Data Analysis and Management Software (DAMS) for the Vrije Universiteit Ambulatory Monitoring System (VU-AMS)

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1. Recording with the VU-AMS device.

1.1 Requirements

Two AA batteries: Use 1.2V rechargeable NiMH batteries or non-rechargeable 1.5V alkaline batteries. Make sure the bottom contact sticks out (in some batteries it is the covered by an outer plastic ring; these won’t work properly with the VU-AMS). Leave rechargeable batteries in the charger up till the very last moment.

Compact Flash card: External memory card. The VU-AMS5fs has been extensively tested with the 1GB 80x Compact Flash card from Transcend (TS1GCF80) and the 2GB Ultra Compact Flash card from SanDisk (SDCFH-002G-U46).

Compact Flash card reader: Card reader unit to extract the VU-AMS data from the Compact Flash card after recording and to erase the card for a next recording. Any brand or built-in Compact Flash card reader will do.

Electrodes: Typically, seven electrodes are needed for a single recording. We use the 'Kendall ARBO H98SG' single use ECG electrode with Wet Gel for the ICG and ECG. For skin conductance we use the Biopac TSD203 combined with their isotonic electrode gel (GEL101).

Lead wire connector: A blue lead wire connector with 7 lead wires is used for the recording of the ECG and thorax impedance. Optionally a second yellow connector for skin conductance recording is needed.

VU-AMS5fs: The ambulatory recording device.

VU-AMSi (for RS232 or USB): An infrared interface cable that either connects to the RS232 serial port of a PC or to an USB port.
Flashcard with latest firmware (optional): The VU-AMS device comes with the latest firmware installed. From time to time updates will be posted on the VU-AMS website (www.vu-ams.nl). These need to be installed once from an update flash card. Detailed instructions on how to install the update are on the VU-AMS website.

Data Analysis and Management Software (DAMS). The VU-AMS device is configured using this program (referred to as ‘DAMS program’) and measurements can be started and stopped with the program. The DAMS program is also used for primary data extraction and for data reduction. It can be downloaded from the VU-AMS website (www.vu-ams.nl).

1.2 Preparing the VU-AMS device

Always use an empty Compact Flash card with all previous files removed from the card before each new measurement. Put the flash card bottom up in the VU-AMS and then place two completely charged AA batteries in the battery holder. Battery clips are vulnerable so do this carefully. Successful placement is signaled by a triple beep tone.

The VU-AMS is now on standby and the green light will flash twice every ten seconds. This indicates the VU-AMS is ready, but not recording. When the VU-AMS is recording the green light will flash once every three seconds.

1.3 Configuring the VU-AMS device for recording

Connect the VU-AMS to the PC with the interface cable. Connect the infrared end of the interface cable to the VU-AMS; the electronic end of the interface cable goes to the serial port or the USB port of the PC. Start the DAMS program and select Device tab in the main menu. Choose to Connect using Serial cable.
You will now see the configuration screen:

![Configuration Screen]

### 1.3.1 Clock Synchronizing

Before starting, make sure to set date and time of the PC correctly. All dates and times in the VU-AMS data files will be based on the time and date read from the PC at start-up, so it is important to make sure your PC has the correct time and date. Do this by clicking on Set Device Time To Computer Time.

**TIP:** Synchronize the watch of the subject/observer to the exact time of the PC used to start up the VU-AMS for optimal time-locked self-report diaries and physiological data. When electronic diaries are used make sure that their clocks are synchronized with the configuration PC too.
1.3.2 Battery Types

Check battery voltage indication (should be about 3.1 Volt for alkaline and about 2.7 Volt for rechargeable NiMH batteries), and re-check time and date. Though battery voltage gives an indication of battery capacity left, for 24 hour recordings it is safest to start with new alkaline batteries or batteries that were in the charger up till the very last moment.

1.3.3 Set Parameters

Click Set Parameters and fill in the recording identification field. Also fill in the distance measured in millimeter between the two front ICG electrodes for later stroke volume estimations.
1.3.4 Set Channels

The typical sampling frequencies are as shown in the figure below. By clicking on Set Channels you are allowed to set sampling frequencies for the various signals. You can disable signals by setting them to ‘Off’ (like we did with the SCL signal). When changing any setting, make sure to save the settings to the device before closing the DAMS program!

![Channel Options](image)

1.3.5 Set Warnings

Here you can activate or deactivate audio warning signals when ICG, ECG or SCL signals exceed their boundary values. You can also activate warning for low recording space and time-sync problems. These beeps are useful in field recordings when subjects are able and sufficiently instructed to reconnect electrodes themselves. Otherwise it is advisable to turn the warning signals off because the beeps will persist as long as the electrodes are not properly reattached.

![Set Warnings](image)
1.3.6 Set Start and Stop Options

Pressing the button on the VU-AMS device shortly always results in a time marker in the data file. Hence the button can be used as an event marker by the subject during field recordings. You can further program the button on the VU-AMS device to act as a start and/or stop button. If the event marker function is used it is advised to either disable the stop button or to explicitly instruct your subjects to only *shortly* press the black button to mark specific events. Accidentally pressing the button for more than 3 seconds may otherwise stop the recording.

![Start Options dialog](image)

When the top option is selected recording will continue by itself when the battery is replaced (which may be needed during recordings lasting >48 hour). Or even when a subject tries to stop the recording using the black event button. In fact to only way to really stop the recording is using the DAMS program.
1.4 Electrode hook up

1.4.1 Attachment of the ECG/ICG electrodes

Clean the skin at the 7 positions indicated in the figure. Rub the skin firmly with an alcohol soaked tissue or, if alcohol is not available, use a clean dry tissue. Attach an electrode by pressing the sticky plastic brim of the electrode on the skin and subsequently pushing the metal stud at the center of the electrode firmly, to properly spread the contact gel.
**ECG:**

1. Slightly below the right collar bone 4 cm to the right of the sternum
2. (GND) On the right side, between the lower two ribs
3. At the apex of the heart on the left lateral margin of the chest approximately at the level of the processus xiphoidius.

**ICG:**

**Electric current generating electrodes**

4. At the back, on the spine, at least 3 cm (1") above electrode 6
5. At the back, on the spine, at least 3 cm (1") below electrode 7

**Impedance measuring electrodes**

6. At the suprasternal notch above the top of the sternum
7. At the processus xiphoidius at the bottom of the sternum
1.4.2. Attachment of SCL electrodes (optional):

Skin conductance can be recorded from the medial phalanges of the index and middle or ring finger or from the thenar and hypothenar eminences of the hand palms. For the phalanges Velcro straps with an electrode holder that is filled with gel is used, whereas for the palms dedicated SCL electrodes can be used or even ECG electrodes as long as they have a gel with a low NaCl content.

As the sweat ducts acts as parallel conductors it is essential to keep the surface area of measurement constant across subjects.

1.4.3. Attachment of the lead wires and lead wire connector

The blue ECG/ICG lead wire connector has to be plugged in the blue socket. Optionally, the yellow SCL lead wire connector is plugged into the yellow socket.

1.4.4. Wearing the device

Put the VU-AMS device in its carrier bag with the lead wire connector facing up. Fasten the device with the strap in the bag and gird it on with the VU-AMS belt (you can also supply your own belts). Make sure the device is attached in a vertical position.
1.5 Signal Quality Control

After connecting the ECG/ICG lead wire plug to the VU-AMS device, the Online Graph option should be used to display the ECG, Z0, dZ (∝ change in impedance due to respiration and heartbeat) and dZ/dt (= Impedance CardioGram) to check for proper quality of the recorded signals.

1.5.1 ECG

A clear QRST-complex should be detectable in the ECG. The R-wave should be upward and it should be the peak with the largest (absolute) amplitude in either direction (but upward had the most preference). If either S-wave or T-wave are of comparable magnitude re-attach the black(+) ECG electrode first more laterally then more medially until a satisfactory QRS complex is seen.
1.5.2. Z0, dZ, dZ/dt

The dZ should be within -0.5 and +0.5 Ohm most of the time. Z0 should always stay within an 8 to 20 Ohm range. The dZ signal should reflect deep breathing clearly. In the ICG the typical upward waveform of the cardiac ejection phase should be clearly detectable. Light movement of the subject should not overly distort it. If these criteria are not met, re-attach the electrodes in the order 7,6,1,3,4,5,2 (see illustration at 1.4 Electrode hook up) until satisfactory signals are obtained. The scrollbar on the Y-axis of the online graph can be used to scale the signals (or hit F5 to auto scale).
1.5.3. SCL

The SCL signal should be within a 1 to 12 micro Siemens range. Spontaneous phasic responses should be discernible in most subjects and an orienting response to a sudden unexpected stimulus should also give a phasic increase (e.g. clapping hands behind the back of the subject).

**NOTE:** In ambulatory paradigms, online signal inspection is your **only opportunity** to re-attach faulty electrodes.
1.6 Starting a measurement

When satisfied, start data recording by pressing Start in the configuration screen. A beep will be heard to acknowledge the start of the recording and the green light will start flashing once every three seconds. Close the configuration screen of the DAMS program and disconnect the VU-AMS device from the interface.

1.7 Marking special events

A small black button is placed on top of the VU-AMS device next to the two lead wire plug connectors. To mark a special event during the recording, push this button shortly. Pushing it will be confirmed by a short beep.

1.8 Is the VU-AMS device recording?

A small indicator light on top of the device will be flashing once every three seconds as long as the VU-AMS is recording.

1.9 Stopping a measurement

The measurement by the VU-AMS device can be stopped by:

1) Reconnecting the device to the PC and connecting again by serial cable by choosing the appropriate action in the DAMS menu under Device. You can now press Stop. This is the preferred method. Close the DAMS program and then disconnect the device from the interface cable.

2) Pressing the event button for more than three seconds. This requires that the option of stopping with the event button was enabled in the Set Start Options menu. After this action the light will flash every 10 seconds to indicate standby mode. The method is preferred when subjects have to stop the recordings themselves at home at a designated time. NB: When the device is returned to you after a day of ambulatory research, make sure to check whether (1) the
measurement has been stopped already with the button (the light flashes twice every ten seconds), (2) is still recording (the light flashes every three seconds), or (3) has stopped because of empty batteries (the light does not flash at all).

3) Removing the batteries. This is strongly discouraged as it may lead to corrupted data files (0 KB).

Once the VU-AMS has stopped recording, the yellow and/or blue lead wire plug(s) may be disconnected from the VU-AMS device and the lead wires from the electrodes. Now remove the batteries and place the Compact Flash Card in the card reader. Move the .5FS data file to a designated directory.

1.10 Saving an .amsdata file

Double click the .5FS data file to open the recording. When you close DAMS it will automatically save the data in a new file with the extension .amsdata. This file can be opened by using the Open data option in the main menu or just double-clicking it. Using .amsdata files (once these are created) will make DAMS load the data much faster. Also all manual scoring will be saved in the .amsdata file.

NB: you can batch convert .5FS files to the .amsdata format. Files recorded with the older AMS 4.6 system can be converted too, but no visible ECG signal will be present as only the inter beat intervals were stored with this device and not the ECG signal itself. Click on batch convert in the menu and select the folder with all .5FS or .ams raw data files together with the .lbl and .cfg files (they need to be placed in one directory). After conversion the folder will contain an .amsdata file for each of the raw data input files.

1.11 Merging multiple .5FS files

If the recording has been interrupted by the experimenter or by the subject (because the participant took a shower or batteries have been replaced), multiple .5FS data files with different start times will be generated. There is a possibility to use a standalone tool, AmsMerge, that concatenates the .5FS files into a single .5FS file that spans the entire recording. The AmsMerge program can be found in Start menu >> Programs >> VU-DAMS folder from version 2.2 and up.
2. Data Analysis and Management with the DAMS program

Use the DAMS program to process the VU-AMS data. Double clicking on a .5FS file will open the file once the DAMS program is set to be the default program to open it with.

The typical flow of VU-AMS data analysis and management is represented by a series of tabs in the main screen:

1. Inspecting the raw data
2. R-peak detection and correction
3. Labeling your data
4. Spectral analysis
5. Impedance scoring
6. Respiration / RSA scoring
7. Exporting the results (label-based)
2.1. Inspect Data

The *Inspect Data* tab simply gives you an overview of your data. All recorded signals are shown as continuous time series. Recording time is at the lower line. Above the recording time, the Inter Beat Interval (IBI) time series is given as extracted from the ECG. The clock time and IBI signal of the entire recording will be presented in all data analysis tabs, and function as orientation point. Zooming can be done by changing the size of the hatched rectangle in the IBI window (select one of the borders of the rectangle and drag with the mouse cursor). Vertical lines represent the times at which the event button was pressed.

All actions for the *Inspect Data* tab are presented in the form of buttons:

These actions and their keyboard shortcuts are also available in the dropdown menu Actions. This setup goes for all tabs in the DAMS program. Only the type of Actions will differ per tab.
The function of these buttons should be self-explanatory. Hovering the mouse cursor over a button will display a short description. The mouse can also be used to zoom in and out: By using the mouse wheel a shorter or a longer period of the recorded data can be shown. Zooming can also be done by dragging the darker grey rectangle just below the time line. Moving the lighter grey rectangle in the middle will move the data either right or left.

Each of the signals can be autoscaled separately by right clicking on the Y-axis of the signal.

### 2.2 Detect R-Peaks

The *Detect R-Peaks* tab will assist you to create an artefact free IBI signal as fast as possible by applying automated artefact and peak detection. The mandatory visual inspection and correction of the resulting IBI signal is made as easy as possible by multiple zoom levels and an automated suspicious beat detector. The default settings of this detector work well on most of the ECG recordings but changing the peak detection settings can be required in case of noisy or strongly deviant ECGs.

After opening either the raw *.SFS* or a saved *.amsdata* file click on the *Detect R-Peaks* tab. The QRS detector software runs three separate automated analyses on the ECG signal. The first automated analysis detects and marks periods with missing data or clipping of the electrocardiographic signal. These periods are called artefacts. A second automated analysis of the QRST waveform detects the
occurrence of all R-peaks. The R-peaks are converted to the inter beat intervals time series which is simply the distance in milliseconds between two consecutive R-peaks plotted against time, giving rise to the continuous line seen in the lower and upper top windows. The third automated analysis checks the plausibility of the duration of each IBI in the context of its surrounding inter beat intervals. This feature was created to ease visual inspection and user-driven correction of the IBI time series.

All actions for the *Detect R-Peaks* tab are presented in the form of buttons:
The function of these buttons should be self-explanatory. Like in all other tabs hovering the mouse cursor over a button will display a short description.

2.2.1 Visual inspection and manual correction

Automated artefact labeling reliably detects clipping and signal loss, but detection of noisy ECG is not perfect. Manual selection of bad ECG signal parts may be additionally needed. The three main windows will help you select the parts of the IBI time series that need to be manually labeled as artefacts. The bottom window is our
overview of the IBI signal of the entire recording that is also present in the other modules (tabs) of the Data Analysis Management Software.

What is marked as a grey bar in the first top window will be displayed in the second middle window. The X-axis of the IBI time series in these windows represents the time at which a beat was recorded. The Y-axis of the IBI time series is the interval duration of that beat in milliseconds. The third lower window displays the actual ECG signal. You can zoom the ECG window in or out by dragging the dark grey area in either of the IBI time series windows. You can also zoom in or out by using the scroll wheel of the mouse on the part of the data you want to see in more detail. By using the mouse wheel a shorter (scroll forward) or a longer (scroll backward) period of the recorded data can be shown. Selecting a different part of the recording can be done by changing the size of the hatched rectangle in the IBI window at the bottom (select one of the border of the rectangle and drag with the mouse cursor) or by moving the rectangle left (backward in time) or right (forward in time).

2.2.2. Removing artefacts

In the ECG artefacts Bar all automatically detected artefacts and user-supplied artefacts are labeled by a red bar. These artefacts are deleted from all further data analyses.
In the main window with the ECG signal the detected R-peaks are marked by vertical lines, mostly blue. A blue line means that the beat was considered to be correct according to the automatic beat detector. Potential mistakes in automated beat detection are termed ‘suspicious beats’ and are flagged by a red or yellow color. Some parts of the data might not be bad enough to be detected by the automated artefact detector and at the same time they are too noisy for the R-peak detector. Hence the R-peak detector will try to make something out of noise and may still score occasional beats as being correct (blue) where they are not. These periods of noisy data will also contain a lot of red and yellow lines which makes them easy to detect.

These noisy parts may arise because an electrode became (partly) detached. This is known to happen occasionally in unsupervised ambulatory recordings. To find noisy parts from the IBI signal, search for deviant parts in the bottom IBI time series window. The IBI time series will be highly irregular with sharp peaks/spikes in the IBI time series wherever the detector failed (as it assigns inter beat intervals that are disproportionally long or short). Zoom out so the entire artefact period is visible in your screen to make deleting easier.

To mark the bad ECG as an artefact, click with the left mouse button in the artefact bar and drag it from left to right until it covers the entire period that is to be marked as an artefact.

*Find the artefact period:*
Select the artefact period:

And remove the beats within the artefact period:

You can also wait until all periods with missing data or artefacts have been marked and then use the option *Delete Beats Under Artefact* in the menu bar or use the shortcut Ctrl+D. The IBI signal should look much more smooth now. As stated
before, the beats within the periods labeled as artefact will be ignored in all further analyses with the Data Analysis Management Software.

2.2.3 Suspicious beat correction

In the main window’s top left corner the number of suspicious beats are displayed. For highly suspicious beats the R-peaks are marked in red. R-peaks in less suspicious beats are marked in yellow and R-peaks marked by blue lines are considered to be correct.

You can easily browse through all suspicious beats from most to least suspicious by pressing Dot/right pointer keyboard key for next, and comma/left pointer keyboard key for previous suspicious beat. Or you can simply use the menu buttons at the top of the window. When you are at a suspicious beat you can either delete a beat by right clicking on it, e.g. when a beat was placed in an obvious wrong location in between beats. Or you can add a beat by left clicking on the correct location of the R-peak, e.g. when a beat was completely missed. Notice that the surrounding beats might also change color when adding or deleting a beat. You can also move a beat
by placing the left mouse button on the vertical line and then move it left or right. Releasing the mouse button will lock the vertical line to its new location.

After your corrections (or in fact at any time) you can select the menu button re-check suspicious IBI’s to see how many beats are still considered suspicious. Just remember that suspicious is not wrong per se!

It can happen that you can have a perfect IBI time series with no misplaced beats, but that the DAMS program still reports some suspicious beats. This is because strong sinus arrhythmia may throw the beat detector off and extrasystolic beats always will. Clearly, suspicious is not always guilty.

**NOTE:** You can also choose to export the inter beat time interval series to a text file for use in different software packages like the CarSpan or Kubios by clicking on the menu buttons ‘Export Beats To ASCII File’. Chose the appropriate directory and file name and save the IBI time series as a text file.

### 2.2.4 Adjustment of R-peak detection in deviant ECG signals.

When an ECG signal is of good/reasonable quality but you can clearly see that the automatic detector placed the beats anywhere but on top of the R-peak, you should rescan the complete ECG signal with different settings for the detection algorithms. The default settings for the algorithm upon opening the .amsdata file can be changed in the main menu by selecting Edit → Settings → QRS Detection. You can also use the Rescan bar to select only a certain part of the recording. Drag your mouse across the incorrectly scored part of the ECG (minimum rescan length is 10 seconds) in the Rescan bar while holding the left mouse button.
A pop up screen with 5 sliders (the same as in the settings screen) appears. You see a high and a low Threshold slider and three Relative weight sliders that change the weight of the peak amplitude, the downward slope, and the upward slope. The algorithm calculates a Peak score based on the sum of these parameters multiplied by their weights, and then divides this by the sum of the weights. The R-peaks of the selected area will be rescored when clicking on Rescan. This peak score will be used in combination with the threshold sliders/settings, such that all peaks with a score between the low and the high thresholds will be considered an R-peak. Set the sliders as desired and press Rescan to apply the new settings on the selected part of the ECG signal. Adjust the settings until satisfied.

*Please also see the “R-Peak Detection” tutorial video for a demonstration: www.vu-ams.nl/support/tutorials/software/r-peak-detection
The default values can be changed in the settings screen:

Peak score = \( (\text{Weight 1} \times X1) + (\text{Weight 2} \times X2) + (\text{Weight 3} \times X3) / (W1 + W2 + W3) \)
2.3 Labeling your data / dividing your data into separate pieces

Here you divide the continuous data collected with the VU-AMS device into logical periods for further analysis. We call this labeling. The aim of labeling is to get an average value for each available parameter, such as HR, PEP, and RSA, for each experimental condition or ambulatory activity.

Click on the *Label Data* tab. In the upper window we see the raw IBI time series and/or the smoothed (and hence lightly time lagged) heart rate signal. Because the heart rate signal is dependent on the quality of the IBI time series, make sure the R-peaks have been detected correctly in the *Detect R-Peaks* tab. In the lower window we see the ‘motility’ signal. This signal is based on the Y axis of the tri-axial accelerometer. The clock time and IBI time series are presented in the two bottom windows, which will help us to quickly locate our current position in the total recording.

All actions for the *Label Data* tab are presented in the form of buttons:
The function of these buttons should be self-explanatory.

### 2.3.1 Creating a Label Configuration File

Before we can actually begin labeling the data, we need to create the blueprint for all possible labels first. This blueprint lists all the experimental conditions or ambulatory activities in our experiment. This is done in the label configuration file (.cfg file). The easiest way to create a label configuration file that suits your purpose is by manually creating or editing a text file. A main category is always indicated by a hash key, (#) followed by the name you want for that main category. Then each level of that category, in the example below these were all the experimental conditions, needs to have a unique numerical value followed by a name for each condition. Save it under a logical name with the extension .cfg.
When you are done creating the label configuration file you need to make sure that the DAMS program recognizes this file. To do this; Go to the main menu → Actions → Edit Label Configuration → Import Label Configuration From File. Now select the label configuration file you manually created and click open. When the same label configuration file is used for a longer time, like for an entire research project, you could click on the option Set Label Configuration As Default.

### 2.3.2 Labeling your data

Now you can start the actual labeling of your data. If you have notes containing the start and stop times of each condition, you can use the top bar where it says “Click and Drag to add Labels”. When hovering the mouse on the bar you will see an indicator of the time window appear. This will help you place the starting point of your label accurately. Click with the left mouse button in the top bar at your starting point and drag the mouse to the right until the desired end time of the label is reached.
A dashed vertical line will also appear on both ends of the label extending into the motility signal. This may help you remove the transition periods with movement between two experimental conditions from the final labeled data.
Note: The motility signal becomes indispensible when labeling VU-AMS data from self reported activities in diaries as often done in 24-hour ambulatory recordings.

A pop up screen with our previously defined categories will appear upon releasing the mouse button. From our category “Experimental_condition” we choose the level “Baseline” and click OK. The pop up window will close now and a colored bar appears representing the new label. You can verify the information in the label by hovering with the mouse on top of it. If you want to edit or delete a label, just right click on it and choose the required action from the popup menu. If you want to change the length of the label click and drag with the mouse on the edges of the label. To reposition a label, click and hold the left mouse button on the label to grab and move it around.

Repeat the labeling process until all relevant periods (i.e. all experimental/ambulatory conditions) are labeled. Each label will be represented by a row in the excel sheet obtained under the Label Information tab.

2.3.3 Use of event button marker lines

In case of an experiment you have the option to use the event button of the VU-AMS device to mark the beginning and ending of each condition. Shortly pressing the event button on the VU-AMS device creates a marker in the data at the exact time the button was pressed. These markers are displayed as lines here, and help us to more easily detect the start and stop times of each experimental condition. So, we can use the marker lines or our notes with start and stop times or a combination of both, to make sure we label the correct periods for all conditions.

When working with the marker lines generated by the event button of the VU-AMS device you have the possibility to automatically place a label exactly between two marker lines. By clicking with right mouse button on the label bar between the two lines, we get the option to place a label between the lines automatically.

Note: In laboratory studies that use a stimulus computer, this computer can be used to send markers through the VU-AMSi infrared interface cable. Please refer to VU-AMS website: www.vu-ams.nl/support/downloads/extras
2.3.4 Time based labels

Instead of predefined category labels representing a specific condition, you can also choose to create time-based labels, where all labels represent a fixed amount of time that can last in duration between 10 seconds and 1 hour. This is especially useful if you want to generate continuous 60 sec ensemble averages of the impedance cardiogram for PEP scoring instead of a large scale ensemble average that spans an entire condition.

To do this use; Actions → Add Time-Based Labels and type in the amount of seconds you want each label to be. The entire data is now cut up into labels with your pre-defined length.

*Please also see the Data Labeling tutorial videos for a demonstration: www.vu-ams.nl/support/tutorials/software/data-labeling
### 2.3.5 Labeling Naturalistic Recordings

The previous example assumed a supervised setting with fixed experimental conditions of which start and end times were under the experimenter’s control. This is of course not the case in ambulatory recordings in naturalistic settings. Still many of the principles apply, as “real life” can also be divided into periods of ‘fixed’ and frequent occurring activities.

To create a label file that will capture most daily activities of the subjects in your target population is a crucial but feasible step in ambulatory data analysis. As the autonomic nervous system is highly sensitive to changes in posture and physical activity it is first of all very important to obtain information about these aspects of a subject’s daily routine. This is usually done by asking all subjects to keep a detailed diary (paper-and-pencil or electronic hand held devices) during the ambulatory measurement day. This diary information about (changes in) posture and physical activity is then used during the labeling procedure. The VU-AMS device also contains a tri-axial accelerometer to support this self-report with objective data. Further categories to be used in the ambulatory labels will entirely depend on the research question and the target population. Here are some examples of categories that could be considered:

<table>
<thead>
<tr>
<th>Category</th>
<th>Levels of Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of activity</td>
<td>Reading, attending a meeting, eating, dancing, PC work, conversing, watching TV, exercising, attending a musical, car driving, ironing, etc.</td>
</tr>
<tr>
<td>Posture</td>
<td>Sitting, standing, lying, walking, etc.</td>
</tr>
<tr>
<td>Physical activity</td>
<td>Heavy, moderate, light, none</td>
</tr>
<tr>
<td>Social situation</td>
<td>Alone, with significant other, with friends, With colleagues, etc.</td>
</tr>
<tr>
<td>Location</td>
<td>At home, at the office, travelling, restaurant, etc.</td>
</tr>
<tr>
<td>Time of day</td>
<td>Work, leisure time, sleep</td>
</tr>
<tr>
<td>Mood state</td>
<td>Angry, friendly/happy, sad, anxious, tired</td>
</tr>
</tbody>
</table>
When you have decided on the type of categories you want to use during labeling you again need to summarize these in a *label configuration file* (default name `label.cfg`). An example for a 24-hour recording project is given in the figure below.

![Example label configuration file](image)
In the label configuration file all ambulatory activities you might want to use as separate conditions in future analyses should be present as all further processing in the DAMS program is tailored to the labels.

When you are done creating the ambulatory label configuration file you need to make sure that the DAMS program recognizes this file. To do this use; Actions → Edit Label Configuration → Import Label Configuration From File Now select the label configuration file you manually created and click open. When the same label configuration file is used for a longer time, like for an entire research project, you could click on the option Set Label Configuration As Default.

Now you can start the actual labeling of your data. Using the subjects’ diary estimate the start and stop times of each activity. The motility signal can be extremely helpful to detect posture transitions and changes in physical activity which are the natural boundaries of changes in real life activities (e.g. when the subject reports “sitting desk work, walking to my car, driving home” three distinct motility patterns will be evident).

Use the top bar where it says “Click and Drag to add Labels” and click with the left mouse button in the top bar at the starting time and drag the mouse to the right until the desired end time of the label is reached. The popup window that appears after the label is drawn will reflect all categories in the label configuration file:
For each labeled period start and end times are given as well as a set of codes and text labels describing the state of subject during that period in terms of location, posture, physical exertion, social situation, type of activity etc..

When done, make sure you have labeled all periods that might be considered of interest. There seems to be no urgent need to also label periods that you consider to be "irrelevant" or that are expected to occur in only a few subjects. However, we advise to always label the entire 24 hour recording as completely as possible. With an average length of labeled periods of 20 minutes this would result in about 72 labels per subject.

2.4 Analyze Frequency

All actions for the Analyze Frequency tab are presented in the form of buttons:
The function of these buttons should be self-explanatory.

2.4.1. **Analyze Frequency explained**

Spectral analysis in the Analyze Frequency tab is performed on the corrected IBI time series according to the following method:

The IBI time series within each label is interpolated with a cubic spline and the resulting function is resampled at 4 Hz. The resampled signal is split into overlapping periods of 256 seconds, each with 1024 data points. The overlap between two consecutive periods is 128 seconds. Periods that have intervals longer than 5 seconds without IBIs are discarded. Missing data from the final period are padded with zero’s. Each period of 1024 data points is convoluted with a smoothness prior matrix ([An advanced detrending method with application to HRV analysis, Mika P. Tarvainen, Perttu O. Ranta-aho, and Pasi A. Karjalainen](https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1742-1242.2009.05007.x)) to yield a stationary signal on which a discrete Fourier analysis is performed after additional convolution with a quadratic window. Power values for each of the 1024 data points are then averaged across all available periods in the condition (Welch method). Next the total power in the 0.0001 Hz to 0.4 Hz range is computed (TP) as well as the power in the 0.04-0.15 Hz band (LF) and the 0.15-0.40 Hz band (HF). It is important to note that the IBI time series is first detrended and ‘corrected’ by interpolation to deal with too short and too long IBIs (e.g. in case of an extrasystolic beat) because slow trends as well as strongly deviant beats can distort the spectrum. Because at least 4 minutes are required to obtain a reliable estimate of the LF power, these values are not supplied for labels with a duration shorter than 4 minutes.
2.4.2 Change Settings

In case you want to change the default settings of the power spectral analysis you can do this in the main menu by selecting Edit → Settings → Frequency Analysis. Settings for preprocessing affect detrending and deviant beat removal (‘artefact’). The frequency bands reflect the typical bands now commonly used in the literature, but can be changed if desired.
2.5 Impedance Scoring

All actions for the Impedance Scoring tab are presented in the form of buttons:
The function of these buttons should be self-explanatory.

2.5.1. Impedance explained

The impedance cardiogram (ICG) is the first derivative of the change in thorax impedance using time as the basis (dZ/dt). This characteristic ICG waveform derives from the change in thorax impedance caused by left ventricular ejection of blood into the descending aorta during the systolic phase of the cardiac cycle. To improve signal quality, the ICG waveform is often obtained by ensemble averaging over beats within a fixed time period, time locked to the R-wave peak. The typical period for ensemble averaging is one minute. In DAMS we deviate from this practice and instead compute a Large Scale Ensemble Average across the entire label (see Riese et al., 2004 for the rationale).

The most important variables extracted from the ICG are the preejection period (PEP) and the Stroke Volume. The PEP is an index of contractility which is only influenced by sympathetic but not parasympathetic activity in humans making PEP the measure of choice to monitor changes in cardiac sympathetic activity non-invasively. The PEP is defined as the interval from the onset of left ventricular depolarization, reflected by the Q-wave onset in the ECG, to the opening of the
aortic valves, reflected by the B-point in the ICG signal (Lozano et al., 2007; Sherwood et al., 1990; Willemsen et al., 1996).

Stroke volume (SV) is the average amount of blood ejected during the cardiac cycle. When multiplied by heart rate this yields the cardiac output (CO), the total amount of blood circulated through the body per minute. SV is computed from the ICG by using the product of the maximal amplitude of the dZ/dt and the ejection time, weighing for blood resistivity, baseline thorax impedance and the total volume enclosed by the measuring electrodes.

NB: The reliability of between-individual differences in Stroke Volume (SV) computed by impedance cardiography remains a heavily debated issue. With ambulatory SV the concerns are even more valid, because movement artefacts and the lack of a phonocardiogram do NOT increase SV reliability. In addition, spot electrodes pick up only half of the impedance measured by band electrodes, and without correction for this, the Kubicek formula yields supraphysiological SV’s. If you use percentual changes in SV strictly in a within subject design all these concerns are greatly reduced.

2.5.2 Automatic detection

The DAMS program runs an automatic scoring algorithm, which tries to detect three specific locations in each ICG waveform (termed ‘ICG complex’) and one in the ECG:

B-point or upstroke, the opening of the aortic valves, marking the end of the electromechanical systole and the beginning of the left ventricular ejection time. The upstroke occurs somewhere in the middle of the first heart sound. An increase in heart rate is usually accompanied by a shift of the B-point to the left (increased sympathetic activation) and a decrease in heart rate by a shift of the B-point to the right (decreased sympathetic activation). However, heart rate may also change purely by changes in parasympathetic activation, in which case no shift in the B-point may be seen.
\[ \frac{\text{d}Z}{\text{d}t} \text{ min} \] or C-point, the point where the velocity of ejection is at its maximum and impedance at its minimum (in the graph, it is drawn in reverse polarity, so the \( \frac{\text{d}Z}{\text{d}t} \) minimum is shown as a maximum by the program).

**X-point** or incisura, the closing of the aortic valves, marking the end of left ventricular ejection time (LVET). The X-point corresponds well to the first high frequency component of the second heart sound. As the LVET is typically between \( 1/3 \) (low heart rate) and \( 1/2 \) (high heart rate) of the total cardiac cycle time, an increase in heart rate (shorter cardiac cycle) should be accompanied by a shift of the X-point to the left and a decrease in heart rate should be accompanied by a shift of the X-point to the right.

**Q-wave onset** in the ECG, marking the start of the electromechanical heart cycle. Currently this is set to a default of 48 ms before the ECG R-wave peak.

These 4 points are shown as vertical (movable) lines in the ICG- and ECG graphs.

### 2.5.3 Visual Inspection and manual correction

Ensemble averaging improves automated detection of the crucial landmarks in the ECG and in the ICG but even after ensemble averaging substantial errors in positioning of the B-point remain (Lozano et al., 2007; Willemsen et al., 1996; Berntson et al., 2004). The number of algorithms proposed to score the impedance cardiogram is countless. We have tried quite a few at the Vrije Universiteit. Our current stance is that automatic scoring simply will not work for all signals. We therefore visually inspect every ensemble averaged ICG complex and manually correct the locations of the 3 key time points when needed. Scoring of the Q-point in the ECG also always needs to be inspected and, when necessary, corrected. Manual scoring is inherently subjective but it does lead to reliable and valid results. To safeguard reliability, scoring should be ideally repeated by multiple raters. We further recommend reading Sherwood et al.'s "Methodological Guidelines for Impedance Cardiography" published in Psychophysiology before starting with scoring and analyzing the impedance cardiogram.
After clicking on the *Impedance Scoring* tab the window is displayed as in the figure on the start of this paragraph. On the right side of the window there is a graphical representation of the current ICG complex. On the left side there is a text box with several frames:

**ICG complex**

![ICG Complex Table](image)

*Average Complex:* This is the number of the ensemble averaged ICG complex (the second one out of 20 is drawn in this example)

*Individual Complex:* This is the ICG complex of one valid single beat within the current label (in this example we are at the first beat out of 263 valid beats that are present in the second averaged complex). You can make the individual ICG complexes (light grey line) visible in the back of the ensemble averaged complexes (black line) by toggling the button *Show/Hide Individual Complexes* in the menu bar. This is helpful when the B-point is not completely clear in the ensembled ICG. The individual complexes can sometimes give you a hint on where to score the B-point. You can even let DAMS play the individual complexes in the background of the ensemble averaged complex by toggling the button *Start/stop looping individual complexes*.

*Start Time:* Start time of the current ensemble averaged complex.

*Stop Time:* End time of the current ensemble averaged complex.

*Ensembling Period:* Duration of the label on which the ensemble average ICG complex was based (regardless of number of discarded beats within the label).
Number of beats: The number of valid beats within the label (this is the total amount of beats within the label minus the beats that were discarded by the artefact detector in the R-peak detection tab).

Percentage of beats discarded: The number of beats within the label that are discarded by the impedance scoring algorithm due to bad ICG signal quality. With the button Show/Hide Raw Averaged Complexes you can show the original (raw) ensemble averaged signal (red line) that contains all beats within the label regardless of the quality of the ICG on top of the ‘clean’ ensemble averaged signal (black line) that contains only beats with high quality ICG complexes.

Marker positions

The distance from the ECG R-peak to all marker lines and the corresponding value of the amplitude of the ICG or ECG at that time point are given in the left panel under the heading ‘marker positions’:

- **Upstroke position:** B-point, position of the dZ/dt upstroke relative to R-Peak in [msec]
- **Upstroke Value:** dZ/dt amplitude at the B-point in [ohms/sec]
- \(dZ/dt\) minimum position: C-point, Position of the \(dZ/dt\) minimum relative to the R-Peak in [msec]

- \(dZ/dt\) minimum value: \(dZ/dt\) amplitude at the \(dZ/dt\) minimum in [ohms/sec]

- Incisura position: X-point, Position of the incisura relative to R-Peak in [msec]

- Incisura value: \(dZ/dt\) amplitude at the X-point in [ohms/sec]

- Q-onset position: Position of the Q-wave onset relative to R-peak in [msec] (default =48 msec)

- Q-onset Value: ECG amplitude at the Q-wave onset in [mV].

- Set complex as missing: The complex is omitted in the output when this box is checked.

**Constant QR vs Q-point scoring.**

The ensemble averaged ECG allows for easy Q-point scoring. The Q-point might look obscured but will appear more clearly when zooming in on the Y-axis.

**Normal:**

![ECG Graph](image)

*Zoomed in on Y-axis:*
A number of additional variables are computed based on values from the marker positions. The values of these variables reflect the mean across the label. For some variables the values are displayed in the ICG scoring screen:

**PEP:** Preejection Period (Q-B interval) in [msec].

**HR Average:** Average heart rate in beats per minute [bpm].

**R - dZ/dt minimum:** ECG R-peak to ICG C-point in [msec].

**LVET:** Left Ventricular ejection time (B-X interval) [msec].

**Z0 Average:** Average thorax impedance in [ohm] during current label.

For other variables values are only given in the *Label Information* tab and in the results files saved from this tab:
**Stroke volume:** The amount of blood ejected per beat in [cm$^3$]. Calculated with the following formula (1):

$$SV = \frac{-\rho_{blood} \cdot L_e \cdot 2 \left( \frac{dZ}{dt} \right)_{min} \cdot t_{ive}}{\varepsilon_0}$$

, where $t_{ive} = t_{incisura} - t_{upstroke}$

**Heather index:** An alternative contractility measure in [ohm/sec$^2$]. Calculated with the following formula (2):

$$HI = \left( \frac{dZ}{dt} \right)_{min} \cdot \frac{t_{R->min}}{t_{R->min}}$$

, where $t_{R->min}$ is the time between the R-peak and $(dZ/dt)_{min}$.

**Minute volume:** The total amount of blood circulated through the body per minute, calculated as:

Stroke Volume * Heart Rate * 0.001 in [l/min]

**Label**

This simply shows the labeled period across which the current ICG complex was ensemble averaged.

```
Label
Experimental_Condition: Standing_1
```
2.5.3 Setting Stroke Volume parameters

There are two parameters that influence the calculation of the stroke volume: the distance between the measuring (yellow) ICG electrodes (Le, we advise to provide this information when filling in the subject ID before you start a recording), and the specific blood resistance (ρ). These variables can be changed by clicking the 'Set parameters...' command in the left panel. If hematocrit was not obtained, the standard value of 135 Ohm.cm can be used.

2.5.4 ICG Scoring principles

Below we give 6 scoring principles that can be used during visual inspection and manual correction of the dZ/dt signal. These principles are shown in order of importance:
1 - morphology
The B-point or upstroke should be at a first or second order zero-crossing in the dZ/dt signal. It should be close to the dZ/dt=0 line, and be the starting point of the longest uphill slope before the dZ/dtmin point. However, rather than appearing as a clear incisura, the B-point may sometimes take the form of a subtle inflexion and may vary considerably from beat to beat. It is therefore very important to inspect the dZ/dt signal closely in order to identify it. Occasionally, there is simply no clearly identifiable point that can be chosen to fit the above description of the B-point. In that case the point of the dZ/dt=0 crossing may be appropriate (see also Sherwood et al., 1990).

The dZ/dtmin is normally visible as a clear peak in the window between the B- and the X-point. In some cases the dZ/dt signal shows a double peak, a bit like rabbit ears. If one of the peaks is clearly (40%) higher then this peak is chosen. If the peaks are of comparable magnitude, choose the first peak.

The X-point or incisura is always a local minimum after the dZ/dtmin. Often it is the lowest point in the entire signal, but not necessarily. In the ideal situation it can be seen as a sharp trough in the ICG signal. This is the most clearly identifiable choice for the X-point. It may be that two or more troughs lie in close proximity without one being clearly the lowest point in all complexes. The latter part of the ICG waveform then looks like a "W". In this case choose the second trough (mostly, this trough is usually followed by the longest uphill slope after the dZ/dtmin point).

2 - consistency
Whatever point you choose, choose that point consistently. If a "less-than-ideal" upstroke is present in all complexes, but an "ideal" upstroke is present in some, choose the less-than-ideal one in all complexes, even those featuring a more "ideal" upstroke. Before starting to score the ICG, try browsing through the entire ICG signal first. You can then decide which points can be most consistently identified, and this holds for both for the B-point and the X-point.

3 - in dubio abstine
You may have quite a lot of one-minute ensemble averages. Sometimes 2 out of the 5 ensembles are ugly, possibly because of arm movement artefacts. Don't try to
make the best of these 2 if you feel pretty confident about the other 3 ensembles. The 3 good ones will give a good estimate of the ICG parameters during that particular period. Simply reject the other two. In general: when in doubt, reject the complex altogether.

4 - physiological plausibility
If you have doubts on whether the dZ/dt signal is correct, or should be rejected, you might use the following physiological guidelines as an indication of where the B- and X-point should be in an ideal situation. This is hazardous for at least two reasons: first it stains the independency of the rating which should be based on morphology only; second large individual differences in physiology exist and the general rules may not always apply.

HR: 40-60 → PEP: 100-140 → LVET 300-450
HR: 60-80 → PEP: 90-130 → LVET 250-400
HR: 80-100 → PEP: 80-120 → LVET 200-350
HR: 100-120 → PEP: 70-100 → LVET 200-300
HR: 120+ → PEP: < 80 → LVET 150-250

Again, if your signal shows B- and X-points outside of these ranges, this does not at all mean that your dZ/dt signals should be discarded. The above table is just a general rule of thumb.

NB: These guidelines are based on adult recordings.

5 - Multiple Rater comparison
Reliability increases if two (or more) raters score the same data set independently. After interrater reliability is established, the various raters should ideally compare their deviant scoring to converge on a single solution, in view of the consistency principle. Mostly one will have picked a different B-point then the other(s). Averaging the B-point location is meaningless. Consensus has to be reached on the correct B-point location to satisfy the consistency criteria.
6 - Keep score of the quality of your rating

Sometimes, scoring is difficult and doubtful, at other times you feel pretty sure. After scoring you might want to generate three parameters for "scoring-quality". Make separate judgments for B-point scoring, X-point scoring and general signal quality on a scale from 0 (yuk!) to 10 (excellent!). Later on, during statistical analysis, request to see the mean of all parameters as a function of your quality rating.
2.6 Respiration / RSA scoring

All actions for the Respiration Scoring tab are presented in the form of buttons:
The function of these buttons should be self-explanatory.

2.6.1 RSA explained

Respiratory Sinus Arrhythmia (RSA) scoring by the DAMS program is based on the peak-valley method (Grossman, van Beek, & Wientjes, 1990; de Geus et al., 1995) that uses the IBI time series extracted from the ECG together with the respiration signal obtained from filtered (0.1 – 0.4 Hz) dZ signal to obtain heart period variability that is associated with respiration. This heart period variability is referred to as RSA. The DAMS program contains an automatic scoring algorithm for detecting the beginning and end of inspiratory and expiratory phases in each respiratory cycle. Inspiratory and expiratory phases include the inspiratory and expiratory pauses which are not detected separately.

For each respiratory cycle the total cycle time between begin of inspiration and end of expiration is extrapolated to a per-minute respiration rate (RR). In addition, RSA is computed per respiratory cycle from two IBIs: The shortest IBI during an interval starting at the begin of inspiration and ending 1000 msec (default) after the end of
inspiration and the longest IBI during an interval starting at the beginning of expiration and ending 1000 msec (default) delay after the end of expiration. RSA is calculated by the subtraction of the shortest IBI from the longest IBI, provided that the shortest IBI (highest HR) is part of an accelerating series within the inspiratory interval and the longest IBI (lowest HR) of a decelerating series within the expiratory interval. This is illustrated in the figure below.

![Cardiac rhythm diagram](image)

If either the decelerating longest or accelerating shortest IBI is missing for a breath cycle, or a negative RSA value is obtained on subtraction, we set RSA in these breaths as missing. Under the Label Information tab two different mean RSA variables are calculated: the mean RSA across all breaths in the label with a valid RSA only, and the “RSA-zero” in which the RSA value is set to be zero for breaths with an invalid RSA. The DAMS labels these variables in the results files as RSA and RSA0 respectively.
2.6.2 Visual inspection and manual correction

The windows of the *Respiration Scoring* tab shows 2 physiological and 2 derived signals for the time period indicated at the X-axis of the graph:

1. **The raw impedance signal** (dZ in Ohm, grey) with the **filtered impedance signal** representing respiratory thorax movement plotted on top of it. For each respiratory cycle, red triangles indicate the start of the inspiration and blue triangles mark the beginning of expiration. The currently selected respiratory cycle is indicated by the combination of a red, purple and blue box. The purple box reflects the overlap of the inspiration phase which is extended by a dZ-HR shift (1000 msec) with the expiration phase. You can activate/de-activate the raw impedance signal in the settings screen. This is accessed from the main menu by selecting *Edit → Settings → Respiration Scoring*.

2. **CardioTachogram**: A beat-per-beat estimate for the Heart Rate (in beats/min, grey with red and blue marks). On this graph the highest heart rate (shortest IBI) during inspiration, provided that it is part of an accelerating IBI series, is
indicated by a fat red mark. The lowest heart rate (longest IBI) during expiration,
provided it was part of a decelerating IBI series, is indicated by a fat blue mark

3. **The time series of RSA values across the consecutive breaths** (in msec).

4. **Respiration Rate** (extrapolated from the respiratory cycle time) across the
   consecutive breaths (in breaths per minute).

When selecting a single breath you will see the following information per breath on
top of the upper window: Inspiration start, expiration start, expiration end, RSA (in
msec), respiration rate (in breath/pm), shortest IBI (highest heart rate) during
inspiration on decelerating slope (msec), Longest IBI (lowest heart rate) during
expiration on a accelerating slope (msec) and weather the breath is accepted or
rejected. Rejection codes signal one of the following reasons why RSA was not
accepted:

- RSA : -1 undetectable ‘shortest IBI’
- RSA : -2 undetectable ‘longest IBI’
- RSA : -3 both ‘longest IBI’ and ‘shortest IBI’ were undetectable
- RSA : -4 ‘longest IBI’ is shorter than the ‘shortest IBI’
- RSA : -5 ‘Irregular IBI detected’
- RSA : -6 ‘Irregular respiration rate’
- RSA : -7 ‘Clipping dZ’

Fortunately, automatic scoring of the respiration signal works quite well in most
subjects. Mostly, it will suffice to just load the .amsdata file into DAMS and browse
through the signal after having set the time axis at a low temporal resolution (e.g.
ten minutes per screen). While browsing through the respiration signal from the
beginning to the end of the file check the following:
• Did the program mark more than 10% of the recording as artifact in either the “clipping dZ”, “Irregular respiration” or “Irregular IBI” bars (pink, blue and yellow markers respectively) at the bottom of the screen? If so the parameters of the scoring algorithm may need to be changed (see below).

• Do all inspirations and expirations appear to be appropriately scored in the upper respiration signal (indicated by blue and red triangles)? If erroneous breaths are scored did the program mark them as artefacts in the bar at the bottom of the screen labeled “Irregular respiration”? If this is not the case you can manually delete a fragment of the signal by clicking and dragging the mouse in this window. NOTE: Pay special attention to the breath cycles measured during the night. Some subjects show strong abdominal breathing which seriously affects detection of the respiration signal by thorax impedance. This can often be repaired by ‘rescoring the cycles’ (under the main menu item Edit → Settings → Respiration Scoring) and changing the ‘Relative Threshold’ parameter of the scoring algorithm (see below).

• Check whether the program has rejected all deviant IBIs (spikes) without removing IBIs that reflect large but true heart rate variability. The difference between a spike and a truly high heart rate variability is rapidly gleaned from the shape of the tachocardiogram. If there is a staircase pattern rather than a sudden single-beat change, the subject may have a generally high heart rate variability which can be verified in the RSA window (e.g. RSA > 200 msec). If there is a sudden single-beat drop or jump then there is a spike. Spikes often represent extrasystolic beats or very delayed beats (which often occur jointly). Note that these beats do not represent an error in judgment of the R-wave detection algorithm (which should have been dealt with earlier during R-peak detection and correction). They do result in IBIs that are twice the length or half the length of most of the other IBIs. This can inflate the RSA value for the breaths in which they occur very strongly, and it is advised to remove these. Hence, make sure all spikes are marked as artefacts in the bar at the bottom of the screen labeled “Irregular IBI”? If this is not the case you can manually delete a fragment of the signal by clicking and dragging the mouse in this window.

• Finally, check whether the per breath estimate of the respiration rate (in the Respiration window) takes on expected values between 7-14 at night, 12-22 across most daily activities except moderate to high physical activity where respiration rate can increase to 30 breath per minute.
2.6.3 Adjustment in respiration and RSA scoring

The DAMS program filters the raw thorax impedance change (dZ) signal to obtain the respiration signal and then detects the beginning and the end of inspiration and expiration in the entire registration using both amplitude and frequency modulation. The RSA scoring algorithm first uses three artefact detection algorithms: it will check for dZ clipping, irregular respiration rates (based on a maximal percentage for deviation of the duration of consecutive breaths) and irregular IBI s (based on a maximal percentage for deviation of the duration of consecutive beats). Parameters governing these artifact detections can be modified in the main menu by selecting Edit → Settings → Respiration scoring.

**NOTE CAREFULLY:** After changing the settings, the respiration signal and RSA are recalculated on the original signal. This means that manually rejected fragments will be restored, so first make sure you have the chosen the optimal settings before manually rejecting fragments of the recording. It will warn you before recalculation.
Relative threshold \([0\ldots1]\) : 0.33 (default)

Purpose: The purpose of this parameter is to alter the sensitivity for the detection of breaths. A breath is defined by two zero crossings (a peak and a valley) in the first derivative of the filtered impedance signal that are separated by a minimum amplitude. The *Respiration Scoring* tab calculates a running average over the 20 seconds preceding the current selected breath cycle of the difference in amplitude at peaks and valleys in the dZ signal. The relative threshold defines the percentage of this average that is used as the minimum amplitude for the ‘tidal volume’ in a respiratory cycle.

Adjustment: A higher threshold decreases the sensitivity (less of the consecutive peak-valley pairs in the filtered impedance will be counted as true breaths – use when too many small wobbles are counted as breaths), and a lower threshold value increases the sensitivity for amplitude differences (more of the consecutive peak/valley pairs will be counted as true breaths – use when the amplitude of the actual breaths becomes low, for instance in nighttime belly breathing).

\[dZ-HR \text{ Phase shift (in msec)}\] : 1000 (default)

Purpose: This defines the delay added to the inspiratory and expiratory phases in which the *Respiration Scoring* tab is allowed to search in the IBI series for a shortest IBI in inspiration or longest IBI in expiration, respectively. Increasing the dZ-HR Phase shift can increase the number of valid RSA values in subjects with low respiration rates whereas at high respiration rates, the default 1000 msec interval may lead to erroneously used IBIs from the next respiratory cycle.

Adjustment: Increasing the phase-shift increases the time-delay.

**Automatic respiration rate artefact detection** : is “on” when ticked

Purpose: The purpose of this option is to automatically reject breaths with an unusually small or unusually high respiration rate as compared to the running average of the 20 preceding breaths. For participants with irregular breathing, the
maximum allowed deviation might need to be increased in order to prevent false rejects.

Adjustment: The ‘maximum allowed deviation’ (default 50%) enables the scorer to specify how much the respiration rate of a breath needs to deviate from the running average in order to be excluded by the automatic scoring program. Increasing the percentage means allowing for larger deviations from the running average.

**Clipping dZ : is ‘on’ when ticked.**

Purpose: The purpose of this option is to automatically reject clipping (i.e. where the raw respiration signal turns into a flat line at dZ = 1 ohm or dZ = −1 ohm).

Adjustment: Although the default values generally seem to work well, some recordings may require an automatic impedance range check that is a fraction more or a fraction less strict. It can be a waste to reject breaths that are not deviant from the normal respiration rate nor show any other deviant features, just because the signal clips for a short moment. Therefore, the option of ‘minimal duration’ (default 2000 msec) is added so clipping is only rejected when it occurs for the time specified by the scorer or longer.

**Irregular IBI check : is ‘on’ when ticked.**

Purpose: The purpose of this option is to automatically reject spikes in the IBI time series, that represent extrasystolic beats or very prolonged beats. Note that these beats do not represent an error in R-peak placement by the DAMS program (which should have been dealt with earlier during manual inspection and correction). They do result in IBIs that are twice the length or half the length of most of the other IBIs. This inflates can inflate the RSA value for the breaths in which they occur very strongly. When the irregular IBI check is ‘on’ these beats are removed from the set of IBIs that are considered when selecting the shortest IBI and longest IBI to compute the RSA.

Adjustment: The allowed magnitude of the difference between consecutive IBIs can be adjusted by changing the ‘maximum allowed deviation’ (default 50%).
2.6.4. Exporting raw breath to breath data

You have the option to export breath to breath results to a tab delimited text output file using the button “Export To RSR File”. These .rsr files give the following information on each respiratory cycle on a single line:

<p>| | | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>1105016 16 11-03-2011 09:04:13 1800 1800 755 755 16.67 1 768.5 -34.16 114.64 148.81 A 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1105016 17 11-03-2011 09:04:16 1700 1200 748 -1 20.48 -2 751.67 -89.87 -1.6 98.27 A 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1105016 18 11-03-2011 09:04:19 2000 5200 716 812 11.54 96 742.17 -55.45 149.61 185.06 A 10</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1105016 19 11-03-2011 09:04:24 1900 1200 635 -1 19.35 -2 737.33 -137.62 18.78 194.4 A 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1105016 20 11-03-2011 09:04:27 2600 1900 685 746 15.09 65 717.2 19.24 74.69 55.39 A 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- column 1 : Subject ID
- column 2 : Respiratory cycle number
- column 3 : Date (dd-mm-yy)
- column 4 : Start of respiratory cycle (hh:mm:ss)
- column 5 : Inspiration time [msec]
- column 6 : Expiration time [msec]
- column 7 : Shortest accelerating IBI in inspiration [msec]
- column 8 : Longest decelerating IBI in expiration [msec]
- column 9: RR [breath per min]
- column 10: RSA [msec]
- column 11: Mean IBI across the cycle [msec]
- column 12: Amplitude dZ at start inspiration [milliOhm/sec]
- column 13: Amplitude dZ at start expiration [milliOhm/sec]
- column 14: Tidal volume [milliOhm/sec] -- calibration is needed to translate this to ml
column 15: Rejected (R) as artefact or accepted (A)

column 16+: Labels (-9999 = not available)

You can import this text file in e.g. SPSS for more fine grained analyses that use breath-to-breath information rather than the averaged values per label that are typically produced under the Label information tab. Please note that amplitude is in milliOhms/sec and needs calibration before volumes have physiological meaning. For respiratory time intervals careful outlier detection is needed before you do further statistical analysis on these breath-to-breath data. In view of the huge number of breath cycles to be quality controlled in 24-hour ambulatory monitoring, some automation of these checks is desirable, for instance by scripting in MATLAB, R or even SPSS.

2.7 Label Information/ Exporting results
After clicking on the *Label Information* tab wait until all cells are finished calculating. The first column in the *Label Information* tab is the subject name, which is the ID that we gave when programming the device for recording. Each row represents a single labeled experimental/ambulatory condition and each consecutive labeled condition is rank-ordered by the *Label ID* field. The rest of the columns contain values for a large number of physiological variables. ICG-based variables only have a value when the scoring under the *Impedance Scoring* tab has been done (e.g. PEP) and the LF and HF power values from spectral analyses on the IBI time series are only present for labels with a minimum length of 4 minutes.

All actions for the *Label Information* tab are presented in the form of buttons:

![Actions Menu](image)

### 2.7.1 Output configuration editor

Click in the main menu → *Actions* → *Edit Output Config* to adjust variable names, order or omit names.

A menu with all variables will appear.
To change variable names click in the left column and type in the new name. The second column will show the factory configured name of that particular variable. To restore the output configuration to the factory configuration, click on *Restore Factory Config*.

To omit variables simply uncheck the box behind the variable.

To change the order of variables in the output, use *Selection up* and *Selection down* buttons. To restore the output order to the factory configuration, click on *Restore Factory Config*.

After changing the output configuration, you can *Save Config As Default*. This output configuration will then be applied to all .amsdata files that are opened / processed.
with this DAMS version by this user on this particular computer. You can switch between factory configuration and default configuration by using *Load Default Config* and *Restore Factory Config*.

### 2.7.2 Export per label

You can either export your data to an excel file (with the extension .xls) or a text file (with the extension .lbldat). Click on the export button in the menu and you will be prompted to enter the location to the output file.

*Be aware that there is a *label ID* with the number 0 by default. This label is the average of the entire recording, and not the average of all the labels. If you do not want this in your output you can permanently make sure the program does not show the *label ID* with the number 0 in the *Label information* tab. To do so select in the main *Edit → Settings → Label information*. Then deselect: *Include label 0 for entire data recording* and save the new settings.*

### 2.7.3 Export for fixed time based labels

By default the exported data will reflect the averaged values across the labels that were generated during *Labeling of your data*, using experimental condition or diary information to define labeled time periods. However there is also the option to
export across fixed periods of time. Click on either the Export ‘Per Minute’ Information to ASCII File or the Export ‘Per Minute’ Information to Excel Spreadsheet button. You will be prompted to enter the duration of the fixed time periods. The output will give averages across consecutive periods of this length in the chronological order of recording. The start and stop times of the fixed time period ‘labels’ will help you link the generated data to the real time of the experiment.

*Note 1: The PEP etc. will be set to missing (-9999 by default), as the ensemble averaged impedance complexes always need manual scoring before values for ICG-derived variables are generated. You need to use Add Time-Based Labels during labeling if you want to produce e.g. one-minute average ensemble PEPs.

*Note 2: Spectral analysis will only output values for LF and HF labels if the fixed periods are chosen longer than 4 minutes.

2.7.4 Batch export

You can export text files in batch mode. This function will generate output files per subject or a merged output file of many subjects from single .amsdata files as long as they are placed in the same directory (or a subdirectory in that directory). So place all files that need to be exported for a certain project in one directory and click on Batch export data under File in the menu bar.
Simply select to export to XLS or to ASCII in single mode or merged mode. Then select the output directory and name the output file.

2.8 Generate reports for the participant

There is an option to generate feedback reports for participants in the forms of heart rate graphs and bar graphs.

2.8.1 Heart rate graph

Click on the Generate Heart Rate graph button. You will see the following screen.

The graph will; show the heart rate and motility signal of the entire recording. You can change names of the x-axis, y-axis of the HR and the y-axis of the motility as well as the graph title itself (or hide it by unchecking the `Draw graph title` box).

You can adjust the degree of smoothing of the signals by Change HRA average length or Change MOT average length. Increasing the length will give a more smooth signal.

For long recordings (e.g. > 24H) you have the option to display the first or second half of the data by using the buttons of the heart rate graph menu.

When finished, you can save the graph to a .png file by clicking on Save.
2.8.2 Generate bar graph

With the heart rate graph it is possible to display the average heart rate across single activities or sets of combined activities. Select or combine various labels into a single bar.

Click on the Generate Bar Graph Of Data button. You will see the following screen:

![Average heart rate during different activities](image)

Now click on Edit Combined Labels, you will see the following screen:

![Edit combined labels](image)

To add bars to the bar graph you need to define what activities should be averaged into a single bar. You can either choose to have a bar represent a single level of a labeling category for example Cycling, or you can combine multiple levels of a category, i.e. cycling and walking into one bar that represents ‘physical active’ periods.
To do this click on *Add New Label*, and enter the category name you want to give to this specific bar (e.g. physical active).

![Image](image1)

Click *OK*. Then enter the space separate list of level codes that need to be averaged for this bar. E.g. 10 for cycling and 11 for walking would be entered like this:

![Image](image2)

When you entered all desired bars, you can save the bar graph setting as default. You can change the name of the X-axis, Y-axis and Graph by clicking on the *Change ... Title* buttons of the bar graph menu. The end result might look like this:

**Average heartrate during different activities**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Heart Rate (beats per minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>92</td>
</tr>
<tr>
<td>Standing</td>
<td>102</td>
</tr>
<tr>
<td>Lying</td>
<td>89</td>
</tr>
<tr>
<td>Sitting</td>
<td>88</td>
</tr>
<tr>
<td>Walking</td>
<td>111</td>
</tr>
</tbody>
</table>
2.9 Export VU-AMS signals

A raw data dump can be obtained from each recorded signal into a text file. Click on Data in the main menu and select to Export Signal To ASCII. You can choose to export any signal to an ASCII file and choose the resolution of the output.

The file has a fixed format, that includes the raw signal but also the cumulative time index and the label codes. Each line represents a single sample from the raw data, with samples spaced in time by the specified resolution. NB: This can generate very large data files in 24-hour recordings!

2.10 Import external signals

Click on Data in the menu and select to (re)import a raw signal dump from a text file. This option allows you to use downsampled data or to import an entirely different signal (as long as the format complies with the DAMS raw data dump format).

Click on Data in the menu and select Load external signal. In the pop-up screen select the ASCII file containing the external signal. This ASCII file should be structured as follows:
Variable_Name → Name of the external signal
03-05-2011/09:30:31 → Start date and start time of the recording

0  597.31 → The first column is the time in msec (starting at zero) and the second
4000  396.95 column is the corresponding value of the external signal
7000  454.38
12000  414.97
17000  437.73
22000  442.08
...

The external signal will appear above the whole IBI recording panel. The mean value of the external signal over each condition will appear in the Label Information tab under ‘External Signal Average’.

Click on Data in the menu and select Clear external signal to remove the external signal.
3. Trouble shooting

3.1 VU-AMS file has zero bytes.

Cause: the VU-AMS has made a recording and probably all data are there but an end-of-file summary has not been placed and the FAT table isn’t updated.

Solution: This can be repaired by closely following the instructions on www.vu-ams.nl > Support > Tutorials > Troubleshooting > Video manual: How to repair a 0KB file recorded with the VU-AMS5fs.

3.2 Deviant flashing

When on standby, the VU-AMS device flashes once every 10 seconds, when recording the VU-AMS device flashes once every three seconds. Faster flashing signals problems:
• The green light is flashing very rapidly
  **Cause:** The Compact Flash card is not (properly) installed.
  **Solution:** Install the Compact Flash card in the proper way.

• The green light is flashing rapidly
  **Cause:** The battery lid is not (properly) fastened.
  **Solution:** Fasten the battery lid in the proper way.

3.3 *Warning beeps*

When the VU-AMS detects that something is amiss it can generate various warning beeps:

• You hear a double beep (the ‘alert beep’), which is repeated after increasingly shorter intervals (from 30 to 10 seconds).
  **Cause:** The battery voltage is becoming low.
  **Solution:** Replace the batteries with fresh ones.

• You hear a triple beep (the ‘warning beep’).
  **Cause:** An electrode comes off, a lead wire gets detached, or the lead wire connector is pulled out by accident.
  **Solution:** No worries. Just attach the electrode again (use a spare one if necessary), reattach the lead wire, or plug the connector back into the socket.

3.3 *Frequently asked questions.*

See [http://forum.vu-ams.nl](http://forum.vu-ams.nl)