The base-level of the application includes 1) loading of data, 2) processing and analysis, 3) graphical and quality review and 4) export of the data. Its design was meant to be open to varied methods used in the study of human movement. Ultimately, these methods are not all that dissimilar to methods in other fields. It is likely those outside the realm of biomechanics would also find this application useful.

Some aspects of data processing are outside the scope of the application. These may require dedicated hardware or complex software solutions, involve high performance computing or complex modeling and simulation.

# Overview

The app has a main application called BAR\_App. This will handle all the configuration settings and dynamic use of modules. Modules are considered any mlapp- or m-file that is dynamically used by the app. Some modules are considered central to the application. These include 1) process\_Groupings, 2) process\_Merge and 3) review\_General. Modules fit into categories named 1) Load, 2) Process, 3) Analysis and 4) Review. These are also the major folders used by the app. Another folder called Subroutines is meant to house low level functions that may have widespread use across other modules. There are examples of some of these methods included with the source code. These will have ‘Custom’ in the file name.

Load modules are mostly functions that read data from a file, package it into a BAR App data structure and load it into the app. They are organized using the file and equipment type. The file type must match the file type of the target file however the Equipment type can vary. An example could be load\_h5\_APDM1Lumbar.m and load\_h5\_APDM1Raw.m. Both read data from the same h5 file but the first reads only the lumbar data while the later reads only the raw data.

Process modules are more general purpose analysis methods. These may include segmentation or other treatment like filtering. They are not considered the end of a processing step and would produce data that is later used in an Analysis module. Process modules are more general in that they may proceed multiple Analysis Modules, whereas the later is considered an end point.

Analysis modules are similar in function to Process modules but differ in scope and intent. Analysis modules are for complex analyses that are more likely to be other mlapp-files. These modules allow users to perform complex operations with significant user input. They often will take time series or aggregate data and produce single metrics or statistics.

Review modules are meant for data visualization. These modules should be mostly mlapp-files that can dynamically produce general or specific figures of the data. For most users the review\_RAW.mlapp module it hoped to be sufficient. For most complex analyses there will be a corresponding Review Module that produces specific figures describing the analysis results.

# Future Work

As of December 12, 2022, the app will only function as hoped within the MATLAB environment. It was hoped that the code could be compiled into an executable that could dynamically use different functions and scripts. This has turned out to be impossible as those scripts need to be compiled at runtime, or a MATLAB server is used. Instead of working on this further the app has been developed as a MATLAB App that can be shared with other MATLAB users.

Future work will produce a quality assurance mechanism within the app. This will allow a user to flag suspect values for further review or exclusion from the results.

A sooner priority is to devise a way to create figures according to group information. This would better allow a user to observe differences between groups. This would be a precursor to offering statistics.

Future versions of the app are hoped to include some level of statistical processing. Currently the export is organized with statistics in mind but there is no capability within the app of doing this. At first it would include calculations for group descriptives and distribution information. Later it could include T-Tests, ANOVAs or more complex modeling.

# Main Application

This section will describe the BAR\_App.mlapp file that is central to the BAR App. It controls the 1) locating and 2) loading of data, 3) processing, 4) analysis, 5) review and 6) export. These functions are mostly accomplished by the different tabs within the app.

## Database Search

Database Search is where all of the file handling will be performed. This starts by setting the Working Database.1 The button will allow a user to select a folder. The app will then check that certain folders exist within it. These include folders named Export, Figures and Results. Export is used as the default target folder when exporting data from the main application. Figures is used by the review\_RAW module and by supported modules as a default folder to save figures to. Results is used to save intermediate data and results. Directories can also be typed into the text field.2 This will not create subfolders but is useful when quickly changing between Working Directories.

Before files can be loaded the app must know where to look for them. Directories can be entered into the search field3, or added through the button4. The app performs a recursive search algorithm that looks through all listed folders and subfolders for the target files. This is generally quick but will be significantly slower on network drives.

### Working Database

The Working Database is expected to be treated as a project folder with specific subfolders. When the button1 is used to select one, the app will check that those subfolders exist. If they do not it will create them. Those folders include: Exports, Figures and Export. Exports contains csv files created by exporting data through the Export tab. Figures is used to save figures created at different locations within the app. Export is the target folder for csv files exported through the Export tab. A Working Database selected through the button1 will also be saved into the config file to be remembered the next time the app is opened.

Users can enter the Working Database through the text field2. This will not create the subfolders or be remembered the next time the app is opened.

### Add Directory to Search

This field contains the directories used by the app the search for the target files. Directories added to the text field with the button4 will be remembered the next time the app is opened. They can also be entered directly into the text field.3 Multiple directories must be listed on separate lines.

### File Extensions and Equipment Types

These are two dropdown lists that specific which files should be searched for. The file extension5 comes after the period near the end of the file name. On some computers the file extensions may be hidden by default. The equipment type6 is the system or equipment that produced the file. This indicates how the data file is organized. When the file extension is selected in the app the equipment type options will automatically update.

The available options are identified when the app is started. It is expected that in the same directory as the BAR\_App.mlapp file there will be a folder called ‘Load’. This should contain all the loading methods named in the format load\_<file extension>\_<equipment type>.m. These files need to organize the data into the required BAR App data structure.

Below the two drop downs is a location to include inclusion7 and exclusion8 tags. Words typed into the Include text field need to be separated by commas. The app will only identify target files that include all of these tags. Words typed into the Exclude text field also need to be separated by commas. Any files including any one of these tags will not be identified by the app. These fields are specifically useful when searching for files from specific experiments or procedures or avoiding files from other projects or analysis efforts.

### Find

This button9 starts the search process to find the target files. The app will identify files with the file extension5 specified, that include the words of the Include7 text field and do not include any of the words in the Exclude8 text field. It is a recursive process where subfolders will also be searched. Searching many subfolders will be slower. It will also be slower searching files located on a network drive.

### Load

This button10 will attempt to load data from the files identified by the app. A progress update will be printed in the log and any errors will also be displayed.

### BAR App Data Structure

Here are the details for the BAR App data structure. Data must be organized into this form for a consistent experience with the app. All the various modules of the app rely on this structure.

|  |  |
| --- | --- |
| - Data | This is the parent level of the structure. |
| - raw | Raw contains raw data. This is data imported directly from a data file. |
| - file | This is an app-determined name for the file. The true file name is not used mainly because 1) illegal characters may be used and 2) file names can be longer than allowed by MATLAB for variable names. The file names are converted to group information and stored at the object level. |
| - meta | This is used to store meta data from the file. Meta data is often included at the top of the files and includes information about who and what recorded the data, and includes other information characterizing the data. |
| - group | This stores group information about the file. The information is pulled from the file’s path by looking for ‘\’ delimiters and is pulled from the file name by looking for ‘\_’ delimiters. |
| - obj | This is called the object level. The idea is this would be named a sensor. Within that sensor there may be various signals and dimensions. |
| - data | This contains the signals. It is largely skipped by the app as it is used to store other information about the data. |
| - sigs | These are the signals that contain the data. They should be numeric arrays with the signals arrayed in columns. Multiple columns represent multiple dimensions of the signal. Multiple dimensions are not required to be located in the same signal. Instead it could be that each dimension is a separate signal. This could be ‘FP1\_X’ or ‘FP1\_Y’ as the signal instead of ‘FP1’ containing two columns. How this is organized largely depends on how the processing or analysis code is written. |
| - freq | This stored the sampling frequency of the signals stored under object. If they have a sampling frequency they are assumed to all have the same. |
| - groups | This contains group information specific to the object. The information is pulled from the object names by looking for ‘\_’ in the name. |
| - pro | Processed contains processed data. These have a similar length to raw data but have undergone some processing method. Process methods may also create results but those would be stored in ana or res.  Sublevels of pro are expected to be the same as raw. |
| - ana | Analysis contains processed results that are not true results but may be used for figures or other analysis methods. They are stored separately from res so they are not exported. They are not stored in pro so they are not mistakenly selected for process or analysis methods. |
| - <Analysis Name> | Under Analysis is the name of the analysis. This could be data.ana.TimeLag, or data.ana.Segment. This is done to separate analysis results so variable names and custom figures can target the results for those analyses. |
| ... | Sublevels for ana are expected to be the same as raw and pro. |
| - meas | Unlike raw and pro, the signals under ana do not contain the data. Under signals are the measures which are the quantified results of an analysis. Measures contains the data in ana and res. |
| - res | These are result metrics. They should be short in length, maybe one value, but may be numerous. They will chiefly be exported by the app. |
| ... | Sublevels for res are expected to be the same as ana. |

### Merge

The merge button11 runs the Merge Module and allows data from a new search to be combined into an existing dataset loaded into the app. This is useful when data from different files need to be combined. This does require a common, but not strictly similar, naming convention between the two files. More on this will be explained in the Process section of the manual.

### Move and Copy

These two methods12, 13 act on files identified by the app. Their data does not need to be loaded into the app. This is useful when many files across multiple directories need to be combined into a single directory.

### Identify Groups

This button14 runs the Groups Module. It has two purposes. First is to identify new or process existing group information so exports do not contain duplicate or extraneous information. The second is to process group information so the merge process is more efficient. More on how to run the Groups module will be explained in the Process section.

### Save Current Data

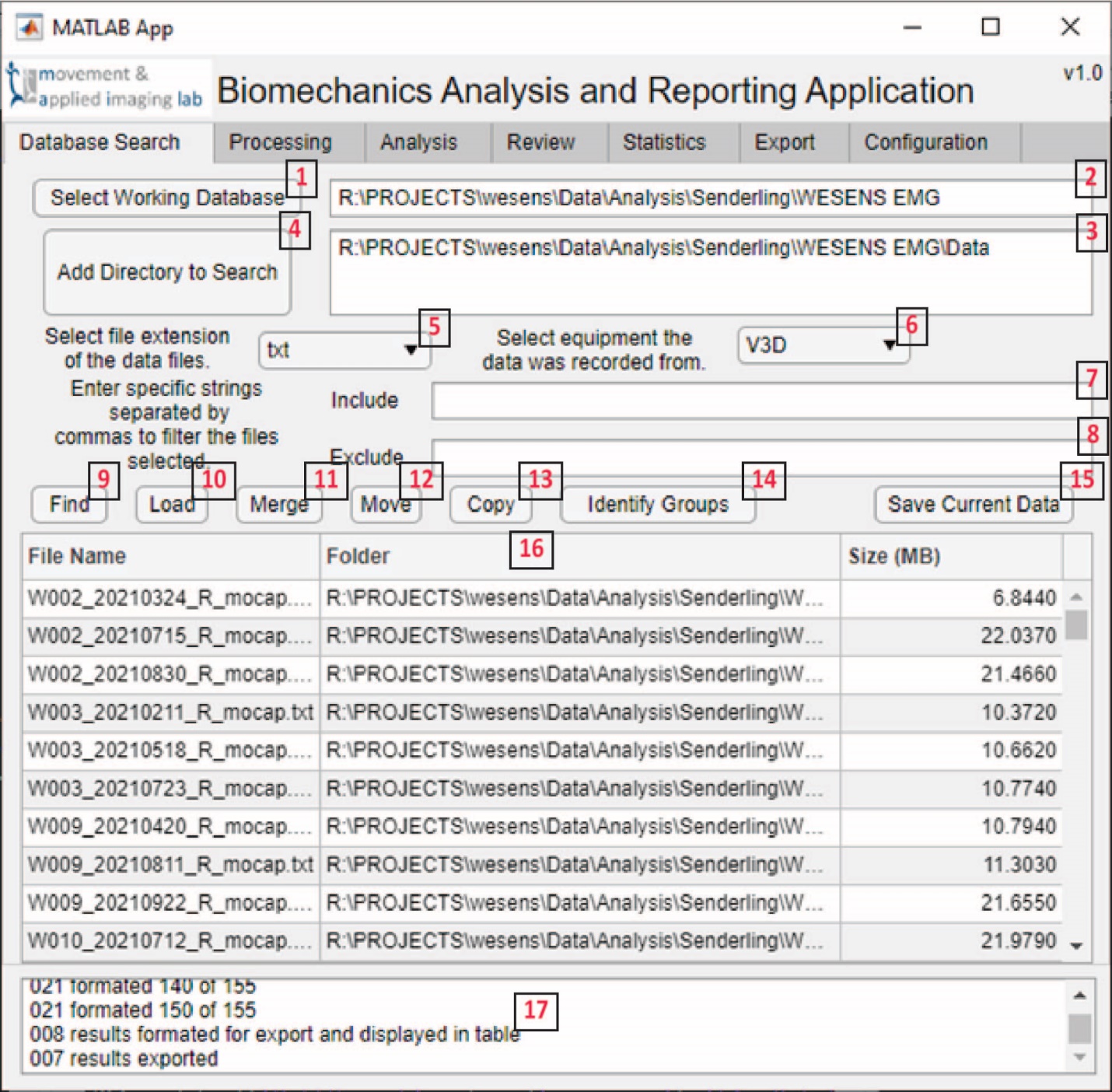
This button saves the current data within the app to a mat-file. This is most useful when used in between processing steps.

### Table

The table16 in the Database Search tab displays the files that were identified by the app. It includes their file name, path and hard drive size.

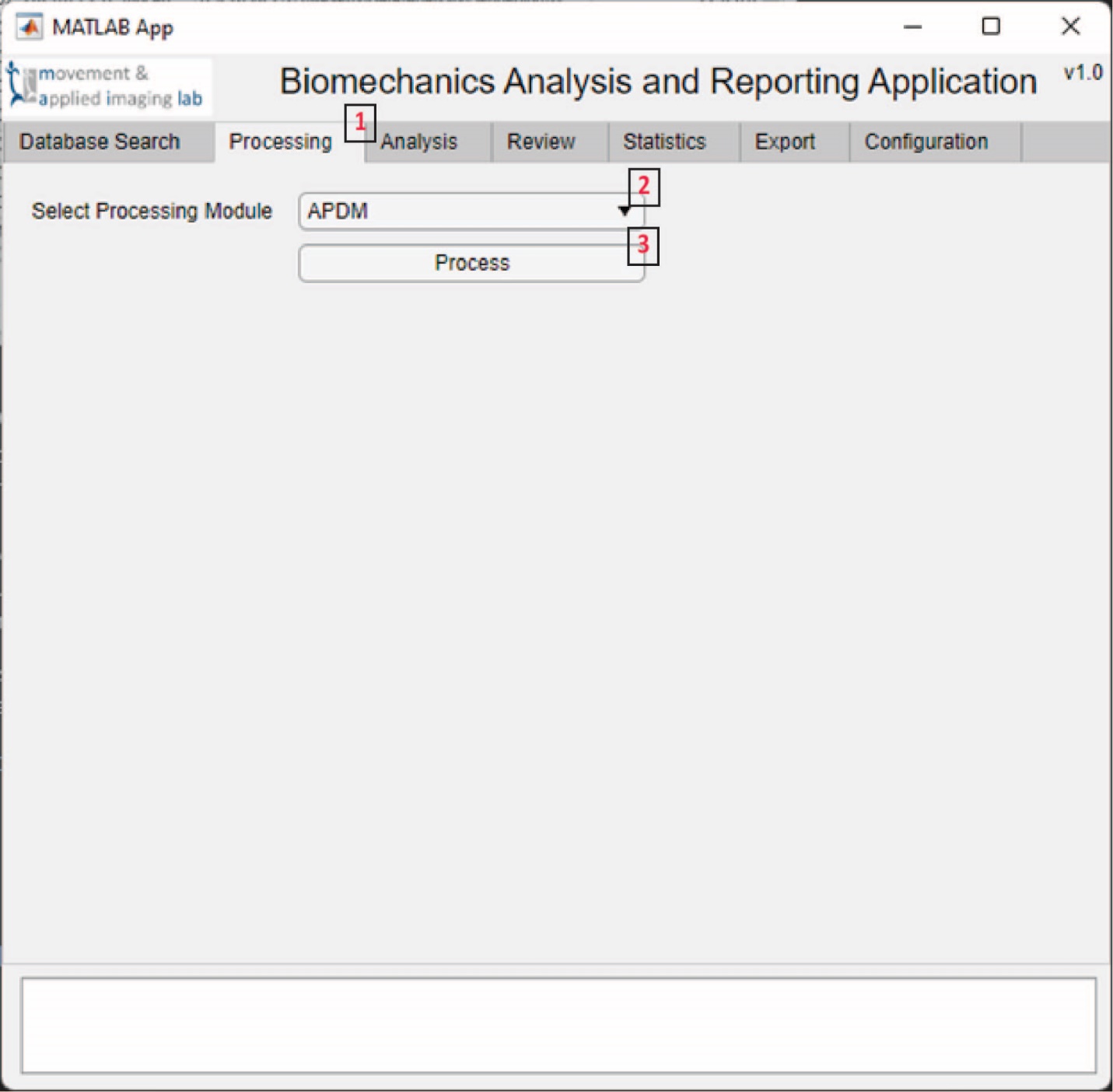
### Log

This log17 is where all messages from the BAR App and its modules end up. Messages are coded with a three letter abbreviation for the app they originate from and a 3 digit number identifying the message. Many of these announce if a process is starting or has completed. Most methods also include an update on how many files they have processed. Some processes also include a catch that will print MATLAB errors to the log.



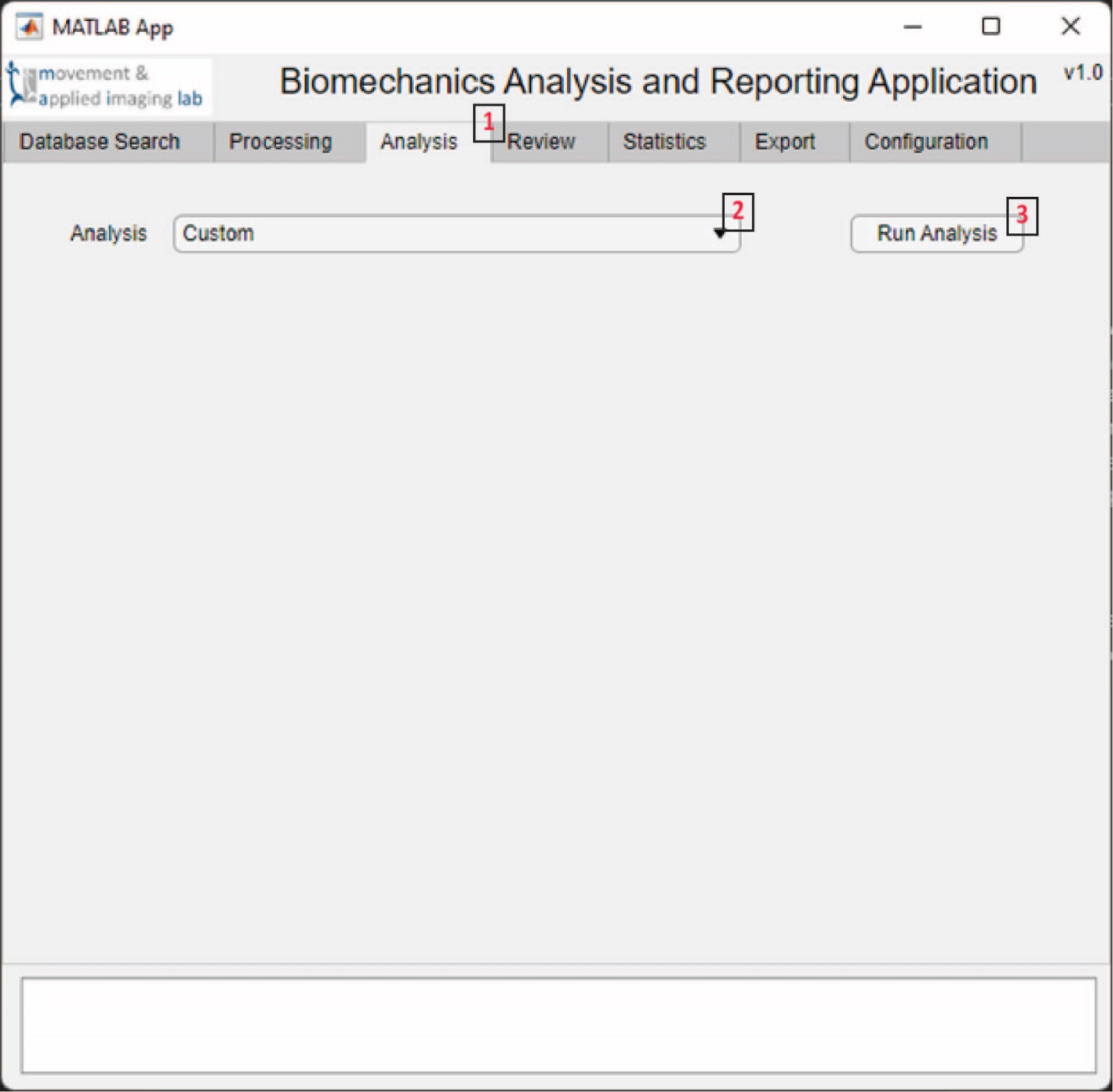
## Processing

The Processing tab1 is used to run Processing Modules. These may be other mlapp-files or m-files. When the app starts it will search the Process folder for files that start with ‘process\_’. The word following this will be the name listed in the dropdown.2 So a file with the name process\_Segment.mlapp would be listed in the dropdown as Segment. Some modules, like the Segment Module, may have other methods. An example would be process\_Segment\_TurnsAPDM.m. This script would not be listed in the BAR App but would be recognized as a method of the Segment Module. Which directories the app looks in for these files is determined in the Configuration tab. Functionally there is little difference between the Processing and Analysis tabs and methods. Data processed with a Processing Module are expected to produce other pro, or raw, data. Data processed with an Analysis Module are expected to produce ana or res data. Once an item is selected from the dropdown select the Process button3 to run it.



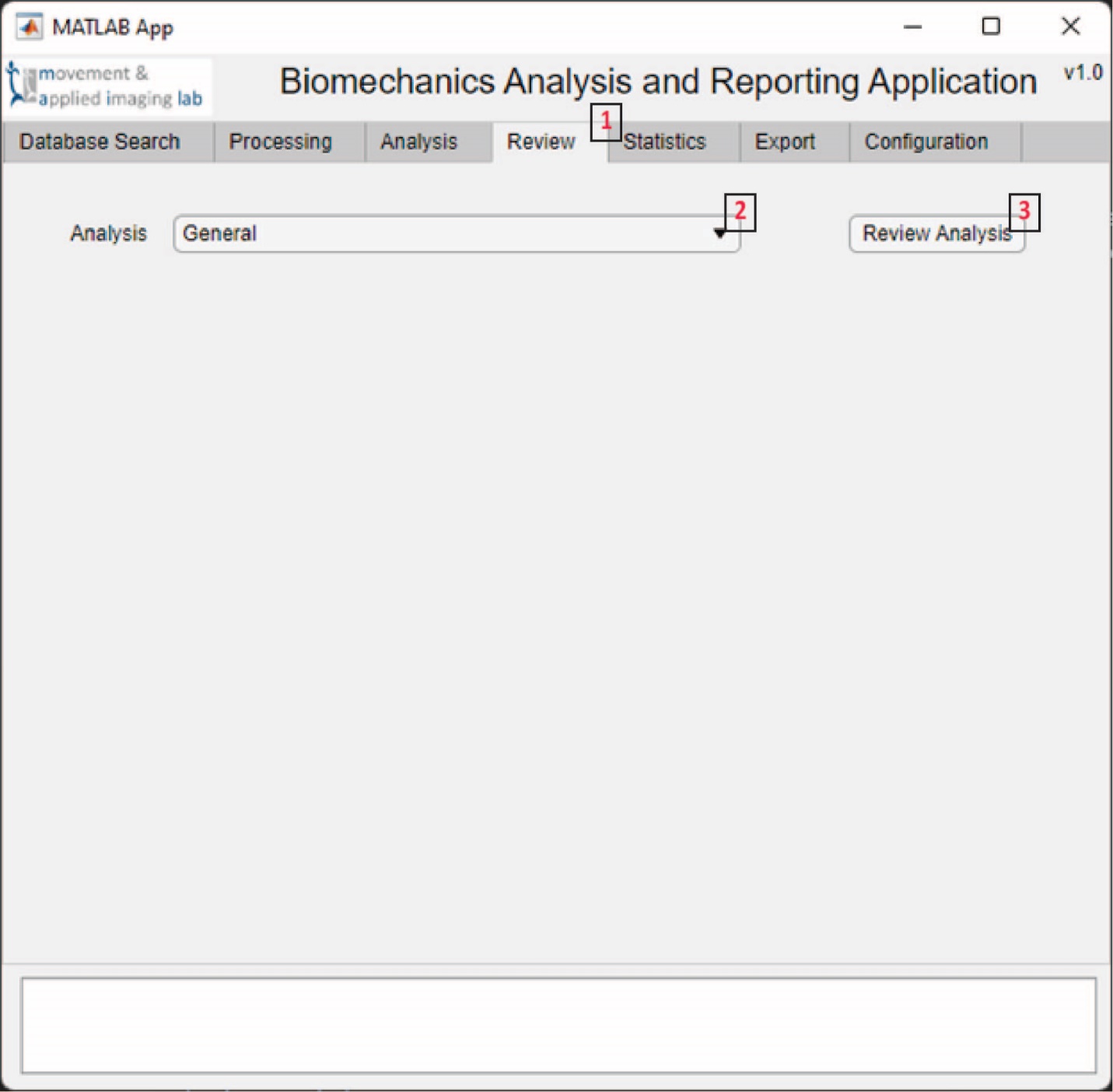
## Analysis

The Analysis tab1 is used to run Analysis Modules. These may be other mlapp-files or m-files. When the app starts it will search the Analysis folder for files that start with ‘analysis\_’. The word following this will be the name listed in the dropdown.2 So a file with the name analysis\_Custom.mlapp would be listed in the dropdown as Custom. Unlike the process modules these methods have not included further dynamic function calling. This is due to the custom and specific nature of some analyses and their reliance on other projects. Analysis methods are not very different from Process methods except they are expected to produce ana or res results that would be used for figures (ana) or exported for statistics (res). Once an item is selected from the dropdown select the Run Analysis button3 to run it.



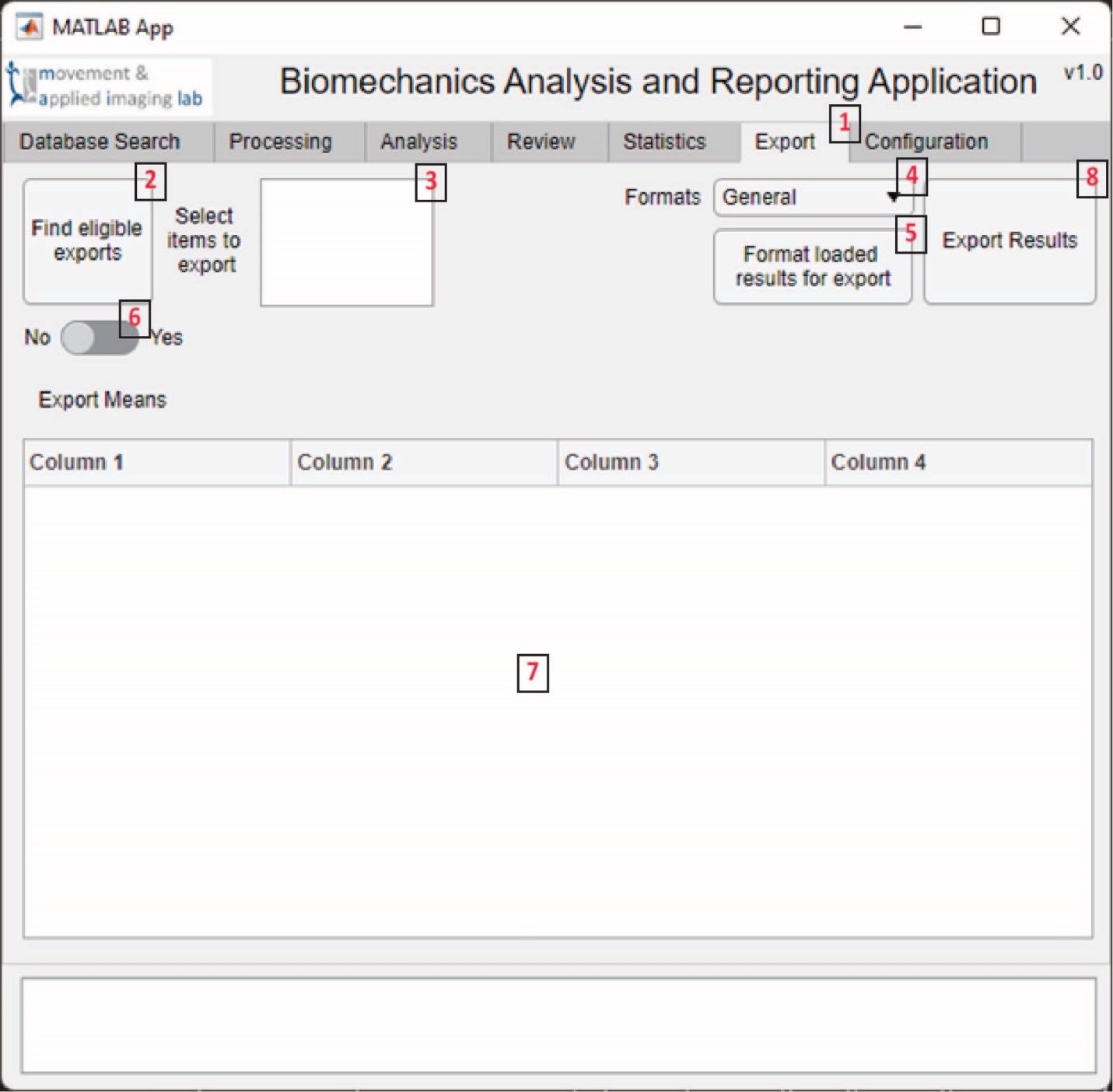
## Review

The Review tab1 dynamically runs Review Modules similar to the Process and Analysis tabs. At the moment there is one Review Module that will also dynamically identify figure scripts. This one module may eventually be incorporated directly into the BAR App. Similar to the Process and Analysis tabs the Review modules are dynamically found. The file names must be review\_<Name>.mlapp, or they may be m-files. The names will end up listed in the dropdown2. Make the selected and then click the Review Analysis button to run it3. The main goal of this tab is to review data and produce figures. More on the single Review General module and the figures will be explained in the Review Module section.



## Export

The export tab1 is used to send data from the app to an xlsx file in a long format that is ready for statistics in another software. First the user must click the ‘Find eligible exports’ button.2 This will find what data types are present in the app (raw, pro, ana, res). Select one of these3 and select a format option from the from the dropdown4. The General format should work for most datasets. Then press the ‘Format loaded results for export’ button.5 There is also an option for means to be calculated or not.6 Selecting ‘No’ will cause all values in the app to be exported. This may produce a very long table if the raw or pro data is selected. Selecting ‘No’ will cause all individual values to be exported. This is useful when the app is used to combine results data from very many files produced by another software. A good example are ascii exports from C-Motion Visual3D that contain the peak joint angles or average step times from a biomechanics evaluation. Formatting the data may take a moment for a large amount of data but is generally quick. Once it has been formatted the results are displayed in the table to they can be reviewed7 before exporting8.

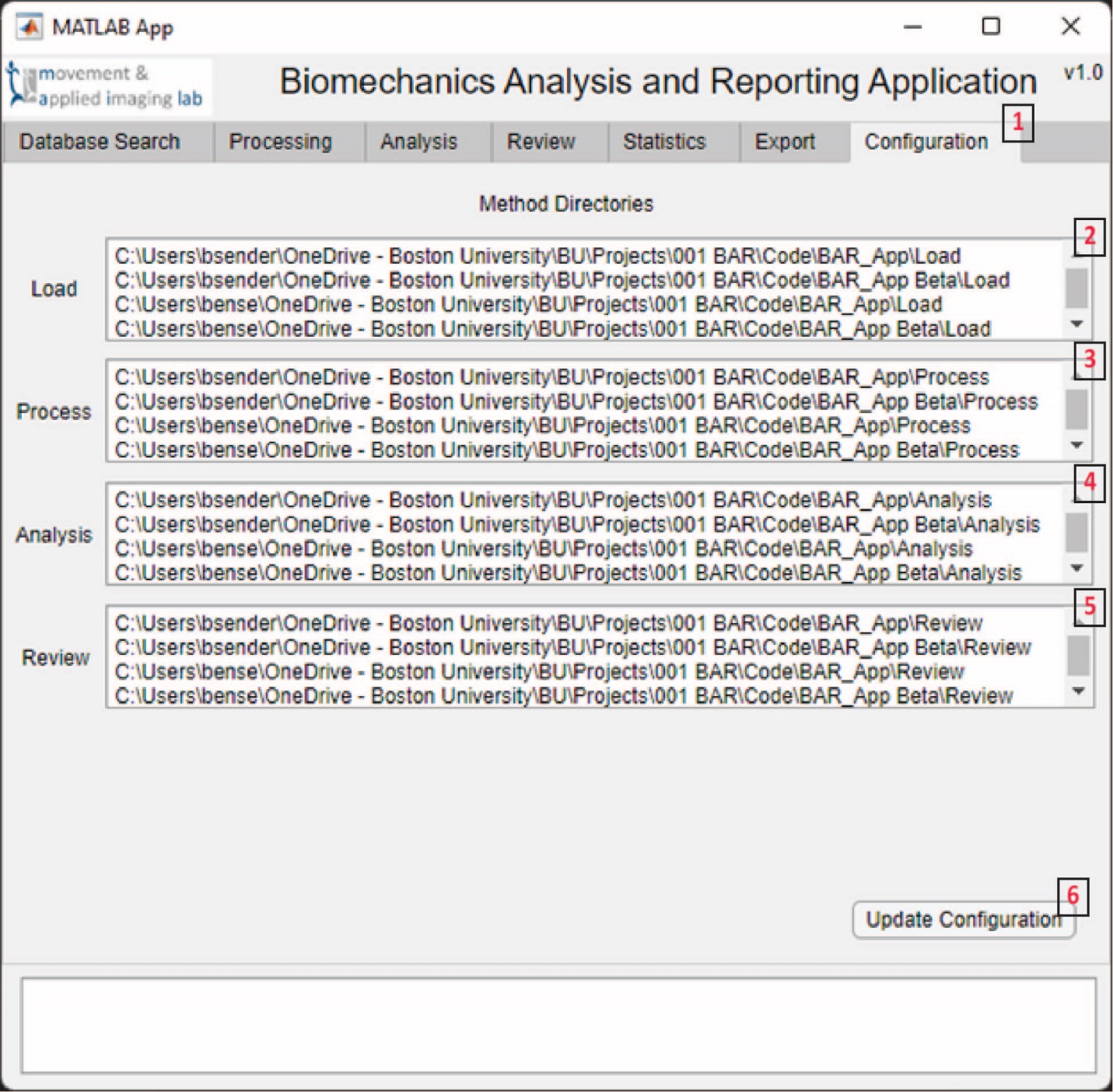


## Configuration

The Configuration tab1 was created to help run the app across different computers and in between sessions. The tab contains four text fields. These contain the directories the app will search to find Load2, Process3, Analysis4 and Review5 methods. Directories can be typed or pasted into the fields and must be listed on separate lines. After being changed the ‘Update Configuration’ button6 needs to be pressed to update the app. This will update the various options across the tabs.

In the example below you can see each field has a ‘Beta’ folder and duplicate folders with a different username. This is an example of how the same methods can be used across computers by the same user.

There is a config.xml file that contains these directories and other information used by the app. This file should be located in the same folder as the BAR\_App.mlapp file. If it is not present the app will create a new blank configuration.



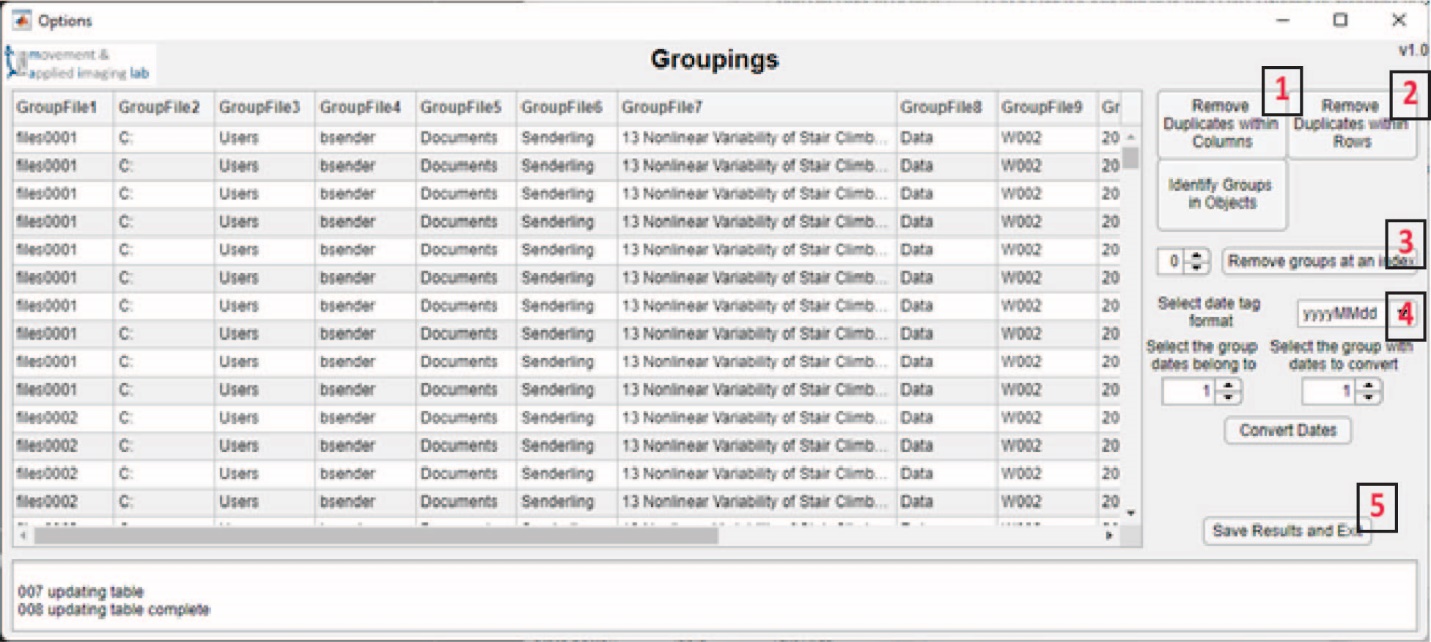
# Process Modules

### Groupings

This module is run from the Database Search tab of the main user interface. It is used to help organize group information used to identify data and perform statistics. It could be subject numbers, visit dates, analysis methods, project names, experiment names, etc. Groups are found primarily during the data loading process. The module then allows those results to be processed.

When data is loaded from a single file the file name is parsed and separated into separate strings. The object names are also parsed. For either case the app will find ‘\’ and ‘\_’ characters and treat them as delimiters to find group information. There is no discrimination during these steps. The groups are found as is. As you can see in the image below the drive letter and user account are also pulled as group information. If a delimiter is repeated, such as ‘\_\_’, this would produce an group filled with empty values.

In the Groupings Module there are generally three methods currently available. First, repeated values in columns1 or rows2 can be removed. An example of repeated information in the columns would be the drive letter or the username. Since this information is repeated throughout all the data it does not offer any discrimination among the results and can be removed to shorten the file. Repeated values in rows would be any string that is found at multiple locations within a file path and file name. An example would be a data file called ‘S001\_20230103.txt’ located in a directory called ‘C:\Users\bsender\Documents\Example Project\S001\20230103’. Because both strings ‘S001’ and ‘20230103’ occur twice the extra values can be removed. Removing them helps conserve processing time in the Merge Module and helps conserve space in any data export. The second method removes groups from any column of data in the table.3 The column number can be entered, and the button pressed to remove that column. This was mainly added after the addition of the third method, which allows strings containing dates to be converted to ordinal numbers.4 The format of the dates needs to be selected as being ‘yyyyMMdd’ (year-month-day) or ‘MMddyyyy’ (month-day-year). The column contains the dates and the column they belong to needs to be selected. The dates will be converted from strings to dates using the selected format. Then they will be ordered within each unique value they belong to. Those ordinal numbers will be added as an additional group. Currently it is assumed the dates will always be at the file-level. Because the dates are converted into ordinal numbers they may cause conflicts in the Merge Module. An ordinal date number would get matched with a trial number, or other integer. For this reason the second method was added. It is best to remove extra groups before running the Merge Module and to convert any dates before data export. Once the processing is complete make sure to click the ‘Save Results and Exit’ button to close the app.5



### Merge

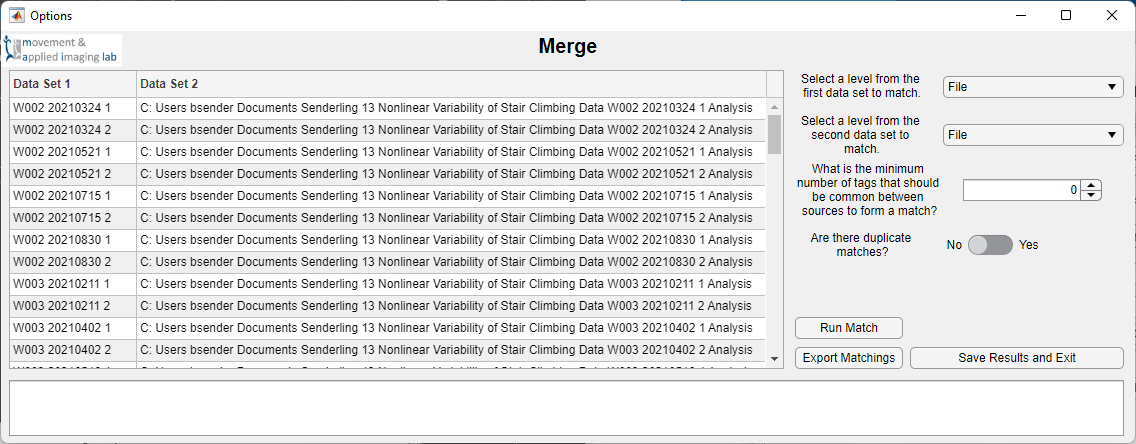
The Merge Module is used to combine datasets. These may include data from different software that are used together in calculations or data that will be used as covariates for statistics. In the later the data may not be used in the app but it is easier to combine programmatically instead of manually later. The merge can take some time for large data sets or for numerous group information.

The module is currently unidirectional. Data from data set 2 will be loaded into data set 1. Data set 1 has been previously loaded into the app while data set 2 has been identified in the file search process. Two options are available for the merge. The File level from data set 1 can be matched with the File level for data set 2. Or the File level for data set 1 can be matched with the Object level for data set 2. During the matching process the group information from one data set will be compared to the other. The total number of matching group information is called the score. The user should select the lowest number of common groups that should be required for a match. In some cases multiple files from data set 2 may be combined into data set 1. In this case duplicate match switch should be set to ‘Yes’. However, in many cases there will not be duplicates and ‘No’ will be selected. This will speed up the matching as previous matches are removed and not considered in future calculations.

In the image below both data sets are being matched at the File level. The first data set has been processed in the Groupings Module and so only has three groups per file. This is a subject number, a date (unconverted) and a trial number. Data set 2 was newly loaded during the module startup and so has not undergone group processing. We can see each of the groups from data set 1 appears in data set 2 once. So the minimal score would be 3.

It is possible that numbers will exist in the group information with different formats. Ex: 1, 01, 001, etc. For these cases there is a check to see if groups can be converted to numbers and produce a match. In this way a file named ‘W002\_20210324\_1’ would be matched with ‘W002\_20210324\_001’ and have a score of three. This is also why it is better to convert group information to dates after a merge is complete.

This process has been found to take longer and will also take significantly longer when using a network drive. Some good practices include using data stored locally on the computer and processing the group information beforehand. To date the algorithm has been found to work well and is reliable, and does not need to be run more than once. However, it is still being developed. To check the process users can export the matching results to save them for later review.



### Segment

The Segment module is part of the Process methods but has its own mini-modules. These mini-modules are found dynamically every time the Segment module is started. They are expected to have the file name ‘process\_Segment\_<Method Name>.m’. These mini-modules are best implemented as scripts with limited user interface. The module’s purpose is to split time series into separate segments. These segments are pro results that can be processed or analyzed further.

Segmentation can be performed on Raw or Processed data. Each time the switch is changed the node tree will be updated with the selection options. These options are the file, object and signal levels of the BAR App data structure. Each time an item is selected in the node tree the module will attempt to process it with the selected method. This is done automatically for individual files, objects and signals. If the segmentation is successful the panels on the left will display the results. The Before panel shows the unsegmented data. Green lines indicate the start of a segment while red lines indicate the end. The After panel shows the segmented data with as many subplots as segments. This figure can be exported to the Figure folder in the Workspace if the ‘Yes’ option is selected to export the figure. If the method is satisfactory then the button ‘Segmental all, save and exit’ can be pressed. This will also create figures if ‘Yes’ is selected.

Segment mini-modules are very specific to individual experiment designs. Currently, only one example is included with the app while a couple others are in development. However, an example mini-module is included to help others create their own. This has the name ‘process\_Segment\_Custom.m’.

Graphical user interface

Description automatically generated

### Treatment

The Treatment Module allows the user to perform data treatment steps on the data ahead of additional processing or analysis. Like the Segment Module this module has mini-modules that are dynamically found by the app. They are expected to have names like ‘process\_Treatment\_<Method Name>.mlapp’. These methods could be scripts or apps but to date have been implemented as apps to make use of the user interface.

The Treatment Module directly serves as an interface for users to add and remove treatment steps. Treatment options can be selected from the dropdown menus and then added or removed. The ‘Process’ button will perform all of the steps and close the module. The table on the left side of the app displays the current steps. These are identified by the unique step number and the treatment name. Currently the treatment parameters are not displayed in the table.

The mini-modules are very short app and mainly involve sending values from the user interface back to the Treatment module. Because of this a Custom example is not provided.

Graphical user interface, application

Description automatically generated

#### Low Pass Filter

This mini-module allows a user to select the parameters for a bidirectional low-pass Butterworth filter. The available cutoff frequencies are between 0 and ½ of the minimum sampling frequency within the data. Currently there is not an option to select parameters more specifically when varied sampling frequencies are present. This method does use FiltFiltM from the MATLAB File Exchange as it has proven significantly faster than the native methods.

Graphical user interface, text, application

Description automatically generated

#### Resample

Resample is a mini-module that allows a user to select a target frequency to resample the data to. It also displays the current sampling frequency. This method uses the MATLAB function resample, which cannot operate on non-integer sampling frequencies. In these cases the sampling frequency will be rounded to the nearest integer.

Graphical user interface, application

Description automatically generated

# Analysis Modules

The follow section describes the different modules available in the current release. Each section starts with 1) a brief description of the module, 2) assumptions regarding the origin of the data, and 3) a description of the results and what their intended use was. Analysis modules arguable perform the most important function of the app and produce the results that would be used for figures, statistics and publications. This User Manual is mainly concerned with the operation of the modules and not necessarily their complex scientific or practical use. References are included where relevant to point users to the most useful publications explain those methods. There are both Custom m- and mlapp-file examples that can be followed to help develop your own Analysis Module.

## MATLAB Dependencies

This analysis will determine what MATLAB products are needed from a selection of m- and mlapp-files. This will mostly be useful to programmers who which to communicate to others what MATLAB products are needed to run their code.

### Assumptions

To run this code there may be some products that are required. These would be products needed to run the BAR\_App.mlapp file. Currently only MATLAB 9.11 is required to run the code. The App Designer would be needed to modify the code.

### Results

The script will produce a list of all the MATLAB products needed to run all the analyzed files. This will look like this.

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Version | ProductNumber | Certain |
| MATLAB | 9.11 | 1 | TRUE |
| Signal Processing Toolbox | 8.7 | 8 | TRUE |
| Statistics and Machine Learning Toolbox | 12.2 | 19 | TRUE |

## Quantitative Sensory Testing

The Quantitative Sensory Testing (QST) module is a single script that processes specific experimental data recorded at the BU MoveLab. The method itself does not require any user input and allows the results to be collected into a single file.

### Assumptions

Technically this script could run on any data loaded into the BAR App but it is expecting xlsx-Medoc data types. This data was recorded from Medoc software and exported as an xlsx file. The procedure was a pressure-pain sensitivity test. In this test an algometer is used to apply pressure to an anatomical landmark. As that pressure is increased at a set rate the subject presses a trigger to indicate the first sensation of slight pain. The xlsx-file will contain information for the pressure, sampling times and the button press. It will also contain information on the sequence and trial numbers, and meta data related to the test.

### Results

The script will produce the following results.

|  |  |  |
| --- | --- | --- |
| Variable | Intent | Description |
| sequenceN | Experiment descriptive | This is the number of the Program Sequence in Medoc that the data comes from. This allows a user to identify a result and trace which trial it came from. |
| trialN | Experiment descriptive | This is the number of the Program Trial in Medoc that the data comes from. Each Program has a Sequence and within each Sequence are Trials. This allows a user to identify a result and trace which trial it came from. |
| valuePeak | Results metric | This is the absolute peak of the recorded pressure. |
| valueEvent | Results metric | This is the instantaneous pressure at the time of the button press. |
| rSquaredAdjusted | Quality metric | This is an Adjusted R2 that describes how well the pressure data fits a linear line. The application of pressure it meant to increase at a set linear rate. Deviations from a linear rate will result in a lower value and indicate lower quality methods. |
| slope | Quality metric | This is the slope of a linear line fit to the data. The pressure should be applied at a set rate. This slope is that rate. |

## Time Lag

The Time Lag Module is used to calculate time lags from time series data. These are often used for state-space reconstruction and additional analyses. It does require input from the user. Currently, only the ability to calculate time lags and to use one method of time lag calculation is available. In the future additional methods would be available and the option to calculate Average Mutual Information (AMI) would be available. A maximum lag does need to be selected. A good rule of thumb is to use the primary frequency of the data. The maximum time lag is entered as a frame count. Lower values will save processing time but the AMI\_Stergiou method used is fairly quick. Occasionally the maximum lag will not be enough to find a time lag and there are options to extend the processing if that is the case. The user can also select if the raw or processed data should be used, and they can select which signals to process. Once the method is complete the results will be displayed in the table. It can be difficult to tell if these values are good or not but a good rule it to treat any time lags under 10 as suspicious. Often, they will be around 1/4th of the primary frequency of the time series.

### Assumptions

This analysis can be performed on any time series data. It does not need to be a particular type or of a particular nature.

### Results

This method will produce the following results.

|  |  |  |
| --- | --- | --- |
| Variable | Intent | Description |
| tau1st  (analysis) | Figure creation | All the lags at which there is a minimum in the AMI verses lag graph. |
| tau1\_rth  (analysis) | Figure creation | The lag at which the AMI drops to 1/5th of its initial value. |
| ami  (analysis) | Figure creation | An array with the lags and their AMI. |
| tau1st  (results) | Results metric | The very first minimum in the AMI verses lag graph. |
| tau1\_5th  (results) | Results metric | The lag at which the AMI drops to 1/5th of its initial value. |

### References

Abarbanel, H. D. I. I., Brown, R., Sidorowich, J. J., & Tsimring, L. S. (1993). The analysis of observed chaotic datain physical systems. Reviews of Modern Physics, 65(4), 1331–1392. <https://doi.org/10.1103/RevModPhys.65.1331>

Thomas, R. D., Moses, N. C., Semple, E. A., & Strang, A. J. (2014). An efficient algorithm for the computation of average mutual information: Validation and implementation in Matlab. Journal of Mathematical Psychology, 61(September 2015), 45–59. https://doi.org/10.1016/j.jmp.2014.09.001

Graphical user interface, application

Description automatically generated

## False Nearest Neighbor

The False Nearest Neighbor (FNN) Module is used to calculate embedding dimensions from time series data. These are often used for state-space reconstruction and in other methods used to analyze dynamical systems. It can be run on any time series data but does require input from the user. Two of these, the R and A tolerances are set to default values in the app that are recommended in Kennel’s publication below. The maximum dimension is also set to a convenient default but can be made higher or lower as needed. Making it lower will save processing time but this method is fairly quick. Likewise, the module can be told to process all dimension or not to. If ‘No’ is selected the method used to calculate the embedding dimension will exit once a good value is found. A time lag is required to run the app and the user can select whether to use the first minimum or the 1/5th value produced by the Time Lag Module. Lastly, the user can specify if raw or processed should be used, and can select which signals to analyze. Once the analysis is complete the table will be updated with the results. Embedding dimensions are integers and typically in the single digits for human movement data. Outliers suggest the presence of noise or artifacts.

### Assumptions

This analysis requires a time lag be calculated first through the Time Lag Module. It does need to be run on time series data but it does not have to be of a particular type of nature.

### Results

|  |  |  |
| --- | --- | --- |
| Variable | Intent | Description |
| dE  (analysis) | Figure creation | This is a single dimensional array with the % FNN for each dimension. |
| dim  (results) | Results metric | This is the selected embedding dimension determined by the algorithm. |

### References

Kennel, M. B., Brown, R., & Abarbanel, H. D. I. (1992). Determining embedding dimension for phase-space reconstruction using a geometrical construction. Physical Review A, 45(6), 3403–3411. https://doi.org/10.1103/PhysRevA.45.3403

Graphical user interface, application

Description automatically generated

## Recurrence Quantification Analysis

This module performs Recurrence Quantification Analysis on time series data. It produces are fairly large number of results and has a significant amount of secondary input parameters. Not all of these have been tested. The user does need to specify those secondary parameters before running the analysis. The method of RQA can be selected. Currently only the RQA method has been tested within the app but there is also cross (cRQA), joint (jRQA) and multi-dimensional (mdRQA). The user can decide to Z-score the time series before analysis. The time series can be normalized according to its Euclidean distance, maximum distance, minimum distance or not at all. A target recurrence rate can be set or a radius set directly. The first is commonly set to 2.5% and this is the default. It does require the analysis to be performed iteratively to reach the target recurrence rate and so takes longer to process. The later requires the user to select a value according the nature of the data. Because the method it only run once at the selected radius it will run faster. A choice of embedding dimension is required. The user can select either the value unique to the time series, the mode, mean or median across all data, or a separate set value. A time lag is required to run the app and the user can select whether to use the first minimum or the 1/5th value produced by the Time Lag Module. The user can specify if raw or processed should be used, and can select which signals to analyze. Once the analysis is complete the table will be updated with the results. Lastly, because this method can take a long time to run there is an option to periodically save the results. This will automatically save the BAR App data structure to a mat-file in the Results folder of the Working Directory. The table will also periodically update with the current results.

### Assumptions

This analysis requires both a time lag be calculated through the Time Lag Module and an embedding dimension calculated through the False Nearest Neighbor Module. It does need to be run on time series data but it does not have to be of a particular type of nature.

### Results

|  |  |  |
| --- | --- | --- |
| Variable | Intent | Description |
| recurrencePlot  (analysis) | Figure creation | This is the full recurrence plot. |
| RQAresults  (results) | Figure creation | This is a Boolean used to indicate if the analysis was successful. |
| DATA  (analysis) | Figure creation | This contains the input time series and is used to create the axis on the recurrence plot. |
| DIM  (results) | Methodological review | The dimension of the output data, maily used for mdRQA. |
| EMB  (results) | Methodological review | The embedding dimension used for state-space reconstruction in the analysis. |
| DEL  (results) | Methodological review | The time delay used for state-space reconstruction in the analysis. |
| RADIUS  (results) | Results metric | The target radius used for the recurrence plot, or the resulting radius found if the recurrence rate was set. |
| NORM  (results) | Methodological review | The type of normalization used. |
| ZSCORE  (results) | Methodological review | A Boolean that is true of the data was z-scored. |
| Size  (results) | Methodological review | The size of the recurrence plot. |
| %REC  (results) | Results metric | The resulting percent recurrence rate if the radius was set or the target recurrence rate if it was specified. |
| %DET  (results) | Results metric | Percent of points on a diagonal line. |
| MeanL  (results) | Results metric | Average length of adjacent recurrent points. |
| MaxL  (results) | Results metric | Maximum length of adjacent recurrent points. |
| EntrL  (results) | Results metric | Shannon entropy of the distribution of the diagonal lines. |
| %LAM  (results) | Results metric | Percentage of vertically adjacent recurrent points. |
| MeanV  (results) | Results metric | Average length of vertically adjacent recurrent points. |
| MaxV  (results) | Results metric | Maximum length of vertically adjacent recurrent points. |
| EntrV  (results) | Results metric | Shannon entropy of the distribution of vertical lines. |
| EntrW  (results) | Results metric | Weighted entropy distribution of vertically weighted sums. |

Graphical user interface, application

Description automatically generated

# Review Modules

Review Modules are used to create figures of the data. They are largely organized into one General Module with separate code being used to create special figures. This is made possible by the organization of the BAR App data structure. In future versions it may be incorporated directly into the BAR App.

### General Review

This module has a number of dropdowns that allow the user to select the data type, data level, the plot type, where to pull additional axes from and data with specific meta data. The dropdown allowing the Analysis or Review Type to be selected will produce specific figure related to those methods. Click the ‘Update Plot’ button to create the figure after making your selections. The ‘Export Plot’ button will export the current figure as a jpg and fig-file. Selecting an additional level to use as additional axes will produce different results depending on the figure. For 2D and 3D plots it will add an addition one or two axis only so a line can be plotted. For 1D and Histogram it will plot additional lines and distributions. Some data can be plotted as an ensemble. When unchecked individual data points and lines will be plotted. If checked the average and standard deviation will be plotted as an average line and grey fill.

### Figures

These mini-modules create figures that are copied into the General Review Module. Like other methods they are dynamically found and assumed to have the name figure\_<Name>.m. The name will appear as a plot type option in the module. Note that this is separate from the dropdown to select the analysis or review type.

#### 1D

This is a one-dimensional (1D) plot with the data as the y axis and the index number as the x axis.

Graphical user interface

Description automatically generated

#### 2D

This is a two-dimensional plot. The first signal or measure selected will be used as the x axis while the second selected is used as the y axis. The dropdown to use additional axis must be selected and two items must be selected.

Graphical user interface

Description automatically generated

#### 3D

This is a three-dimensional plot. The first signal or measure selected will be used as the x axis, the second selected as the y axis and third as the z axis. The dropdown to use additional axis must be selected and two items must be selected.

Graphical user interface

Description automatically generated

#### Histogram

This is a histogram of the selected data. It will work on individual files, objects and signals, but is best used on large amounts of data. If additional dimensions are selected, they will be plotted as separate distributions.

Chart, histogram

Description automatically generated

#### Time Lag

This figure is specific to Time Lag Module results. It will plot the AMI for each selected signal against its lag. The 1st minimum will be circled in red and the 1/5th value circled in blue. In the image below the ensemble option is checked. If unchecked the additional minimums would be plotted as single black dots.

Graphical user interface, application

Description automatically generated

#### False Nearest Neighbors

This figure is specific to the False Nearest Neighbor Module. It creates two plots using the selected data. The top plot shows the % FNN against the embedding dimension and the selected value circled in red. This plot will use the selected items. The lower plot shows the distribution of embedding dimensions for only the selected items.

Graphical user interface, application

Description automatically generated

#### Recurrence Quantification Analysis

This figure is specific to the Recurrence Quantification Analysis Module. It produces a number of figures. The first two at the top are the binary and weighted recurrence plots. For their x and y axes the time series are show. These plots are only shown for the first valid result selected. Below these the module will display histograms of each selected measure. These include only the selected data.

Diagram

Description automatically generated

# Appendix A Data Types

|  |  |  |
| --- | --- | --- |
| File Type | Equipment Type | Description |
| agd | Actigraph | Actigraph uses agd-files in much of its processing in ActiLife. However, they are not the csv exports with the results. These files are not read by the BAR App but can be copied and moved. |
| csv  (unavailable) | Actigraph  (unavailable) | These are the csv exports from Actigraph ActiLife. It does include the spreadsheet exports called: DailyDetailed, DailyTotals, HourlyDetailed, HourlyTotals, SedentaryAnalysis, SleepScores and WearTimeValidation. It does not include the Variables spreadsheet.  (unavailable) |
| csv | BAR | These are csv exports from the BAR App that can be loaded back into the app. |
| csv | Delsys | These are comma separated values exported from Delsys using the Delsys File Utility. When exporting data it is required the option to include headers is checked. Delsys has a number of sensor and file types so this code may not work for all csv-Delsys files. |
| h5 | APDM0Meta | This data type is the meta data from an h5 APDM file. These can be the raw data recordings or processed data from APDM. Only the meta data is loaded to make use of its contents. This increases the speed of the code compared to loading the entire h5 file. |
| h5 | APDM1Raw | This includes both the raw data and the meta data from an h5 APDM file. This is only the raw acceleration, gyroscope and magnetometer and not the quaternions. |
| h5 | APDM1RawLumbar | This includes the meta data and only the raw data from a Lumbar sensor from an h5 APDM file. It includes the acceleration, gyroscope and magnetometer but not the quaternions. Loading only this sensor will save computation time and file size. |
| h5 | APDM2Results | This includes all the data from an h5 APDM results file. This does not include processed data and was produced after processing a raw h5 file with an executable. Meta data is included. |
| h5 | APDM3Qua | This includes the quaternions from all sensors in an h5 APDM file. It also includes the meta data. Raw data is not included. |
| h5 | APDM3QuaLumbar | This includes only the quaternions for the Lumbar sensor from an h5 APDM file. Meta data is included. |
| m | MATLAB | These are the scripts used in MATLAB. |
| mat | BAR | These files contain a single BAR App data structure. |
| mat | QTM | MATLAB data file exports from Qualisys QTM. |
| mlapp | MATLAB | This is the file type of the MATLAB Applications used in App Designer. |
| qtm | QTM | These are the motion capture recordings from Qualisys QTM. They are not loaded into the app but allow the app to move and copy them. |
| txt | V3D | These are text file ascii exports from C-Motion Visual3D. |
| xlsx | Medoc | These are Excel files exported from Medoc software. There are very few options or alternate versions but these may vary with the testing equipment and Program configuration. |