Resp. user manual

Spike2 scripts for recording and analysing

Respiratory signals

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Introduction

This script *Resp$_x$.s2s* is one of a family (*PTcal, FV_online* and *Resp$_x$* and others) intended for recording and analysing respiratory data. They require Spike2 v8.10 or higher. We recommend that you keep these scripts together in the same folder, for example, in *scripts* inside the Spike$_x$ directory in *My Documents*.

- *PTcal.s2s* calibrates a pneumotachograph (air flow meter) by analysing the flow trace generated by repeated strokes of a syringe of known volume.
- *FV_online.s2s* uses this calibration together with data on the ambient recording conditions to record respiratory data and convert the raw air flow signal into BTPS flow and volume traces *online*.
- *Resp$_x$.s2s* analyses respiratory data recorded using *PTcal* and *FV_online*. However, it can also generate BTPS-corrected volume and flow traces from a raw flow signal. Thus it can be used as a *stand-alone* script for analysing respiratory signals recorded by other methods.
- *InvertChan.s2s* flips the polarity of an *atps* flow trace to inspirational flow is negative if the raw data was recorded with the opposite sign convention.

You can perform the following tasks using *Resp$_x$.s2s*:

- Enter and Store subject and experimental details together with the data.
- Generate a volume channel corrected to BTPS based on a flow channel.
- Generate a BTPS flow channel from a volume channel
- Reversibly remove offsets and baseline drift from volume and flow traces.
- Measure timing and amplitude of IC manoeuvres.
- Measure Forced Vital Capacity (FVC) manoeuvres, e.g., FEV_{1s}, peak expiratory and inspiratory flow and forced expiratory time.
- Perform breath by breath (*BxB*) analysis and plot the results as additional channels in the data file. Breath by breath analysis includes:

    1. Breathing frequency, breath duration (T_{tot}), Inspiration duration (T_i), expiration duration (T_e), duty cycle (T_i / T_{tot}), Tidal volume, EELV, instantaneous and actual minute volume, peak and mid-tidal inspiratory- and expiratory flow.
    2. Lung Compliance and Work of breathing
    3. Peaks and troughs of a selected pressure channel and volume at these peaks and troughs. You can also measure mean pressure during inspiration and expiration and pressure at onset and end of a breath and peak of inspiration.

- Flow-Volume (f-v) loops:

    1. Generate mean f-v loops based on a sequence of several consecutive breaths or from several discrete manoeuvres. For example you can generate a mean FVC plot. Measurements from flow volume loops include: TLC, IRV, EILV, V_t, IC, EELV, and ERV.
    2. Measure expiratory flow limitation*:* Measurements include: V_t overlap: the percentage of V_t that meets or exceeds maximal expiratory flow loop at iso-volume.
    3. Mid-tidal expiratory/inspiratory flow as a percentage of corresponding iso-volume maximal flow from maximal flow volume loop.
    4. Measures of Inspiratory flow reserve*:*
    5. Peak/Mid-tidal inspiratory flow as a percentage of iso-volume maximal flow.
    6. Peak/Mid-tidal expiratory flow as a percentage of iso-volume maximal flow.
    7. Area of inspiratory and expiratory components of a flow -volume loop.
    8. Area of tidal f-v loop relative to maximal f-v loop within a selected volume range.

- Plot Volume-pressure loops and mark areas corresponding to elastic and resistive components of work of breathing.

User Guide

Most of the functionality of the Spike2 software remains available while this script is running and so the script does not duplicate these features. Thus, you need to be familiar with the usual Spike2 methods to perform such tasks as adjusting x- and y- axis ranges, showing, hiding, selecting, overdrawing and deleting channels etc., in order to take full advantage of this script.

The script assumes that inspiration is represented as downward deflections of flow and volume traces in the raw data files. If your flow and volume traces are upside-down with respect to this convention, you can create inverted copies in Virtual channels. For example, if channel 1 is the raw flow channel, use the Virtual channel expression: *ch(1) * -1* . Save the Virtual channel(s) to disk using the *Save Channel* option on the *Analysis* menu. Alternatively, you can use the utility script, *Invert Chan n.s2s*.

Run the *Resp* script for the first time using the *Run script* command on the Spike2 *Script* drop-down menu. A button labelled ñ*Resp"* will be added to the Script Bar. You can click on this button to run the script in future.

Script toolbar

The main script toolbar has 20 buttons that can be operated by clicking on them with the mouse or pressing a keyboard shortcut. Most toolbar buttons have a tool-tip that gives further information on the buttonôs function.

Clicking on a toolbar button usually opens a dialog where you can enter further information. You can click on the title bar of script dialogs and drag them to a convenient position on the screen. Next time around the dialogs should re-appear where you left them.

In most cases, the dialogs do not limit what you can do while they are open. You are free to drag cursors, show, hide and re-size views and use most of the main Spike2 menus. The down-side of this freedom is that you can óshoot yourself in the footô. For example, you can crash the script by deleting files or channels that the script needs. Use common-sense!

Quit

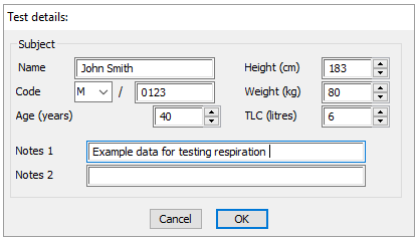
This button closes the script, hides the report and gives you the option to clear previously stored text.

New file

Click here to select a file to analyse. Any previously open data file will close automatically when you open a new one. There are *Are you sure?* queries so that you can go back and print or save any unsaved information before the old file closes.

Subject Details

This button opens a dialog for entering info. on the subject and the nature of the study. The information in this dialog is saved in the elements 4 and 5 of the *File Information* Elements 1-3 of the File Information are reserved for flow calibration data created by the *FVOnline* script.

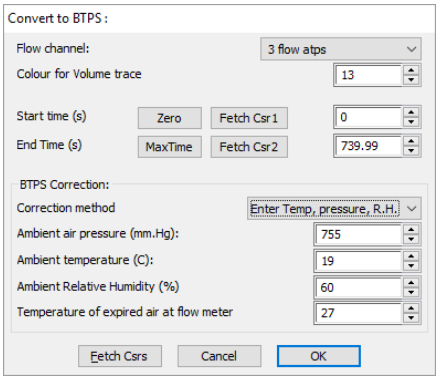


Vol from Flow

If you recorded the data using the *FV_Online* script, then the file will already contain calibrated flow and volume traces corrected to BTPS and you will not need this feature. You can proceed directly to the Drift Remove option. However, if you have an ATPS flow trace only, or you are not satisfied with the BTPS correction generated by *FV_Online*, then click on this button to generate BTPS flow and volume traces. (*In the latter case, we recommend that you hide the unwanted flow and volume traces first to avoid confusion*).

The flow channel must be a visible Waveform or RealWave channel and contain the string "*atps*" in the title in order to be shown in the channel list. Virtual channels are not

accepted. If your flow channel is a Virtual channel (*v1*, *v2* etc.), then you need to save it to a permanent RealWave channel before running this script. Use the *Save Channel* option on the Spike2 *Analysis* menu. Run the script again and select this permanent copy of the flow channel in the *Volume from Flow* and other dialogs in this script. You can hide the original channel to increase the space available to other channels**.**



You can select the time range to process by editing the start and end times in the dialog or by dragging the cursors in the time view. You can also click on the buttons next to the *Start* and *End* time items in the dialog in order to toggle the cursors between their current positions and the start or end of the file.

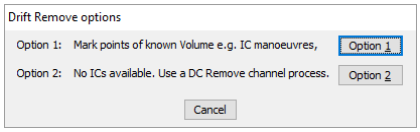
You can choose the colour of the volume trace by entering the index of the desired colour in the Spike2 colour palette. There are 40 colours available on the palette numbered (in columns) 0 ï 39.

There are two options for correcting volume and flow traces to BTPS. The usual method is to enter the ambient air pressure, temperature and relative humidity together with the temperature of expired air at the flow meter. These values are used to correct inspired and expired flow by the method described in Appendix 1. Alternatively, you can look up the necessary correction factors in a published table and enter them in the dialog. Either way, the correction is based on the assumption that *negative flows represent inspiration.*

When you click on OK, the new volume trace displays along with a BTPS corrected flow trace. The original, uncorrected flow trace is hidden. The factors used for correction to BTPS are shown on the toolbar and included in the channel comments of both flow and volume channels. Double-click on a channel title or ðhoverô over it with the mouse pointer to view the comment.

If you want to try out several different sets of BTPS correction factors, then simply click on the Vol from Flow button again and choose the option to *Replace existing BTPS flow and Volume channels* in the dialog. The existing channels will be deleted and you can then choose new parameters when the *Convert to BTPS* dialog reappears.

Remove Drift



Even a slight offset of the flow meter output can build up into a significant drift in the volume trace. The script provides two alternative methods for removing this drift. Click on the Drift Remove button and select one of two drift compensation options in a dialog.

Option 1

A common strategy for estimating drift is to ask the subject to perform Inspired Capacity (IC) manoeuvres at regular intervals during a recording. We assume that volume at maximal inhalation is approximately equal in each case, and attribute any discrepancy between the final volumes of successive ICs to a linear drift of the trace with time. We can then generate a corrected volume trace by subtracting this estimate of drift from the raw volume trace using a Virtual channel.

If your data contains ICs then select Option 1. If more than one volume channel is visible then a dialog opens for you to select the volume channel to process. When the

main drift removal dialog opens, the original volume channel is hidden. It is replaced by a Virtual channel (*Vol.corr.)* set up to display the original volume with drift subtracted.

Subtract Volume drift

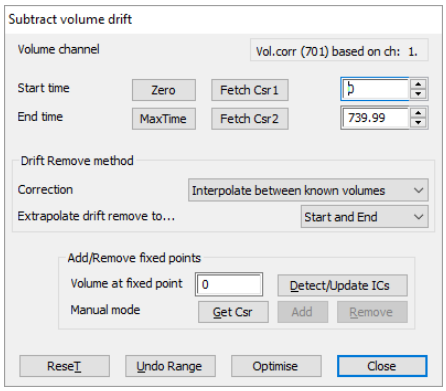
This dialog has the following sections:

Time range

You can select the relevant time range via the tools in the dialog or by dragging cursors. The volume trace will only be shown in the range bracketed by the cursors. If you drag the cursors closer together, then part of the volume trace will disappear and re-appear if you drag in the other direction.

Drift Remove method

You can select the type of drift removal from the drop-down list. The options are:



Interpolate between known volumes.

This method is appropriate if you have multiple independent estimates of the actual volume distributed throughout the recording. For example, you may know the true volume at peaks of several IC manoeuvres. These known volumes will be compared with the ‘apparent’ volume at each time to measure the drift. The script then generates a drift monitor trace by linear interpolation between these known drift values. This drift channel is then subtracted from the apparent volume.

Linear best fit between known volumes

This option is similar to the previous one except that the drift channel is derived not by ‘joining the dots’ with straight lines but by a single straight line of best fit between all of the known values.

Offset and user-defined drift

In this case you choose a single point of known volume and apply a user-defined linear volume drift relative to that point.

Extrapolate drift remove to…

There are three options:

- *No extrapolation.* Here the drift correction starts at the first fixed point and extends to the last one.
- *Start and End.* The drift correction is extrapolated over the entire time range. In the case of *interpolation between known volumes*, the linear drift between the first two fixed points is extended back to the start and the drift between the last two points is extended to the end of the time range.
- *Range cursors.* Each of the above drift remove methods can be applied to a single time range or *multiple* time ranges marked by cursors. To create a range, click on the Fetch Cursors button and drag the cursors to the required positions. You can have multiple ranges, each with different amounts of drift removal. You can combine ranges with an offset and user-defined drift with *either* interpolation between known volumes *or* linear best fit. You cannot combine interpolated and linear best fit ranges in the same file.

Adding /Remove fixed points

Volume fixed points, e.g. **ICs**, can be detected automatically in *Interpolate* or *Linear best fit* modes. A manual method is available if you prefer. You must mark the fixed volume points manually in *Offset and user-defined drift* mode.

Auto-detect

The automatic method should work if all of the ófixed pointsô that you need to enter are at the same volume. Enter this volume in the Volume at fixed pt selection box. The default value will be zero. You may wish to set this value to the total lung capacity (TLC) measured separately. Note that the value should be ***negative*** to fit with the convention used here that inspired flows and volumes are downward deflections.

Next, click on Detect/Update ICs. The script will search for ICs in the current time range and add a fixed point marker at every one that it finds. If all is well, the corrected volume trace (*Vol.corr*) will flatten out because the drift has been subtracted and ticks in the channel labelled *'fixed pts'* will mark the fixed points that were detected. The original volume trace will be shown in grey, overdrawn with a ñdrift lineò showing the estimated drift based on your chosen method.

Auto-detection is based on ICs being larger and longer-lasting than normal breaths and is not infallible. If spurious *fixed points* were marked or some fixed points were missed, then you will need to edit the fixed points trace manually. Note that the *Detect/Update* button will not be available if there are already fixed points in the time range. The button will enable if you delete the previous fixed points using the Reset button, -see below.

Edit fixed points

Make sure that the Drift Remove method is set to *Interpolate…* mode so that you can see the position of each fixed point marker. (*Note that you can flip between Interpolate and Linear best fit modes at any time*). Zoom in on the area of interest, e.g. a time range of 2 ï 3 minutes. Click on the Get Csr button (hotkey: G) to fetch the cursor. The cursor will ósnapô to the minimum volume in the displayed range (excluding 5% at the left and right edges). This will usually be an IC. If the cursor has snapped to a position that you want to mark as a fixed point then click on the Add button (hotkey: A) to insert it. If not, you can drag the cursor to its final position before adding. Alternatively, you can drag the scroll bar to change the visible range and try pressing **G** again.

You can click on the Remove button (hotkey: R) to delete an unwanted fixed point marker at or near the cursor. The Remove button will work if there is a fixed point within a range of 20s after the cursor.

Insert fixed points manually

After a bit of practice, you can mark a series of fixed points manually. Use one hand to press the keyboard shortcuts for fetching the cursor and adding and removing markers (G, A and R). Use the other hand to scroll through the data file by dragging the thumb along the X-scroll bar. Start by zooming in on a time range that is sufficiently short that there is unlikely to be more than one IC at a time in the display. Scroll to the start of the relevant time range. Then, drag the thumb steadily to the right until the first prospective fixed point appears towards the middle of the window. Press the G to optimise the traces and fetch the cursor. With luck, the cursor will snap to the required position so that you wonôt need to drag it to its final position. You can just click on A to add a marker or R to remove an existing one before scrolling on to the next candidate. Simply, click on the *Space bar* whenever you need to re-optimise the traces. Note that when adding fixed points manually, you can set a different reference volume for each point by typing in the new value prior to pressing the Add button. Remember that volume fixed pints should be negative so do donôt forget the *minus* sign.

Offset and User defined drift

This setting allows you to specify a single fixed point of known volume manually, using Get Csr and Add buttons. After adding the fixed point you can specify a constant drift by typing a value into the *Drift (ml/s)* item and pressing *Tab* to apply it. The drift will be extrapolated to the start and end of the file or the start and end of the current time range if Range cursors were selected in the *Drift Remove method* settings. You can adjust the drift in steps of 1 ml/s by clicking on the spinner arrows of the *Drift* selection box. After clicking once on a spinner arrow to select it, you can make further adjustments using the keyboard arrows (ŷŹ).

Reset Click here to remove all fixed points so that you can re-start the drift compensation process from scratch.

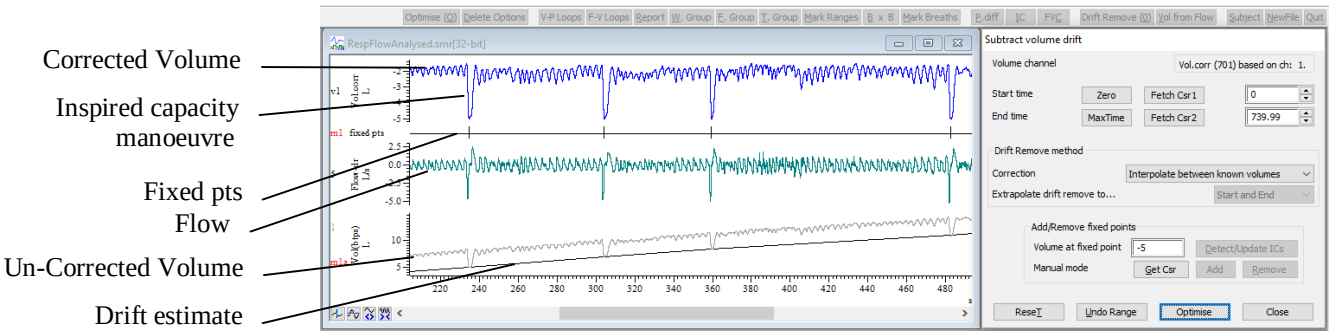
Undo Range Click here to remove drift compensation from all of the ranges bracketed by the range cursors.

Optimise You can click on this button or its hotkey: *Space bar* to optimise the traces at any time. This optimisation is especially useful because ignores the large transient artifacts on a drift-compensated flow trace at the start and end of a time range

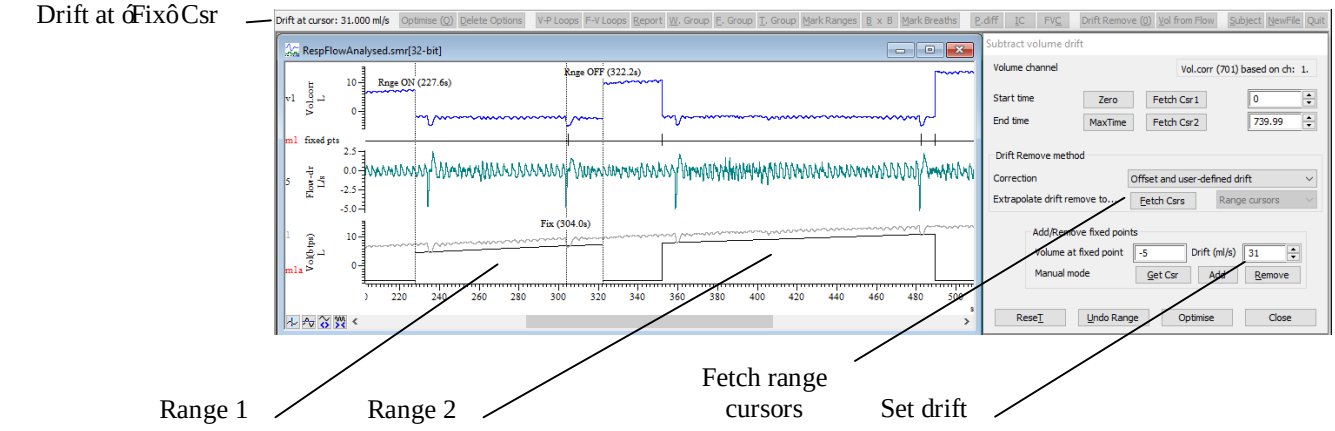
Close Click here to close the dialog, save the current drift compensation and apply the drift compensation to the flow channel (title changes to *Flow-dr*). The uncorrected Volume channel with overdrawn drift traces will be hidden Drift mode reverts to ó*Marker*ô in order to maximise the space available for other traces. You can return to the Drift Remove button later and change the drift compensation mode or add and remove fixed points as often as necessary during the analysis.

Drift Remove examples

Interpolate between known volumes from start to end:



Multiple ranges each with user-defined offset and drift

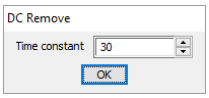


Remove drift pt. 2

If your data does not contain points where the volume is known, then the above method is not applicable. The fall-back position is to apply a *DC Remove* channel process with a long time constant, *p* (>20s) to the volume channel. *DC Remove* subtracts from each data point at time *t*, the mean level over the time range *t-p* to *t+p*. This eliminates long-term drift but has little effect on relative measurements such as tidal volume. However, measurements of absolute levels on the volume trace, EELV, for example, will be of limited validity.

Option 2

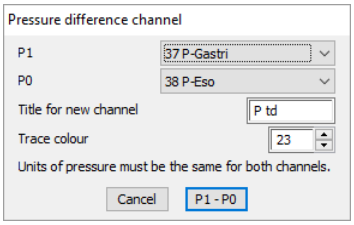
If you select this drift remove method, then you must enter a DC Remove time constant in a dialog. The process will be applied when you click on OK and a corresponding corrected flow trace will appear.



Switch between drift options

You can re-analyse drift processed using Option-1 by pressing Reset in the *Subtract Volume drift* dialog. If you chose Option 2, then you can change the DC Remove time constant by clicking Drift Remove on the toolbar. However, if you wish to change from Option 1 to Option 2 or *vice versa* then you will need to delete the current drift compensated traces via the Delete Options toolbar button before you re-analyse.

Pressure difference



It is a common requirement to derive the pressure across the diaphragm as the difference between channels recording pressure in the stomach and the oesophagus. This button allows you to create such a pressure channel by subtracting pressures recorded on two other traces. Pressure channels must have titles that begin with a capital 'P' in order to appear in the channel selection lists. Similarly, you should choose a channel title beginning with 'P' for the new channel. The destination channel will be a RealWave channel with a trace of the colour that you select. The expression used to create the channel e.g., *ch(3)-ch(6),* will be saved to the channel comment. You can create extra channels based on pressure and pressure difference channels via the breath by breath (*BxB*) measurements dialog (*see below*). You can invert the trace by switching P1 and P0.

Measurements

Most of the remaining toolbar buttons are concerned with measuring respiratory parameters. Where measurements are made from a particular feature such as an IC or FVC manoeuvre, the script will attempt to place cursors in the correct positions automatically. However, you can make final adjustments by dragging the cursors to the required positions before pressing the Accept key to save the measurement.

Forced Vital Capacity

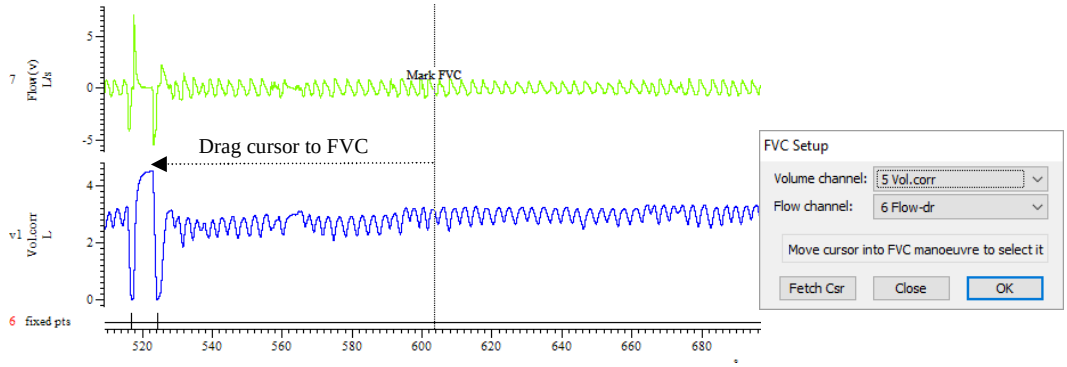
The FVC button (hotkey: C) opens a dialog for taking measurements from an FVC manoeuvre. Select the volume and flow channels in the dialog and then adjust the time range of the data file to bring an FVC into view. Next, drag the cursor labelled *Mark FVC* into *the forced expiration phase* of the FVC in order to select it and click on OK. Click on the Fetch Csr button if this cursor was scrolled out of the visible range.

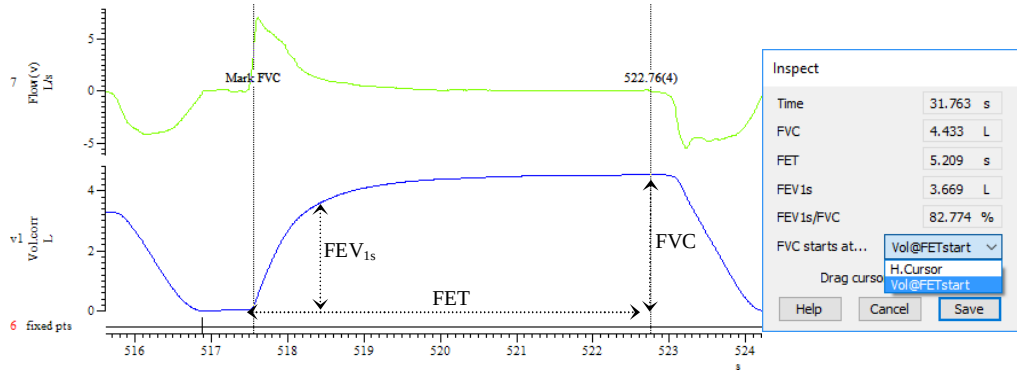
The time range should now zoom in on the FVC with cursors marking the onset of the forced expiration and the position of the maximal expiration. The onset of the FVC (*Cursor1*) is determined by measuring the peak flow (after smoothing with a time constant of +/-40ms) and then extrapolating this flow rate back to zero as recommended in the ATS guidelines.

The *Inspect* dialog will show the FVC statistics corresponding to the cursors positions. You can choose the start point for measurements as the horizontal cursor marking breath onset or the vertical cursor(1) If you are not satisfied with the default positions for the start of the FVC or the position of maximum expiration, then you can drag the cursors to your preferred positions. The measurements shown in the dialog will update accordingly. Click on the Save button to store the results. The cursors will jump to the peak expired flow (*PEF*) during the FVC and peak inspired flow (*PIF*) immediately following it and the flow values will be shown in another *Inspect* dialog. Click the Save button to store these values or the Cancel button to discard them.

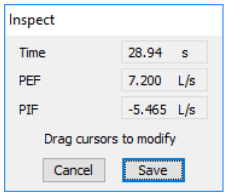
At this point, the results are encoded within a TextMark at the time of the FVC channel. The TextMark appear as a coloured rectangle in the channel entitled *Tmk*. A new dialog will give you the option of measuring another FVC or returning to the main toolbar. You can inspect the contents of TextMarks by double-clicking on a particular TextMark and viewing the contents in a dialog. Alternatively, you can view the TextMarks contents in a 'tip' box by lingering over it with the mouse pointer.

FVC measurements





Peak flow results

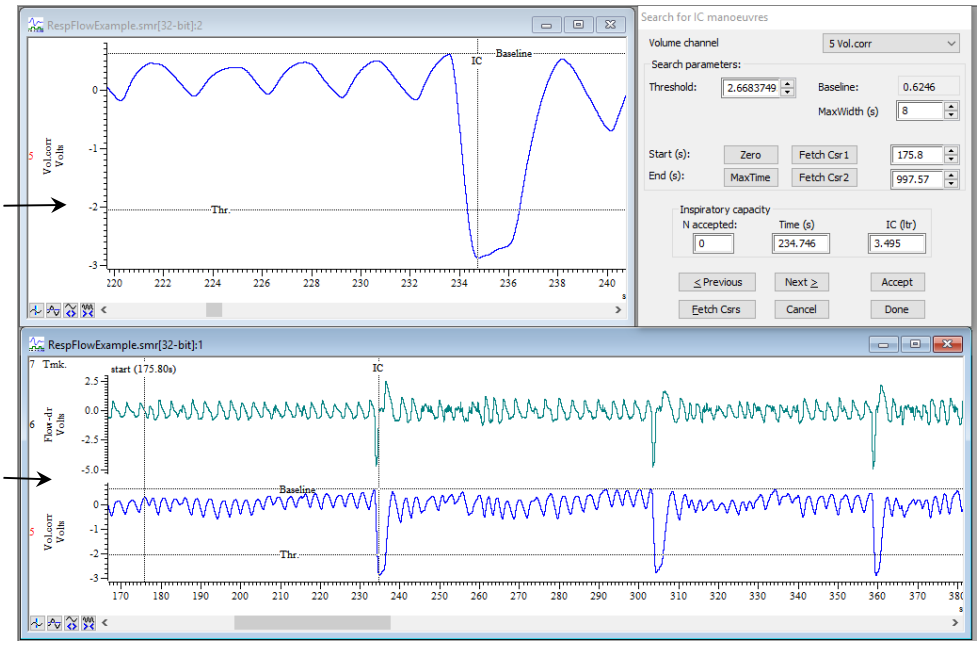


Inspired Capacity Clicking this button opens a dialog for you to find and take measurements from IC manoeuvres. Adjust the X-range to show the entire time range. Then fetch and drag cursors to bracket the time range to search for ICs. The horizontal cursors mark the volume change that must be exceeded for a breath to be recognised as an IC. The absolute position of the horizontal cursors is unimportant. It is the gap between them that counts. This is the threshold volume shown in the dialog. The default threshold is about 90% of the maximum breath amplitude in the selected time range. This value should be suitable in most cases, but if not, you can adjust it by dragging the horizontal cursors or editing the threshold setting in the dialog. The MaxWidth setting excludes breaths that exceed the specified duration.

Click on the Next button (hotkey *right arrow*) to search for the first potential IC in the time range. If all is well, then the ÐICô cursor will jump to the trough of the first detected IC and a close-up view will show in a separate window. The baseline cursor will jump to mark the local maximum (time range IC peak ± maxwidth) and the time and amplitude of the IC relative to the baseline will show in the dialog.

Close-up view →

Main view →



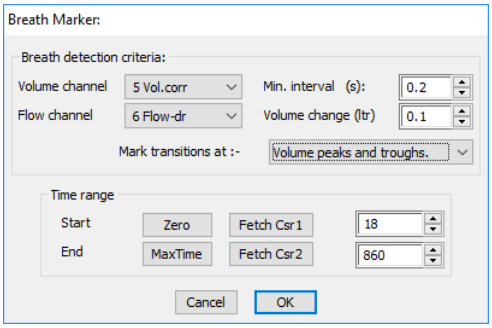
At this point, you can drag the Baseline cursor and IC cursors to their final positions, if necessary. You can drag the cursors in either of the two windows. Press Accept (hotkey: *space bar*) to store the measurement in a TextMark (code 02). Click Next to advance to the next detected IC and repeat the above procedure until you have measured all of them. You can adjust the baseline and threshold cursors between searches and use the Previous button (hotkey: *left arrow*) to search backwards to detect any ICs that were overlooked, initially. Press Done when you have finished or Cancel to abandon the process.

Mark Breaths

Before attempting to measure respiration statistics of individual breaths we must mark the start and end of each breath. The dialog allows you to select the volume and flow channels and the criteria for detection of a breath. These are:

- *Min. Interval*, Set the shortest interval between volume peaks (expirations) that can represent a breath.
- *Volume Change*, Set the minimum rise in volume after a trough (inspiration) or fall after a peak (expiration) that must occur before a new breath is detected. Probably the easiest way to set the level change is to drag the two horizontal cursors in the volume trace so that the gap between them is less than the amplitude of the smallest breath that you wish to include. The value in the *Volume change* box will change accordingly. You can double-click on the volume channel to zoom in on it, if necessary and double-click again to restore the previous display. Alternatively, you can type a new value in the selection box or use the spinner controls and the horizontal cursors will move to the levels that you set.

There are two options for where to mark the onset and end of breaths. You can select *Volume peaks and troughs* or *Last point of zero flow*. This makes little difference for most breaths. However, it does affect measurements of breath timing when there are significant periods of virtually zero-flow between breaths.

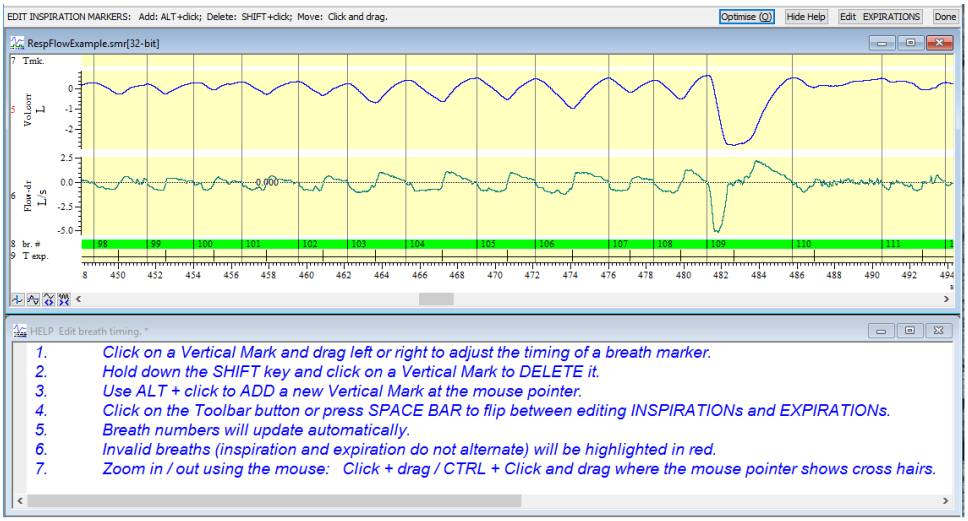


Finally, select the time range by dragging the cursors or using the dialog tools.

When you click on OK, the dialog closes and two new channels are added to the data file. The coloured State channel, labelled *br#,* marks the start of each breath (onset of inspiration) and includes the breath number. Immediately below this channel is a marker showing the onset times of expiration (labelled *T exp*). If you performed drift removal over discrete time ranges then these ranges will also be marked in a state channel labelled *Ranges*

Edit Breath markers

At this point you have the opportunity to review the breath timing marks and edit any that you disagree with. Click the toolbar Accept button to adopt the default breath markers or click on Edit to inspect them in more detail and adjust them if necessary.



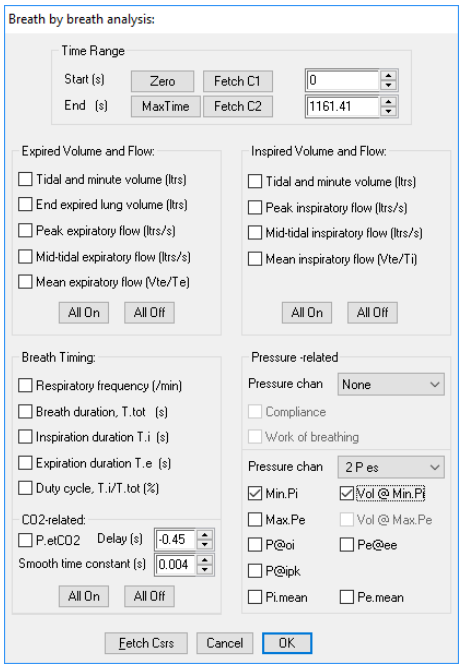
In editing mode, the breath onset times are highlighted by vertical markers, you can toggle between highlighting onset of inspiration and onset of expiration via the Edité button on the toolbar. You can optimise the flow and volume traces via the toolbar Optimise button (hotkey: Q).

Editing the timing marks is done using the mouse via a drag-and drop interface. Click the Show Help button to display a crib sheet of instructions for the various options.

Click on the Done button when you have finished editing to return to the main script toolbar. You will not be allowed to proceed if you try to leave the markers in an untidy state, that is, if inspiration and expiration marks do not occur alternately. You can go back and insert the missing markers at the breaths highlighted in red or click the RESET button on the toolbar to abandon editing and re-start with via Mark Breaths.

B x B

This button opens a set up dialog for you to plot a range of breath by breath (*B*x*B*) statistics as additional channels in the data file. Set the time range as before by dragging cursors or using the tools in the dialog.



Next, check the boxes next to the measurements that you require. The *End-tidal* CO_2 checkbox and related items are only available if the relevant channel (i.e., a waveform channel with the string ñCO_2" in the title) is visible.

You have the option to introduce a time shift in the $P_{et}\,CO_2$ trace in order to align the output of the gas analyser with the other traces. Negative values shift the CO_2 trace to the left. You can also add a smooth process to reduce noise on the $P_{et}\,CO_2$ trace.

Measurements related to pressure such as *Compliance* and *Work of Breathing* are only available after you have nominated an appropriate pressure channel. Abbreviated titles of pressure channel in the dialog are displayed in full in a tooltip when you drag the mouse pointer over the relevant checkbox.

B x B results

When you click on OK, the results that you requested are calculated. This may take several seconds and during this time, the data view will be hidden. When the window reappears, the results that you requested will be shown in RealMark channels added to the original data file. In most cases, the results channel will be drawn as data points joined by straight lines. The points are plotted at the end of the breath to which they refer. The contents of each channel are indicated by the channel title and the channel comment. You can view the comment as a ñtipò by pointing at a channel title with the mouse. In some cases, related channels are overdrawn on a common y-scale.

Expired volume and flow

Tidal and minute volume

Checking this box generates 3 channels:

- exp V_t is expired tidal volume of the immediately preceding breath
- i.Ve $_{1min}$ is *instantaneous* minute volume, i.e., predicted minute volume based on the preceding breath
- Ve_{1min} is actual volume expired in the preceding minute.

Ve_{1min} and i.Ve $_{1min}$ are shown overdrawn to save space. You can ungroup them if you wish by dragging their channel numbers with the mouse.

EELV

End expired lung volume is shown overdrawn with the corrected volume trace.

Peak/Mid-tidal/Mean expiratory flow

These channels are shown initially with separate Y-axes. If more than one of these channels exists then you can overdraw them on a common y-scale by clicking on the toolbar button labelled F. Group. Press this button again to toggle between ógroupedô and óun-groupedô flow channels.

Inspired volume and flow

Checking boxes in this group has the same effect as described above except that the measurements are based on the inspiration phase of each breath. The results will have a negative sign because, the script represents inspired flow and volume as a downward deflections. Note that the F. Group button overdraws both inspired and expired flow measurements on a common y-axis.

Breath timing

Respiratory frequency

Check this box to plot the instantaneous frequency of each breath. The default display mode is dots plotted at the end of each breath. You can change the display by right-clicking on the channel area, selecting *Draw Mode* and changing the settings in the pop-up dialog. Options include changing the dot-size or switching to *Line* or *Skyline* modes.

$T_{tot}/T_i/T_e$ duty cycle

Breath duration, and duration of inspiration and expiration phases are displayed with separate y-axis and the points plotted at the end of the breath. The T. Group button on the toolbar allows you to switch to showing these timing channels in the space-saving, overdrawn mode. Press T. Group again to separate the y-axes. Duty cycle, T_i/T_{tot} is plotted as a percentage on a separate axis.

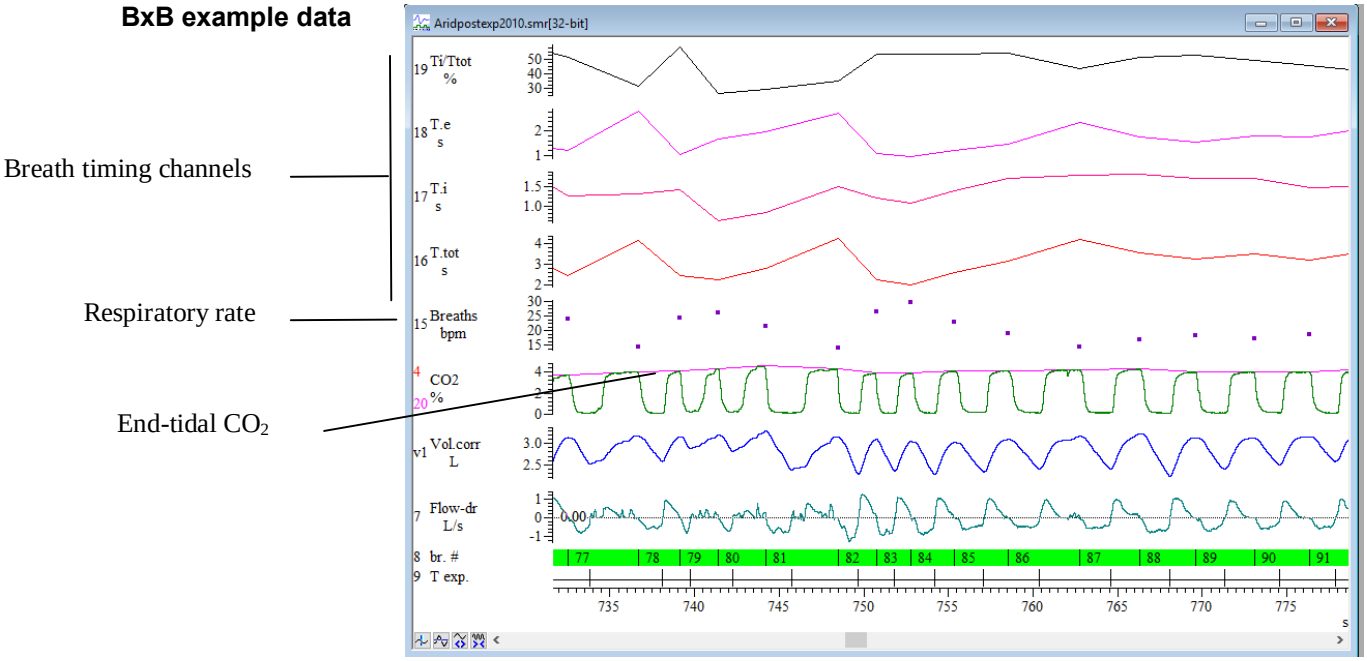
End-tidal CO_2

Some methods of measuring end-tidal CO_2 can introduce a time shift of the monitor trace relative to the other respiratory parameters. The BxB dialog allows you to enter an offset to advance or delay the CO_2 monitor trace so that CO_2 peaks are aligned correctly with the end of the relevant breath. Enter *negative* values to shift the CO_2 trace left (i.e.

compensate for a delay). There is also an option to apply a Smooth channel process to reduce the effect of noise and glitches on the CO_2 trace.

The *etCO_2* trace is displayed overdrawn with the raw data. The traces should align closely if you have chosen the correct time delay between the CO_2 and flow/volume traces. If you wish to display the plot on its own y-axis, you can do it manually by dragging the channel number up or down to the gap between adjacent channels and then dropping. You can restore the overdrawn display by reversing the above procedure followed by double-clicking the common y-axis and checking the box labelled *Lock axes*.

BxB example data



Pressure-related data

You must select a suitable pressure channel first in order to enable the checkboxes for the various measurements. Pressure channels must be visible and have a channel title beginning with a capital óPô

Compliance

A simple estimate of the compliance of the lungs and thorax together is the tidal volume divided by the peak trans-pulmonary pressure difference. Checking this box generates two plots, labelled C_i and C_e, based on inspired and expired tidal volume and pressure, respectively.

Work of breathing

Checking this box generates plots of inspiratory elastic work ($E._{wob}$), inspiratory resistive work ($R._{wob}$) and total inspiratory work of breathing ($iWOB_{tot}$). There is also a measure of work of expiration (*exp.wob*) The results are based on area measurements made on *Volume-Pressure* (*V-P*) loops derived from each breath. The method is the same as that used for individual *V-P* loops described later except that the loops are not saved for visual inspection. Automatic measurements of work of breathing may give spurious results if the *V-P* loop has an unusual shape. If you have any doubts about the results for an individual breath, we recommend that you double-check the result by generating the *V-P* loop manually.

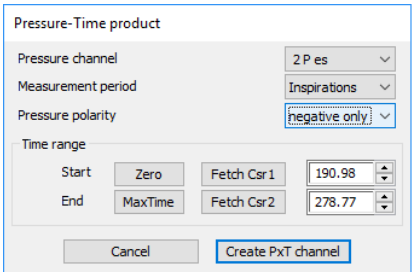
Note that it is sometimes not possible to measure work of expiration. In such cases the trace is set to a negative value (-1). By default, the work-related traces are drawn separately. You can overdraw the traces related to inspired work on a common Y-axis by clicking on the W. Group button (hotkey: W). Click again to restore the previous format.

Min P_i / Vol@minP_i etc.

Pressure measurements are disabled until you choose a suitable pressure channel. You can then choose from: minimum and maximum pressure during each inspiration and maximum during expiration (*Min P_i*, *Max.P_i*, *Max P_e*) and the corresponding volumes (*Vol@minP_i*, *Vol@maxP_e*) or pressure at onset of inspiration, peak of inspiration and end of expiration ($P@_{oi}$, $P@_{ipk}$ and $P@_{ee}$). Also, mean pressure during inspiration (*Pi.av*) and expiration (*Pe.av*) can be plotted. Each measurement is plotted in a separate channel. You can take pressure measurements from more than one pressure channel by making multiple passes through the *BxB* dialog choosing a different pressure channel to measure each time. In order to distinguish between pressure measurements from different source channels, the channel number of the source channel is appended to channel titles in the time view. The title of source pressure channels is included in the headers of tables of results.

Pressure .Time product

PTP is the product of integrated pressure (i.e. area subtended by the pressure trace) during inspiration or expiration multiplied by the respiratory frequency. It is related to work of breathing but reflects the energy expenditure during isometric as well as dynamic phases of respiration. Work of breathing measurements reflect energy expenditure during the dynamic phase only (i.e. when the volume is changing). The script enables you to plot, for example, the PTP of gastric, oesophageal or trans-diaphragm pressure during inspiration or expiration for each breath. The result has units of $cmH_20.s.min^{-1}$.



In the dialog, select the source pressure channel, the measurement period (either *Inspiration* or *Expiration*) and whether to measure negative pressure only, positive pressure only, or the sum of +ve and ï ve pressures. Finally, set the time range for measurements by dragging cursors or typing start and end times in the dialog before clicking on Create PxT channel.

If you have already create a PxT channel from the current source channel you will be prompted to either create a new channel or to add new data to the existing channel, overwriting previous data if necessary.

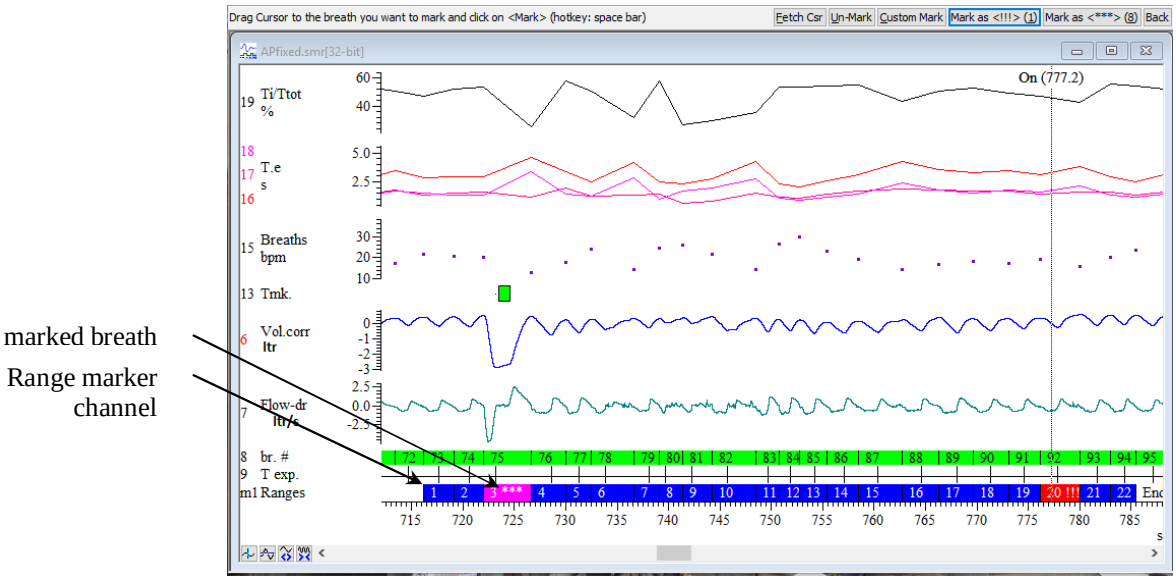
Analyse in stages

We recommend that you generate the breath by breath measurements that you need in a single time range that includes all the data of interest. You can mark multiple sub-ranges to *report on* prior to printing out the table of results.

However, you *can* perform breath by breath measurements over multiple time ranges neatly, so long as you analyse *non-overlapping* data sections in sequence from the beginning to the end of the file. The script will then *append* results from the current time range to existing channels where possible. The gaps between adjacent sections of data will be connected by straight lines extending from the last valid data point in one section to the first valid point in the following section. Thus the traces will appear rather like an old-style chart recording where the pens continue to trace out a line even when no data is being recorded. Note that it is not possible to *insert* data into existing channels between sections of already analysed data. If you try, new channels will be created. If you analyse a time range that overlaps with data in a pre-existing channel of the same title, you will have the option to delete the old data.

Mark Ranges

This button displays a set of tools for marking areas of interest. Later, when you tabulate the results, you can opt to report only on the marked ranges.



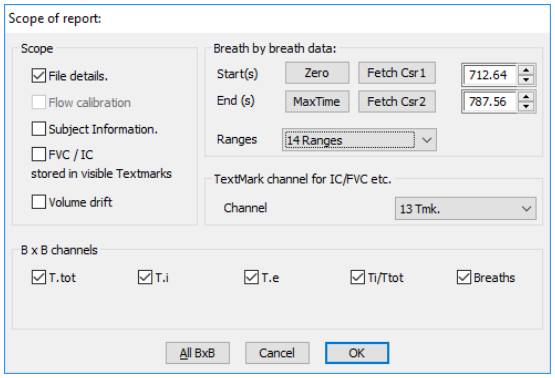
To mark a range, simply drag the cursors labelled óOnô and óOffô to bracket the required range and click on the Add Range button (hotkey: *space bar*). The range, including the breaths in progress at the cursor positions, will be marked in a state channel (title: *Ranges)* with the breaths numbered consecutively. You can mark as many ranges as you want in this way by scrolling the data and fetching and dragging the cursors. Positioning the cursors inside adjacent marked ranges will mark all the intervening breaths, forming a single range with the breaths re-numbered accordingly. Similarly, you can delete all or parts of existing ranges by dragging the cursors to bracket the target area and clicking on the Delete Range button (hotkey: D).

If you removed drift from discrete time ranges at an earlier stage of the analysis, then these ranges are marked automatically as part of the Breath by Breath analysis (*B x B* dialog).

Mark breaths toolbar

You can highlight individual breaths within a marked range via the Mark Breath button. Simply drag the cursor into the required breath and click one of the three Markė buttons. These allow you to label the breath with asterisks, exclamation marks or a code of your choice (Custom Mark). The marked breaths will be labelled, displayed in a different colour and the codes will be shown in the report. You can create a heading for a range in the report by applying a custom mark to the first breath in that range. Click on Un-Mark to delete a mark from the breath indicated by the cursor. Click on Back to return to the Mark Ranges toolbar.

Report This button prints a table of results in a simple spreadsheet format, a *grid* view.. You can select the scope of the report by selecting a time range and checking boxes in the set up dialog.



File details prints the Filename , date and time of recording etc.

Flow calibration prints the equation used to convert the raw pneumotach output to Flow (only if the *FV_Online* script was used to record the data).

Subject details Shows the information that was entered in the *Subject* details dialog

Breath by breath data You can set the time range by dragging the cursors or using the tools in the dialog. You can restrict the printout to marked ranges within the chosen time window by selecting the appropriate *Ranges* channel in the dialog. If *None* is selected then results for all breaths in the time range will be printed.

The option to print measurements from FVC and IC manoeuvres will only be available if the TextMark channel where these results are stored is visible and selected in the dialog (*Tmk*). Select the *BxB* channels to report on by checking the appropriate checkboxes.

The All BxB buttons flips the state of these checkboxes between all on and all off. You can save the report as a grid file using the *Save As* option on the Spike2 *File* menu.

Example Report

File details

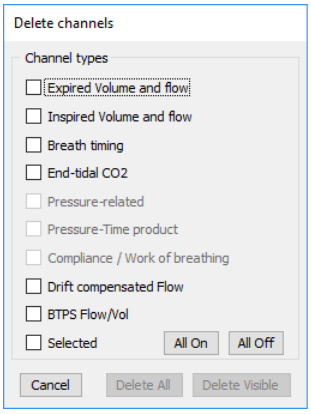
IC data

BxB data Range 1

	A	B	C	D	E	F	G	H	I
0	FILE DETAILS								
1	Name	APfixed.smr[32-bit]							
2	Recorded	07/08/2010							
3	Start (s)	17:38:28							
4	Duration (dhms)	1777.0s (hms: 0 : 29 : 37)							
5									
6	TEXTMARKS:								
7	Time	IC	FVC	FET	FEV1s	FEV1s/VC	PEF	PIF	
8	(s)	(ltr)	(ltr)	(s)	(ltr)	(%)	(ltr/s)	(ltr/s)	
9	723.214	3.505							
10									
11									
12									
13	RANGE 1								
14	BREATH BY BREATH DATA								
15		Label	End Time	Breaths	T.tot	T.i	T.e	Ti/Ttot	
16	#		(s)	bpm	s	s	s	%	
17									
18	1		719.09	20.655	2.905	1.513	1.392	52.070	
19	2		722.03	20.390	2.943	1.572	1.371	53.417	
20	3	***	726.63	13.045	4.600	1.180	3.419	25.657	
21	4		730.03	17.667	3.396	1.970	1.426	58.013	
22	5		732.51	24.148	2.485	1.265	1.220	50.918	
23	6		736.66	14.461	4.149	1.317	2.832	31.737	
24	7		739.12	24.383	2.461	1.429	1.032	58.052	
25	8		741.41	26.214	2.289	0.615	1.674	26.885	
26	9		744.21	21.445	2.798	0.829	1.969	29.614	
27	10		748.47	14.082	4.261	1.509	2.751	35.428	
28	11		750.75	26.330	2.279	1.212	1.067	53.172	
29	12		752.77	29.686	2.021	1.079	0.942	53.370	
30	13		755.37	23.074	2.600	1.408	1.193	54.136	
31	14		758.50	19.161	3.131	1.720	1.411	54.929	
32	15		762.76	14.085	4.260	1.857	2.403	43.599	
33	16		766.33	16.816	3.568	1.808	1.760	50.673	
34	17		769.60	18.352	3.269	1.731	1.538	52.945	
35	18		773.10	17.137	3.501	1.713	1.788	48.920	
36	19		776.21	19.307	3.108	1.466	1.641	47.181	
37	20	!!!	780.01	15.784	3.801	1.630	2.172	42.866	
38	21		782.96	20.349	2.949	1.643	1.306	55.714	
39	22		785.49	23.701	2.532	1.376	1.155	54.356	
40									
41	Mean			20.012	3.150	1.447	1.703	46.984	
42	stdev			4.522	0.724	0.330	0.651	10.371	

Delete Selected This button provides a quick method to delete channels that were created by the script. You cannot delete sampled waveforms using this dialog. Channels are organised into categories and channels of that group will be deleted if the check box is checked. You can opt to delete all channels of the selected types or only those that are currently visible.

If you delete *Drift compensated flow* channels then the previously hidden *btps* Volume and Flow channels will appear in their place.

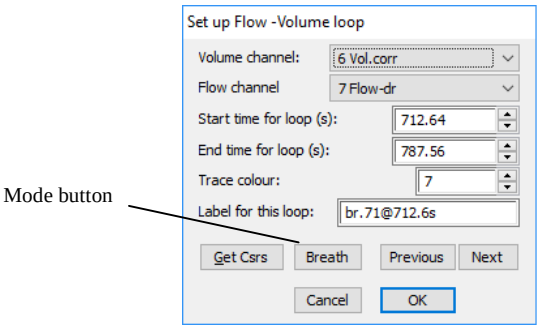


If you opt to delete *btps* volume and flow channels then they will be replaced with the original *atps Flow* channel. You can then regenerate the *btps* Flow and Volume channels via the Vol from Flow toolbar button.

You can select channels for deletion by holding down *Ctrl* and clicking on channel numbers to highlight them. Be aware that you can permanently delete channels other than those created by the script, e.g. the keyboard marker channel using this method (*but not waveforms*).

Flow-Volume loops

Plotting tidal exercise flow-volume loops within the maximal flow-volume envelope provides a method to assess the degree of ventilatory demand in relation to ventilatory capacity (Johnson *et al* 1999). This script has a series of tools for generating and taking measurements from such pairs of loops. You can access them via the F-V Loops button.



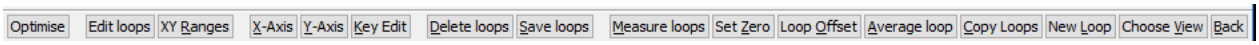
The Set up dialog opens when you press the F-V loop button for the first time. Make sure that the correct volume and flow channels are selected in the dialog and then adjust the view to display the range of breaths that you are interested in.

Next, click on Get Csrs to display the vertical cursors that you need to mark the time range for the loop. When they first appear, the cursors will snap to adjacent expirations thus marking a single breath (breath mode). You can jump to neighbouring breaths using the Previous and Next buttons. You can also set the cursors to snap to other features by clicking repeatedly on the Mode button until the label changes to the one you want. Available modes are: *Breath*, *Inspiration*, *Expiration* and *FVC*. You can also create a loop from multiple breaths by dragging the cursors to bracket several breaths and the using the Next or Previous buttons to snap the cursors to the nearest peak or trough on the volume trace, depending on the current Mode setting.

Of course, you are not obliged to use these tools to position the cursors. You can drag them into whatever positions you see fit. You can use the horizontal cursor as an aid, for matching the volume level at the start and end of the range to ensure that the loop joins up neatly. The dialog will display the time range corresponding to the cursor positions. You can select the trace colour of the loop by setting the index of the required colour in the Spike2 palette. By default, the label for the loop is based on its time of onset. However, you are free to enter whatever label you wish. The loop view will appear when you click on OK and the options on the F-V loop toolbar will become available.

Flow-Volume loops toolbar

The toolbar has 16 buttons. Click on the New Loop button on the toolbar to re-open the

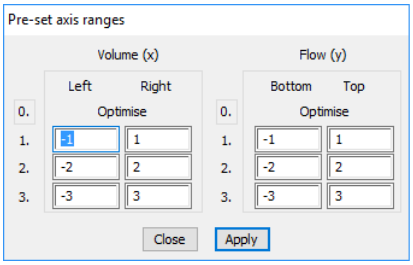


Set up dialog so that you can add another loop to the view. If there is more than one possible destination view then a dialog will open for you to specify which view you want to work on.. You can add up to 24 loops to a single XY view in this way.

You can show and hide loops and make many other adjustments to the display by right-clicking on the loop view with the mouse and choosing an option from the context menu

XY Ranges

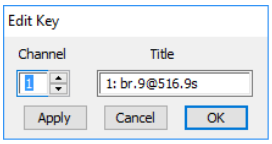
This button allows you to set up three preset *x*- and *y*- axis ranges for the loop views that you create. Simply type the three ranges that you want in the dialog and click on Apply. Note that you can set an inverted axis if you wish by setting the bottom (left) value higher than the top (right) one.



Any ranges that you set up will be stored from one analysis session to the next. Thus, you may only need to click on this button once to do an initial set up. One of the numbered presets for *x* and *y* will be highlighted (grey square) to indicate the current selection.

X-axis / Y-axis Click on one of these buttons to cycle to the next preset axis range that you set up via the XY-ranges button. One of these settings is always *Optimise* to show all the data in all of the loops in the view. These buttons update the axis ranges on the loop view which is currently selected (the front view) and they become the default for any new loop views that you create.

Key Edit When you create a new loop, you can choose a label for it in the New loop dialog. By default, this label contains the breath number and the time, though you are free to edit it. This label then appears in the key of the loop view. If you need to change the label of a loop in the key then click on the loop view to select it, followed by Key Edit. Simply, select the channel number of the loop to edit in the dialog. The current label will be displayed. You can replace it with a new label and click on Apply to display it.

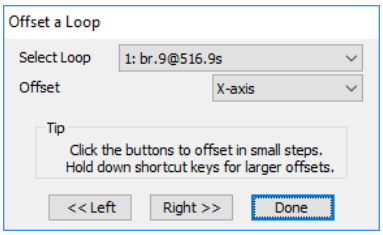


Back This button closes the F-V loop toolbar and returns you to the main toolbar.

Choose View This button will be enabled if one or more flow-volume views are already open. It opens a dialog for you to choose which view to work on. You can use this option to analyse flow-volume loops that were created in a previous analysis session and opened with the *Open* command on the Spike2 *File* menu. The Choose View dialog opens automatically when you click on the F-V Loops button if there is a choice of destinations for any loops that you might create. The view that you select as the destination for loops will be brought to the front (i.e. it will have a coloured title bar).

Copy Loops This button allows you to copy one or more loops from one Loop view to another open Loop view. Simply specify the source view, the destination view and a specification for the channels to copy (for example, ñ*1,2,4..6*ò) in the pop up dialog and click on OK.

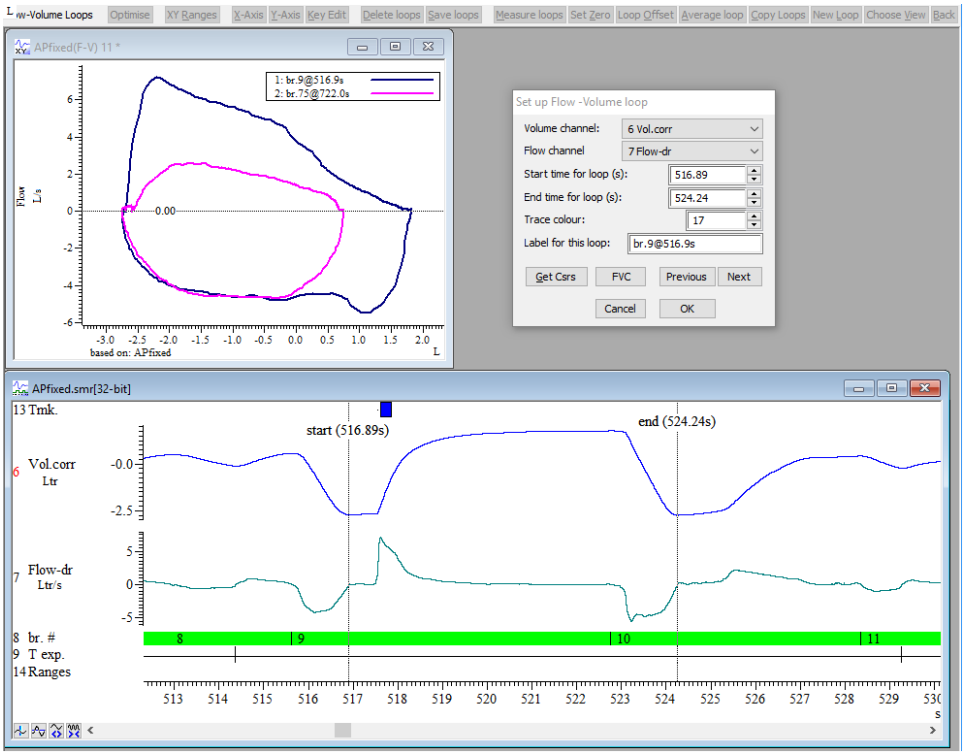
Offset Loops This button allows you to translate a selected loop along the X- axis (volume) or Y-axis (Flow) in order to align it with another loop, for example, to remove any residual drift. Simply, select the loop to offset and the axis from the drop-down lists in the dialog. Then click on the << Left or Right >> or Down, Up buttons to shift the loop in small increments or use the left and right and down Up arrow keys on the keyboard to progressively increase the offset until you release the button.



Set Zero toolbar

Before taking measurements from a set of flow ï volume loops, it may be necessary to adjust the axes to a standard reference frame. For example, this might involve setting the TLC to zero. When you click the Set Zero button the Set zero toolbar displays. Select the axis you want to adjust and then drag the cursor that appears to the desired zero position and click the Apply button on the toolbar or press *Enter* to assign the cursor position to zero. Click on Back to return to the F-V loop toolbar.

Typical screen layout when creating Flow-volume loops


Flow-Volume Loops
Optimise
XY Ranges
X-Axis
Y-Axis
Key Edit
Delete loops
Save loops
Measure loops
Set Zero
Loop Offset
Average loop
Copy Loops
New Loop
Choose View
Back
APfixed(F-V) 11 *
1: br.9@516.9s
2: br.75@722.0s
Flow L/s
based on: APfixed
L
Set up Flow -Volume loop
Volume channel:
6 Vol.corr
Flow channel
7 Flow-dr
Start time for loop (s):
516.89
End time for loop (s):
524.24
Trace colour:
17
Label for this loop:
br.9@516.9s
Get Csrs
FVC
Previous
Next
Cancel
OK
APfixed.smr[32-bit]
13 Tmk.
start (516.89s)
end (524.24s)
6 Vol.corr
Ltr
7 Flow-dr
Ltr/s
8 br. #
9 T exp.
14 Ranges
s

Average Loop

This option allows you to generate a mean loop from selected loops in the current XY view. The mean loop can be based on a single loop containing several consecutive breaths or a series of individual loops. This latter option may be useful for combining data from several IC or FVC manoeuvres.

In the set up dialog, choose the loops to average by entering a channel specification. This has the form of a comma separated list of channel numbers. You can also use the format ñ1,3..5ò to select channels 1, 3, 4 and 5. There are two methods available for generating the mean loop.

Linear Mean

Here, points in the mean loop are based on the mean vertical distance from the X-axis (zero flow). The X-axis is divided into a user-defined number of bins and the mean value is calculated for each bin in each loop. The mean loop is the grand average of these values. If any component loop has no data points in a bin, then its value is calculated by linear interpolation between the values of adjacent bins. This type of average may produce the desired result over most of the volume range. However, the average may become unreliable close to the upper and lower limits because the number of loops contributing to the mean may vary.

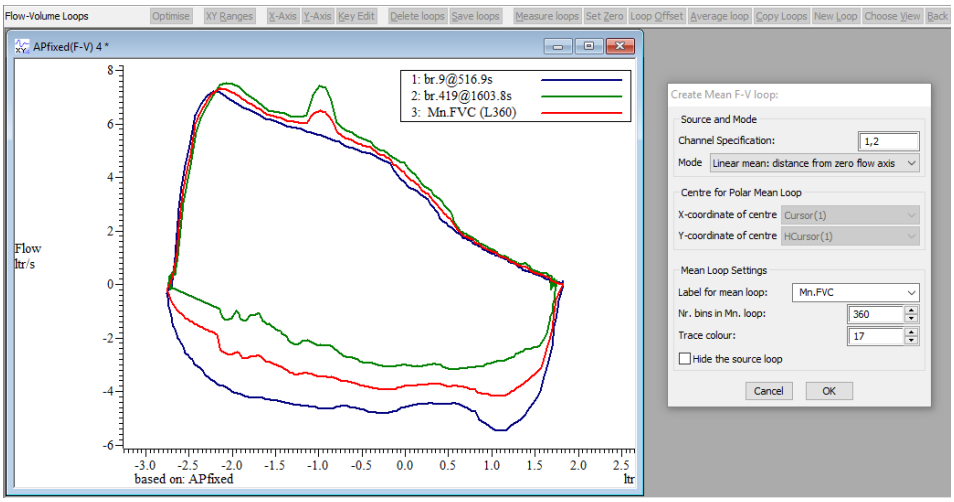
Polar Mean

This is an alternative approach that does not produce anomalies at the extremes of the volume axis. The mean loop is formed by measuring the mean radial distance to each loop from a point inside all of the loops. The shape of the loop will depend on the coordinates of the centre from which the measurements are made. The Set Up dialog gives three options for setting these coordinates:

- Middle of the volume / flow range
- Centre of gravity (mean volume and mean flow values from all the data points in all of the loops
- Intersection of horizontal and vertical cursors (manual control)

Note that the algorithm for calculating polar mean loops depends on the assumption that the points succeed each other in a clockwise direction. An error message will display and the mean loop will not be drawn if any angle between successive data points in the source is counter-clockwise by more than 45 degrees. You can try repositioning the centre point and try again if you wish.

Mean loop generation



Mean loop settings

In the case of a linear mean, the number of bins in the mean loop refers to the number of subdivisions of the x-axis that are used to construct the mean. In the case of a polar mean, it is the number of sectors used. For example a polar loop with 360 sectors will have a resolution of 1 degree of arc with each data point being the mean of all the data points within a 1 degree sector relative to the chosen centre point. Information about how a mean loop was generated will be appended to the loop label automatically. For example, (L300) means a linear mean with 300 bins, whereas (P360) mean a polar mean with 1 degree resolution.

Save Loops

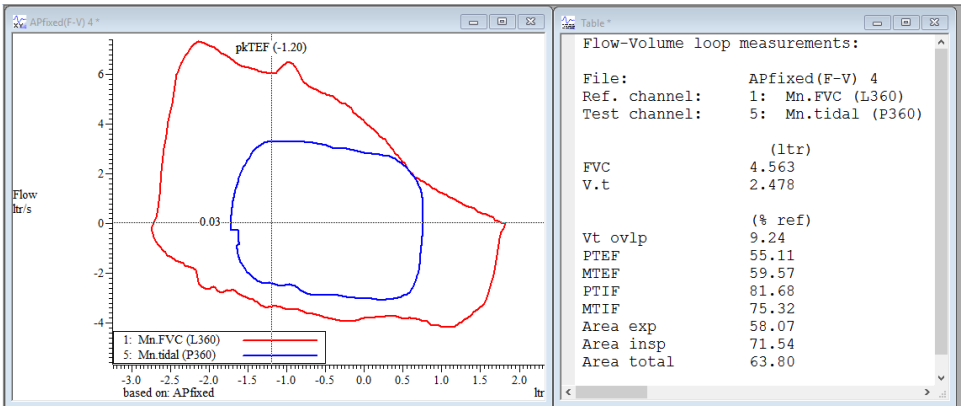
Use the Choose View button to select the view to work on if more than one loop view is open. Then click on the Save Loops button to open a dialog for saving the current flow-volume loop view under a name of your choice.

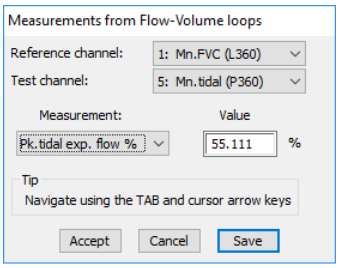
Delete Loops

Select a view and enter a specification for channels to delete in the pop-up dialog and click on OK.

Measure Loops

This facility allows you to make mainly comparative measurements between two flow volume loops, referred to here as the reference and test loops. These measurements are important for assessing ventilatory constraints during exercise. The reference loop typically would be an individual or mean FVC loop while the test would be a normal breath or mean of several normal breaths. Select the measurement you require from the drop-down list. You can use a mouse wheel to navigate this list if you wish.





The first measurement on the list is Residual Volume. Clearly, this value cannot be derived from the flow-volume loops themselves. However, if residual volume is known from spirometry, then enter it in the dialog. This reference point will be added to the flow-volume loop view by adding the residual volume to the End expired lung volume of the reference loop. When you select other measurements, cursors will move to the appropriate positions and a measurement will appear in the dialog. You are free to drag the cursors if you are not satisfied with their default positions. The only exception is V_t overlap which is not set automatically. You *must* drag the cursors to mark the zone where test and reference curves overlap. Note that the cursors are ócrossedô when they first appear, that is the $V_{t(ov)}$ low marker is to the right of the $V_{t(ov)}$ high marker. This has the effect of setting the overlap percentage in the dialog to zero. Uncross them manually to set a positive value.

Each measurement will be added to the report when you click on Accept. If you repeat a measurement, the new result will replace the old one in the table. If the residual volume

was entered then TLC, i.e. FVC +RV, will be shown in the table and EELV and EILV will also be shown as a proportion of TLC. The Save button allows you to save the table of results to disk as a text file.

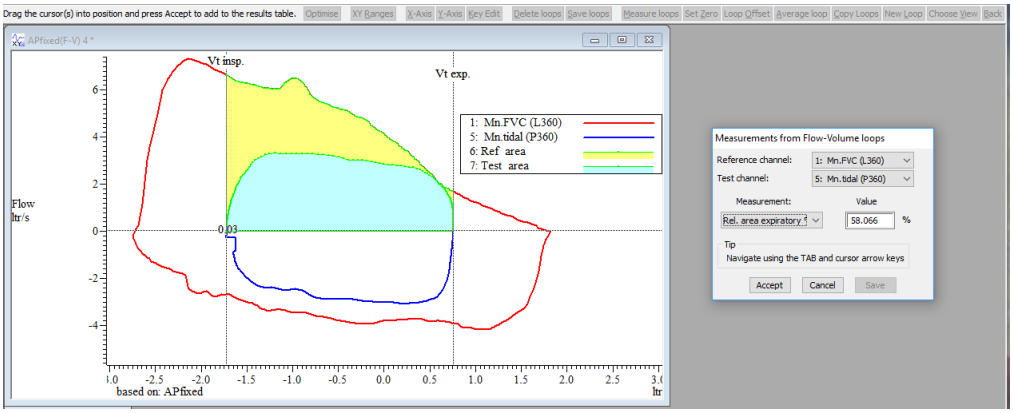
Notes on F-V loop measurements

The following abbreviations are used in the table:

RV	Residual Volume
FVC	Forced Vital capacity
ERV	Expired reserve volume
V_t	Tidal volume
IC	Inspired capacity
EILV	End inspired lung volume - as a percentage of TLC if known.
EELV	End expired lung volume as a percentage of TLC
V_t ovlp	percentage of the tidal breath that meets or exceeds the reference loop.
PTEF/MTEF	Peak and Mid-tidal expiratory flow as percentage of reference.
PTIF/ MTIF	Peak and Mid-tidal inspiratory flow as percentage of reference.

Relative area measurements refer to the area of the reference and test loops that are bounded by the cursors. When you drag the cursors the areas being measured will be highlighted.

Example: Measure Relative Area of Loops

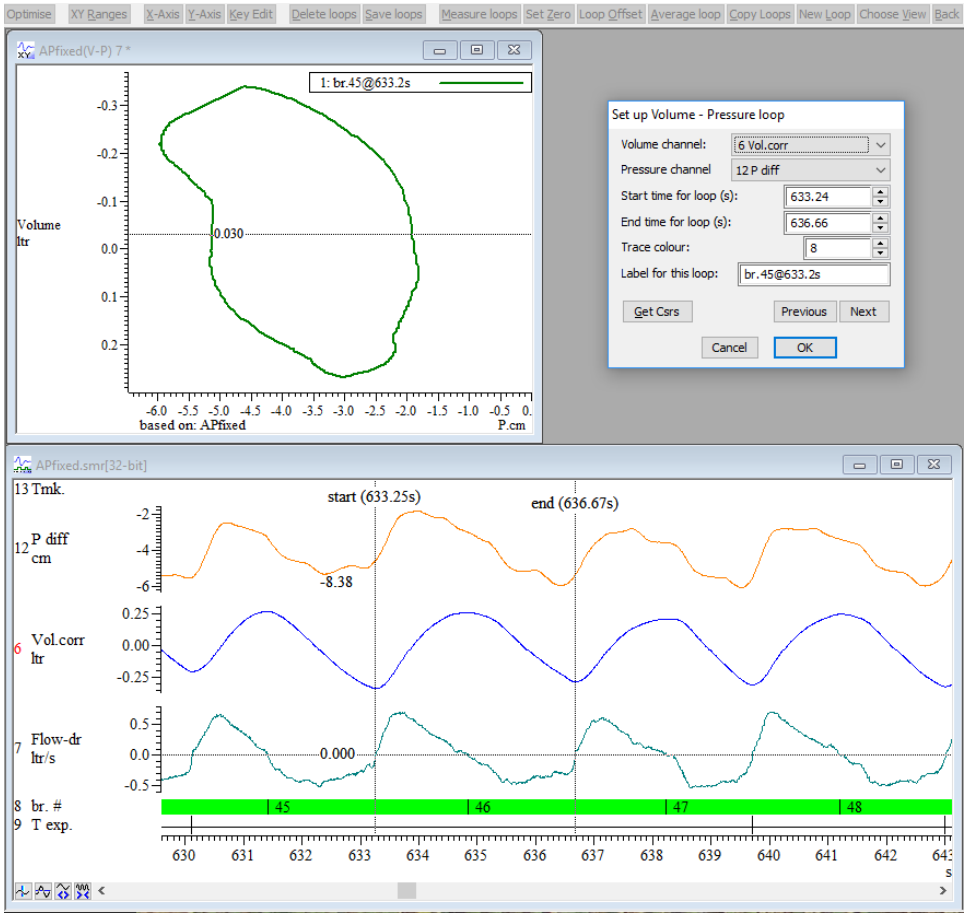


Volume Pressure loops

The method of generating and processing Volume-Pressure loops is broadly similar to that used for Flow-Volume loops. Click on V-P Loops to get started. A *Choose View* dialog will open for you to select the destination for a new loops if one or more loop views are already open on the desktop. A *Set Up* dialog allows you to choose the relevant channels and select the segment of trace in the time view that you want to use to create the loop.

The simplest method is to ózoom inô on the time range of interest using the usual Spike2 tools. Next, click on Get Csrs to fetch the cursors. The cursors will automatically snap to the start and end of a breath (adjacent peaks on the volume trace). You can use the Next or Previous buttons to jump to adjacent breaths. You can also generate a multi-breath loop by dragging the cursors to the desired positions. The Next and Previous buttons advance each cursor to the adjacent peak on the volume trace so that the number of breaths bracketed by the cursors will remain the same. The default label for the loop will be based on the start time but you can edit it to whatever you want. The loop will be created when you click on OK.

V-P loops Set up

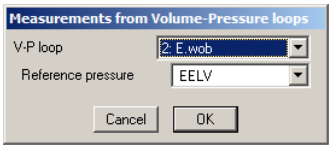


The *V-P loops* toolbar has the same buttons as the one for *F-V* loops and most of them (Delete loops, Save loops, Set Zero, Loop Offset, Copy Loops, Choose View and Back) behave identically. The Average Loop function differs only in that only the polar method of calculating the mean loop is available.

V-P Measurements

The main measurements that you can make from an individual or mean volume pressure loop is the elastic and resistive (and viscous) components of the work of inspiration. These can be calculated from the area measurements based on the *V-P loop (*see Roussos *et al*. 1986).

When, you click on Measure Loops, a dialog opens for you to select the particular loop that you are interested in and the reference pressure. By default, the reference level is the pressure at EELV. However, you can adjust this by selecting *Cursor(1)* from the drop-down list and dragging it to the position you require.



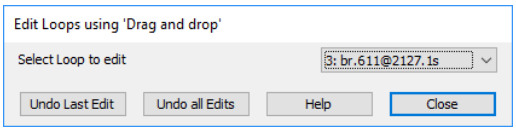
When you click on OK, a diagonal is drawn through the loop between EELV and EILV. The area of the triangle formed by this diagonal and the reference pressure (pink) is taken to represent the elastic component of work of breathing (*E.wob*). The area of the loop to the left of the diagonal (yellow) represents the resistive and viscous component (*R.wob*). The results for elastic, resistive-viscous and total work of breathing are printed below the x-axis. These are the results that are calculated automatically for each breath when you select the Work of Breathing options in the *BxB* control panel.

Edit loops

Occasionally it happens that a very small number of artifactual data points spoil the appearance of a Flow-Volume or Volume-Pressure loop. More seriously, a few misaligned data points can defeat the built-in method for marking and measuring the area of sections of a loop as shown in the example below.

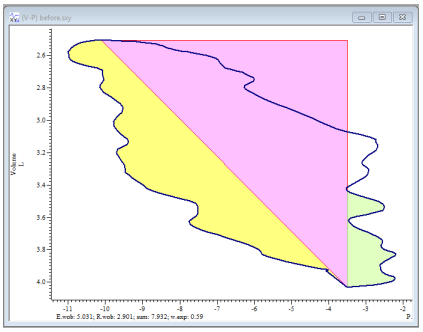
The area that defines *expired work of breathing* in this Volume-Pressure loop is not shaded or measured correctly because a few points on the loop cross the vertical drawn from the maximum inspired volume. Problems like this can be fixed by making minimal adjustments to the position of a few data points.

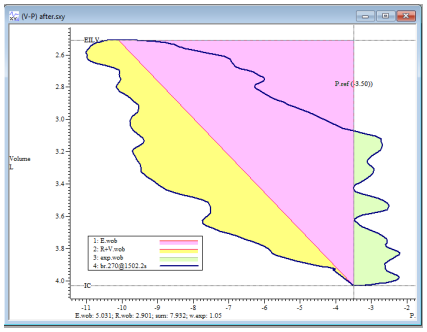
Click on the Edit loops button. Select the loop to edit via the drop-down list in the dialog. You can now drag individual data points to new positions with the mouse. Click on the Help button for detailed instructions.



Briefly, hold down the *Alt* key and the left mouse button to highlight the data points. When you drag over an editable data point, the pointer changes to a ógun sightô. Hold down *Ctrl+Alt* and drag with the mouse to pick up the data point and drag it to a new position. Drop it by releasing the left mouse button. You can now repeat the process for other data points. Buttons in the dialog allow, you to undo the last edit or undo all edits in the current session if you make a mistake. Press Close to finish editing. You can re-calculate area measurements by deleting the old loops marking areas via Delete loops and clicking on Measure loops again.

Before and after editing





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Johnson BD,Weisman IM, Zeballos RJ and Beck KC (1999) Emerging concepts in the evaluation of ventilatory limitation during exercise: the exercise tidal flow-volume loop**.** ***Chest*** **Vol. 116 pp.488-503**
http://www.chestjournal.org/cgi/content/full/116/2/488

Flatau PJ, Walko RL, and Cotton WR (1992): 6th order polynomial solution for variation in saturation vapour pressure of water with temperature. ***Journal of Applied Meteorology*** **Volume 31: pp.1507–1513**.
http://ams.allenpress.com/perlserv/?request=get-abstract&issn=1520-0450&volume=031&issue=12&page=1507

Roussos C, Campbell EJM (1986) Respiratory muscle energetics: In *Handbook of Physiology, The Respiratory system, Mechanics of breathing.* Bethesda MD, Am Physiol Soc., 1986, section 3 Vol III, pt 2 pp. 481-509.

Appendix 1

The following equations are used to correct measured inspired and expired flows to body temperature, pressure at sea level and saturated with water vapour:

Calculation of BTPS correction factors

$Corr_{inspired} := (\mathbf{P}_{bar} - (\mathbf{P}satH_20_i * \mathbf{RH}/100) * (273 + \mathbf{T}_{body}) / ((\mathbf{P}_{bar} - 47) * (\mathbf{T}_{amb} + 273))$

$Corr_{expired} = (\mathbf{P}_{bar} - \mathbf{P}satH_20_e) * \mathbf{T}_{body} / (\mathbf{P}_{bar} - 47) * (\mathbf{T}_{expired} + 273)$

where:

$\mathbf{P}_{bar}$	ambient barometric pressure (mm Hg)
$\mathbf{T}_{amb}$	ambient temperature (C).
$\mathbf{T}_{expired}$	temperature of expired air at the flow meter (C).
$\mathbf{T}_{body}$	body temperature (C).
RH	relative humidity (%)
$\mathbf{P}satH_20_i$	Saturation vapour pressure of water at ambient temperature
$\mathbf{P}satH_20_e$	Saturation vapour pressure of water at the temperature of expired air at the flow meter
$\mathbf{P}satH_20$	at body temperature is 47.0mmHg.

The saturation vapour pressure of water varies with temperature in a way that is well described by a 6th order polynomial (Flatau. et al 1992).

$\mathbf{P}satH_2O := (a0 + a1*tC + a2*tC^2 + a3*tC^3 + a4*tC^4 + a5*tC^5 + a6*tC^6) * Pa_{to}mmHg$

where:

a0:=6.1117675;
a1:=0.443986062;
a2:=0.143053301e-01;
a3:=0.265027242e-03;
a4:=0.302246994e-05;
a5:=0.203886313e-07;
a6:=0.638780966e-10;
tC:=temperature (C)-0.15.
$Pa_{to}mmHg$ (conversion factor from Pascals to mm Hg) = 0.750061683