Capnometry With EMG
Software Application User Guide

Contents

1 Introduction

This guide introduces the Capnometry with EMG biofeedback application, part of the Mind-Body Training Tools suite. This set of applications is designed to develop skills in mind-body awareness and self-regulation, particularly in a context of mindfulness and meditation practice.

The guide has two purposes: firstly to give an overview of capnometry and of EMG, and secondly to teach you how to use the software – though it is more of a reference than a tutorial. Other training material is available on the StressResilientMind.co.uk website.

The application is designed to train optimal breathing. A capnometer measures end-tidal carbon dioxide in exhaled air, which is known to correlate with the level of carbon dioxide in blood. The latter is an important physiological parameter, as it controls vasodilation, most prominently in the brain. Over-breathing or hyperventilation causes depletion of blood carbon dioxide and thus restriction of oxygen delivery to brain cells, while conversely capnometry biofeedback is a means of training optimal oxygen delivery to brain cells.

From a practical point of view a key aspect of optimal breathing is refined awareness of muscle usage in relation to breathing, and the ability to fully release the out-breath. EMG or electromyography is a measure of muscle tension. EMG measurement enables us to detect different patterns of breathing, most notably chest-based breathing versus abdominal breathing. The former is more likely to be associated with over-breathing.

Breathing is influenced by stress, emotions and other non-volitional factors but at the same time we can consciously control how we breathe to a degree.

The application monitors partial pressure of carbon dioxide in inhaled air (PP CO_2) via a capnometer, and also EMG. Think of PP CO_2 as the concentration of CO_2. The software calculates the end-tidal CO_2, or the peak in the PP CO_2 signal over the course of a breath.

The Capnometry with EMG application offers a breath counting feature, common to several applications in the MBTT suite. This functionality is described more fully in section 5. The purpose is to support mindfulness practice and to objectively measure mindfulness performance.

In keeping with others in the suite, the Capnometry with EMG application was designed to support *your* aims, not to supplant them. Achieving good ET CO_2 scores is not necessarily the only consideration – the biofeedback application is designed to enhance or expand your subjective awareness.

The guide assumes that you have read the Software Installation and Set-up Guide, and therefore know how to start the application.

The application works with several devices. For an up to date list of supported hardware, please see the StressResilientMind.co.uk website.
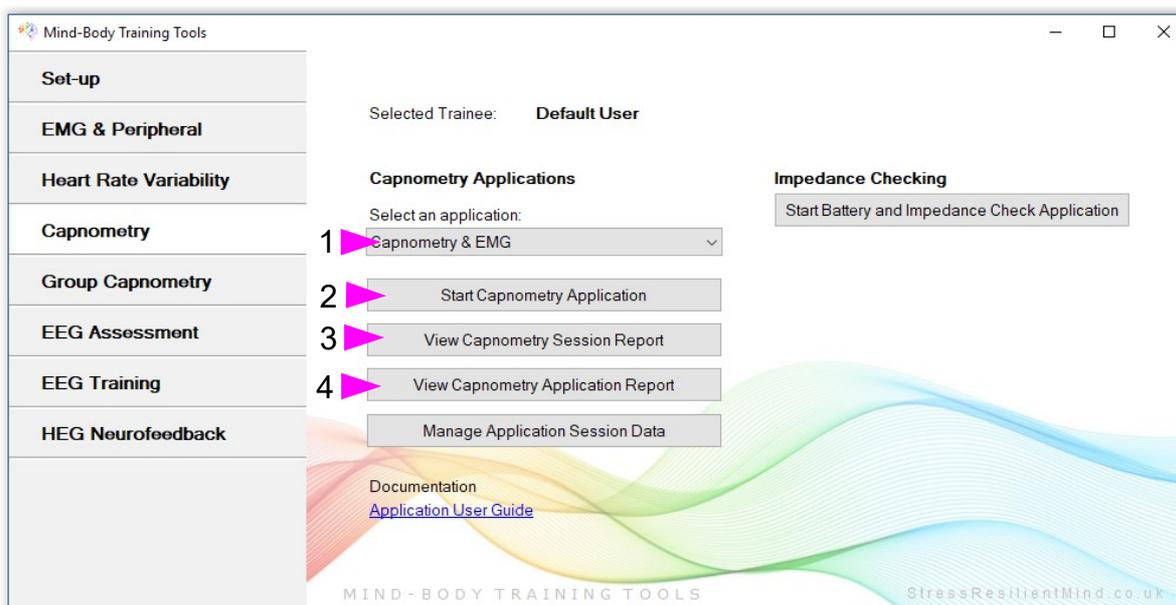
2 Launching the Application

Figure 1 – Capnometry tab of the Platform application

Figure 1 above shows the Capnometry tab of the Platform application. First you need to select the "Capnometry & EMG" application from the drop-down list control (labelled 1). Then click the button to launch the app (labelled 2). Make sure you have your BioEra licence key (dongle) inserted into a USB socket. After a few seconds a new window will appear on your screen. Note, to run this application you must have licensed both the capnometry and peripheral biofeedback modules of the product.

2.1 Hardware Set-up

The physical aspects of hardware set-up (how to connect and use your sensors, etc.) are dependent upon the type of amplifier you are using, and are covered in a separate document (Hardware Set-up Guide).

Before you start the application you configure the device set-up options, accessible by clicking a button in the Set-up tab of the Platform. In the dialog, select the type of amplifier (biofeedback device) you are using, firstly in the **capnometer source control**, and secondly in the **EMG source control**. Note, all the source settings are remembered the next time you start the Platform.

You may select 'Simulator' in each of the source controls. In simulator mode, you can learn how to use the software without the encumbrance of actually sampling the breath. (The application simply uses recorded data as a source.)

As with other applications, in the top right corner of the main window you'll see buttons for configuring the devices (and discussed in more detail in the hardware guides). Also there are two lamps which are initially red but should turn green when you start the application (by pressing the play button). If you do not see this happen, it means that the application has not been able to establish a connection with one or other of your devices.
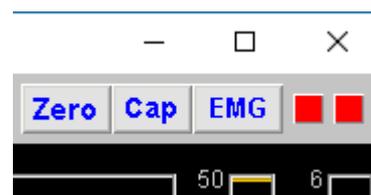

Figure 2 – Amplifier status

See the Installation and Set-up Guide for further details of device set-up.

Capnometers can take up to several minutes after being started, to warm up fully and give a meaningful signal. For some devices the signal takes a while to appear, for this reason.

2.1.1 Zeroing The Capnometer

When there is no exhaled air flowing into the capnometer, the signal (PP CO_2) should go to zero. You can see this happens in figure 3 below, at least for the first few breaths (later the breathing is so rapid it doesn't have time). Sometimes this doesn't happen, and if you see that the trace hovers a few points above zero, you need to take steps to re-zero your device. In fact it's a good idea to do this every so often anyway, because if the signal drifts the other way, i.e. below zero, you won't see it.

In summary, zeroing a capnometer is in effect re-calibrating its signal.

In the application, depending on your device, there may be a button that allows you to do this from within the software. For example, in figure 2 above you can see a "Zero" button.

At the time of writing this is only implemented for the "Respironics-compatible" device. For it to work properly, the device must be disconnected from the breath for a period of several seconds before clicking. When you click, you should see the trace disappear and the lamp turn red for a period of a few seconds. If this doesn't happen, wait longer.

3 Physiological Parameters

This section explains the physiological parameters used in the application.

3.1 Capnometry

The capnometer measures partial pressure of carbon dioxide (PP CO_2) in exhaled air. Figure 3 below shows the variation in this signal – it rises to a peak during the exhalation phase of the breath. The height of this peak is key – it is known as the end-tidal partial pressure of CO_2 (ET PP CO_2) and is known to correlate with the blood level of CO_2.
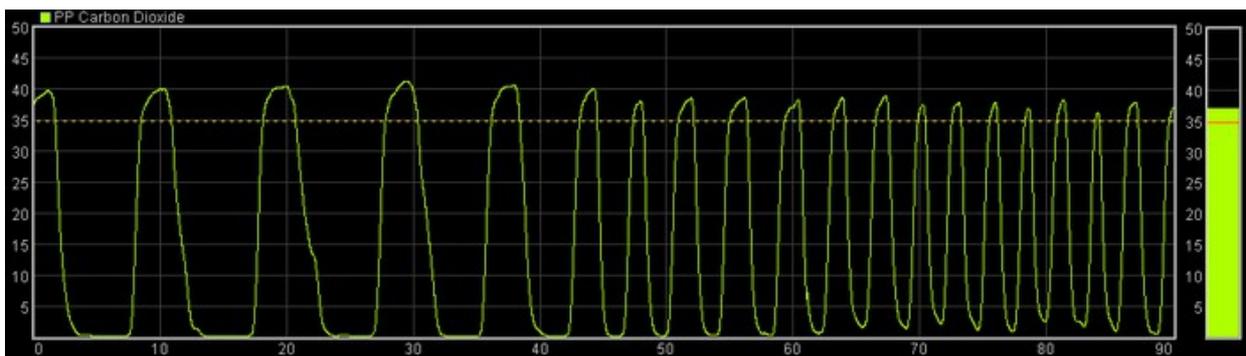
Figure 3 – Carbon dioxide signal

Although we think of carbon dioxide as a waste product, it has important functions in the body. Firstly, it controls the pH (acidity) of blood, which is a critical parameter because it dictates how the blood binds to oxygen and then releases it to tissues. Secondly, blood carbon dioxide influences vasoconstriction and vasodilation, most particularly in the brain where it is the main determinant.

These two factors together mean that partial pressure of carbon dioxide in the blood determines the oxygen delivery to brain cells.

3.1.1 Hyperventilation

Hyperventilation or over-breathing is a common form of breathing dysregulation. It causes the partial pressure of carbon dioxide in blood to become depressed, resulting ultimately in reduced oxygen delivery to brain cells. Low carbon dioxide is known as hypocapnia. Hyperventilation can be acute of chronic, and has numerous associated symptoms.

Under-breathing, by contrast, is rare, and from a practical point of view is extremely unlikely in the absence of lung disease.

Capnometry is the best way of measuring over-breathing (which is a matter of degree). In over-breathing, ET PP CO_2 is low.

3.1.2 Optimal Breathing

Conversely, in optimal breathing ET PP CO_2 is high, thus maximising blood CO_2, and oxygen delivery to brain cells. (This assumes that there is no lung disorder making ET CO_2 unnaturally high.)

Optimal breathing training aims to maximise ET PP CO_2.

3.1.3 Calculated Parameters

From the PP CO_2 trace, the software calculates:

- End-tidal (or peak) PP CO_2 – once per breath

- Breathing Rate (in breaths per minute)

These two parameters are shown in the long term display (figure 7), and can be used as the basis of audio feedback (section 4.6).

3.1.4 Breathing Calibration

To calculate the above parameters, the software needs to accurately and consistently detect the turning points of the breath (beginnings of inhalation and exhalation). This calibration should happen automatically during the first minute or so of the session. It's possible that sudden changes in breathing can cause the software to lose its calibration so that it no longer detects the breath turning points. You can tell this has happened because the breathing rate and ET PP CO_2 no longer update for each breath – but it should be a very rare event. In such cases you can recalibrate the breathing by pressing a button, in the bottom left of the application's window, labelled 4 in figure 5 below.

3.2 Electromyography (EMG) – Muscle Tension

As noted in the introduction, EMG is a measure of muscle tension (actually an electrical correlate of muscle tension). More specifically EMG is an oscillating voltage. For practical purposes you don't need to concern yourself with the oscillating nature of the signal, but it is covered in more detail in the Basic EMG Application User Guide.

To measure EMG, we need to attach three sensors to the skin. Two of these are known as the *active* sensors. From the raw signal the software derives a parameter that reflects tension in muscles between (and to some extent around about) the two active sensors. When these muscles tighten the signal goes up, and then down again when they relax. See the Hardware Set-up Guide for more details on your device's sensors.

Clearly, where we site the sensors determines which muscles we are measuring (so placement is important).

3.2.1 Muscle Tension in Breathing

In the context of breathing training we will want to measure activity in muscles associated with breathing. Different styles of breathing are reflected in the use of different muscle groups. As mentioned in the introduction, of particular interest is chest-based breathing versus abdominal breathing.

3.2.1.1 Breathing Muscles

Many muscles may be involved in breathing. In general they tighten on the in-breath and release on the out-breath. The main muscle groups are:

- The diaphragm – this is a sheet of muscle that separates the abdomen from the chest. It's attached to the spine at the back and lower ribs at the front. When relaxed it is shaped like a dome or a parachute, and when it tightens it pulls down, drawing air into the lungs.

- The intercostal muscles – these lie between the ribs and when tightened they collectively lift the rib cage upwards and outwards, drawing air into the lungs.

- Upper chest muscles, shoulders and even some neck muscles – unlike the diaphragm and intercostals these are "designed" more as reserve breathing capacity (needed for e.g. aerobic exercise). Again unlike the diaphragm and intercostals they will become fatigued with continuous use.

Other muscles may "join in" in subtle ways with the breathing movements, that really aren't necessary for breathing – e.g. nostrils may flare.

3.2.1.2 Abdominal Breathing

Relaxed breathing predominantly involve the diaphragm and intercostals – especially the diaphragm. When the diaphragm pulls down to draw the breath in, we see and feel the belly moving outwards. You can often see this pattern in sleeping babies and even pets. Abdominal breathing is natural and instinctive in the absence of threat and stress.

Generally the breathing rate is slow.

3.2.1.3 Chest-based Breathing

In stressful situations, muscles everywhere tend to tighten up – including the breathing muscles – as though we needed to literally brace ourselves against some threat. This affects the breath – we tend to take more air in and then not let it out fully. (Think of the startle response as an exaggerated form of this tendency – we take a sharp breath in, and then hold it.)

This pattern leads to the upper chest and shoulder muscles becoming more involved – having not let go of the previous breath we are forced to use these muscles to take more air in. In many people this style of breathing has become habitual, to the point where muscles may even become painful because of fatigue.

The movement tends to be a lifting upwards of the chest, as opposed to the "sideways" movements of abdominal breathing.

Chest-based breathing tends to be faster than abdominal breathing.

In reality, abdominal breathing and chest-based breathing are two poles on a spectrum rather than distinct categories.

3.2.2 Sensor Placement

We can use EMG to highlight the difference between chest-based and abdominal breathing. I mentioned earlier that where we place the sensors determines which muscles contribute to the

measurement. A convenient placement for breathing training is on the wrists. This picks up muscle tension in the hands, arms, shoulders and to some extent even upper chest and even neck – but not the diaphragm. That means that with the wrist placement, chest-based breathing shows up as a prominent undulation in the signal – as tension rises on the in-breath and falls on the out-breath. By contrast abdominal breathing shows as a relatively stable (flat) trace.

Another placement useful for monitoring breathing involves one active sensor sited over the scalene muscle and the other active over the trapezius muscle. This placement is less convenient and requires some anatomical knowledge.

3.3 Derived EMG Parameters

By analysing the EMG signal in relation to the cycle of the breath (as measured by the capnometer) the application derives the following parameters:

- Minimum EMG – at the beginning of each inhalation the software registers the minimum EMG over the preceding breath cycle.

- Maximum EMG – at the beginning of each exhalation the software registers the maximum EMG over the preceding breath cycle.

- Chest score – the difference between the above two, calculated once per breath.

In chest-based breathing there is a relatively large difference between minimum and maximum EMG over the breath cycle, while in abdominal breathing the difference is relatively low. So chest score is an indicator of the degree of chest-based breathing.

In figure 4 below, the magenta trace is a wrist-placement-derived EMG signal showing a prominent chest-based breathing rhythm. The green-yellow trace is breath (note, this graphic does not derive from the capnometry with EMG application).
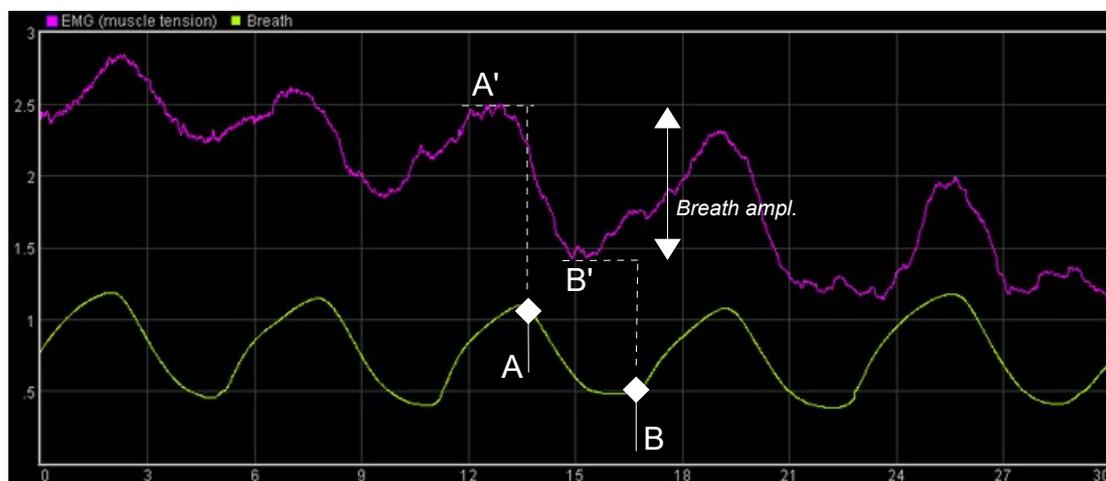

Figure 4 – Chest score calculation

You can see how the software derives the above parameters: at the beginning of the exhalation phase of the breath (A), the previous maximum is noted (A'), then at the beginning of the inhalation (B) the previous minimum is noted (B'). The difference between A' and B' is chest sore – you can think of it as a kind of amplitude in the "breath wave".

3.3.1 Limitations of the Chest Score Parameter

Chest score is by no means a perfect measure of chest-based breathing – it's important you understand its limitations.

Chest score will be high when the subject takes large breaths and relaxes the chest and shoulder muscles by letting the breath right out again. But there is another form of chest breathing, involving quick, shallow breaths. In this case the EMG doesn't change much over the cycle of each breath, so the chest score will be relatively low.

On the other hand the application will still show this style of breathing because the EMG itself is relatively high.

A further limitation is that movements unrelated to breathing will skew the chest score to an artificially high value.

4 User Interface

Figure 5 below shows the user interface of the Capnometry with EMG application.

1. Standard Controls   2. Short Term Display

8. Threshold 1 Display

3. Threshold 2 Display

7. Long Term Display

5. Audio Controls

4. Recalibrate Breathing Button

Figure 5 – Main window

4.1 Standard Controls (Start / Stop, etc.)

A set of buttons – Play, Stop and Pause – are the same in all the applications in the suite. They should be self-explanatory.

The button marked with a red asterisk is a simple event marker. You can use it to mark adventitious happenings and changes in session conditions (e.g. you turn on or off breath pacing). It is particularly useful for coaches and therapists. Events thus marked are represented in the long term chart (see section 4.4 below) by a vertical white line. They are also recorded in the session data file and are shown in session report charts (as dotted vertical lines) (see section 6).

Note that pressing the escape key during a session has the same effect as pressing the red asterisk with your mouse (i.e. it is an alternative).

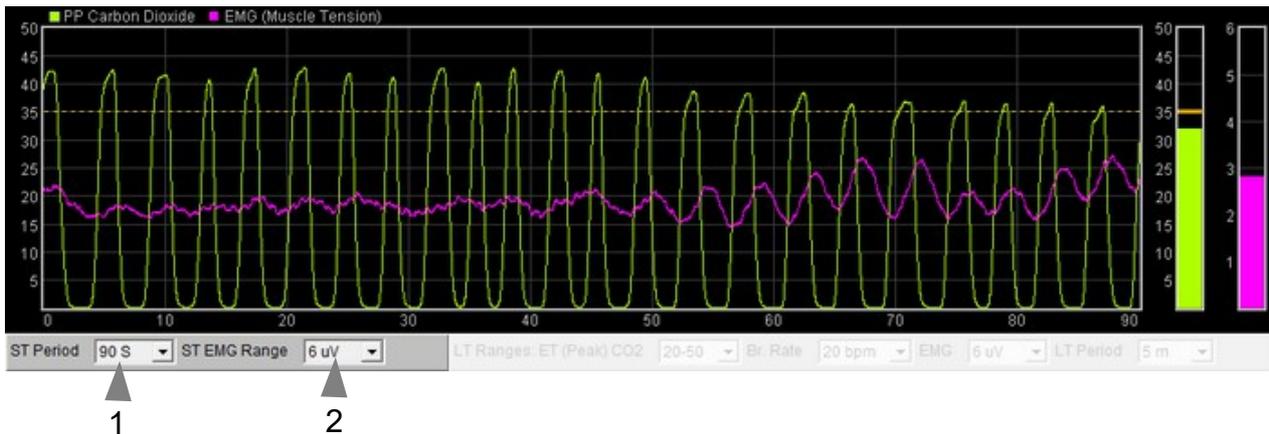## 4.2 Short Term Display and Controls

Figure 6 – Short term display and controls

The short term chart (figure 6 above) shows the raw PP CO_2 signal in green-yellow and the EMG trace in magenta. There two associated controls, labelled 1 and 2 in figure 6. The first sets the period, or horizontal (time) scale, and the second sets the vertical range for the magenta EMG trace. The vertical range of the PP CO_2 trace is fixed at 0 to 50. The units (of partial pressure) are millimetres of mercury (mm Hg). By clicking on the coloured squares you can change which scale is displayed on the vertical axis.

4.3 Numeric Displays

These are positioned close to the bottom of the window, just above the audio feedback controls.

Averages are calculated over a 60 second interval.
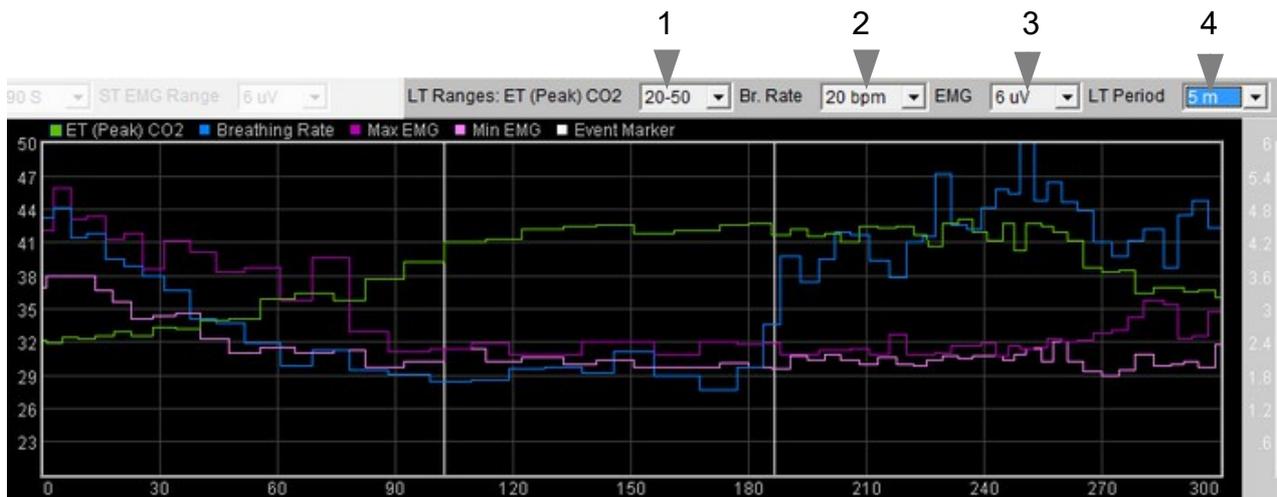
4.4 Long Term Display and Controls

Figure 7 – Long term display and controls

The long-term chart (figure 7) shows end-tidal (peak) PP CO_2 in green, breathing rate in blue, and maximum and minimum EMG in dark and light magenta respectively. The controls (drop-down lists) are positioned above the chart (1 to 4 in figure 7) .

ET (Peak) CO₂   Controls the vertical range (scale) of the green end-tidal CO_2 trace. Click the green square (upper left of chart) to see this range displayed in the chart.

Br. Rate   Controls the vertical range of the blue breathing rate trace. Click the blue square (upper left of chart) to see this range displayed in the chart.

EMG   Controls the vertical range of both the maximum and minimum EMG traces (dark and light magenta, respectively). Again you can see this range displayed if you click on either of the magenta squares.

LT Period   Controls the horizontal (time) range.

4.5 Threshold Display and Controls

Threshold-based feedback is designed to follow a consistent pattern throughout all the applications, and therefore it made sense to describe threshold functionality in a single place, viz. The Guide to Audio and Threshold-based Feedback (a separate document). I recommend you read that before trying to make sense of this section.

(Controls for threshold-based audio feedback are covered in section 4.6 below.)

In the capnometry with EMG application there are two threshold displays, found at left and right sides of the application's main window, labelled 3 and 8 in figure 5 above. Threshold 1 on the left is shown in figure 8.
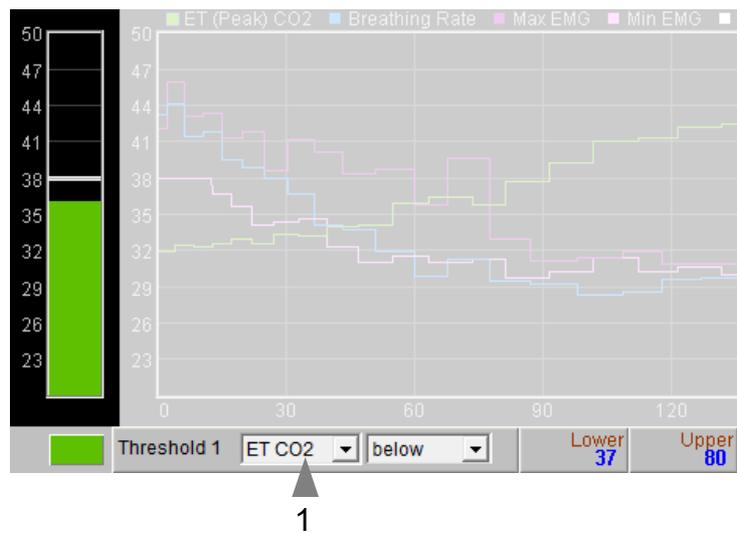

Figure 8 – Threshold display & controls

For each threshold you can choose the feedback parameter via a drop-down list control – in figure 8 this control is labelled 1.

Please note: changing the selected feedback parameter forces the application to have to restart, and you will lose your earlier session data. If session data is important to you, it's better to make your selection at the start of your session, and then stick with it.

For threshold 1 the options are: ET CO_2 or breathing rate.

For threshold 2 the options are: EMG, Minimum EMG, or breathing rate.

As an example of how you might use threshold-based feedback, suppose you wish to maintain a steady breathing rate of around 6 breaths per minute with your ET PP CO_2 maintained above 40 mm Hg. First set the breathing rate threshold feedback (right side) to inform you if the breath is either too fast or too slow. To set this up, you would set the condition to 'outside', then drag the threshold levels so that the upper is say around 7 bpm and the lower is say around 5 bpm. Second, set the ET CO_2 threshold to warn you if you drop below 40 – set the condition to 'below' and drag the level to 40. You will probably want to turn on audio feedback for the threshold feedback, which is covered in the next section.

4.6 Audio Feedback Controls

Again, audio feedback functionality is consistent between applications and so is described in one place, i.e. The Guide to Audio and Threshold-based Feedback, which you should read before trying to make sense of this section.

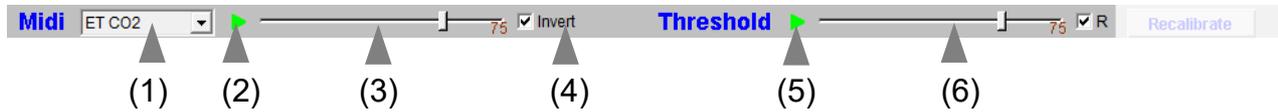Figure 9 below shows the controls available for audio feedback.

Figure 9 – Audio feedback controls

4.6.1 Midi

When activated, a musical note is played once per breath whose pitch reflects the chosen feedback parameter.

Drop-down list control (1) in figure 9 above sets the parameter for midi feedback. The options are:

ET CO_2; breathing rate; minimum EMG; maximum EMG; threshold 1 (ratio); threshold 2 (ratio).

Please note: changing the selected feedback parameter forces the application to have to restart, and you will lose your earlier session data. If session data is important to you, it's better to make your selection at the start of your session, and then stick with it.

4.6.2 Threshold

To recap, a sound is played whenever one of the threshold parameters goes out of range (or comes back within range). Function depends on the settings of the threshold controls covered in section 4.5 above.

5 Breath Counting Functionality

The Capnometry with EMG application offers a breath counting function aimed at supporting mindfulness practice. This enables users to test the accuracy of their own breath counting. This is useful in a context of mindfulness of breathing meditation practice, where the meditator counts breaths up to a target of say, ten. Distraction and mind-wandering cause the meditator to lose count, and perhaps to lose awareness of the breath completely. However, with greater engagement in the practice, better focus or concentration, and greater skill in meditation, this is less likely to happen. The breath counting function thus offers an objective assessment of performance in mindfulness meditation. Such a method of tracking mindfulness is discussed in the book "The Science of Meditation" by Daniel Goleman and Richard Davidson. Professor Davidson developed such an assessment to aid his group's research into meditation (please note, they did not use Mind-Body Training Tools).

5.1 Steps To Using Breath Counting Functionality

- The trainee should set the target count, e.g. 10, using the drop-down list control (see below).
- To begin a counting trial, the trainee should press the space bar once.
- The trainee then counts breaths, counting after each exhalation (the software also counts number of exhalations).
- When the trainee reaches the target count e.g. 10, he/she should press the space bar again (once). If the count is accurate (i.e. if the software agrees with the trainee) a bell sound indicates success. If the trainee has lost count or is inaccurate, another sound indicates this.
- With each press of the space bar, whether accurate or not, a new counting trial begins – the trainee should begin counting exhalations at once, again, and the software will do likewise.

The results of each trial are written to the session data file, and are included in the session report. The overall accuracy is given, e.g. if the trainee performs ten trials and accurately counts for six of these, the overall rate is given as 60%.

Since breathing rate is probably a factor in accuracy (losing count is more likely if you're breathing slowly) the software also reports mistakes per minute.

5.2 Controls

There is only one control, a drop down list to set the target breath count. This is found at the top of the screen, just to the right of the event marker button (which shows a yellow asterisk – see figure 4 above).

The lamp display next to this control lights up whenever the space bar is pressed.

5.3 Software Reliability

Clearly the software's ability to accurately count breaths depends upon its correctly and reliably detecting each exhalation within the raw breath signal. From time to time the software may lose track of the breath – in my experience this happens extremely rarely. If it does happen, the software will recalibrate, and usually it does recover, but it means that the result of the counting trial during which the recalibration happens will be likely invalid.

6 Session Reports

The application records data so that you can generate a report for your sessions. The report contains summary data and graphs showing the progression of the feedback parameters over the whole session (excepting the first minute or so, during which time data is not written to allow for warming of the capnometer).

To generate and open a session report, click the button labelled 3 in figure 1. A dialog window opens in which you can select various options (see figure 10).

The software creates the report in html format. It will be opened using your computer's default web browser, e.g. Google Chrome. (Note that a live internet connection is not needed.) The html file is saved, so you can for example email it to someone. See the Installation and Set-up Guide for details of file storage.
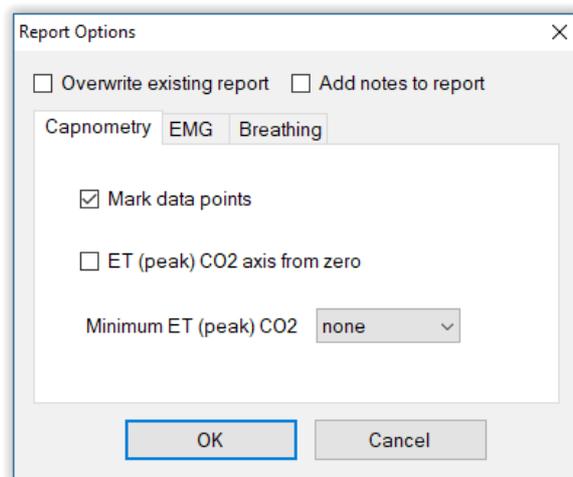

Figure 10 – Report options

6.1 Report Options

Most of the options should be self-explanatory.

If you change your mind about options on seeing your report, you can regenerate the report by clicking the report button (3 in figure 1), then checking 'Overwrite existing report'.

Options relating to either CO_2 data, EMG data and other breathing data are found under separate tabs.

Drop-down list controls allow you to set maximum or minimum values for several of the parameters. Setting these limits is a basic way of excluding "artefacts", for example if you spoke to someone during the session this is likely to affect the calculations.

6.2 Adding Notes to a Report

You can choose to write some notes for your session report. Checking 'Add notes to report' (top right of the dialog) allows you to do this.

You may wish to add notes after having first seen the report. In this case, simply click the button (3 in figure 1) again, and check the Add notes option. This will regenerate the report with your added notes.
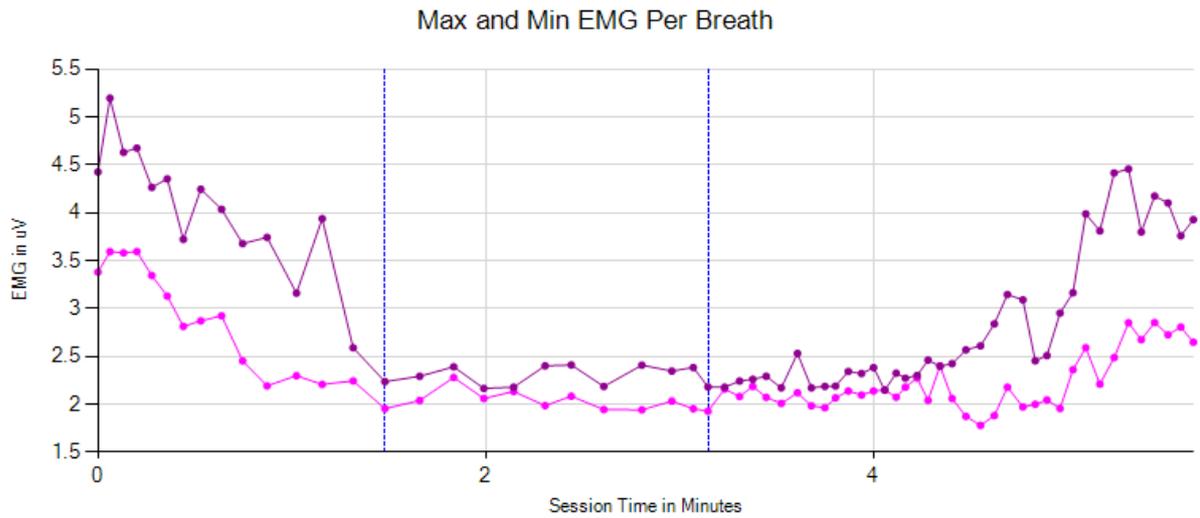
6.3 Sample Session Report

Please note, the formatting of the report has been changed slightly to fit this document.

Training Session Report

Training Application	Capnometry with EMG
User Name	Default User
Session Date	25/05/14 17:01

End-tidal (Peak) PP CO2

Breathing Rate

Max and Min EMG Per Breath
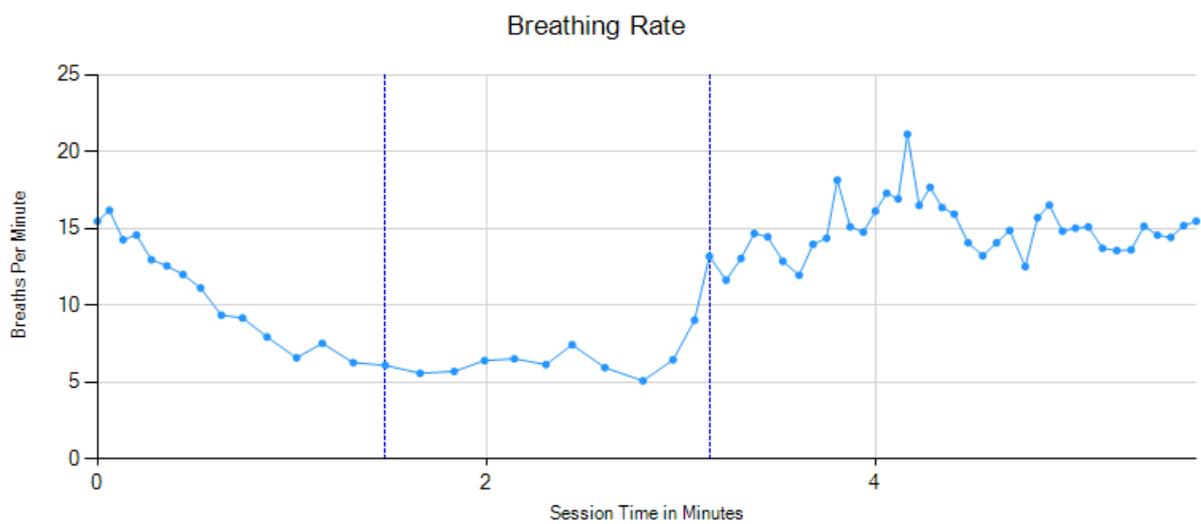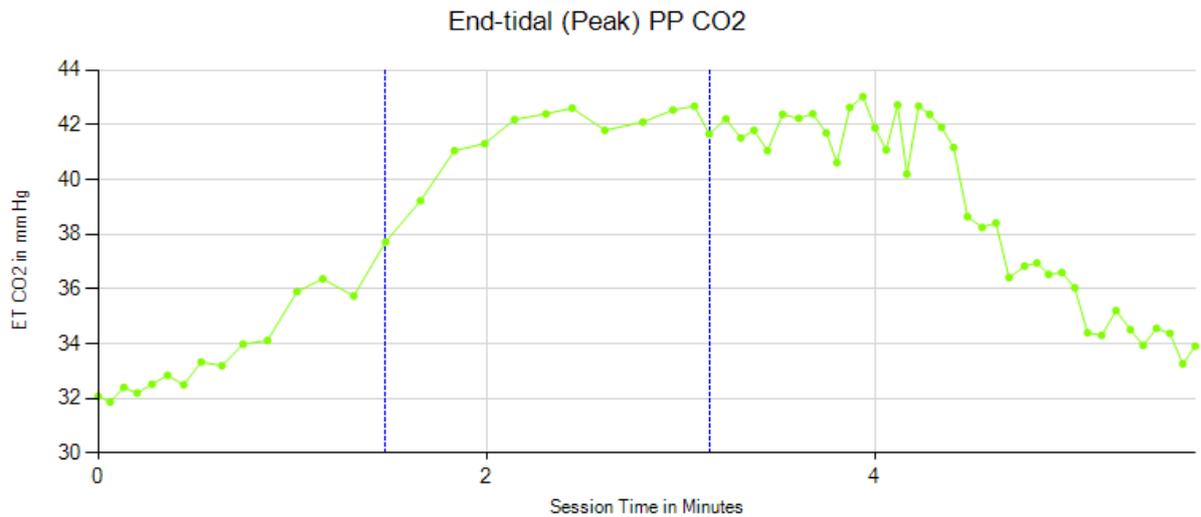
Chest Score

Breathing Summary Data

Parameter	Mean	Max	Min	S.D.
Peak CO_2	38.2 mm Hg	43.0 mm Hg	31.9 mm Hg	3.8 mm Hg
Breathing Rate	12.6 bpm	21.1 bpm	5.1 bpm	3.9 bpm
Minimum EMG	2.3 uV	3.6 uV	1.8 uV	0.5 uV
Maximum EMG	3.0 uV	5.2 uV	2.2 uV	0.9 uV
Chest Score	0.7 uV	1.9 uV	0.0 uV	0.5 uV

7 Application Report

An application report summarises all the sessions for the currently selected user, in charts and a table.

To generate and open an application report, click the button labelled 4 in figure 1. A dialog window opens in which you can select various options (see figure 11).

As with session reports, the software creates the application report in html format. It will be opened using your computer's default web browser, e.g. Google Chrome. (Note that a live internet connection is not needed.) The html file is saved, so you can for example email it to someone. See the Installation and Set-up Guide for details of file storage.
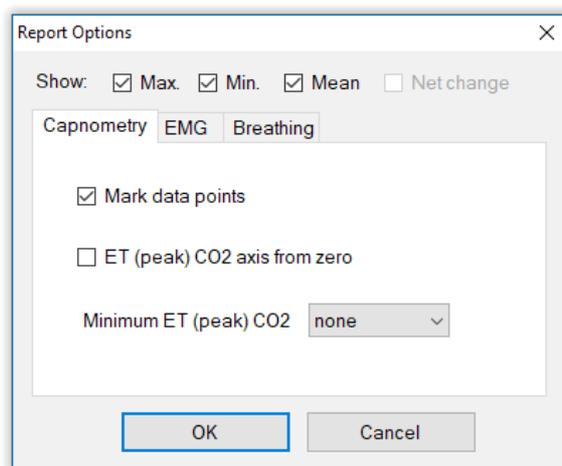

Figure 11 – Report options

7.1 Report Options

The application report options dialog is an adapted version of the session report options dialog. Many of the options are the same, and should be self-explanatory. See section 6.1 above.

As with all of the application reports in the suite, there is a chart for each of the main parameters tracked in the application – in the case of the Capnometry with EMG application that means end-tidal PP CO_2, breathing rate, minimum EMG, maximum EMG and chest score. For each chart you can opt for line graphs for the maximum, minimum and mean. The line graphs have one point per session.