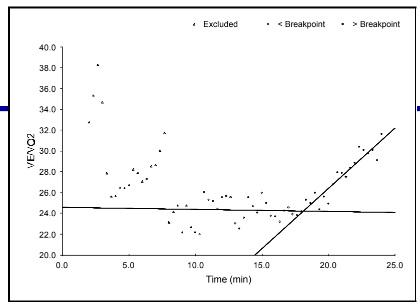
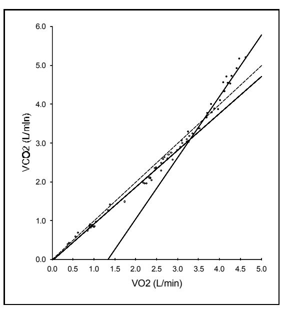
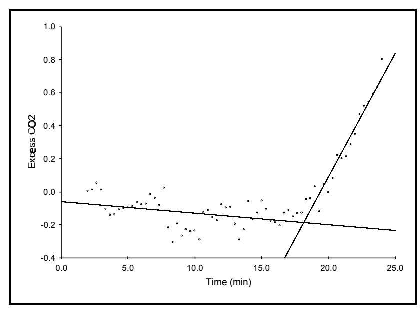
WinBreak

Automated software program for the detection of the gas exchange threshold







version 3.7

USER GUIDE

WinBreak version 3.7
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WinBrease

Automated software program for the detection of the gas exchange threshold

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SECTION A. GENERAL

A.1 INTRODUCTION

The gas exchange or ventilatory threshold has had a long history in exercise science and cardiorespiratory medicine. It is also a concept that has sparked considerable controversy over the years, particularly when interpreted as an index of the so-called anaerobic threshold or as causally related to the lactate threshold (Meyers & Ashley, 1997; Svedahl & MacIntosh, 2003). Yet, despite the controversy, the concept has persisted, as it continues to be regarded by many as a useful practical marker of cardiorespiratory fitness and endurance capacity, a more appropriate, individually tailored criterion for exercise prescriptions compared to various arbitrary percentages of maximal capacity, and a meaningful non-invasive clinical measure of cardiorespiratory health.

In fact, it could be argued that the gas exchange threshold would have enjoyed a much greater popularity among scientists and practitioners if it was not for certain difficulties related to its determination. First, the difficulty lies in the fact that the scientific literature contains a wide variety of possible indices of the gas exchange threshold and the comparative evaluations of the validity and reliability of these indices do not always agree. The diversity of approaches is remarkable. The literature includes proposals focused on VCO_2 by VO_2 plots, the ventilatory equivalents, excess CO_2 production, the respiratory exchange ratio, ventilation and ventilatory frequency, and heart rate, among several others (Anderson & Rhodes, 1989; Hughson, 1984; Svedahl & MacIntosh, 2003). Second, most of the proposed indices rely on subjective criteria for determining a "breakpoint," or change in the slope of plotted ventilatory data. Given the often erratic nature of such data, this subjectivity commonly leads to guesswork, a situation that makes trained scientists feel uncomfortable.

As a solution to the problems associated with the subjective nature of the traditional methods of determination, there have been several attempts to develop computerized methods, based on certain "objective" criteria. Specifically, such attempts have focused on (a) piecewise (2- or 3-phase) linear regression analyses, to identify a piecewise solution that provides a better fit to the data compared to a singular linear solution (e.g., Beaver et al., 1986), (b) time series analyses (combined with other methods, such as hidden Markov chains), to identify a breakpoint while accounting for serially correlated noise in the data (e.g., Kelly et al., 2001), (c) fitting smoothing spline functions and examining the form of the derivatives (e.g., Sherrill et al., 1990), and others. While these approaches constitute significant advances, most have not found their way into day-to-day practice because (a) some of the mathematical concepts involved are complex and far-from-easy to implement independently and (b) the researchers who proposed these methods have not made any software programs to perform the necessary computations publicly available. Today, some integrated metabolic analysis software packages offer a method for the "automatic" estimation of the gas exchange threshold (usually based on the "V-slope" method proposed by Beaver et al., in 1986 or the "simplified V-slope" method proposed by Sue et al. in 1988), but the exact methods used are poorly documented and the computational details are not disclosed. Furthermore, since all methods can and do fail to produce satisfactory solutions in the cases of certain data sets, relying on a single method of determination leaves users with no recourse in cases of unsatisfactory solutions, other than having to resort to subjective criteria.

WinBreak was developed to address these problems. This is achieved by (a) combining the intuitive appeal of graphical methods with the objectivity of statistical modeling, (b) offering multiple parallel methods of determination as opposed to a single method, and (c) allowing users to experiment with a variety of solutions and visualization options. Specifically, following Gaskill et al. (2001), *WinBreak* uses the following three graphical methods:

1. **The V-slope method**: This method consists of plotting CO_2 production over O_2 utilization and identifying a breakpoint in the slope of the relationship between these two variables. The level of exercise intensity corresponding to this breakpoint is considered the gas exchange threshold.
2. **The method of the ventilatory equivalents**: This method consists of plotting the ventilatory equivalents for O_2 (V_E/VO_2) and CO_2 (V_E/VCO_2) over time or over O_2 utilization and identifying the level of exercise intensity corresponding to the first rise in V_E/VO_2 that occurs without a concurrent rise in V_E/VCO_2.
3. **The Excess CO_2 method**: This method has been operationalized in various ways. In *WinBreak*, the operationalization of Excess CO_2 follows that proposed by Gaskill et al. (2001). According to their definition, Excess $CO_2 = (VCO_2^2 / VO_2) - VCO_2$. When Excess CO_2 is plotted over time or over O_2 utilization, the gas exchange threshold is thought to occur at the level of exercise intensity corresponding to an increase in Excess CO_2 from steady state.

WinBreak produces the plots required for implementing these three methods with one mouse click, enabling users to obtain a quick graphical representation of the their data. Furthermore, using a feature called the "Visualization Tool", *WinBreak* applies mathematical algorithms designed to identify a breakpoint in the plotted relationships. Specifically, for the method of the ventilatory equivalents and the Excess CO_2 method, *WinBreak* uses the standard algorithm proposed by Jones and Molitoris (1984) for identifying the breakpoint of two lines. For the V-slope method, *WinBreak* uses five algorithms:

1. **The Jones and Molitoris (1984) algorithm**, as implemented by Schneider et al. (1993). This method considers two regressions, $y = b_0 + b_1x$ and $y = b_0+b_1x_0+b_3(x-x_0)$, and then searches for the value of x_0 that minimizes the residual sum of squares.
2. **The "brute force" algorithm proposed by Orr et al. (1982)**. This method consists of calculating regression lines through all possible divisions of the data into two contiguous groups, and finding the pair of lines yielding the least pooled residual sum of squares.
3. **The "V-slope" algorithm proposed by Beaver et al. (1986)**. This method consists of dividing the VCO_2 by VO_2 curve into two regions, fitting linear regressions through them, and identifying the point at which the ratio of the distance of the intersection point from a single regression line through the data to the mean square error of regression is maximized.
4. **The "Dmax" algorithm proposed by Cheng et al. (1992)**. This method consists of calculating a third-order polynomial regression curve to fit the data and drawing a straight line connecting the first and last data points. The breakpoint is then defined as the point yielding the maximal distance between the curve and the straight line.
5. **The "simplified V-slope" algorithm proposed by Sue et al. (1988) and Dickstein et al. (1990)**. This method again calculates regression lines through all possible divisions of the data into two contiguous groups, and finds a breakpoint at which the first regression has a slope of less than or equal to 1 and the second regression has a slope higher than 1.

In addition, *WinBreak* allows users to examine the complete computational details of all these methods, to compare the fit of the two-regression solutions to a single-regression solution, and to view and contrast plots of the residuals produced by these solutions. Finally, *WinBreak* allows users to shift the location of the breakpoint and observe the resultant changes in the slope of the regression lines. This functionality is supplemented by an extensive array of data manipulation tools (e.g., averaging, interpolation, outlier removal, smoothing), ease of use, and the ability to save and print fully customized, presentation-quality graphics.

A.2 SUMMARY OF FEATURES

- Only such product in the world
- Automated and integrated analysis and presentation of data
- The most popular and powerful graphical methods for identifying the gas exchange threshold, combined with nearly all the statistical methods that have been proposed in the exercise physiology literature
- Complete computational details
- Extensive array of data manipulation options (averaging, interpolation, outlier removal)
- Five methods of data smoothing (running-window average, low-pass FFT filter, Savitzky-Golay least squares filter, cubic spline filter, polynomial from second to tenth order)
- Plots of residuals
- Fully customizable graphics (labels, fonts, axis scaling, symbol styles, line styles, sizes, and colors)
- Graphical printouts accompanied by summary of computational results
- Ability to save graphics in Windows® Metafile and bitmap formats, compatible with most major word processors and presentation packages
- Reads data in ASCII format and saves data in ASCII (comma-delimited, tab-delimited) and Microsoft® Excel® formats
- Easy to use; very short learning curve
- Great as an educational tool
- Inexpensive

A.3 SYSTEM REQUIREMENTS

WinBreak was developed for IBM®-compatible computers running the Microsoft® Windows® (Win32) operating system. This includes all 32-bit variations of Windows®, including Windows 95®, Windows 98®, Windows 98 SE®, Windows NT®, Windows XP®, Windows 2000®, etc.

Although the main executable file is approximately 4 MB, the total free disk space required for installation is around 23 MB. Any generated data and graph files will require additional disk space.

In terms of hardware, a computer with an Intel® Pentium® processor at 300 MHz and 64 MB of RAM will suffice, although the data processing and graphing speeds will improve with more advanced configurations.

A.4 INSTALLATION

WinBreak may arrive in one of two forms: (a) on an installation CD or (b) in a zip file downloaded from the internet. In the latter case, you will have to first un-zip the file to retrieve its contents. This can be accomplished by several utilities, such as WinZip® (http://www.winzip.com) or PKzip® (http://www.pkzip.com).

From the Windows® "Start" menu, select "Run…". Then, click on "Browse…" and direct the file browser to the *WinBreak* "Setup" program, located on the CD or in the directory in which you expanded the contents of the zip file. This will execute the *WinBreak* installation program. The first dialog box that will appear will be similar to the one shown in **Figure A.1**. The default installation directory is called "WinBreak" and is located within the "Program Files" directory on the C: drive. If you wish to change this location and, instead, install *WinBreak* elsewhere, click on the button labeled "Change Directory" and select the desired location. To install *WinBreak*, click on the big square box with the computer icon.

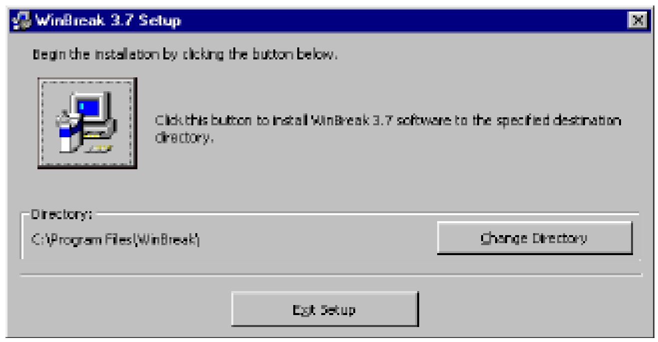


Figure A.1. If you want to install *WinBreak* in a different directory, click on "Change Directory". To install, click the big square button.

The installation program will copy the required files to the selected location and register several additional system files (see **Figure A.2**). During this process, the installation program may detect that your computer already has newer versions of these system files. In this case, choose to keep your existing files since system files are supposed to be backwards compatible. In addition to the core *WinBreak* executable, the installation program will also copy a modifiable configuration file (winbreak.cfg), some sample data files in a sub-directory named "Data" and a copy of this user guide in Portable Document Format (PDF) in a sub-directory named "manual." To uninstall *WinBreak*, select "WinBreak" from the "Add/Remove Programs" Control Panel.

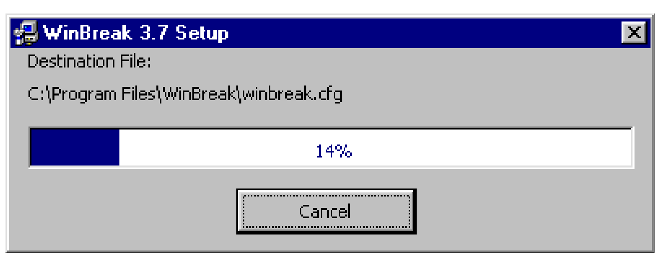


Figure A.2. The installation program will copy and register all the required files automatically.

SECTION B. WORKING WITH DATA

B.1 ACCEPTABLE DATA FILE FORMAT

To ensure compatibility with metabolic analysis systems and software packages, *WinBreak* accepts data files in ASCII format, since most software programs that accompany metabolic analysis systems can export data in this format. Although the structure of the data files varies widely from system to system (and, in some cases, can even be customized), all ASCII data files have certain similarities that allow *WinBreak* to read the data. Specifically, all files include several lines at the top that contain information about the participant and the conditions of the test (these lines are ignored by *WinBreak*) and then list the data either in comma-delimited, tab-delimited, or fixed-width form. *WinBreak* reads the entire data matrix, but only uses the following four variables: (a) time, (b) oxygen uptake, (c) carbon dioxide production, and (d) ventilation. More details on how to customize *WinBreak* to read data from your metabolic analysis system are presented in the section entitled "Changing the data file settings".

Note that, if a system does not export data in ASCII format, but can export data in formats recognized by some other spreadsheet or database program (e.g., Microsoft® Excel®), you can use that other program to convert the data to ASCII. Finally, also note that *WinBreak* will "remember" both the location of your data files and the file extension of these files (e.g., PRN, CSV, DAT, etc), to facilitate and accelerate the process of accessing and reading your data.

B.2 CHANGING THE DATA FILE SETTINGS

When you start *WinBreak* for the first time, you must specify the structure of the data files produced by your metabolic analysis system, so that *WinBreak* can read and meaningfully interpret the data. To do this, select "Data File Settings" from the "File" menu in the main *WinBreak* window. The dialog box shown in **Figure B.1** will appear. This procedure typically needs to be carried out only once (unless you change your metabolic analysis software). *WinBreak* will save your settings and reuse them the next time you start it.

First, you must open one of the data files exported by your metabolic analysis system, using an ASCII text editor (e.g., the Windows® Notepad® program), and count the number of lines at the top of the file that contain information other than numerical metabolic analysis data. Typically, the first lines will contain information about the test subject, the date of the test, the temperature, etc. Make sure that your count *does not* include "wrapped" lines (in Notepad®, set the "Word Wrap" option *off*), but *does* include lines that contain data column labels (e.g., "Time", "V_E", "VO_2", "RER", etc). In the dialog box, you can use the drop-down menu marked "Lines to Ignore from the Top" to specify how many lines at the top of the data file do not contain

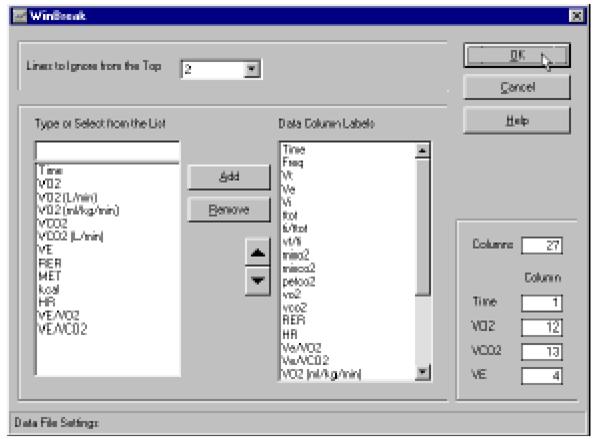


Figure B.1. The dialog box used to change the data file settings

numerical metabolic data.

Second, you must specify the number and the name of the data columns in your data files. On the left side of the dialog box shown in **Figure B.1**, there is a list of variables commonly found in metabolic analysis data files. You can either (a) select labels from the list and click "Add" to add them to *WinBreak*'s "Data Column Labels" list (you can also double-click on the label) or (b) you can type your own labels in the text box under "Type or Select from the List" and click "Add" to add them to the list. *WinBreak* will automatically count the labels as you add them. It is very important that you enter exactly as many data labels as there are data columns in your data files and that you specify the correct order.

As you are entering the data column labels, *WinBreak* will try to detect the position of the following four variables: (a) time [a data label "Time"], (b) oxygen uptake [a data label "VO2" or "VO2 (L/min)"], (c) carbon dioxide production [a data label "VCO2" or "VCO2 (L/min)"], and (d) ventilation [a data label "VE"]. If your metabolic system uses milliliters instead of liters as the unit of measurement, use "VO2" and "VCO2" as labels for the respective columns. Since, by convention, *WinBreak* uses L/min, it will automatically convert milliliter values to liters when reading the data. *WinBreak* will show the position of the four variables that it has detected

Note that, in case of duplicate entries in the "Data Column Labels" list, *WinBreak* will warn you, but will accept the duplicate entry if you confirm that this is what you want to do. Keep in mind, however, that, if you make duplicate entries for the four variables of primary interest (Time, VO_2, VCO_2, and V_E), *WinBreak* will consider as valid entries the ones listed last.

Check to ensure that the number and the order of data column labels are correct. If necessary, you can change the order by highlighting a label and clicking the up or down arrow keys to change its position on the list. You may also highlight a label and click "Remove" to delete it from the list. When finished, click "OK" to close the dialog box and continue.

B.3
LOADING NEW SETTINGS

The data file settings, as well as numerous other settings, including all graph formatting settings, are automatically saved when users exit the program in a file called "winbreak.cfg" located in the *WinBreak* root directory. Therefore, users will always restart the program with the same settings they were using when they last exited the program. While this is convenient in most cases, some additional flexibility is required for laboratories with multiple metabolic analysis systems and software packages. For these situations, *WinBreak* allows users to save and subsequently load multiple alternate settings files. This way, they can switch from data files generated with one metabolic analysis software package to data files generated with another software package with just one intermediate step, instead of having to edit the data file settings (as described in section B.2). To load a new settings file, select "Load New Settings…" from the "File" menu in the main *WinBreak* window, as shown in **Figure B.2**.

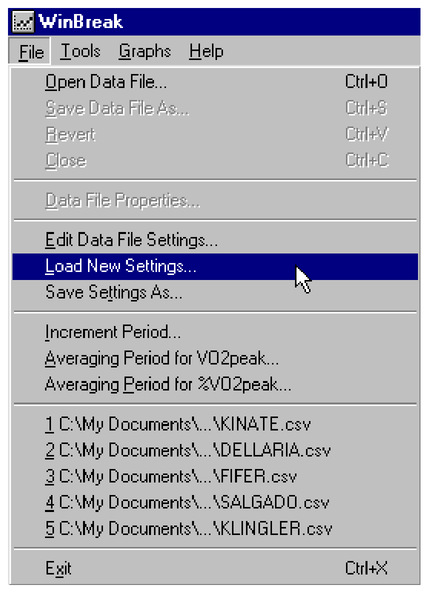


Figure B.2. To load new settings from a file, select "Load New Settings" from the "File" menu in the main *WinBreak* window.

The dialog box that will appear will allow you to search your computer for files with the extension ".cfg", the default extension for *WinBreak* settings files. Select the settings file that you want to use and click on "Open". You have to make sure that any data files you open after this point conform to the settings specified in the newly loaded settings file. Otherwise, the data will not be loaded properly or *WinBreak* may be unable to operate.

You can also modify or edit the file settings at any time and save the new settings for future use. The procedure for saving settings files is explained in the next section.

B.4
SAVING THE SETTINGS

Once you have made changes to the *WinBreak* settings, regardless of whether they were changes to the data file settings or to graph formatting, you can save the settings to a configuration file for future use. This way, if you ever want to reuse these settings, you would only need to load the particular settings file instead of having to re-create all the changes manually. To save the current settings, select "Save Settings As…" from the "File" menu in the main *WinBreak* window, as shown in **Figure B.3**. In the dialog box that will appear, you will be asked to specify a file name for the new settings file. The default file extension for *WinBreak* settings files is ".cfg". Therefore, if you omit a file extension, the extension ".cfg" will be added. If you specify a file name that already exists in the same location, *WinBreak* will ask for a confirmation but, upon confirmation, will overwrite the older file.

Also note that you can overwrite the default settings file "winbreak.cfg" if you specify this as the file name for your settings file. However, if you subsequently make additional changes to the settings, these will be overwritten again when you exit *WinBreak*. The reason is that *WinBreak* always overwrites "winbreak.cfg" with the settings that are selected when the user exits the program. This allows *WinBreak* to start by recalling the same settings that were selected the last time that the program was used. Therefore, overwriting "winbreak.cfg" is generally not recommended and *WinBreak* will issue an alert when users try to do so.

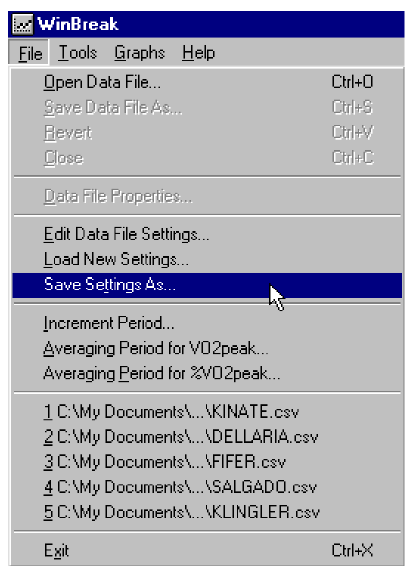


Figure B.3. To save the current settings to a file for future use, select "Save Settings As" from the "File" menu in the main *WinBreak* window.

B.5
OPENING A DATA FILE

Before you open a data file, you must specify the sampling or averaging rate that was used to produce the data in the file. Use the up and down arrow keys in the frame marked "Sampled/Averaged Every" to change your selection. Use "0" for breath-by-breath sampling. If you need averaging, *WinBreak* can do that for you (see the section titled "Data Averaging and Filtering"). *WinBreak* will remember your selection and present it as the default option the next time you use it.

To open a data file, click on "Open Data File" from the "File" menu, as shown in **Figure B.4**. Alternatively, you can also click on the file folder icon on the toolbar. In the dialog box that will appear, you can change the default extension, to see a full listing of the files in each folder. *WinBreak* will remember the extension of the file you choose, as well as the location of the file, so you will not have to look around to locate your data files the next time you use the program.

Opening a data file will fill the spreadsheet with the data in the file. The data are displayed to allow you to examine them visually, but you cannot directly edit individual values through the *WinBreak* spreadsheet. If you need to filter out aberrant values, you can do that through *WinBreak*'s outlier removal and data averaging facilities.

If, upon reading the data file, *WinBreak* determines that the data are expressed in milliliters, it will convert the VO_2 and VCO_2 data to liters and will inform you of the conversion in the frame marked "Unit Conversions".

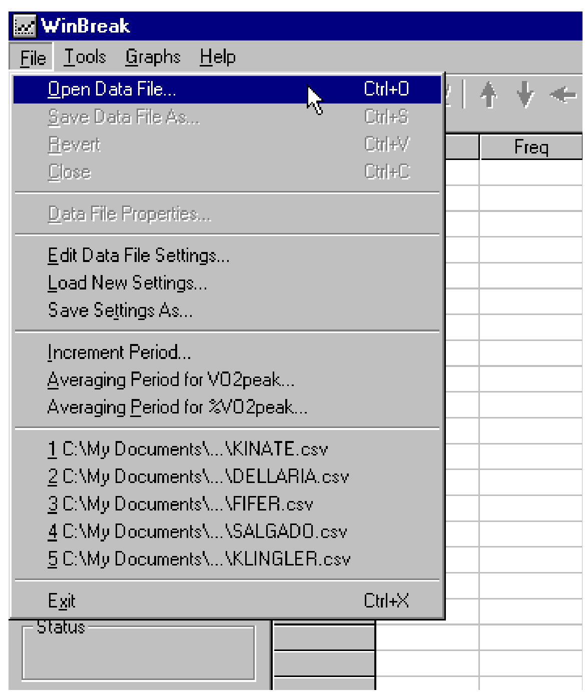


Figure B.4. To open a data file, you can select the option from the "File" menu or click on the open file folder icon on the taskbar.

B.6 DATA FILE PROPERTIES

To examine the properties of an open data file, click on "Data File Properties" from the "File" menu in the main *WinBreak* window. A window similar to the one shown in **Figure B.5** will appear. The properties shown include the name, extension, location, and size of the file, the dates that the file was created, modified, and accessed for the last time, as well as the settings used in reading the file.

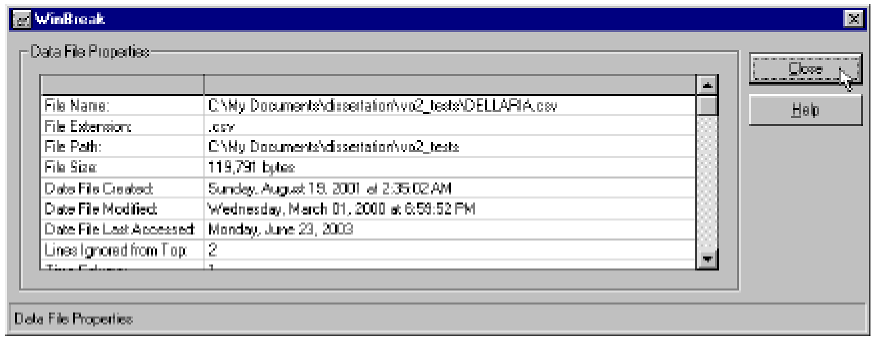


Figure B.5. The window showing the properties of a data file..

B.7 CLOSING A DATA FILE

To close the data file that is presently open, you can select "Close" from the "File" menu or simply click the button marked "X" on the toolbar, as shown in **Figure B.6**. This will close any open graph windows and clear the spreadsheet.

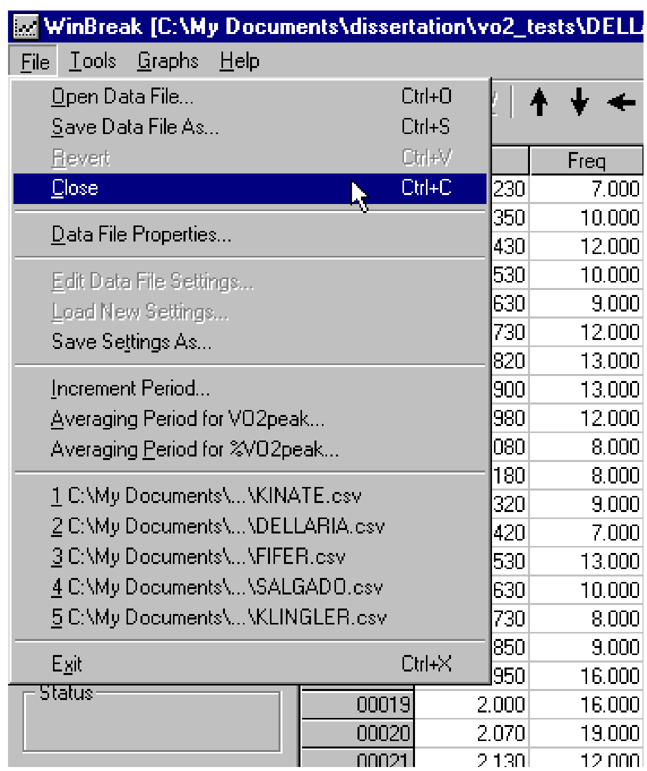
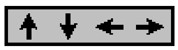


Figure B.6. To close a data file, you can select the option from the "File" menu or click on the button marked "X" on the taskbar.

B.8 SETTING THE CALIBRATION/WARM-UP AND TEST TERMINATION TIMES



Before you can process and analyze your data, you must specify the calibration or warm-up and test termination times. This will instruct *WinBreak* to ignore any data points before and after the actual testing protocol.

In order to quickly scroll around large data sets, users can click on the four arrow buttons on the taskbar. These will scroll the viewable part of the spreadsheet, so that one can see the top or bottom row, and left-most or right-most data column with a single mouse click. You can then click on the up and down arrow keys in the frames marked "Calibration/Warm-Up" and "Test Continued Until", to set the calibration or warm-up and test termination times, respectively, as shown in **Figure B.7**. *WinBreak* will remember your selections the next time you use it. Presumably, the calibration/warm-up period will be constant for each testing protocol. The test termination time may be the same for experimental conditions with fixed duration or may vary from one test participant to the next in the case of tests of maximal capacity or time-to-exhaustion protocols.

After making your selections, click the button marked "Set" to finalize your settings. This will display (a) the index of the first row of data to be included in the analyses, (b) the index of the last row of data to be included in the analyses, (c) the total number of data rows to be considered in the analyses, and (d) the highest recorded value of oxygen uptake in a status bar panel at the bottom of the main *WinBreak* window.

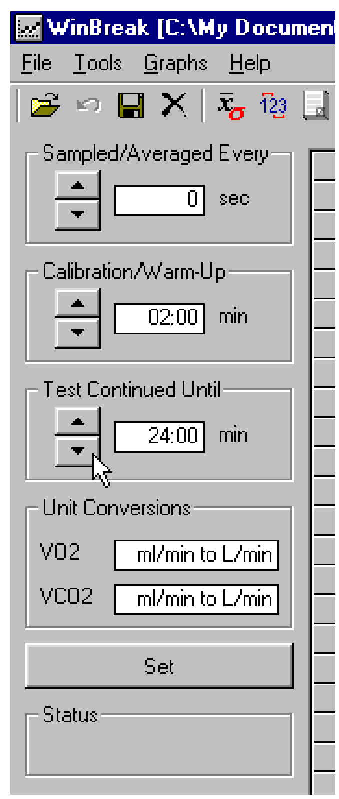


Figure B.7. After you open a data file, use the up and down arrow keys to set the calibration / warm-up and test termination times. Then, press "Set" to fix these times.

B.9 CHANGING THE INCREMENT / DECREMENT PERIOD

To accelerate the process of setting the "Calibration / Warm-Up" and "Test Continued Until" times, *WinBreak* allows users to specify the increment or decrement period that they want to use. You can access the relevant dialog box by selecting "Increment Period" from the "File" menu in the main *WinBreak* window. This will open the dialog box shown in **Figure B.8**. Use the up and down arrow keys to specify the desired increment / decrement period and click "OK" to continue. The next time you select "Calibration / Warm-Up" and "Test Continued Until" times, each mouse click will increase or decrease the selected time by the number of seconds you specified. *WinBreak* will save your preference and reuse it.

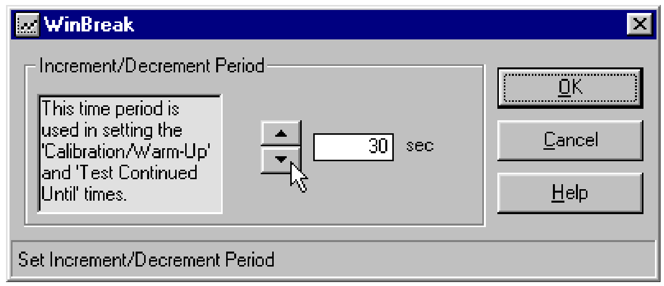


Figure B.8. The increment / decrement period is used to adjust the warm-up and test termination times.

B.10 CHANGING THE AVERAGING PERIOD FOR ESTIMATING VO_2peak

As will be shown in subsequent sections, *WinBreak* estimates the occurrence of the gas exchange threshold in terms of absolute VO_2 (in L/min), in terms of the percentage of VO_2peak, and in terms of the time point during the test. If the data are averaged (e.g., every 20 or 30 seconds), these estimates are less likely to be influenced to a great extent by breath-to-breath fluctuations in VO_2. When the data are collected on a breath-by-breath basis, however, the estimates can be influenced greatly by such breath-to-breath fluctuations. Therefore, some averaging is necessary to address this potential problem. By convention, *WinBreak* retains and shows the exact time point at which the gas exchange threshold occurred and the VO_2 recorded at that breath (i.e., without averaging). It does, however, use averaging in estimating the %VO_2peak at which the gas exchange threshold occurred. It does so by averaging both in estimating VO_2peak and the %VO_2peak attained at the point of the threshold. The process for selecting the desired options for the former is described here and the process for selecting the desired options for the latter is described in the following section.

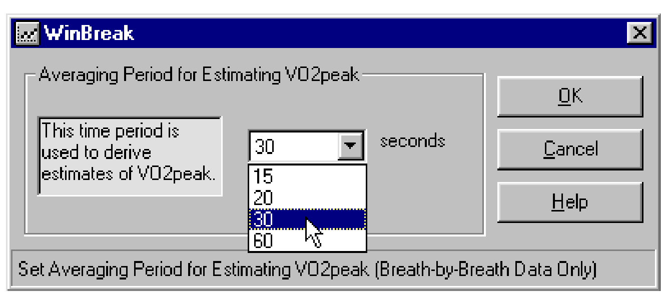


Figure B.9. Select the averaging period used in estimating VO_2peak.

To set the desired averaging period used in deriving estimates of VO_2peak, select "Averaging Period for VO2peak" from the "File" menu in the main *WinBreak* window. This will open the dialog box shown in **Figure B.9**. You can choose to estimate VO_2peak based on data averaged every 15, 20, 30, or 60 seconds. Use the drop-down menu to make your selection and click "OK". If no data set is open or if the calibration / warm-up and test termination times have not been set, *WinBreak* will simply store this value for future use. If a data set is open and the calibration / warm-up and test termination times have been set, *WinBreak* will re-calculate VO_2peak using the new averaging period.

B.11 CHANGING THE AVERAGING PERIOD FOR ESTIMATING %VO_2peak

Particularly when the data in the *WinBreak* data set were collected on a breath-by-breath basis, it is possible that values of oxygen uptake will fluctuate, with high values being followed by low values and vice versa. This creates a problem for subsequent analyses, since the oxygen uptake value at a particular breath may not be an accurate and informative reflection of the percentage of maximal aerobic capacity that had been reached at the time (or workload) that the breath occurred. For example, if a particular breath happens to yield an uncharacteristically low value of oxygen uptake, then the estimate of %VO_2peak reached at the time that the breath occurred will be an underestimate. Therefore, some averaging is necessary to address this problem. *WinBreak* allows users to derive estimates of the percentage of VO_2peak reached at different times by averaging either 5-9 seconds or 3-7 breaths surrounding the breath in question. You can set this period by selecting "Averaging Period for %VO2peak" from the "File" menu in the main *WinBreak* window. The dialog box shown in **Figure B.10** will appear. Select the averaging period you want to use and click "OK".

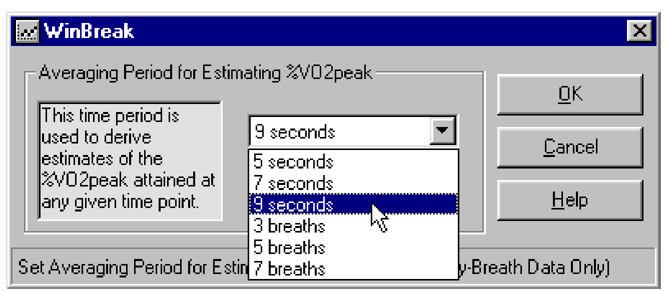


Figure B.10. Select the averaging period used in estimating % VO_2peak.

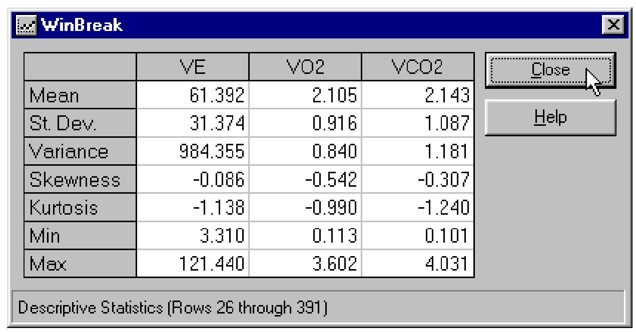
B.12
DESCRIPTIVE STATISTICS

To get a quick view of the statistical characteristics of a data set, you can select "Descriptive Statistics" from the "Tools" menu of the main *WinBreak* window. This will open the dialog box shown in **Figure B.11**.

WinBreak calculates the mean, standard deviation, variance, skewness, kurtosis, minimum, and maximum values of VO_2, VCO_2, and V_E. Skewness and kurtosis are calculated by the formulas shown below:

$$Skewness = \frac{n}{(n-1)(n-2)} \sum \left(\frac{x_i - \bar{x}}{S} \right)^3$$

$$Kurtosis = \left\{ \frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum \left(\frac{x_i - \bar{x}}{S} \right)^4 \right\} - \frac{3(n-1)^2}{(n-2)(n-3)}$$



	VE	VO2	VCO2
Mean	61.392	2.105	2.143
St. Dev.	31.374	0.916	1.087
Variance	984.355	0.840	1.181
Skewness	-0.086	-0.542	-0.307
Kurtosis	-1.138	-0.990	-1.240
Min	3.310	0.113	0.101
Max	121.440	3.602	4.031

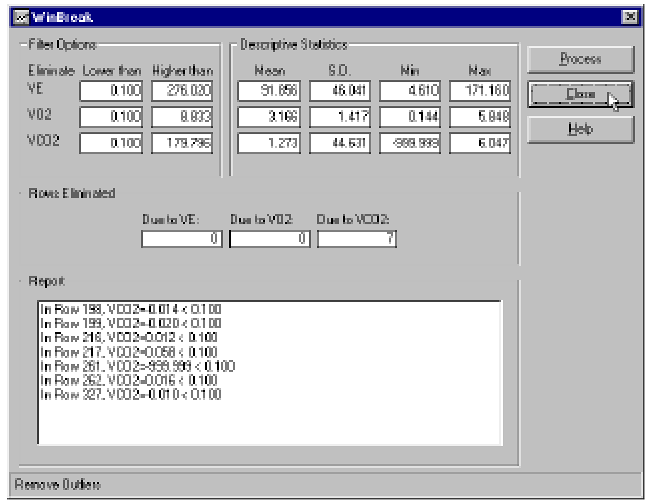
Figure B.11. In the Descriptive Statistics dialog box, *WinBreak* displays the mean, standard deviation, variance, skewness, kurtosis, minimum, and maximum of V_E, VO_2, and VCO_2.

B.13
REMOVING OUTLIERS

Occasionally, due to a malfunction in the data collection equipment or the interface between the metabolic analysis hardware and software, certain aberrant values, clearly outside the physiological range, may be recorded in your data set. Such values would obviously lead to erroneous results if they were to be included in the statistical analysis of gas exchange data. Therefore, *WinBreak* offers a facility that allows users to remove rows of data containing values of VO_2, VCO_2, or V_E that exceed certain limits. This facility is accessible, after you set the "Calibration / Warm-Up" and "Test Continued Until" times, by selecting "Remove Outliers" from the "Tools" menu in the main *WinBreak* window. The dialog box shown in **Figure B.12** will appear.

WinBreak will automatically display the mean, standard deviation, minimum, and maximum value for VO_2, VCO_2, or V_E in the frame entitled "Descriptive Statistics". It will also fill in the boxes marked "Lower Than" and "Higher Than" with the values corresponding to the mean ± 4 standard deviations (or 0.1 if subtracting 4 standard deviations from the mean results in a negative number) for VO_2, VCO_2, and V_E. You can change these numbers to set the upper and lower limits of the filter as you wish. Once you specify the filter limits and click "Process," *WinBreak* will remove the rows containing out-of-bounds values from the data set, update the spreadsheet, and inform you of the changes in the areas marked "Rows Eliminated" and "Report".

Figure B.12. Change the "Lower Than" and "Higher Than" values to filter out rows of data containing data values that fall outside these limits.



B.14 DATA AVERAGING AND FILTERING

WinBreak provides a facility for averaging and filtering breath-by-breath data. Note that this option is available only if you have specified that the data in the data file were sampled on a breath-by-breath basis. Otherwise, *WinBreak* assumes that the data have already been averaged.

You can access the data averaging and filtering dialog box, shown in **Figure B.13**, by selecting "Data Averaging" from the "Tools" menu in the main *WinBreak* window. From the data averaging options, you can choose to average 15-sec, 20-sec, 30-sec, or 60-sec segments. From the data filtering options, you can choose to ignore aberrant values during the averaging process, by setting a cut-off at 3, 5, 10, 20, or 50 times smaller or larger than the average of the two adjacent values. This should help you eliminate non-physiological values that were recorded due to an equipment malfunction. Note that this filtering is only applied to the VO_2, VCO_2, and V_E values. After pressing "OK", *WinBreak* will perform the necessary calculations and present the averaged data in the spreadsheet. An example of the effects of data averaging (20-seconds) is shown in **Figure B.14**.

Figure B.13. In the case of breath-by-breath data, you can choose an averaging period and direct *WinBreak* to ignore data points that exceed certain limits.

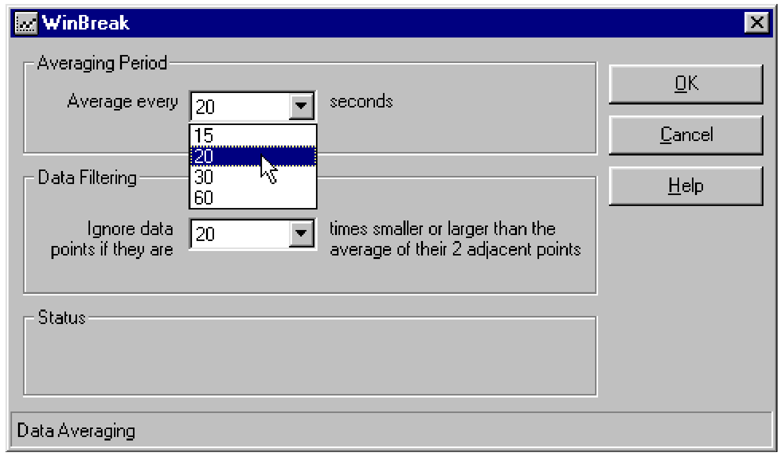
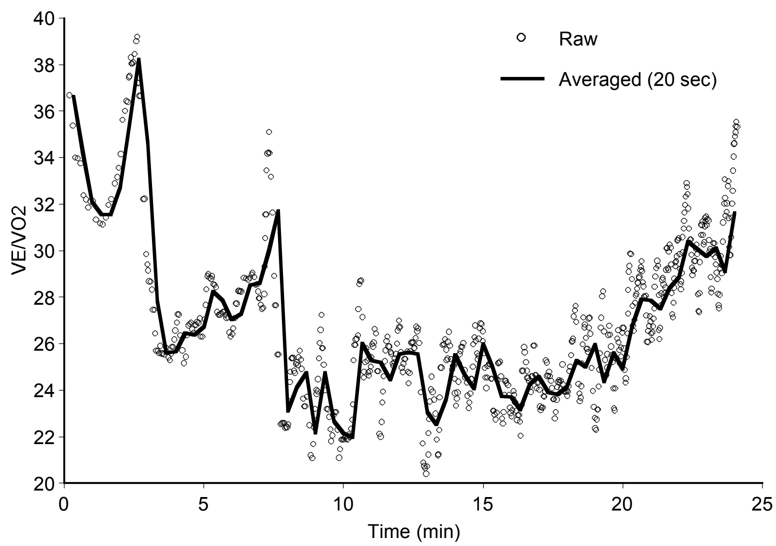


Figure B.14. An example of V_E/VO_2 data averaged every 20 seconds.



B.15
DATA INTERPOLATION

Occasionally, you may wish to transform data that were collected on a breath-by-breath basis and, therefore, at irregular time intervals to data that are equally spaced in time. The procedure used to accomplish this is called interpolation. Specifically, *WinBreak* uses polynomial interpolation. This means that each interpolated value is calculated by fitting a polynomial curve to the 3 or 5 data points surrounding a certain time point and then estimating what the value of VO_2, VCO_2, and V_E would be at that time point on the basis of the polynomial.

To access the data interpolation facility offered by *WinBreak*, select "Data Interpolation" from the "Tools" menu of the main *WinBreak* window. The dialog box shown in **Figure B.15** will appear. First, select whether you wish to use polynomial curves fitted over the 3 or 5 data points surrounding each time point (1 before and 2 after or 2 before and 3 after, respectively). The 5-point interpolation is generally recommended because it is less susceptible to single extreme values and wild fluctuations in the data that could produce even more extreme interpolated values due to the relative inflexibility of polynomials.

Figure B.15. To transform breath-by-breath data to data that are equally spaced in time, use data interpolation. Select whether you wish to use polynomial curves fitted over 3 or 5 points and what the time interval of your data should be.

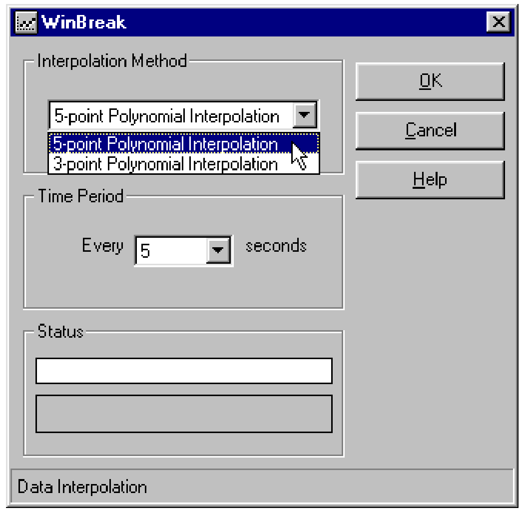
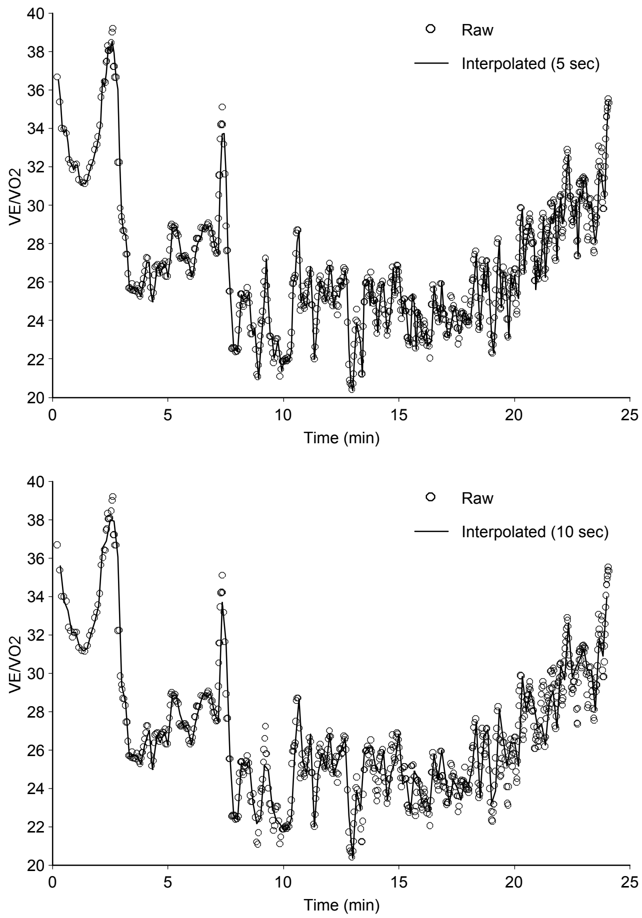


Figure B.16. An example of V_E/ VO_2 data interpolated at 5-second (top) and 10-second (bottom) intervals.



Then select the desired time interval of the new, interpolated data set. Notice that you can choose to obtain data spaced every 5 to 12 seconds. If you wish to obtain regularly spaced data at longer time intervals, then use data averaging, an option that allows you to obtain data spaced every 15 to 60 seconds.

After you make your selections, click "OK". *WinBreak* will perform the necessary calculations and update the spreadsheet with the interpolated values. Examples of data interpolated every 5 and 10 seconds (with 5-point polynomials) are shown in **Figure B.16**.

Occasionally, if one or more of the first data points in the original breath-by-breath data set occur after the first time interval (e.g., if you have chosen a 5-second time interval and the first recorded breath occurred at the 6th second), the data interpolation procedure will produce zero values for those early time points. In such cases, *WinBreak* will remove these rows of data and inform you of this occurrence. Also note that, occasionally, breath-by-breath data sets may contain duplicate entries for time (e.g., two, typically consecutive, data points recorded as having occurred at the same millisecond). Because the data interpolation algorithm cannot function with duplicate entries in the abscissa, *WinBreak* will replace any rows containing duplicate time values with a single row containing the average values of the replaced rows and inform you that this operation has taken place.

B.16 SMOOTHING BY MOVING WINDOW AVERAGE

Changes in the ventilatory indices used by *WinBreak* to detect the gas exchange threshold are generally slow, considerably slower than breath-to-breath and other ventilatory fluctuations that are not of metabolic origin. This means that, for the purposes of detecting the occurrence of the gas exchange threshold, a certain degree of data smoothing (i.e., removal of high-frequency components unlikely to be of metabolic origin) may be helpful, both by facilitating the visual inspection of the data and by reducing the possibility of adversely influencing the breakpoint-detection algorithms. That said, data filtering must generally be conservative and its results examined carefully. As a case in point, although data smoothing, if done correctly, may not shift the *location* of the gas exchange threshold within a data set, it may nevertheless change the numerical estimate of the level of O_2 uptake at which the threshold occurred. It is, therefore, recommended that data smoothing be used only when necessary (i.e., in cases of highly convoluted data sets) and that efforts be made to confirm any threshold-detection results derived from smoothed data by also examining the raw data.

WinBreak uses five data smoothing methods, each based on a different approach to smoothing. It is, therefore, important that users familiarize themselves with the nature of each method and develop an understanding of the types of smoothing that should be expected from each method. This should help them determine which of the five methods would be most appropriate in each case.

The *first* data-smoothing method, which is also conceptually the simplest, is the method of the running-window average. Essentially, a "window" of specified breadth is systematically moved through the data set, one data point at a time. Each time the window is moved, the data point at the center of the window is replaced by the average of the values in the window. The procedure can be repeated several times, to achieve additional smoothing. Users can select the breadth of the data window (from 5 to 25 points) and specify how many passes of the running window through the data set (from 1 to 5) should be performed. The wider the running window and the higher the number of passes, the larger the degree of smoothing that is achieved. Of course, as the degree of smoothing is increased, the similarity of the smoothed data to the original data set is reduced. It is, therefore, recommended that users avoid using very broad windows in conjunction with a large number of passes, even in cases of very large data sets.

To use the running-window average smoothing method, click on the "Running Average" option, in the "Data Smoothing" submenu, under the "Tools" menu in the main *WinBreak* window. The dialog box shown in **Figure B.17** will appear. Use the drop-down menus to select the breadth of the running window (in terms of data points) and the number of passes through the data set to be performed. *WinBreak* also gives you the option of removing the lowest and highest value within each window before averaging, so that the average will not be affected by any extremely low or extremely high values. If you do not wish to use this option, uncheck the check boxes labeled "Take out highest & lowest". If you do not want to apply the filter to VO_2, VCO_2 or V_E, uncheck the respective check box. Then, click on "Process". *WinBreak* will perform the necessary calculations and replace the values in the spreadsheet with the smoothed values. Click on "Close" to close the dialog box. Examples of the effects of running-window average smoothing can be found in **Figure B.18**.

Figure B.17. In the running-window average smoothing filter dialog box, select the breadth of the data window and the number of passes to be performed.

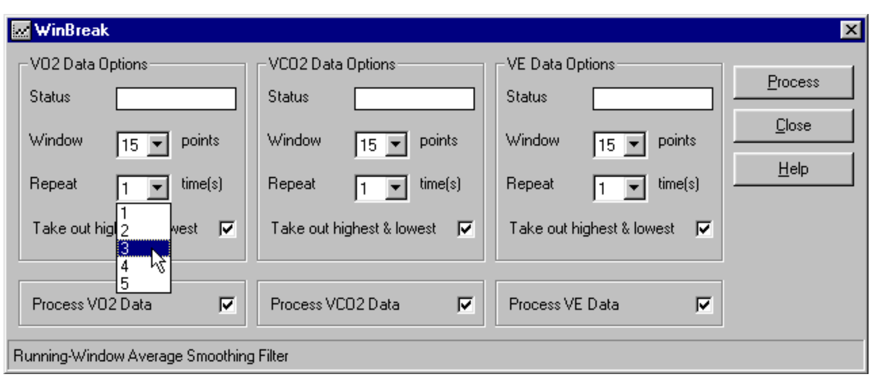
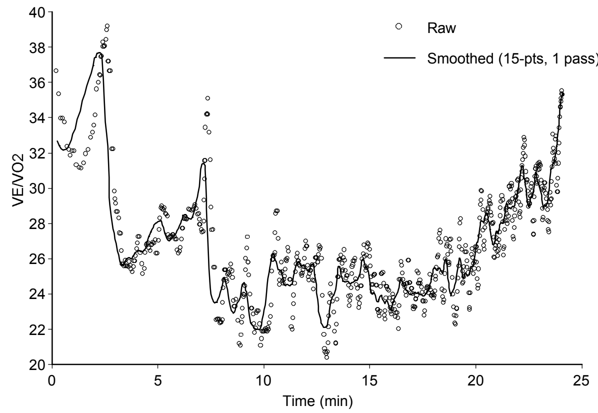
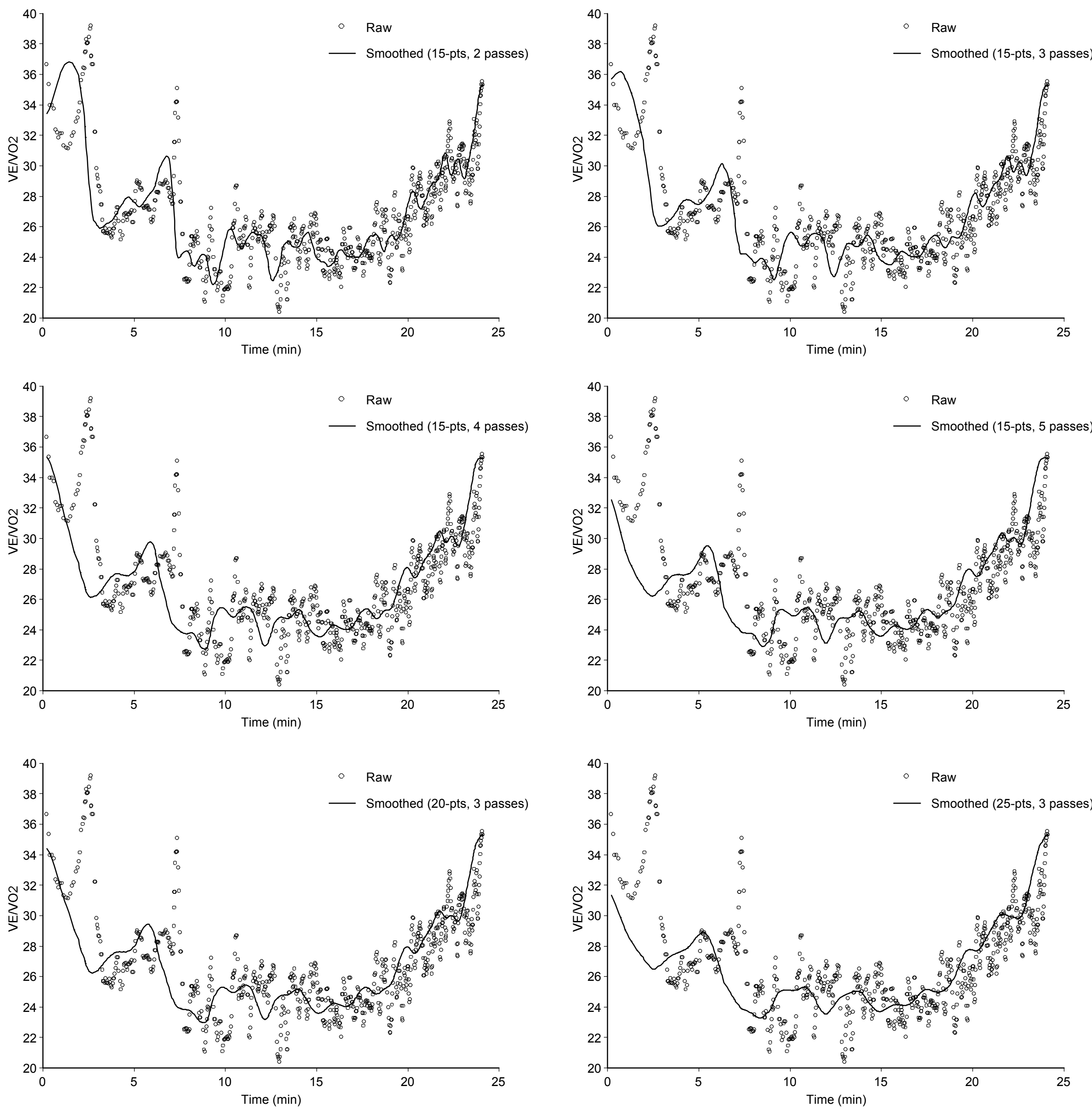


Figure B.18. Examples of V_E/VO_2 data smoothed using different options of the running-window average smoothing filter.





B.17 SMOOTHING BY LOW-PASS FFT FILTER

The *second* data-smoothing method uses a Fast Fourier Transform (FFT) low-pass filter. The Fourier transform decomposes or separates a waveform or function into sinusoids of different frequency which sum to the original waveform. Through the use of a low-pass FFT filter, users can, therefore, remove the high-frequency components of a physiological waveform and leave only a small percentage of low-frequency components. The assumption is that the breath-to-breath variations, which will make up most of the high-frequency components are not of metabolic origin. On the other hand, changes in the relationships between VCO_2 and VO_2 or between the ventilatory equivalent of oxygen and time, for example, which may be significant from a metabolic standpoint change at a rate that is much slower than breath-to-breath variations (Beaver et al., 1986). Therefore, the prudent removal of the high-frequency components should remove most of the ventilatory "noise" while unveiling the slow changes that are of metabolic interest. For more on the technical aspects of FFT, users are referred to Brigham (1988; *The Fast Fourier Transform and its applications*, Englewood Cliffs, NJ: Prentice-Hall) and Cooley and Tukey (1965; An algorithm for the machine calculation of complex Fourier series, *Mathematics of Computation, 19*, 297-301).

To use the low-pass FFT smoothing filter, click on the "Low-pass FFT Filter" option, in the "Data Smoothing" submenu, under the "Tools" menu in the main *WinBreak* window. The dialog box shown in **Figure B.19** will appear. Move the slider to the left or right to set the desired cut-off percentage of the frequency spectrum. The percentage shown indicates how much of the frequency spectrum will be retained after the high-frequency components are filtered out. If you do not want to apply the filter to VO_2, VCO_2 or V_E, uncheck the respective check box. Click on "Process". *WinBreak* will perform the necessary calculations and replace the values in the spreadsheet with the smoothed values. Click on "Close" to close the dialog box. Examples of the effects of the low-pass FFT filter with different cut-off frequencies can be found in **Figure B.20**.

Figure B.19. In the low-pass FFT smoothing filter dialog box, select the percentage of the frequency spectrum to be retained.

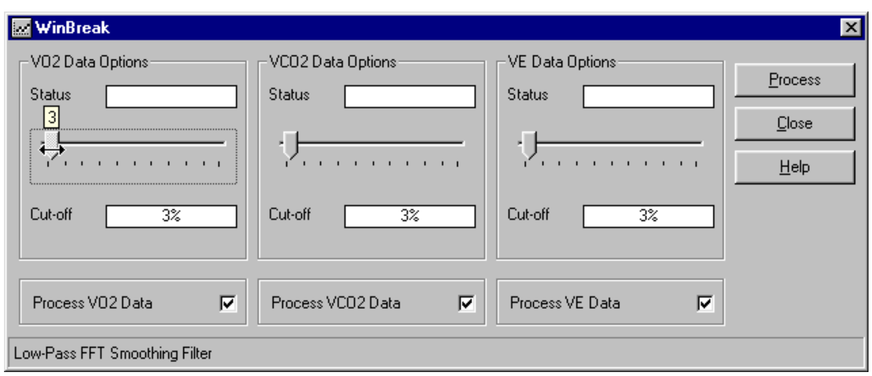
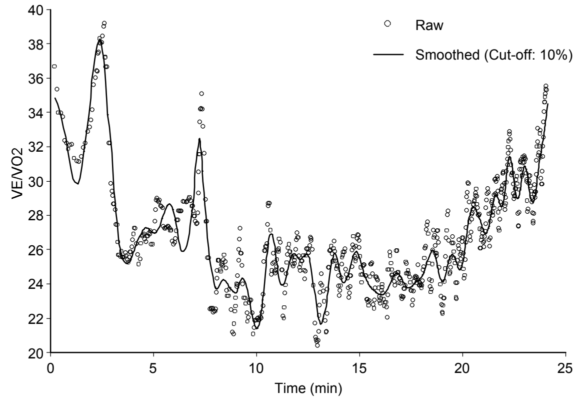
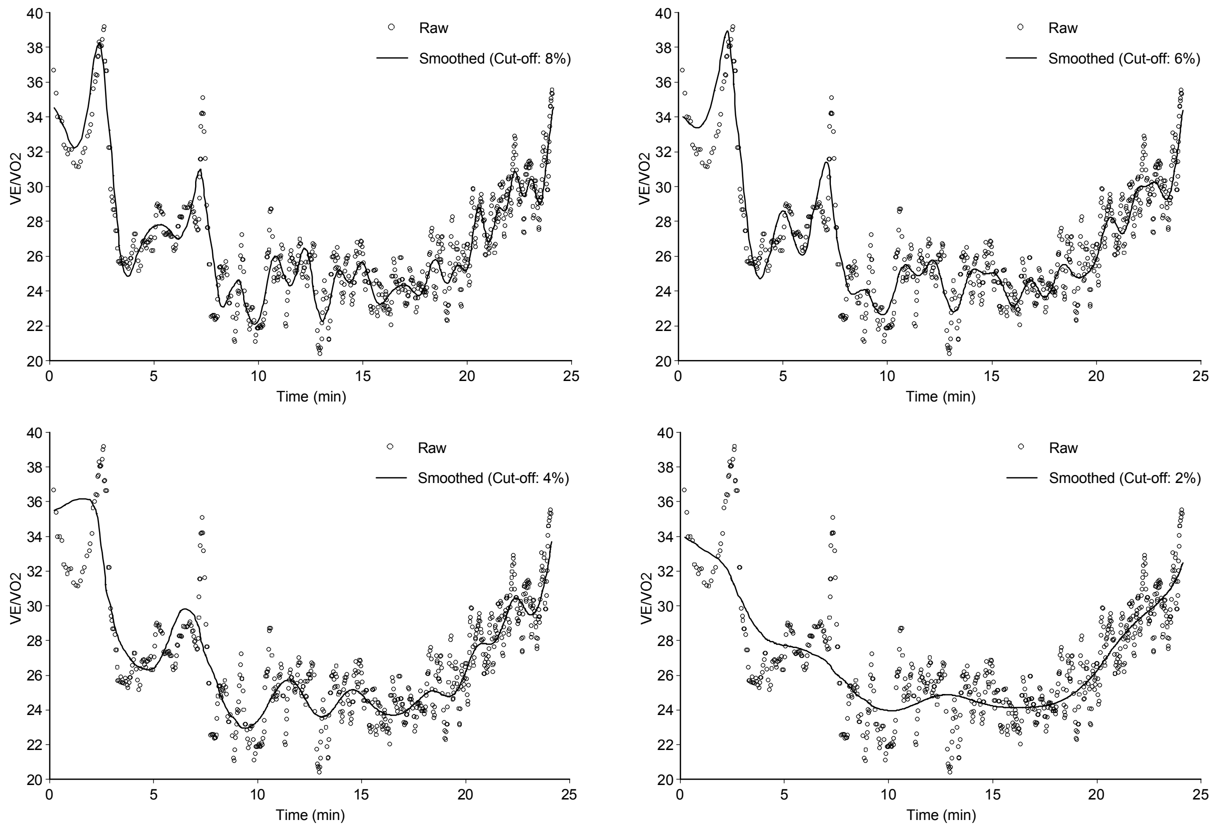


Figure B.20. Examples of V_E/VO_2 data smoothed using different frequency cut-off levels in the low-pass FFT filter.





B.18 SMOOTHING BY SAVITZKY-GOLAY FILTER

The *third* data-smoothing method is the Savitzky-Golay filter, described by Abraham Savitzky and Marcel J.E. Golay (1964; Smoothing and differentiation of data by simplified least squares procedures, *Analytic Chemistry, 36*, 1627-1639). The procedure is similar to the running-window average method in that a window of a certain width is systematically moved through the data set, replacing each raw value with a combination of itself and some nearby values. The difference is that, in the Savitzky-Golay procedure, the underlying function within the moving window is approximated not by a constant whose estimate is the average but by a higher-order polynomial.

To use the Savitzky-Golay smoothing filter, click on the "Savitzky-Golay Filter" option, in the "Data Smoothing" submenu, under the "Tools" menu in the main *WinBreak* window. The dialog box shown in **Figure B.21** will appear. Use the drop-down menus to select the breadth of the running window (odd numbers, from 5 to 25 data points) and the number of passes through the data set to be performed (from 1 to 200). If you do not want to apply the filter to VO_2, VCO_2 or V_E, uncheck the respective check box. Then, click on "Process". *WinBreak* will perform the necessary calculations and replace the values in the spreadsheet with the smoothed values. Click on "Close" to close the dialog box. As is the case with the running-window average smoothing filter, the wider the running window and the higher the number of passes, the larger the degree of smoothing that is attained. Examples of the effects of the Savitzky-Golay smoothing procedure, used in conjunction with various combinations of options, are shown in **Figure B.22**.

Figure B.21. In the Savitzky-Golay smoothing filter dialog box, select the breadth of the data window and the number of passes to be performed.

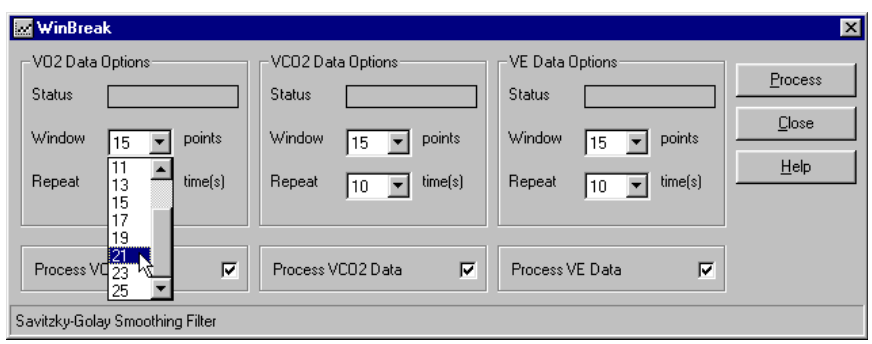
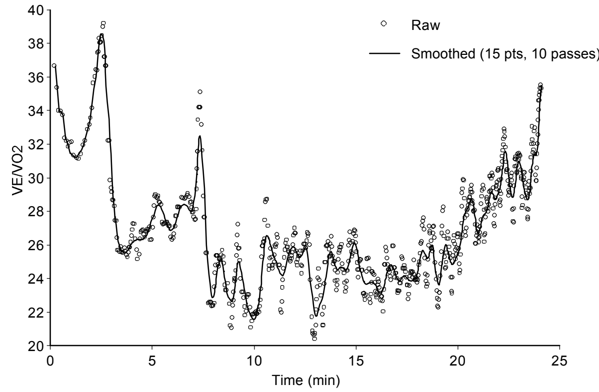
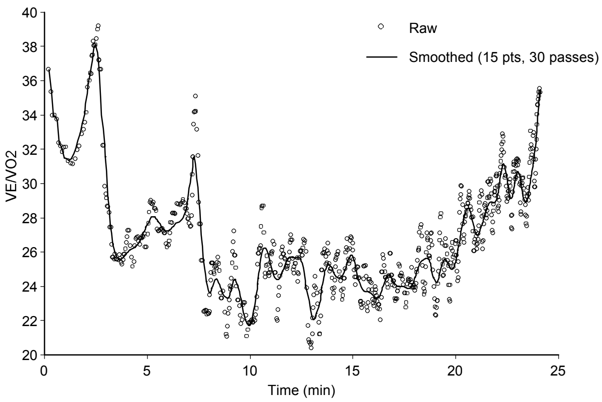
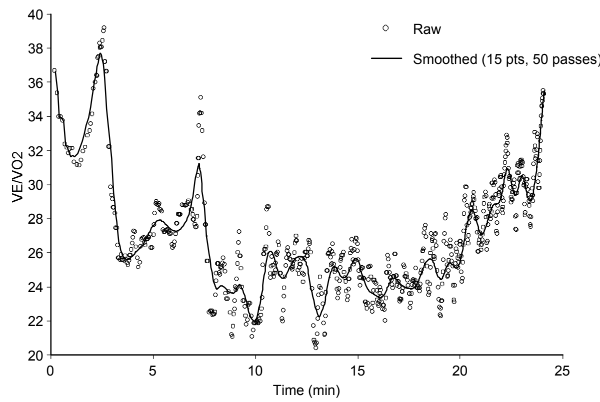
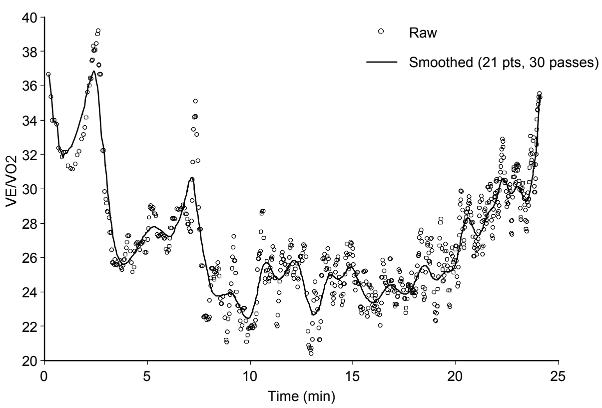


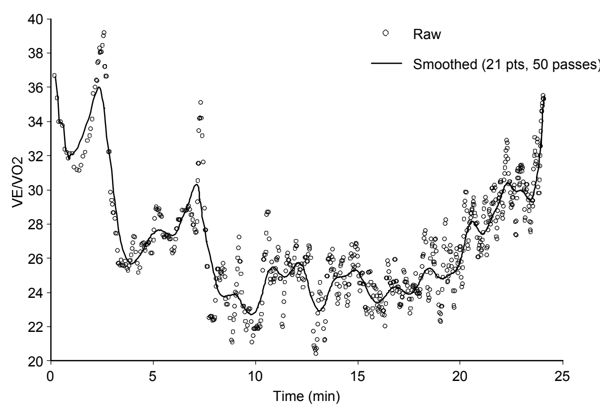
Figure B.22. Examples of V_E/VO_2 data smoothed using different options of the Savitzky-Golay smoothing filter.

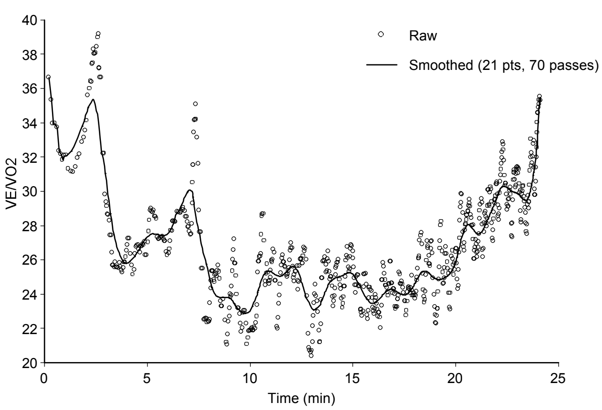


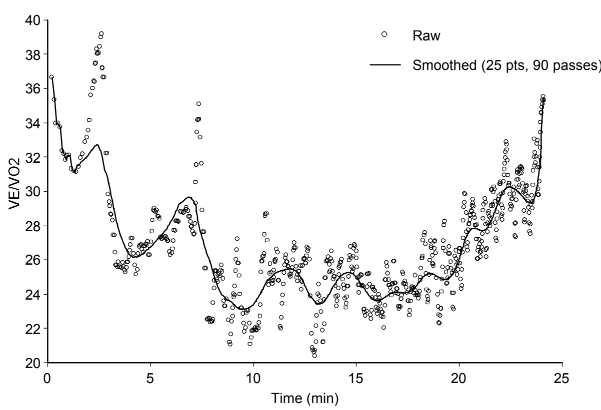












B.19 SMOOTHING BY CUBIC SPLINE CURVE FITTING

The *fourth* data-smoothing option is the cubic spline, based on the computational procedures proposed by Carl de Boor (1978; *A practical guide to splines Applied Mathematical Sciences Series, vol 27*. New York: Springer-Verlag. pp. 240-242) and implemented in the PPPACK algorithm. Spline smoothing is based on the assumption that a smooth function underlies the data and attempts to recover the function by minimizing a smoothing parameter representing a compromise between the desire to stay as close to the original data as possible and the desire to obtain a smooth function.

To use the cubic spline smoothing filter, click on the "Cubic Spline" option, in the "Data Smoothing" submenu, under the "Tools" menu in the main *WinBreak* window. The dialog box shown in **Figure B.23** will appear. Users must select a value of the parameter S, described by de Boor as the "upper bound on the discrete weighted mean square distance of the approximation from the data". In practice, there is rarely any basis for knowing how to select this value for a given data set in advance. Thus, de Boor notes that "more naively, S represents a knob which one may set or turn to achieve a satisfactory approximation to the data" (pp. 242-243). In other words, users may have to experiment by selecting different values of S. Thankfully, in most cases, the different values of S will have little effect on the shape of the smoothing spline. If you do not want to apply the filter to VO_2, VCO_2 or V_E, uncheck the respective check box. Once the S parameter has been set, click on "Process". *WinBreak* will calculate the values of the smooth function and update the spreadsheet. It will also present the values of the first derivative of the spline function. Click on "Close" to close the dialog box. An example of the effects of smoothing a data set using the cubic spline smoothing procedure is shown in **Figure B.24**.

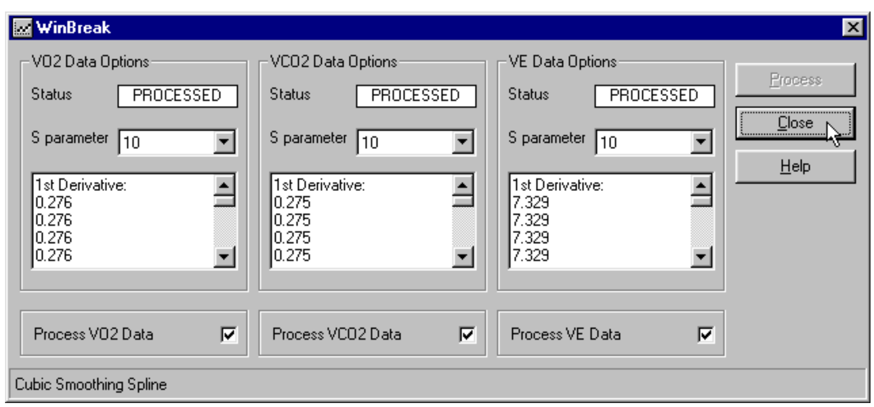


Figure B.23. In the cubic smoothing spline dialog box, select the value of the S parameter and click on "Process".

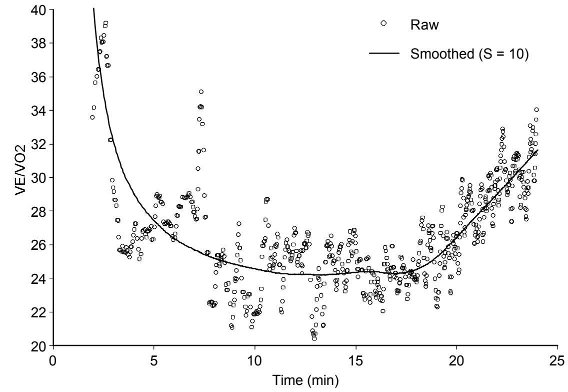


Figure B.24. Example of V_E/VO_2 data smoothed using a cubic smoothing spline.

B.20 SMOOTHING BY POLYNOMIAL REGRESSION CURVE FITTING

The *fifth* data-smoothing option is least-squares polynomial regression. Polynomial regression equations are of the form $f_x = a_0 + a_1x + a_2x^2 + \ldots + a_nx^n$. *WinBreak* allows users to fit polynomial curves of orders from second to tenth. Lower-order polynomials are smoother, whereas higher-order polynomials generally provide a closer fit to the original data.

To use the polynomial regression smoothing option, click on the "Polynomial Regression" option, in the "Data Smoothing" submenu, under the "Tools" menu in the main *WinBreak* window. The dialog box shown in **Figure B.25** will appear. First, use the drop-down menus to select the degree of polynomial fit you wish to obtain. If you do not want to apply the smoothing to VO_2, VCO_2 or V_E, uncheck the respective check box. Then, click on "Process". *WinBreak* will perform the necessary calculations and replace the values in the spreadsheet with the smoothed values. It will also display the a_0 to a_n coefficients of the polynomial regression equation. Click on "Close" to close the dialog box. Examples of applying smoothing using polynomial regressions of various orders are shown in **Figure B.26**.

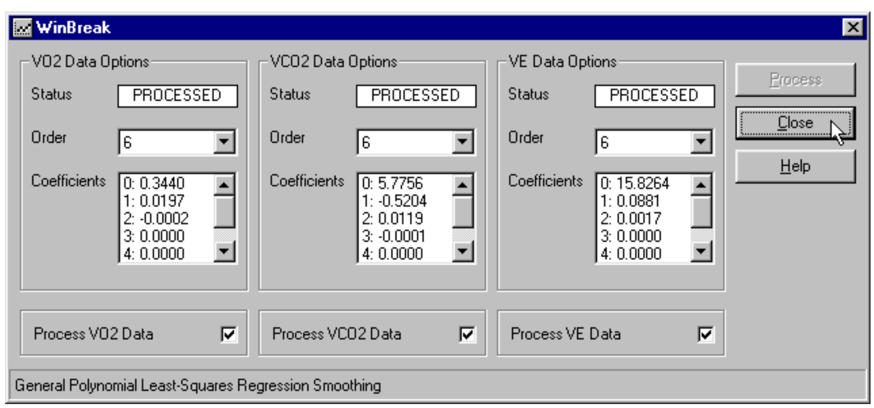
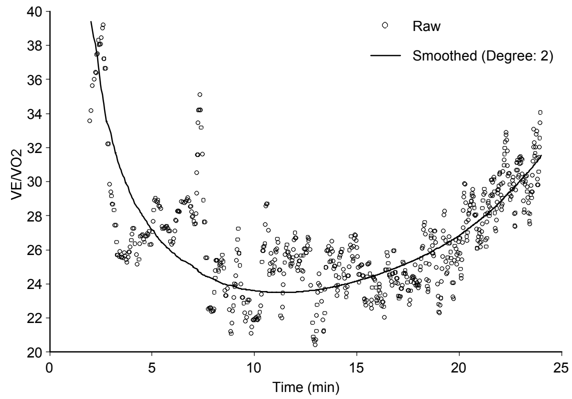
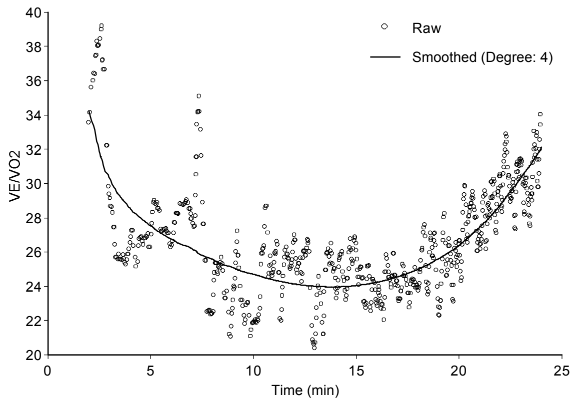
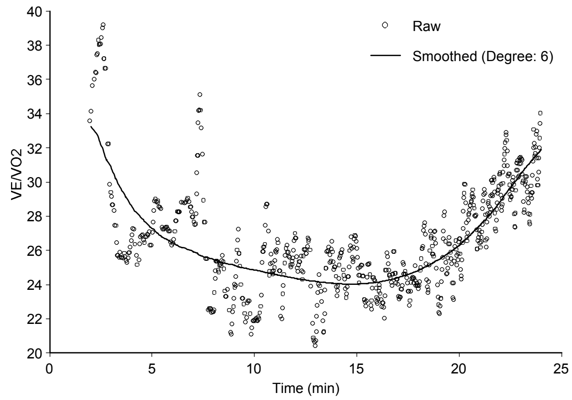


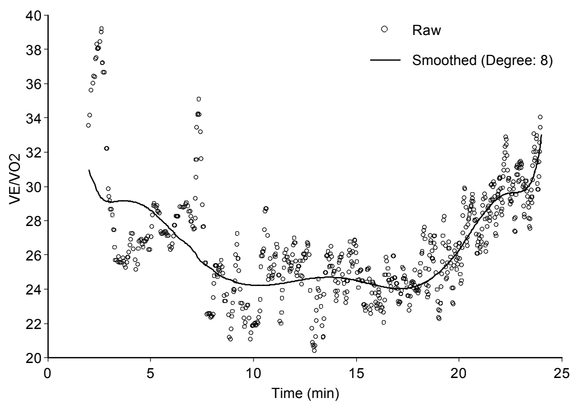
Figure B.25. In the polynomial least-squares regression dialog box, select the order of the polynomial and click on "Process".

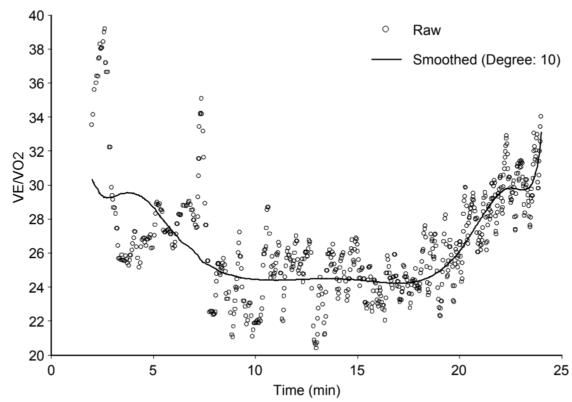
Figure B.26. Examples of V_E/VO_2 data smoothed using polynomials of different orders.



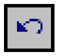






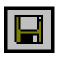


B.21
REVERTING TO THE ORIGINAL DATA



After you apply data averaging, interpolation, filtering, or smoothing, you may wish to return to the original data. You can do this by clicking "Revert" from the "File" menu or the taskbar in the main *WinBreak* window. This will close any open graph windows and restore the original values in the spreadsheet. After you revert to the original data, you must again set the calibration / warm-up and test termination times by clicking "Set".

B.22
SAVING A DATA SET



WinBreak allows users to save the data set in a new file. This may be useful, particularly since *WinBreak* can remove extraneous information from the top and bottom of data files generated by metabolic analysis software packages and can perform additional operations, such as averaging, interpolating, filtering, and smoothing that may be more cumbersome to perform with other programs. The new data files generated by *WinBreak* could then be imported in other mathematical, statistical, or data-plotting programs.

To save the data in a file, select "Save Data File As…" from the "File" menu (see **Figure B.27**). Users can choose among several file formats, including comma-delimited and tab-delimited ASCII formats and Microsoft® Excel® format (default option). This range of options should be sufficient to enable compatibility with most popular data analysis and plotting programs. Nevertheless, users also have the option of copying and pasting data from the *WinBreak* spreadsheet directly to another program. You can do this by selecting the desired data range from the *WinBreak* spreadsheet, clicking the right mouse button, and selecting "Copy" from the pop-up menu, to copy the data to the clipboard. Then, move to the other program, select the location at which you wish to add the data, and "paste" the data (consult the program's manual on how to "paste").

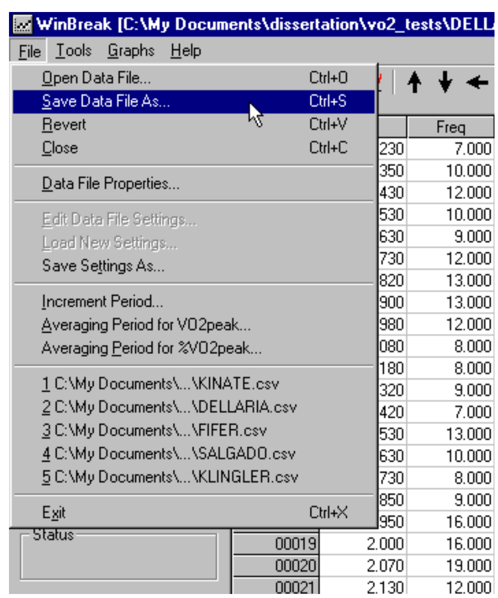
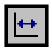


Figure B.27. To save a data set, select "Save Data File As…" from the "File" menu in the main *WinBreak* window or click the floppy computer disk icon from the taskbar. *WinBreak* can save data in comma-delimited and tab-delimited ASCII files, as well as in Microsoft® Excel® spreadsheets for compatibility with other data analysis and plotting programs.

SECTION C. WORKING WITH GRAPHS

C.1 THE GRAPH BROWSER



WinBreak offers a feature called "Graph Browser," which allows users to obtain quick visual representations of the data set. Specifically, the Graph Browser can display the 17 graphs shown in the menu in **Figure C.1**. The different graphs are available either from the drop-down menu or from the left and right arrows on the task bar of the Graph Browser window, which will rotate through the set of graphs in the same order shown in the menu. Users can (a) save or print each graph by selecting the respective options in the "File" menu or (b) rescale the axes or customize each graph by selecting the respective options in the "Graph" menu (see **Figure C.2**).

Figure C.1. The Graph Browser can display the 17 different plots shown in the menu. Use the drop-down menu labeled "Graph" to jump directly to a certain graph or use the left and right arrows on the task bar to rotate through the set in the same order shown here.

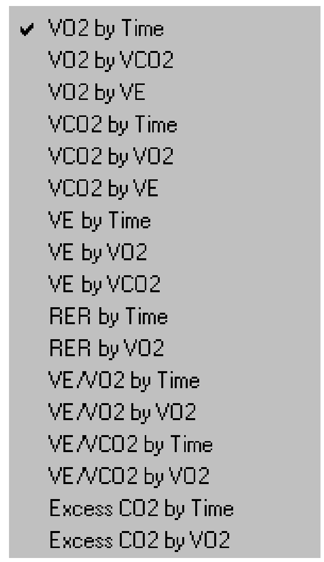
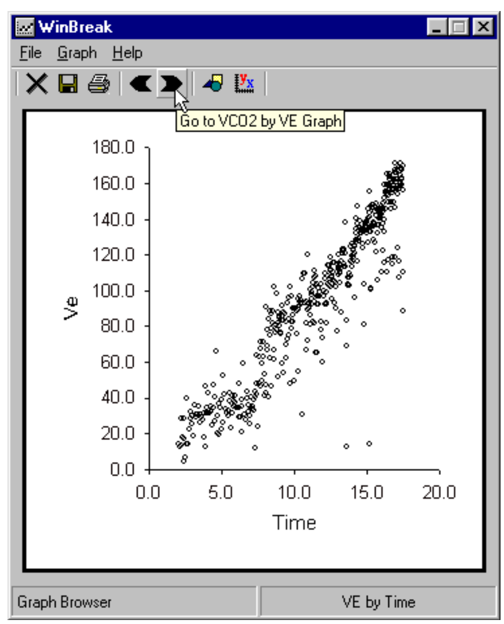


Figure C.2. In the Graph Browser window, click on the left and right arrows on the taskbar to rotate through the 17 different plots of the data. Using the other buttons on the taskbar, you can save, print, rescale, or customize the graphs.



C.2 THE RESPIRATORY COMPENSATION POINT

During the initial stages of an incremental exercise test, V_E increases in proportion to CO_2 output. This is called isocapnic buffering. Thus, the relationship between V_E and VCO_2 is positive linear. However, after the gas exchange threshold has been exceeded and metabolic acidosis has occurred, V_E starts to increase more rapidly than VCO_2. This accentuated ventilatory response is called "respiratory compensation" (or "ventilatory compensation"). Because the point where the respiratory compensation starts must follow the gas exchange threshold, the identification of this point is useful in the process of determining the gas exchange threshold, as it can serve as the "upper boundary" for the calculations involved in this process.

WinBreak includes a module for the detection of the point of respiratory compensation. The module is accessible by selecting "Find Respiratory Compensation Point" from the "Tools" menu of the three graphical modules used for the determination of the gas exchange threshold (i.e., the V-slope, ventilatory equivalents, and Excess CO_2 modules). Alternatively, users can access this module by clicking on the button marked "RC" on the taskbar. This will open the window shown in **Figure C.3**.

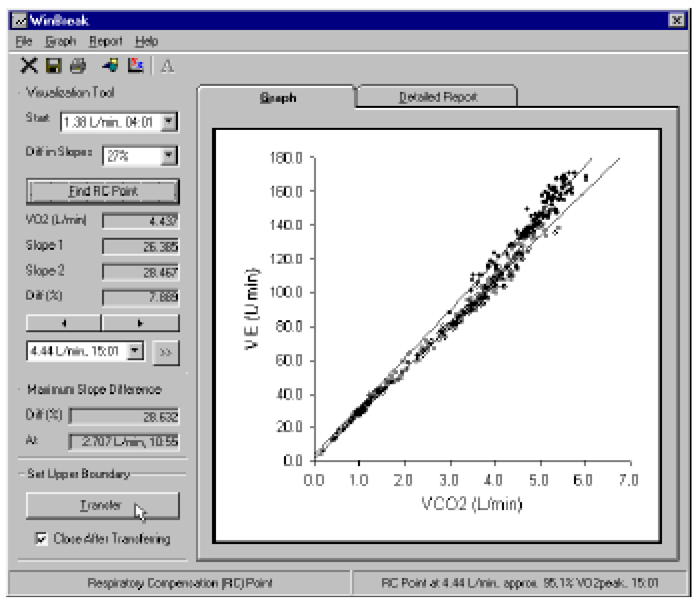
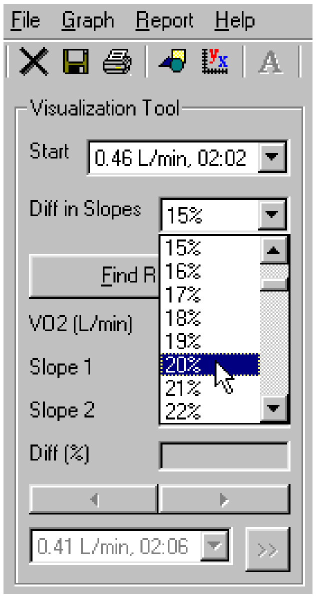


Figure C.3. The module for the determination of the respiratory compensation point. Select the desired percentage of difference between the first and second slope in the relationship between V_E and VCO_2 and click on "Find RC Point".

The method implemented in *WinBreak* for the determination of the respiratory compensation point generally follows the recommendations by Beaver et al. (1986). According to these authors, the respiratory compensation point is determined as follows: "The V_E vs. VCO_2 data are divided into two linear segments [i.e., two regions, each of which is fitted with a linear regression]. The intersection of the two segments is the [respiratory compensation] point if the change in slope between them is greater than a preselected amount (15% of the initial slope). If a [respiratory compensation] point is found, its location is transferred to the VCO_2 vs. VO_2 curve [see the V-slope sections below] and used as the upper boundary for the calculation [of the gas exchange threshold]. Certain subjects, notably patients with obstructive lung disease, may not have a [respiratory compensation] point" (p. 2023).

Figure C.4. The module for the determination of the respiratory compensation point. Select the desired percentage of difference between the first and second slope in the relationship between V_E and VCO_2 and click on "Find RC Point".



To use the respiratory compensation module, use the drop-down menus to select (a) the starting point for the calculations and (b) the percentage by which you want the second slope to be higher than the first, as shown in **Figure C.4**. Option (a) is useful because, in some cases, the early data points may include non-linear segments, which should be excluded for the search of the actual respiratory compensation point to be meaningful, as this usually occurs after the midpoint of incremental exercise tests. Option (b) determines the amount by which the slope of the second linear regression through the V_E by VCO_2 data should be higher than the first. According to Beaver et al. (1986), a reasonable number is 15%. In *WinBreak*, you can select any number between 5% and 100%.

Once the two selections have been made, click on "Find RC Point". *WinBreak* will compute all possible two-segment regressions and then search (from beginning to end) for the first occurrence of a slope difference that equals or exceeds the percentage selected in the "Diff in Slopes" menu. It will then present (a) the slope of the first regression, (b) the slope of the second regression, (c) the percentage of difference between the two slopes (which should be equal to or slightly higher than the percentage selected in the "Diff in Slopes" menu), (d) the maximum slope difference found in the data set, and (e) the location (in terms of VO_2 and time) of the maximum slope difference. *WinBreak* will also re-plot the V_E by VCO_2 graph, showing the two regression lines through the data. The symbols representing the data points of the first and second regressions (as well as any data points excluded from the early phases of the data set) can also be different, to facilitate the visual inspection of the results.

Depending on how small the selected percentage of difference is between the slopes of the second and first regressions, it is possible that, upon visual inspection, users may decide that the automatically determined point is a non-satisfactory estimate of the respiratory compensation point. In such cases, users can manually shift the location of the tentative respiratory compensation point higher or lower either by clicking on the left and right arrows (for small shifts) or by using the drop-down menu (for larger shifts) and clicking on the button marked ">>", as shown in **Figure C.5**.

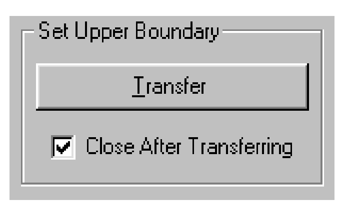
Figure C.5. Click on the left and right arrows or use the drop-down menu to manually shift the tentative respiratory compensation point.

WinBreak will respond by re-plotting the regression lines and re-calculating the regression slopes, as well as the percentage of difference between them. Alternatively, users may opt to change the desired percentage of difference between the second and first slopes and perform a new search for a tentative respiratory compensation point. Any change in the "Diff in Slopes" menu will reset the panel, delete any previous results, and return the V_E by VCO_2 graph to its original state, with no visible regression lines.

For users who wish to receive additional information about the calculations that were involved in selecting a tentative respiratory compensation point, *WinBreak* offers a complete account. This is available by clicking the tab entitled "Detailed Report". Each time a search for a tentative respiratory compensation point is performed, the Detailed Report will include the results of all the regression analyses involved.

Finally, once a satisfactory respiratory compensation point has been identified, users can click on "Transfer", as shown in **Figure C.6**, to make that data point the upper boundary in the calculations for determining the gas exchange threshold.

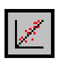
Figure C.6. Once a satisfactory respiratory compensation point has been identified, click on "Transfer" to set this data point as the upper boundary for the gas exchange threshold calculations.



C.3 THE V-SLOPE METHOD IN GENERAL

The first method for detecting the gas exchange threshold offered by *WinBreak* is the V-slope, originally described by Beaver et al. (1986). The method consists of plotting CO_2 production against O_2 utilization and identifying a breakpoint in the relationship between these two variables. This is achieved mainly by computing linear regressions based on two contiguous segments of the data, and identifying a point that yields a substantial increase in the slope of the second regression compared to the first.

Although the visual identification of a breakpoint in the VCO_2 by VO_2 relationship may be relatively easy in many cases of averaged data, it often proves very difficult in the case of breath-by-breath data due to the densely cluttered data points, the frequent fluctuations of VO_2 and VCO_2 from higher to lower values, and various kinds of breath-to-breath irregularities. Similar difficulties also impact the statistical methods used for the determination of a breakpoint, since it is possible that even a single erratic data point (with large "leverage") can cause a transient but large change in the slope of a regression. Therefore, some type of averaging or interpolation of data is generally recommended, particularly in the case of large data sets, before using the V-slope method.



To display the V-slope graph window, click on "Show VCO_2 by VO_2 Graph" from the "Graphs" menu in the main *WinBreak* window (or click the button on the taskbar). This will open the window shown in **Figure C.7**.

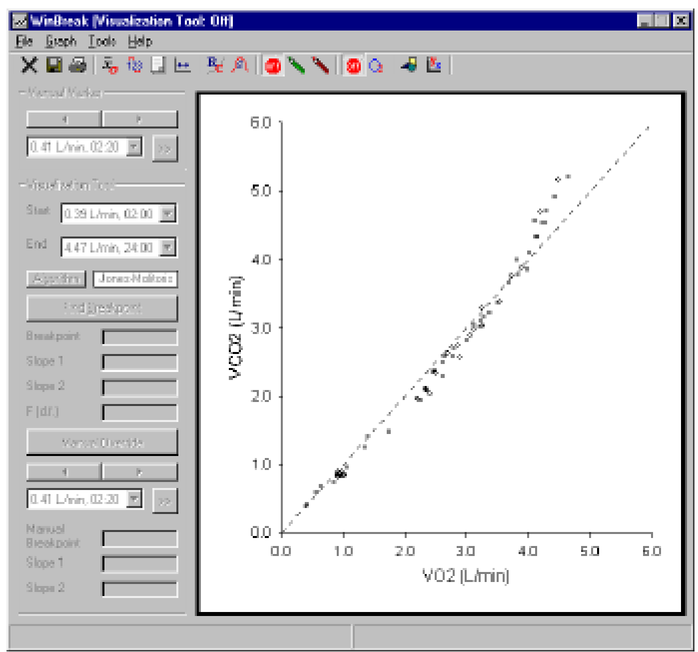
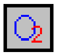


Figure C.7. The V-slope graph window.

WinBreak uses a method called "Visualization Tool" across all three modules for the statistical determination of the gas exchange threshold (i.e., V-slope, ventilatory equivalents, and Excess CO_2). To activate the Visualization Tool, open the "Tools" menu, select "Visualization Tool" and click on "VCO_2 as a Function of VO_2" or the button marked "O_2" on the taskbar.



This will activate several options in the frame labeled "Visualization Tool" on the left side of the window. As a first step, it is important to set a time frame of data on which to apply the statistical calculations for the determination of the breakpoint. In most cases, it would be appropriate to set as the starting point for the calculations (using the drop-down menu labeled "Start") a time that is at least 1-2 minutes after the beginning of the test. A gas exchange threshold is unlikely to occur during this period and, moreover, because of transient changes in ventilatory parameters that take place in the beginning of exercise, the initial segment of the data may have a slope that differs significantly from that of the subsequent minutes. According to Beaver et al. (1986), "at the start of incremental exercise, VCO_2 rises with a slower time constant than VO_2 due to the capacitive effect of changing tissue CO_2 stores. This distorts the VCO_2 vs. VO_2 curve and produces an initial curved region that [should be] excluded from the analysis. We have found that omitting the data of the first minute after the start of incremental exercise to be usually adequate, but any initial segment of the curve above this with a slope of < 0.6 [should also be] excluded" (p. 2023).

Likewise, it is recommended that any segment of the data near the end of incremental exercise showing evidence that the level of respiratory compensation has been exceeded should also be excluded from the calculations (using the drop-down menu labeled "End"). To formally evaluate whether and at which point this has occurred, users are advised to use the module for determining the respiratory compensation point (i.e., examine the V_E by VCO_2 plot and locate the point at which there is an increase in slope by approximately 15% or so, according to Beaver et al., 1986). If a respiratory compensation breakpoint is found, the time point at which it occurred should then be used as the upper boundary for the gas exchange threshold calculations.

Once the "Start" and "End" points for the calculations have been set, users must select among the five algorithms available in *WinBreak* for the statistical determination of the breakpoint in the VCO_2 by VO_2 relationship. The selection of the algorithm to be used is done by clicking on the button marked "Algorithm" in the "Visualization Tool" frame on the left side of the window. This will open the dialog box shown in **Figure C.8**. The five algorithms differ substantially, so it is important that users understand the approach followed in each. In some cases, all 5 algorithms will yield the same results, but it is also quite possible, particularly in cases of breath-by-breath data, that the results will differ, perhaps to a great extent. In most cases, given the fact

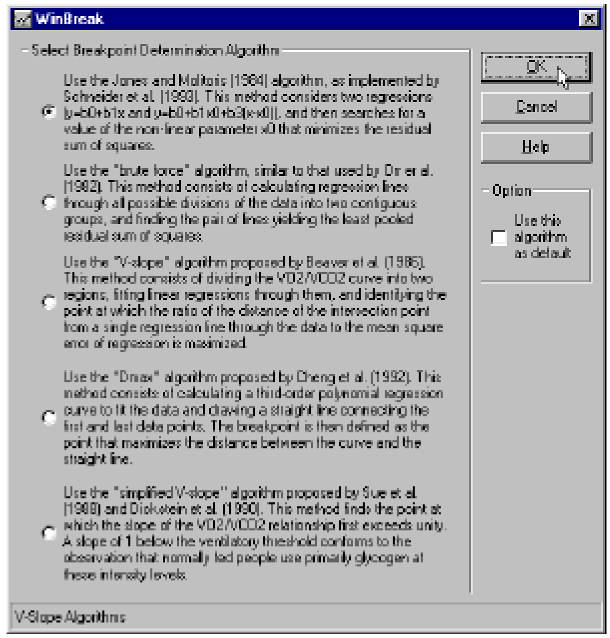


Figure C.8. The five algorithms used to identify a breakpoint in the VCO_2 to VO_2 relationship via statistical procedures. Move the selection to the one you wish to use and click "OK".

that the calculations for most data sets take only a few seconds to complete, it is a good idea to revolve through all five algorithms and compare their results. *WinBreak* not only reports *F* values for the improvement in fit conferred by two-regression models over single-regression models, but it also enables users to visually inspect the fit of the two models through plots of the residuals (see relevant section below). Furthermore, users have access to the complete computational details produced by each of the five algorithms through the "Detailed Reports" module (see relevant section below).

An example of a graph produced by the Visualization Tool is shown in **Figure C.9**.

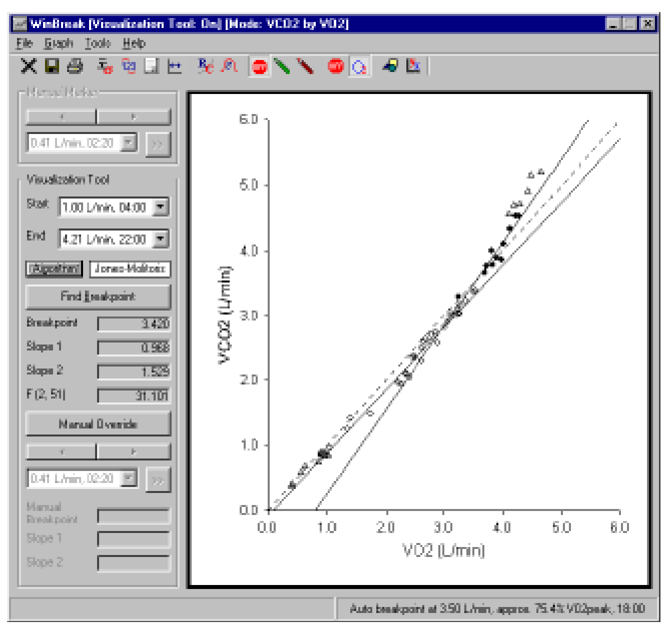


Figure C.9. The V-slope graph window with the Visualization Tool activated. A breakpoint has been identified and the two regression lines are shown.

C.4 THE V-SLOPE USING THE JONES AND MOLITORIS (1984) ALGORITHM

The Jones and Molitoris (1984) algorithm, used for the detection of gas exchange threshold by Schneider et al. (1993), considers two regression equations, one before and one after the breakpoint x_0:

$$y_i = b_0 + b_1x \quad x \leq x_0$$
$$y_i = b_2 + b_3x \quad x > x_0$$

The following constraint forces the two regression lines to join at x_0:

$$b_0 + b_1x_0 = b_2 + b_3x_0$$

By solving for b_2,

$$b_2 = b_0 + b_1x_0 - b_3x_0$$

the two equations can be rewritten as:

$$y_i = b_0 + b_1x \qquad x < x_0$$
$$y_i = b_0 + b_1x_0 + b_3(x-x_0) \qquad x \geq x_0$$

This is a four-parameter regression, consisting of three linear parameters (b_0, b_1, b_3), and one non-linear parameter (x_0). The method searches for the value of x_0 that minimizes the residual sum of squares (RSS_{min}). Once this value is found, then the mean square error (MSE) is computed as

$$MSE = RSS_{min} / (n - 4)$$

Then, an F value with 2 and n-4 degrees of freedom is computed, comparing the improvement over a single-regression model with a residual sum of squares RSS_S.

$$F_{(2, n-4)} = (RSS_S - RSS_{min}) / (2MSE)$$

Thus, the output of the Jones and Molitoris (1984) algorithm includes the intercept, slope, and RSS of a single line, the RSS of each iteration in the search for x_0, the value of x_0 that minimizes the RSS, the intercepts and slopes of the two lines intersecting at x_0, the normalized residuals (i.e., the deviations of the observations from the fitted joined lines divided by their standard deviation), and an F value for the test of improvement over a single line.

C.5
THE V-SLOPE USING THE ORR ET AL. (1982) ALGORITHM

A "brute force" algorithm was originally proposed by Orr et al. (1982) as a way of identifying breakpoints in the V_E by VO_2 relationship. In *WinBreak*, the same method is used for finding a breakpoint in the VCO_2 by VO_2 relationship. According to Orr et al. (1982), "a single linear regression is initially fit to all data points and is used for later statistical comparisons. A brute-force method is then used to fit two lines to the data. Regression lines are calculated for all possible divisions of the data into two contiguous groups, and the pair of lines yielding the least pooled residual sum of squares is chosen as representing the best fit" (p. 1350).

The output of the Orr et al. (1982) algorithm includes the intercept, slope, and RSS of a single line, the intercepts, slopes, and pooled RSS for each piecewise regression, the values of VO_2 and VCO_2 at the point that minimizes the pooled RSS, and an *F* value for the test of improvement over a single line.

C.6
THE V-SLOPE USING THE BEAVER ET AL. (1986) ALGORITHM

The original "V-slope" method was proposed by Beaver et al. (1986). The procedure consists of a series of stages, some of which are not carried out automatically by *WinBreak*, but should instead be done by the users through the data analysis and conditioning options offered by *WinBreak* and their metabolic analysis software. Specifically, first, the breath-by-breath data points are transformed "by interpolation into data points at regular time intervals so that the analysis is not biased by irregular distribution" (p. 2022). Second, a moving-average filter is used to smooth the breath-by-breath fluctuations with a width that depends on the amount of noise in the data" (p. 2022). A width of 9 seconds was used in the studies reported by Beaver et al. (1986). The authors recommend that "it is best to use as little filtering as possible to avoid distortion of the underlying curve shape by the filtering process" (p. 2022). Third, some fluctuations in VCO_2 with recognizable physiological origin can be corrected. Specifically, Beaver et al. (1982) recommend that the change in CO_2 transport away from the lungs be added to the measured respiratory VCO_2 "to give a better approximation to the CO_2 transport from the tissues to the lungs and a smoother VCO_2 curve" (p. 2022). The change in CO_2 transport away from the lungs is defined as

$$\delta VCO_2 = [\beta]\ Q\ \delta PaCO_2$$

where δVCO_2 is the change in CO_2 transport away from the lungs by pulmonary blood, $[\beta]$ is the solubility of CO_2 in blood, Q is the cardiac output, and $\delta PaCO_2$ is the variation of arterial CO_2 partial pressure, approximated by the change in end-tidal PCO_2 ($\delta PETCO_2$). Fourth, the procedure involves setting the lower and upper boundaries for the calculation of the gas exchange threshold, as described previously. To recap, regarding the lower boundary, Beaver et al. (1986) noted that "at the start of incremental exercise, VCO_2 rises with a slower time constant than VO_2 due to the capacitive effect of changing tissue CO_2 stores. This distorts the VCO_2 vs. VO_2 curve and produces an initial curved region that [should be] excluded from the analysis. We have found that omitting the data of the first minute after the start of incremental exercise to be usually adequate, but any initial segment of the curve above this with a slope of < 0.6 [should also be] excluded" (p. 2023). Regarding the upper boundary, ideally, it should be set at the level of the respiratory compensation point. Beaver et al. (1986) noted that "the V_E vs. VCO_2 data are divided into two linear segments … The intersection of the two segments is the RC point if the change in slope between them is greater than a pre-selected amount (15% of the initial slope). If a [respiratory compensation] point is found, its location is transferred to the VCO_2 vs. VO_2 curve and used as the upper boundary" (p. 2023).

Finally, once the data have been interpolated, smoothed, and corrected, and the lower and upper boundaries for the determination of the gas exchange threshold have been set, "the VCO_2 vs. VO_2 curve is divided into two regions, each of which is fitted by linear regression. The intersection between the two regression lines is the tentative [gas exchange threshold] point. The point dividing the two regions is moved systematically until the two lines best fit the data by maximizing the ratio of the greatest distance of the intersection point from the single regression line of the data to the mean square error of regression. This solution is then accepted as a [gas exchange threshold] if the change in slope from the lower segment to the upper segment is > 0.1. This test eliminates spurious results due to statistical variations in the data" (p. 2023).

Consistent with this procedure, *WinBreak* first fits a single linear regression through the data, and calculates its intercept, slope, and RSS. It then calculates the intercept, slope, and RSS of all possible contiguous two-segment regressions. For each, it identifies the intersection of the two lines and the distance of the intersection from the previously calculated single line using the standard geometric formulas of Bowyer and Woodwark (1983; *A programmer's geometry*. London: Butterworths). Based on this information, it computes the ratio of the distance between the intersection point and the single regression line to the mean square error of regression. Finally, the breakpoint is defined as the point that maximizes this ratio and satisfies the condition that the change in slope from the first to the second regression line is > 0.1. The output of the algorithm consists of all the computational details, as well as an *F* value for the test of improvement over a single line.

C.7 THE V-SLOPE USING THE CHENG ET AL. (1992) ALGORITHM

The "Dmax" algorithm was proposed by Cheng et al. (1992). According to Cheng et al. (1992), a third-order curvilinear regression is first fitted to the VCO_2 vs. VO_2 data. This order was chosen because, in pilot work, the data produced by a third-order curvilinear regression yielded higher correlation coefficients with the original data compared to lower-order regressions, whereas higher-order regressions did not significantly increase the correlation coefficient. Next, a straight line is drawn connecting the two end points of the curve. Then, the distances of all the data points along the curve to the straight line are calculated. Finally, "the point yielding the maximal distance (Dmax) derived from the computation [is] taken as the threshold" (p. 519). An example is shown in **Figure C.10**.

In *WinBreak*, the output of the Cheng et al. (1992) algorithm includes the raw and polynomial regression-fitted values of VO_2 and VCO_2, the distance of each data point from the straight line, the Dmax point, the intercepts and slopes of the linear regressions from the first data point to Dmax and from Dmax to the last data point, and an *F* value for the test of improvement over a single line.

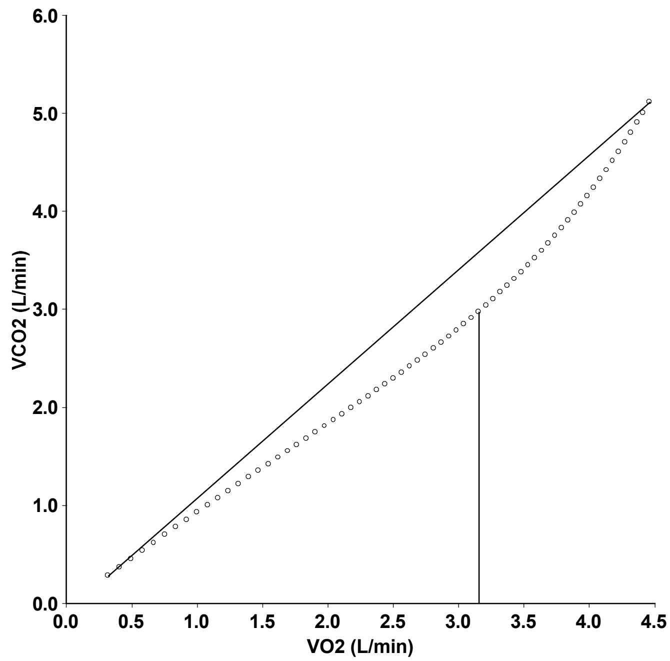


Figure C.10. An illustration of the Dmax method for determining the gas exchange threshold from VCO_2 and VO_2 data. The threshold is defined as the point yielding the largest distance between a third-order polynomial curve and a straight line connecting the first and last points.

C.8 THE V-SLOPE USING THE SUE ET AL. (1988) ALGORITHM

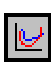
The "simplified V-slope" algorithm was originally proposed by Sue et al. (1988) and was subsequently computerized by Dickstein et al. (1990). First, "a line parallel to the line of identity [i.e., slope of 1] is drawn through VCO_2 vs. VO_2 points during the incremental phase of the exercise test" (p. 933). Then, "the point at which the VCO_2 departs from the line (begins to increase more rapidly than VO_2) is taken as the 'V-slope' [gas exchange threshold]" (p. 933). According to Sue et al. (1988), "the basis for drawing a line with a slope of 1 through the points below the [gas exchange threshold] was established empirically because, in our patients and normal subjects, and in the subjects described by Beaver et al., the slope of a line drawn through points below the [gas exchange threshold] closely approximated 1, conforming to the finding that the muscle uses primarily glycogen for energy in normally fed people" (p. 933). Sue et al. also noted that "the VCO_2 vs. VO_2 points drawn on a line with a slope = 1 do not indicate the VCO_2/VO_2 (gas exchange ratio, R) is equal to 1, but rather than the ratio of increase in VCO_2 / increase in VO_2 is close to 1. Any additional increase in VCO_2 out of proportion to the increase in VO_2 with increasing work must be attributed to the CO_2 evolved from the buffering of metabolic (lactic) acid because (a) subjects do not hyperventilate at this point in exercise; and (b) the CO_2 evolved is too great to be attributed to hyperventilation" (p. 933). In the computerized implementation of the "simplified V-slope" method developed by Dickstein et al. (1990), the analysis was concentrated on the subset of data with a workload of > 5 Watts and a respiratory exchange ratio of < 1.0. According to Dickstein et al., "this subset of data was chosen to minimize the obscuring effects of the hyperventilation response at the onset of exercise and the respiratory compensation phase that usually occurs just before termination of peak exercise" (p. 1365).

To implement the "simplified V-slope" method, *WinBreak* again calculates regression lines through all possible divisions of the data into two contiguous groups, and finds a breakpoint at which the first regression has a slope of less than or equal to 1 and the second regression has a slope higher than 1. The output of the algorithm includes the intercept, slope, and RSS of a single line, the intercepts, slopes, and pooled RSS of each piecewise regression, the values of VO_2 and VCO_2 at the breakpoint, and an *F* value for the test of improvement over a single line.

C.9 THE METHOD OF THE VENTILATORY EQUIVALENTS

The second method for detecting the gas exchange threshold offered by *WinBreak* is the method of the ventilatory equivalents. This methods consists of plotting the ventilatory equivalents for oxygen (V_E/VO_2) and carbon dioxide (V_E/VCO_2) and identifying the point at which there is an increase in V_E/VO_2 without a concurrent increase in V_E/VCO_2 (Davis et al., 1979; Reinhard et al., 1979). This method became popular when Caiozzo et al. (1982), in an oft-cited comparative analysis, determined that this index showed a higher correlation (0.93) with the blood lactate threshold compared to changes in ventilation, the respiratory exchange ratio, and CO_2 output.

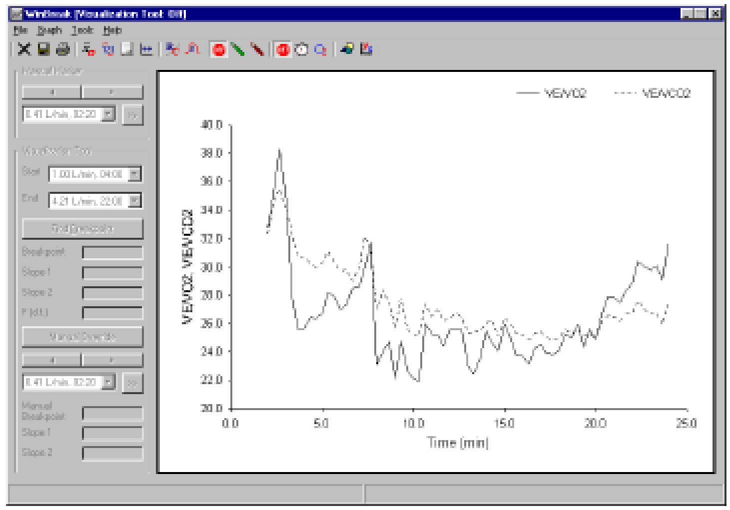
According to the description offered by Reinhard et al. (1979), "during an incremental exercise test, the ventilation equivalent for oxygen (V_E/VO_2) and the ventilation equivalent for carbon dioxide (V_E/VCO_2) show the following characteristics: V_E/VO_2 decreases already during the '0-watt' period beyond resting levels. V_E/VO_2 continues to decrease during the following work increments, has a minimum value at about one third of the maximum exercise capacity, and then increases continuously until exhaustion. The maximum value during exercise is in the range of the resting values. When V_E/VO_2 has reached its minimum during exertion, the V_E/VCO_2 continues to decrease and reaches its minimum at approximately two thirds of the maximum exercise capacity. The maximum of V_E/VCO_2 is markedly below the resting level" (p. 37). According to Reinhard et al. (1979), "the work load level with a minimum of V_E/VO_2 represents the [gas exchange threshold]" (p. 38). According to Davis et al. (1979), however, the gas exchange threshold corresponds to "the time at which V_E/VO_2 exhibits a systematic increase without a concomitant increase in V_E/VCO_2. In some, perhaps most cases, the two criteria might coincide, whereas in other cases they might differ somewhat. *WinBreak* uses the criterion proposed by Davis et al. (1979), namely a breakpoint in V_E/VO_2.



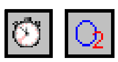
To display the ventilatory equivalent graph window, click on "Show V_E/VO_2, V_E/VCO_2 Graph" from the "Graphs" menu (or click the button on the taskbar). This will open the window shown in **Figure C.11**. The default graph format presented by *WinBreak* consists of plotting both the V_E/VO_2 and the V_E/VCO_2 data as a function of time, using both symbols and lines. Using the options in the "Graph" menu, you can change the appearance of the graph to fit your taste. This may be necessary in order to decipher the behavior of your data, particularly if you choose to visualize the data as a function of VO_2 rather than time. In this case, it may be easier to examine the two data series separately, using just symbols. It may also be useful to average and filter your data (e.g., in 15-sec or 20-sec segments) in order to obtain a more clear picture.

In the graph of the ventilatory equivalents, the Visualization Tool can work both with the data plotted as a

Figure C.11. The ventilatory equivalent graph window.

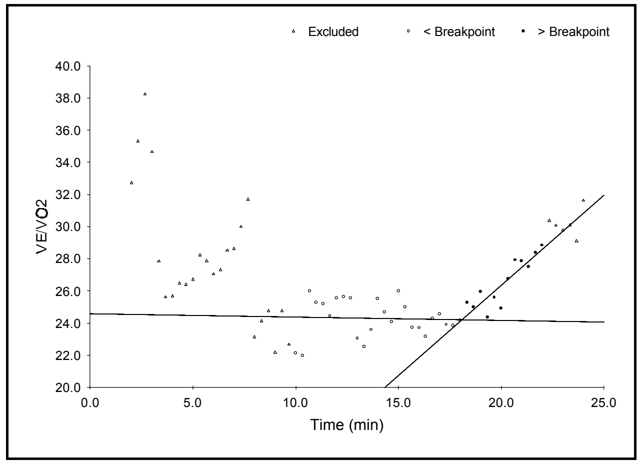


function of time and as a function of VO_2. You can activate the "Visualization Tool" by selecting among "V_E/VO_2 as a Function of Time" or "V_E/VO_2 as a Function of VO_2" under the "Visualization Tool" submenu of the "Tools" menu. The same can be accomplished by clicking on the respective icons on the taskbar (the timer icon sets the Visualization tool to "by Time" mode, whereas the "O_2" icon sets it to "by VO_2" mode). In the ventilatory equivalents module, the Visualization Tool uses the Jones and Molitoris (1984) algorithm.



Once the Visualization Tool has been activated, the options in the frame marked "Visualization Tool" on the left side of the window also become active. Use the "Start" and "End" drop-down menus to set the lower and upper boundaries for the calculations to determine the occurrence of a breakpoint in V_E/VO_2. It is especially important to set the "Start" time at the end of the decreasing trend in V_E/VO_2 described by Reinhard (1979). As noted in the description of the typical V_E/VO_2 behavior, this index shows an initial decreasing phase, followed by a stabilization "at about one third of the maximum exercise capacity" (p. 37) and, some time thereafter, by a continuous increase "until exhaustion" (p. 37). It is the change from the stable phase to the increasing phase that is considered indicative of the gas exchange threshold. Therefore, the time that includes the first breakpoint, namely that from the decreasing phase to the stable phase, must be removed before the Jones and Molitoris (1984) algorithm is applied (see **Figure C.12** for an example). Otherwise, if the change from the initial decrease to stability is more pronounced or abrupt compared to the change from stability to the final increase, the algorithm will place the breakpoint at the first change, which is not indicative of the gas exchange threshold. The output of the Jones and Molitoris (1984) algorithm includes the intercept, slope, and RSS of a single line, the RSS of each iteration in the search for x_0, the value of x_0 that minimizes the RSS, the intercepts and slopes of the two lines

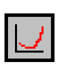
Figure C.12. An example of using the Visualization Tool in the ventilatory equivalents module. Notice that the data points in the initial decreasing phase have been excluded from the analysis by setting the "Start" time at the 10th minute.



intersecting at x_0, the normalized residuals (i.e., the deviations of the observations from the fitted joined lines divided by their standard deviation), and an F value for the test of improvement over a single line. The complete output is available through the "Detailed Reports" module (see relevant section below). Also, the fit of the model can be inspected visually and compared to the fit of the single-line model through the plots of the residuals (see relevant section below).

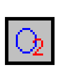
C.10 THE METHOD OF EXCESS CARBON DIOXIDE

The third method for detecting the gas exchange threshold offered by *WinBreak* is the method of Excess CO_2. The literature contains several variants of this method. According to Anderson and Rhodes (1989), for example, Excess CO_2 is calculated as VCO_2 minus the product of the respiratory quotient at rest and VO_2. In *WinBreak*, the operationalization of Excess CO_2 follows that proposed by Gaskill et al. (2001). According to their definition, Excess CO_2 = $(VCO_2^2 / VO_2) - VCO_2$. When Excess CO_2 is plotted over time or over O_2 utilization, the gas exchange threshold is thought to occur at the level of exercise intensity corresponding to an increase in Excess CO_2 from steady state.



To display the Excess CO_2 graph window, click on "Show Excess CO_2 Graph" from the "Graphs" menu in the main *WinBreak* window (or click the button on the taskbar). This will open the window shown in **Figure C.13**. The default graph presented by *WinBreak* consists of plotting the Excess CO_2 data as a function of time, using both symbols and lines. Using the options in the "Graph" menu, you can change the appearance of the graph to fit your taste.

In the Excess CO_2 graph, the Visualization Tool can work both with the data plotted as a function of time and as a function of VO_2. You can activate the "Visualization Tool" by selecting among "Excess CO_2 as a Function of Time" or "Excess CO_2 as a Function of VO_2" under the "Visualization Tool" submenu of the "Tools" menu. The same can be accomplished by clicking on the respective icons on the taskbar (the timer icon sets the

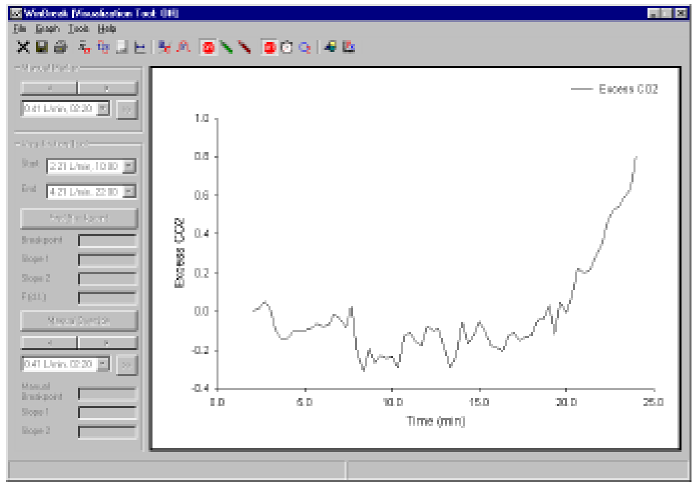
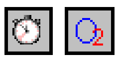


Figure C.13. The Excess CO_2 graph window.



Visualization tool to "by Time" mode, whereas the "O_2" icon sets it to "by VO_2" mode). In the Excess CO_2 module, the Visualization Tool uses the Jones and Molitoris (1984) algorithm.

Once the Visualization Tool has been activated, the options in the frame marked "Visualization Tool" on the left side of the window also become active. Use the "Start" and "End" drop-down menus to set the lower and upper boundaries for the calculations to determine the occurrence of a breakpoint in Excess CO_2. An example of using the Visualization Tool in the Excess CO_2 module is shown in **Figure C.14**. The output of the Jones and Molitoris (1984) algorithm includes the intercept, slope, and RSS of a single line, the RSS of each iteration in the search for x_0, the value of x_0 that minimizes the RSS, the intercepts and slopes of the two lines intersecting at x_0, the normalized residuals (i.e., the deviations of the data from the fitted joined lines divided by their standard deviation), and an F value for the test of improvement over a single line. The complete output is available through the "Detailed Reports" module (see relevant section below). Also, the fit of the model can be compared to the fit of the single-line model through the plots of the residuals (see relevant section below).

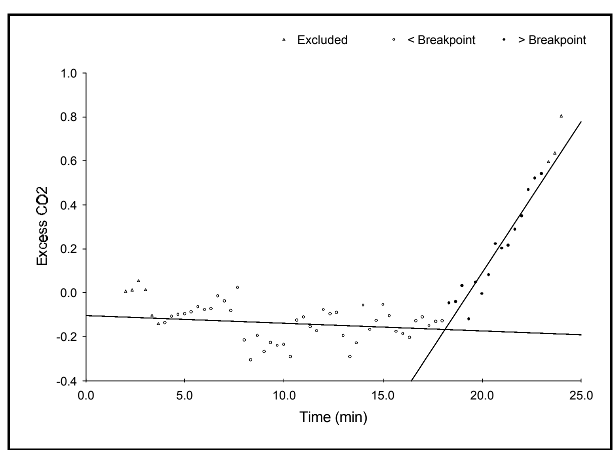


Figure C.14. An example of using the Visualization Tool in the Excess CO_2 module.

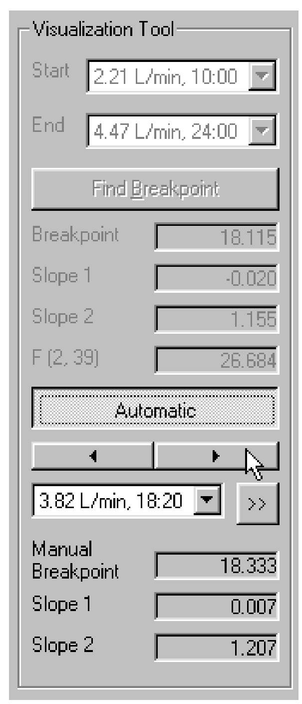
C.11 THE VISUALIZATION TOOL

The "Visualization Tool" is a collection of uniform visualization and data analysis options in all three graph modules within *WinBreak* (see **Figure C.15**). With the Visualization Tool, you can ask *WinBreak* to automatically identify a breakpoint in the data (within time limits that you set), plot two regression lines through the data (for data before and after the breakpoint), and manually shift the breakpoint lower or higher while observing the changes in the graph.

To activate the "Visualization Tool" in any of the three graph modules, go to the "Visualization Tool" submenu under the "Tools" menu. In the VCO_2 by VO_2 graph window, the only option is "VCO_2 as a function of VO_2". In the V_E/VO_2, V_E/VCO_2 window, the options are (a) "V_E/VO_2 as function of Time" and (b) "V_E/VO_2 as a function of VO_2". Likewise, in the Excess CO_2 graph window, the options are (a) "Excess CO_2 as a function of Time" and (b) "Excess CO_2 as a function of VO_2".

When you select the option that you want, the tools in the panel marked "Visualization Tool" are activated. First, you should use the "Start" and "End" drop-down menus to set a time frame within which to look for a breakpoint. This option is provided so that you can exclude parts of your data within which you know that it would be impossible for the gas exchange threshold to occur (e.g., in the first 1-2 minutes or after 95% VO_2peak). You can also use these options to exclude parts of your data that may contain a significant breakpoint other than the gas exchange threshold (e.g., the early phases of the V_E/VO_2 data). Once you set the start and end of your time frame, you can click on "Find Breakpoint" to ask *WinBreak* to locate the breakpoint in your data. For averaged data, this should happen almost

Figure C.15. The Visualization Tool panel. With the "Start" and "End" menus, users can set the lower and upper boundaries of the calculations for the determination of the gas exchange threshold. Clicking on "Find Breakpoint" performs the calculations. To override the automatically selected breakpoint, click on "Manual Override" and use the left and right arrow keys or the drop-down menu to shift the breakpoint to a new point and observe the changes. To return to the automatically selected breakpoint, click on "Automatic".



instantaneously. For breath-by-breath data, this process may take a few seconds.

When the computation is completed, *WinBreak* will update the graph, showing one series of data and one regression line before the breakpoint, one series of data and one regression line after the breakpoint, and a third series containing any excluded data (outside of the set time frame), (b) the breakpoint that was detected, (c) the value of the two slopes (before and after the breakpoint), and (d) the *F* value (and corresponding degrees of freedom) for the improvement of the two-regression model over the single-regression model (i.e., one straight line).

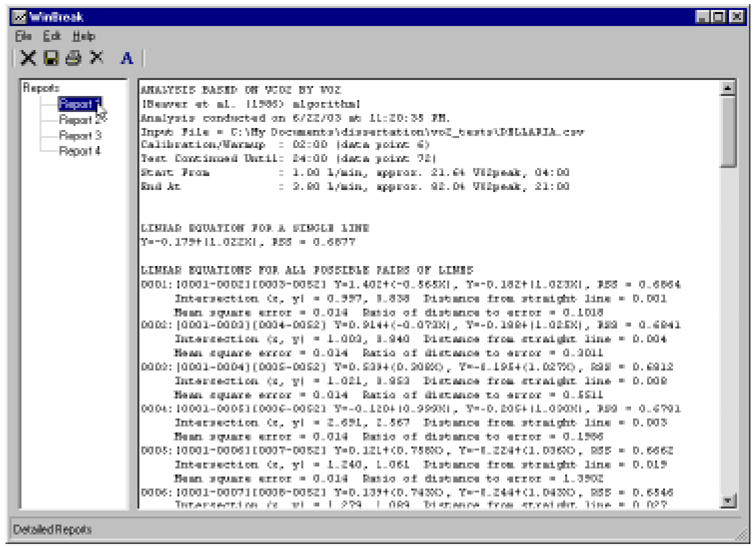
This also activates the button marked "Manual Override". This allows users to experiment with alternative solutions by manually shifting the breakpoint lower or higher. You can do so either by using the left and right arrow keys (for small shifts of a few points) or the drop-down menu containing all the data points within the time frame you specified and clicking the button marked ">>". For each new data point selected, *WinBreak* recalculates the values of the slopes before and after the new breakpoint and also re-plots the graph to let you visualize the effects of your selection. To reset the graph to the automatically estimated breakpoint, click on the button now marked "Automatic". Note that you can always select a new time frame and ask for a new estimation of a breakpoint. Furthermore, you can switch from a graph of the data over time to a graph over VO_2 by selecting the appropriate option from the "Visualization Tool" menu (under "Tools"). Finally, you can turn the "Visualization Tool" off and return to the previous view of your data by selecting "Visualization Tool Off" from the same menu or by clicking the "Off" button on the taskbar).

C.12 DETAILED CALCULATION REPORTS

For each automatic calculation of a breakpoint, *WinBreak* produces the full output of the algorithm that was used. This information can be examined by selecting "Show Detailed Report" from the "Tools" menu of the main *WinBreak* window as well as each of the three graph windows (or by clicking the button on the taskbar). This will open the window shown in **Figure C.16**. Each set of results is numbered sequentially in each session and can be seen by selecting the corresponding report number from the list shown on the left side of the window.

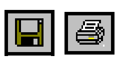
Each report includes (a) the type of analysis (i.e., the graph module that was used and the algorithm that was selected), (b) the date and time of the analysis, (c) the calibration / warm-up and test termination times, (d) the "Start" and "End" times of the set time frame, (e) the parameters (intercept, slope) of fitting a single straight line through the data, (f) the residual sum of squares for each step in the iterative process to identify the breakpoint, (g) the estimated intercepts and slopes of the two lines (i.e., before and after the breakpoint),

Figure C.16. The Retailed Report window.



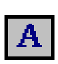
and (h) an *F* value for the improvement in fit over the single straight line, with its associated degrees of freedom. For more detailed descriptions of the output of each algorithm, see their descriptions in earlier sections.

You can save or print either one report at a time or all of them at once. If you want to save or print only one report, highlight the corresponding title from the list on the left side of the window and click on "Save Report As…" or "Print Report" from the "File" menu (or click on the diskette or printer icon from the toolbar), respectively. If you want to save or print all the reports at once, highlight the top heading ("Reports") from the list and then click on "Save Report As…" or "Print Report" from the "File" menu (or click on the diskette or printer icon from the toolbar), respectively. The reports are saved as ASCII files, with a .TXT default extension.



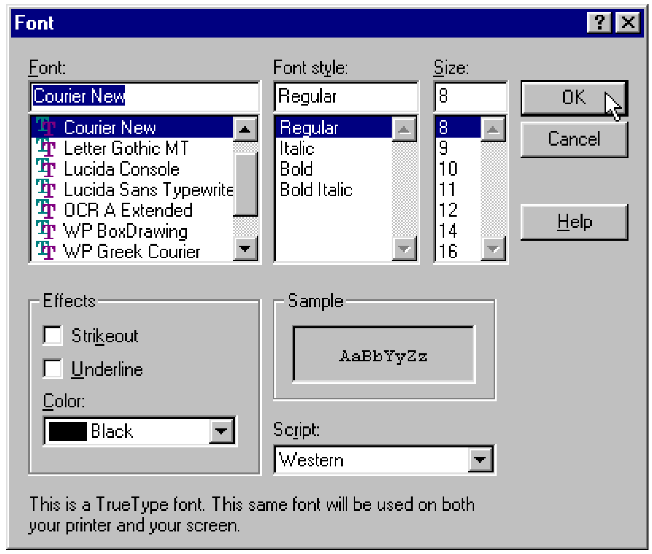
A similar procedure is used when you want to clear one of the reports or all of the reports. To clear just one report, highlight the title of the report from the list and then click "Clear Report" from the "File" menu (or the button marked "X" from the toolbar). If you want to clear all the reports at once, highlight the top heading ("Reports") and then click "Clear Report" from the "File" menu (or the button marked "X" from the toolbar).

Users can also select (highlight) parts of a report (or an entire report by clicking on "Select All" in the "Edit" menu), and click on "Copy" from the "Edit" menu, to copy the selection to the clipboard. This way, users can transfer all or parts of the data to another program.



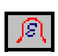
Finally, users can change the appearance of reports by selecting "Change Font" from the "Edit" menu (or clicking the "A" icon on the taskbar). This will open the dialog box shown in **Figure C.17**. Select the desired font name, style (italicized, boldfaced), size, and color, and press "OK". Please note that (a) only fixed-width fonts are shown and (b) the "strikeout" and

Figure C.17. To change the font of the detailed reports, select the desired font attributes and click OK. Only fixed-width fonts are shown.



"underlined" effects are not supported. *WinBreak* will remember all the attributes of the font that you select (i.e., font name, size, color, and whether the font is italicized or boldfaced).

C.13 PLOTS OF RESIDUALS



To obtain a quick graphical representation of the fit of the two-regression model compared to the single-regression model, click on "Show Plot of Residuals" from the "Tools" menu in each of the three *WinBreak* graph modules (or on the button on the taskbar). This will display a tabbed dialog box consisting of three tabs.

The *first* tab (**Figure C.18**, top) presents the residuals of the single-regression model across all the data points within the time frame that you selected. A good indication that a breakpoint is present is when there are large residuals in the second half of the plot, particularly if they have a consistent (increasing) pattern.

The *second* tab (**Figure C.18**, bottom) is accessible when a breakpoint has been identified through the Visualization Tool. In this case, the graph will display the residuals resulting from fitting the two-regression model to the data, with a breakpoint located at the position identified through the Visualization Tool (either automatically or manually). The fit to the data should be considered satisfactory if the residuals are more closely clustered around the zero line compared to the plot of the residuals from the single-regression model. You can flip back and forth between the first and second tabs to compare the fit of the two models.

The *third* tab contains the same information as the first two tabs, but in textual form. The data and residuals from the single-regression model are shown first and the those from each of the two regressions of the two-regression model (if a breakpoint has been determined in the Visualization Tool, either automatically or manually) are shown next.

When you click on the third tab, entitled "Detailed Report", the "Change Font" option in the "Report" menu, as well

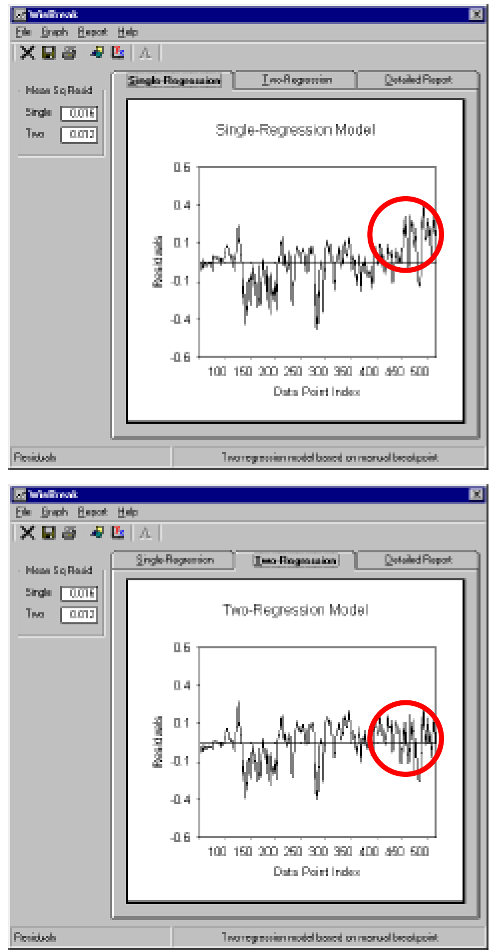


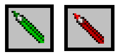
Figure C.18. The plots of the residuals for a single-regression model (top) and a two-regression model (bottom). Notice that the systematic increase in the size of the positive residuals seen with the single-regression model has disappeared in the two-regression model. The elimination of such systematic patterns in the residuals and the return to a random scatter around zero are signs of a satisfactory solution.

as the button on the taskbar marked "A", are activated. These allow you to change the font of the report. Clicking on these options will open a dialog box similar to that shown in **Figure C.17**. Select the desired font attributes and click "OK". *WinBreak* will remember your selections.

Note that you can select and "copy" all or part of the text of the detailed report to the clipboard and move this text to another program by "pasting" it. You can select part of the text by "dragging" the mouse over your selection (I.e., moving the mouse while holding the left button down) or you can select the whole text of the report by clicking on the "Select All" option in the "Report" menu. Then, either click on "Copy" from the "Report" menu or click the right mouse button while the mouse pointer is on the marked text and select "Copy" from the pop-up menu.

Finally, note that you can save and print either plot of residuals or the textual output by selecting the tab that interests you and clicking on either the "Save As" or "Print" options from the "File" menu or by clicking on the respective buttons on the taskbar. For more information on printing and saving graphs, see the relevant sections below.

C.14 AUTOMATIC AND MANUAL MARKERS



To enable users to cross-examine the results from the analyses performed in each of the three graph modules, *WinBreak* offers a "marker" feature. The markers are shown by selecting "Marker" from the "Tools" menu in each of the three graph modules in *WinBreak* or by clicking on one of the marker icons in the taskbar. You can activate and use the markers both when the Visualization Tool is on and when it is off. Even after you turn the Visualization Tool off, the markers will remain visible until you choose to hide them by selecting "Marker Off" from the "Marker" menu (under "Tools") or by clicking on the "Off" button on the taskbar. There are two types of markers, automatic and manual (see **Figure C.19**).

An *automatic* marker is a vertical line on the graph, positioned at the location of a breakpoint *automatically* determined from another graph module (i.e., in the VCO_2 by VO_2 graph window, you can choose to display an automatic marker positioned at the level corresponding to the breakpoint identified either in the V_E/VO_2 or the Excess CO_2 graph modules, and so on).

A *manual* marker is a similar vertical line that is positioned at the location of a breakpoint *manually* determined from another graph module. If no "manual" breakpoint was determined, then a manual marker is still displayed, but it is located at the same point as the automatic marker (i.e., the two markers will overlap). An additional feature of the manual markers is that they can be re-positioned by the user. This may be useful as an exploratory tool, since, each time that the manual marker is moved, the VO_2, % VO_2peak, and time of the new position are displayed in the left panel of the status bar.

To move the manual marker, you can use either the left and right arrow keys (for small shifts by a few data points) or the drop-down menu containing all the data points in the series and clicking the button marked ">>" (see **Figure C.20**).

Figure C.19. The automatic and manual markers displayed in the Excess CO_2 graph window.

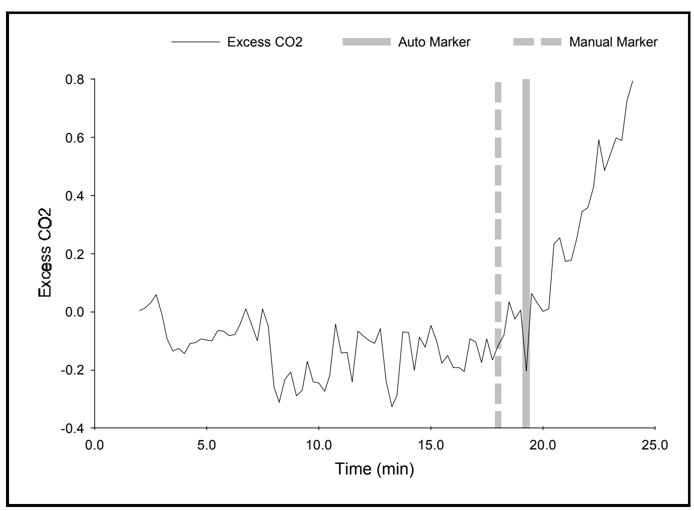
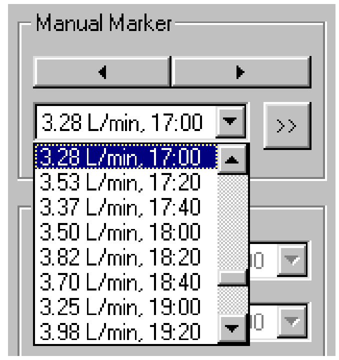
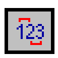


Figure C.20. You can use the left and right arrow keys, as well as the drop down menu containing all the points in the data set to re-position the manual marker. After selecting the desired data point from the menu, click on the button marked ">>".



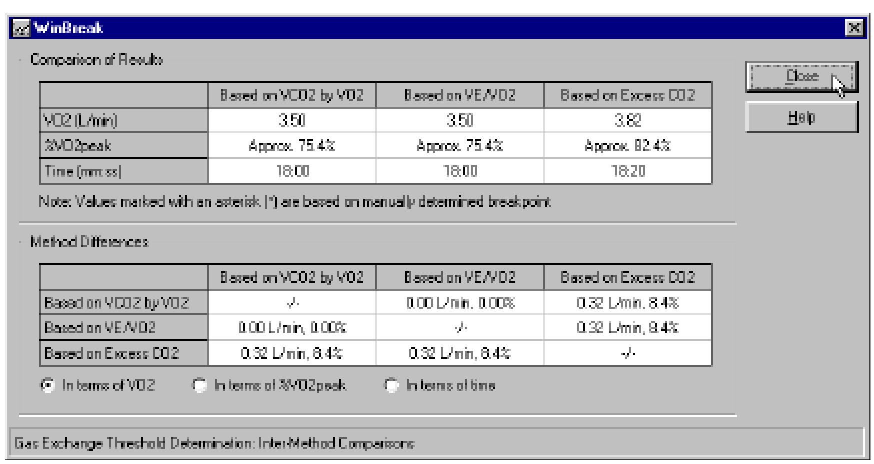
C.15 INTER-METHOD COMPARISONS



In some cases, the estimates of the gas exchange threshold from the V-slope, the ventilatory equivalents, and the Excess CO_2 methods will be identical or at least fairly close to each other. Perhaps in other cases, the estimates will differ substantially. Such cases clearly create a problem that must be resolved. For example, a resolution might be achieved by averaging or interpolating the data, by smoothing, or by selecting more appropriate lower and upper boundaries for the threshold calculations (e.g., specifying a different respiratory compensation point).

In addition to the ability to display markers on each graph indicating the location of threshold estimated by the other graphical methods, as explained in the previous section, *WinBreak* also offers a summary of inter-method comparisons. The window shown in **Figure C.21** is displayed by selecting "Inter-Method Comparisons" from the "Tools" menu in the main *WinBreak* window and each of the three graph windows. The top panel shows the estimates of the gas exchange threshold in terms of absolute VO_2, $\%VO_2$peak, and time. The bottom panel shows the differences between the estimates derived from the V-slope, the ventilatory equivalents, and the Excess CO_2 methods. The differences can be expressed in terms of absolute VO_2 (L/min and %), $\%VO_2$peak, and time. To switch between these different ways of displaying the differences, click on the respective radio buttons.

Figure C.21. The "Inter-Method Comparisons" window. The top panel shows the results from the three methods in terms of absolute VO2, % VO2peak, and time. The bottom panel shows the differences between the three methods.



C.16 CUSTOMIZING A GRAPH

To aid users in visually inspecting the data, *WinBreak* offers a complete array of graph formatting options in the "Graph" menu (see **Figure C.22** for an example). Some options, such as those under "Customize" (symbol styles, sizes, and colors, line styles, sizes, and colors, marker styles, sizes, and colors, axis and legend font styles, sizes, and colors, and labels), "Axis Scaling", and the "Show Legend" option appear in all three graph modules. Others are unique to each graph. Specifically, in the V_E/VO_2, V_E/VCO_2 and Excess CO_2 graph windows, users can select whether they want to display the data as a function of Time or as a function of VO_2. Also in the V_E/VO_2, V_E/VCO_2 graph, users can select whether to display just the V_E/VO_2 data, just the V_E/VCO_2 data, or both (both are shown by default). In both the V_E/VO_2, V_E/VCO_2 and Excess CO_2 graphs, users can select whether to plot the data using symbols, lines, or both (both symbols and lines are shown by default). Again, in both the V_E/VO_2, V_E/VCO_2 and Excess CO_2 graphs, users can select to show or hide the gridlines. Finally, in the VCO_2 by VO_2 graph, users can select to show or hide the line of identity (the line is shown by default). You may want to experiment with the various graph formatting options to better visualize your data, as well as to prepare a graph for saving and printing (see the respective sections below).

Clicking the "Customize" option (or the button on the taskbar) will display a tabbed dialog box (tabs are similar to "pages" that users can flip through), with each tab containing a different set of options. *WinBreak* will remember all the custom settings, separately for each of the three graph modules.

Each tab contains elements such as drop-down menus (for selecting different styles or sizes of lines and markers), text boxes (for changing the text of labels), or buttons linking to other dialog boxes (for changing colors and fonts). To change a color,

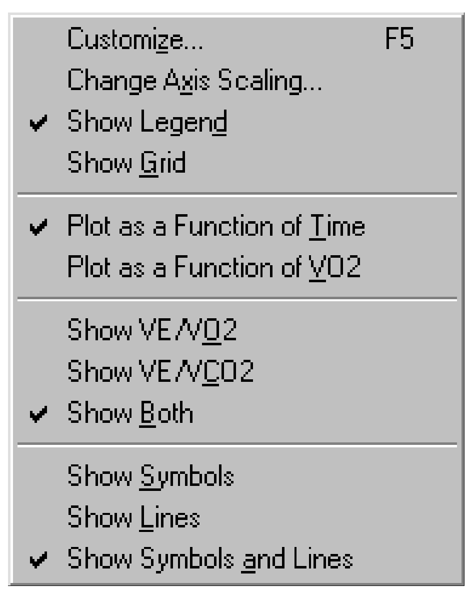


Figure C.22. An example of a "Graph" menu. The one shown here is from the ventilatory equivalents module. The options with the check marks are the default.

click on the button labeled "Change" next to the color swab. The dialog box shown in **Figure C.23** will appear. You can either choose one of the basic colors by clicking on it or click on "Define Custom Colors" to select among the colors supported by your video hardware. To change a font, click on the button labeled "Change" under the font sample. The dialog box shown in **Figure C.24** will appear. Users can select a new font name, style (italicized or boldfaced), size, and color. Note that the "strikeout" and "underline" effects are not supported.

The tab labeled "General" (see **Figure C.25**) contains settings pertaining to the data series displayed in the graph, the data axes, and the legend. Specifically, users can change (a) the style, size, and color of symbols, (b) the style, size, and color of lines, (c) the size, color, and font of the two axes, and (d) the font of the legend. Symbol and line styles and sizes can be changed by the drop-down menus. Symbol and line colors can be changed by clicking on "Change" and selecting among the available options from dialog boxes that will appear. Font

Figure C.23. To change the color of a graph element, select any of the basic colors or click on "Define Custom Colors" to select among all the colors supported by your video hardware.

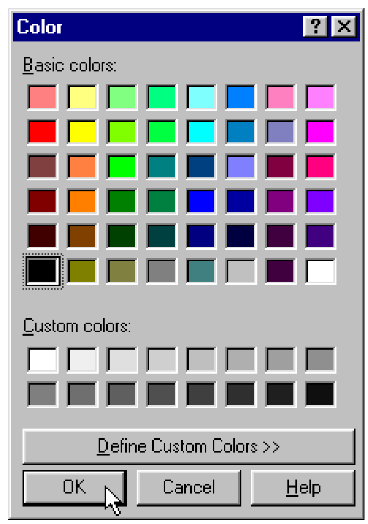
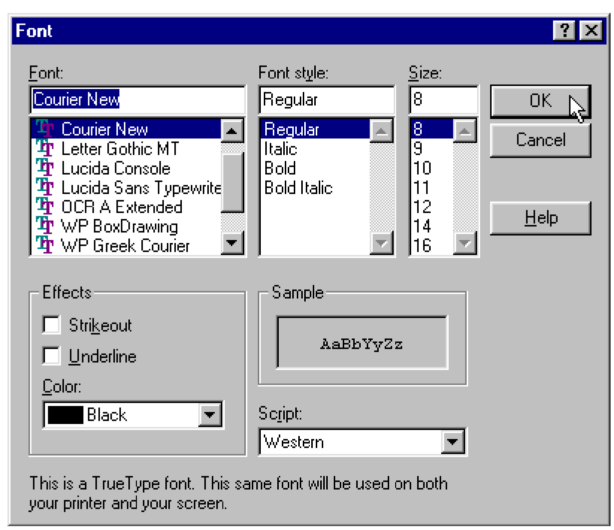


Figure C.24. To change the font of a graph label, select the font name, style, size, and color. Note that the "strikeout" and "underline" effects are not supported.



attributes, including font style, size, and color can be changed by clicking "Change" and selecting among the available options in the dialog box that will appear. The sample shown under "Font" will display the font that was selected.

The tab labeled "Visualization" (see **Figure C.26**) contains settings pertaining to the Visualization Tool. Specifically, when the Visualization Tool is used, the data set under analysis is divided in three parts, and each part can be displayed with different visual characteristics: (a) the excluded data points are those that occurred either before the "Start" setting or after the "End" setting, (b) the data points before the detected breakpoint, and (c) the data points after the detected breakpoint. For each of these three parts of the data set, users can select the style, size, and color of the symbols and the style, size, and color of the lines to be used. Symbol and line styles and sizes can be changed by the drop-down menus. Symbol and line colors can be changed by clicking on "Change" and selecting among the available options from dialog boxes that will appear.

The tab labeled "Markers" (see **Figure C.27**) contains settings pertaining to the markers (for a description of Markers, see the relevant section below). Specifically, users can set the style, size, and color of the automatic and manual markers. Line styles and sizes can be changed by the drop-down menus. Colors can be changed by clicking on "Change" and selecting among the available options from dialog boxes that will appear.

The tab labeled "Labels" (see **Figure C.28**) allows users to change the text of all axis labels in the graph, as well as the appearance of the labels by changing the font style, size, and color. Font attributes, including font style, size, and color can be changed by clicking "Change" and selecting among the available options in the dialog box that will appear. The sample shown under "Font" will display the font that was selected.

After the new settings have been selected, click "OK". This will update the appearance of the graph using the new

Figure C.25. The tab labeled "General" contains options for each data series, the data axes, and the legend.

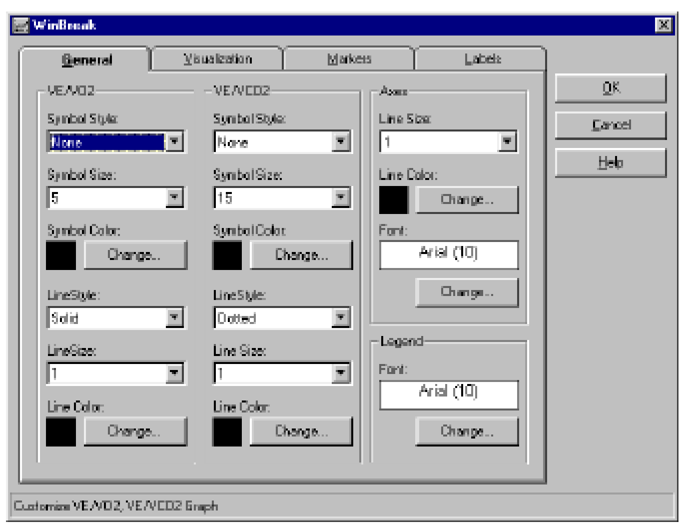


Figure C.26. The tab labeled "Visualization" contains options for the data points before and after the breakpoint, as well as the data points excluded from the analysis.

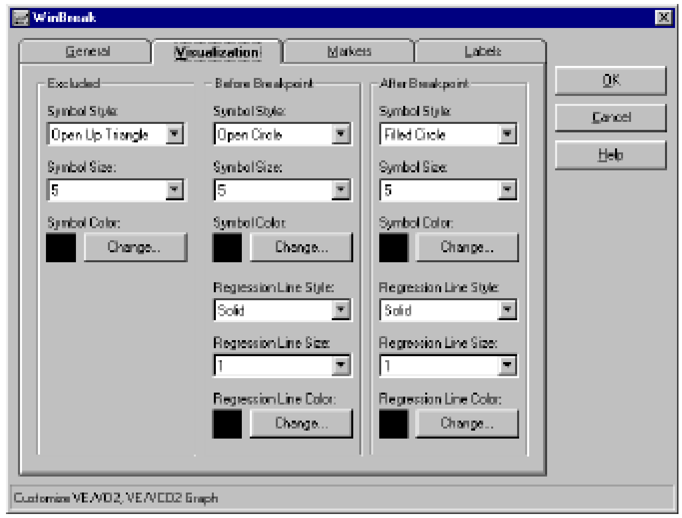


Figure C.27. The tab labeled "Markers" contains options for the automatic and manual markers.

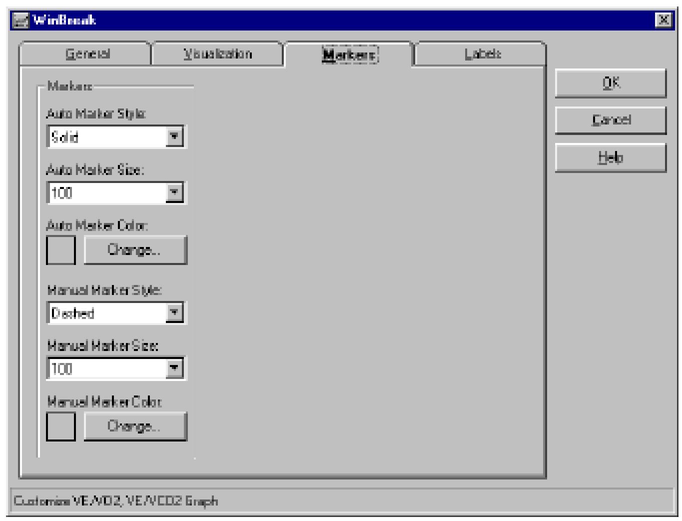
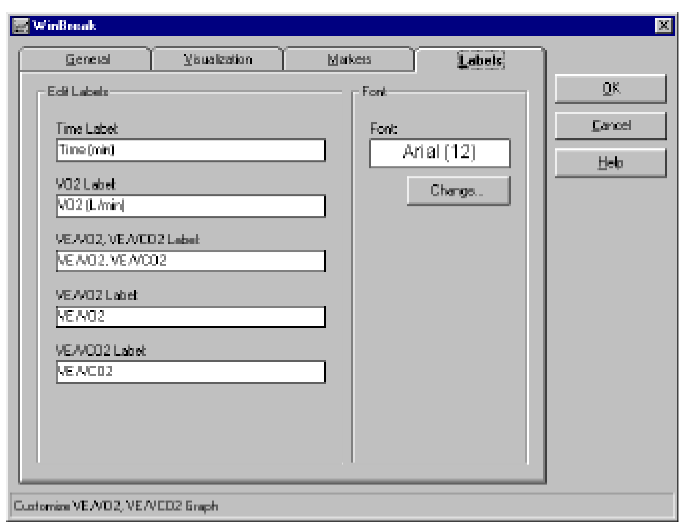
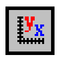


Figure C.28. The tab labeled "Labels" allows users to change the text of all the labels in a graph.



settings. Even if a certain graph element (e.g., markers) was not visible before you used the customization module, when you choose to make it visible, it will appear with the new settings you selected through the customization module.

C.17 RESCALING THE AXES OF A GRAPH



Initially, each graph will appear with what is considered an "optimal" scaling of the axes, as determined by a standard computer algorithm. However, this can be changed by clicking on the "Change Axis Scaling" option in the "Graph" menu (or on the button on the taskbar). This will display the dialog box shown in **Figure C.29**. You can use this dialog box to customize the axis scaling by changing the minimum value, the maximum value, and the number of divisions of both the horizontal and the vertical axis of the graph. After entering your choices, click "OK". If you wish to revert to the original values, click "Reset".

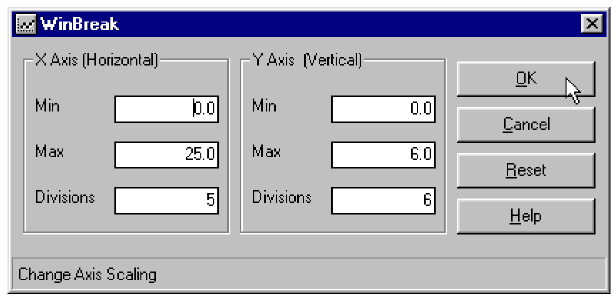


Figure C.29. The dialog box used to change the axis scaling settings.

C.18 SAVING A GRAPH

WinBreak allows users to save the graphs it produces. This is done by selecting "Save [Graph] As" from the file menu or clicking the diskette icon on the taskbar. This will open a standard dialog box asking for a file name under which to save the graph.

WinBreak can save graphs in two formats: (a) Windows Meta File (with .WMF as default file extension), which is the default option, and (b) Bitmap (with .BMP as the default file extension). Of these, the Windows Meta File format is preferable in most situations because it offers (a) excellent presentation quality (it is not a bitmap or a compressed format, so there is no loss of sharpness or detail), (b) excellent compatibility with popular word processors (e.g., Microsoft® Word® or Corel® WordPerfect®) and presentation software (e.g., Microsoft® Powerpoint®), and (c) much smaller file size compared to the Bitmap format. Although most programs can incorporate WMF and BMP graphics, in some cases, you may have to install the appropriate conversion filters (consult your program's manual and set-up routine for instructions).

From the "Save As" dialog box, choose "Windows Meta File" from the menu labeled "save as type" to save a graph in the Windows Meta File format. Choose "Bitmap File" from the same menu to save the graph in Bitmap format.

Note that, after you insert a WMF file into a Microsoft®

Powerpoint® presentation, you can double-click on the graphic and Powerpoint® will ask you whether you want to convert the file to native Powerpoint® format. If you choose to do so, you will then be able to alter the graphic in any way you wish (change the colors, thickness of lines, labels, etc).

C.19 PRINTING A GRAPH

Users can obtain hard copies of the graphs produced by *WinBreak* by clicking "Print [Graph]" from the "File" menu (or by clicking on the printer icon on the taskbar). In each of the three graph modules, in addition to the graph itself, *WinBreak* also prints out (a) the name of the data file on which the analysis was based, (b) the initial sampling rate, (c) the calibration/warm-up and test termination times, (d) the VO_2peak value, (e) if the markers are visible, the position (in terms of VO_2, percentage of peak, and time) of the automatic and manual markers, (f) if the visualization tool is active, the start and end of the selected time frame, the position of the automatically estimated breakpoint (in terms of VO_2, % VO_2peak, and time) with the value of the two slopes associated with it, and, if used, the manually set breakpoint (in terms of VO_2, % VO_2peak, and time) with the value of the two slopes associated with it. This provides a fairly complete overview of the data presented in the graph and, as such, a printout of this sort should prove valuable for record-keeping and future reevaluations of the data without the need for a complete reanalysis.

SECTION D. SUPPORT

D.1 GETTING CONTEXT-SENSITIVE HELP

WinBreak has an extensive, program-wide context-sensitive help system. Help can be obtained at any point by (a) hitting the function key "F1" (simplest way), (b) selecting "Show Help" from the "Help" menu of the topmost window, or (c) clicking on the "Help" button, if the topmost window is a dialog box. *WinBreak* will respond by displaying an illustrated help screen, explaining the operation that you are about to perform or the options that you have available.

Additionally, you can select "Show Help Contents" or "Search Help" from the "Help" menu in any window. The former option will display the dialog box shown in **Figure D.1**. This is essentially the table of contents of the online version of this user guide, organized by chapters and sections. You can double-click on any book icon to open the respective chapter or any question mark icon to open and read the respective section. The latter option allows you to search the entire contents of the help file by keywords. As you type your keyword, the help module will narrow the list of topics to those that contain the keyword. Then, double-clicking on the title of the topic that interests you will open the help window for that topic.

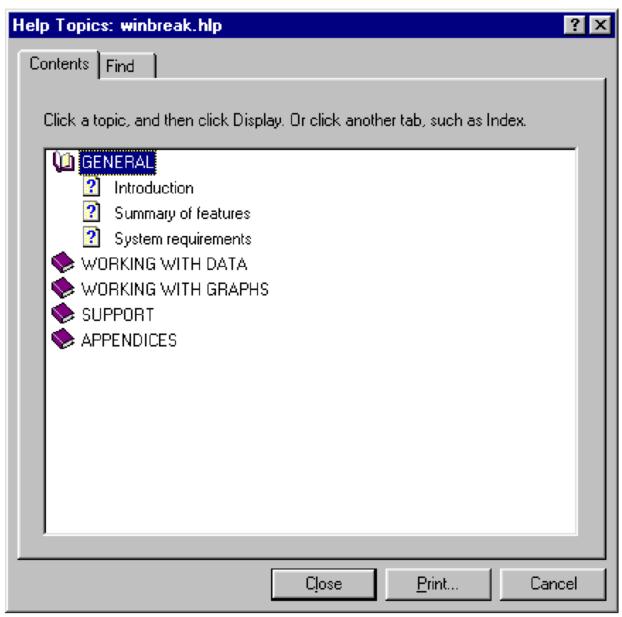


Figure D.1. The dialog box that displays the table of contents of the help file. It is accessible by clicking "Show Help Contents" from the "Help" menu. Double-clicking on a book icon will open the respective chapter. Double-clicking on a question-mark icon will open the respective section.

D.2 REGISTERING FOR E-MAIL SUPPORT

In addition to the automated context-sensitive help system, registered users of *WinBreak* are entitled to free support via e-mail. Questions, comments, reports of bugs, and requests for future enhancements may be submitted either via e-mail to the addresses:

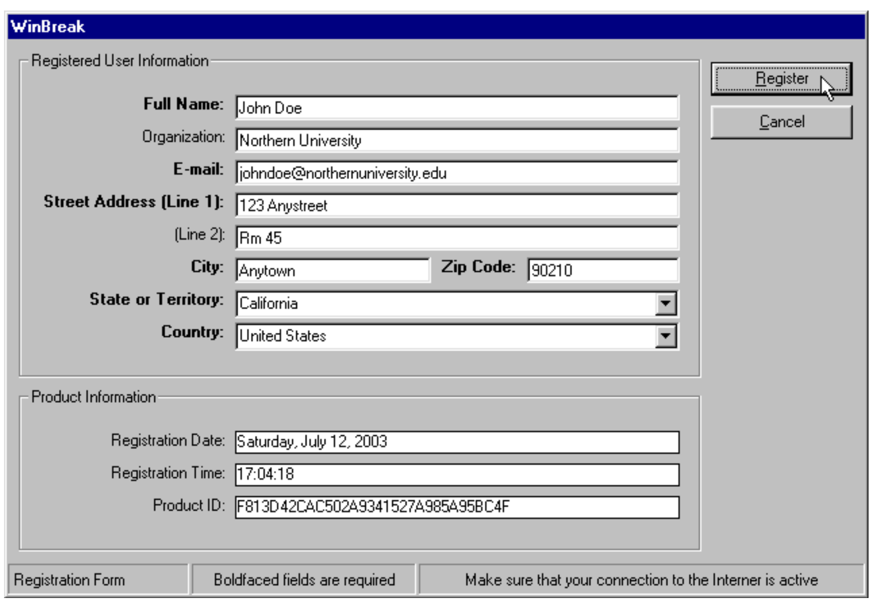
winbreak@epistemic.net or *support@epistemic.net* or by completing the online form at the "Support" section of our web site at

http://www.epistemic.net/

However, to obtain support, users must provide proof or registration by entering the "Product ID" of their installation of *WinBreak*. The product ID is displayed on the splash screen shown when *WinBreak* loads and by selecting "About" from the "Help" menu. For accuracy, you can select and copy the Product ID to the clipboard of your computer and then paste it into the e-mail that you send or the online form that you complete. This Product ID must be registered with *Epistemic Mindworks*, the software company that developed *WinBreak*. This is a way of limiting software piracy and ensuring that users who have purchased this software product legally receive the best support possible. Please note that the personal information that you enter into the registration form will *never* be made public or shared with other companies.

To register your copy of *WinBreak*, select "Register for Support" from the "Help" menu of the main *WinBreak* window. This will open the dialog box shown in **Figure D.2**. The required fields are boldfaced. After entering your information, make sure that your computer is connected to the Internet and the connection is active. Then, press "Register". *WinBreak* will establish a connection with the registration server at *Epistemic Mindworks*, enter the information into the support database, and inform you that your registration is complete.

Figure D.2. To receive e-mail support, users must register their copy of *WinBreak*. The registration form is accessible by clicking "Register for Support" from the "Help" menu of the main *WinBreak* window. Complete your information, make sure that your connection to the Internet is active, and click "Register".



Please note that, because the Product ID is tied to certain aspects of the configuration of your computer at the time of registration, it is possible that certain major hardware and/or software changes to your computer may result in the inability to recognize the registration as valid. In this case, please contact *Epistemic Mindworks* at the e-mail addresses provided earlier and explain the problem. You can also contact *Epistemic Mindworks* via postal mail at the address below:

Epistemic Mindworks
235 Sinclair Avenue, Suite 211
Ames, IA 50014
United States of America

E-mail: winbreak@epistemic.net
Web: http://www.epistemic.net/

When reporting a bug, please provide adequate information that would allow the replication of the problem, as well as any error messages you received. If possible, send the data set and/or configuration file that created the problem as e-mail attachments. Minor updates that resolve bugs identified by users will be provided periodically.

Finally, please note that the unauthorized duplication and distribution of the *WinBreak* software program and this user guide and all content included herein are strictly prohibited. Violations will be prosecuted to the maximum extent possible under the provisions of the laws of the United States of America and international treaties for the protection of copyright.

D.3 CHECKING FOR UPDATES

To check whether a newer version of *WinBreak* has been released, select "Check for Updates" from the "Help" menu of the main *WinBreak* window. This will open the dialog box shown in **Figure D.3**. After making sure that your connection to the Internet is active, click on "OK". *WinBreak* will connect to the *Epistemic Mindworks* server, check the latest version, and inform you of whether an update is available.

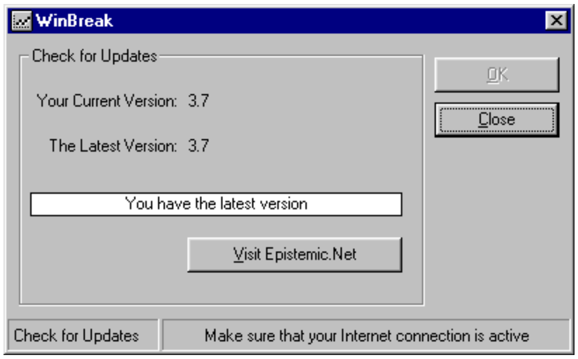


Figure D.3. To check if newer versions of *WinBreak* have been released, select "Check for Updates" from the "Help" menu of the main *WinBreak* window. Make sure that your connection to the Internet is active, and click "OK".

SECTION E. APPENDICES

APPENDIX 1. Taskbars

APPENDIX 2. A typical analysis scenario

APPENDIX 3. Bibliography

E.1 TASKBARS

WinBreak uses three taskbars, one in the main window (see **Figure E.1**), one in each of the three graph modules (see **Figure E.2**), and one in the Detailed Reports module (see **Figure E.3**).

Figure E.1. The taskbar of the main *WinBreak* window.

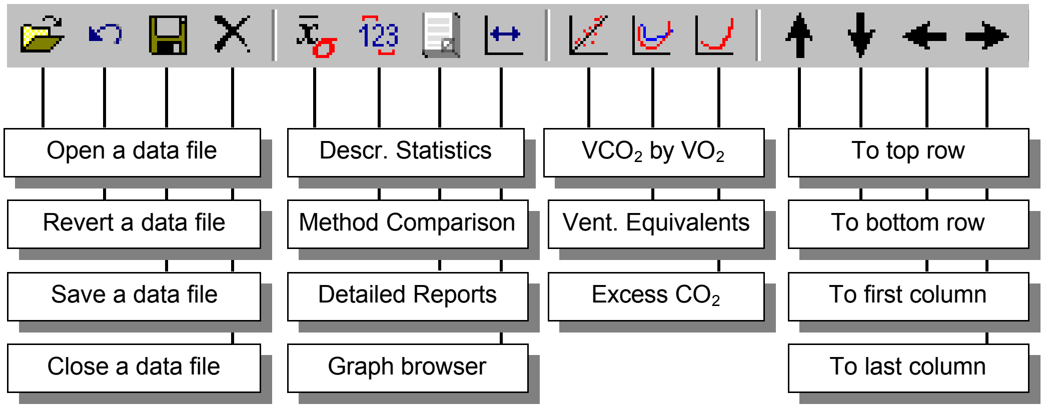


Figure E.2. The taskbar of the graph modules.

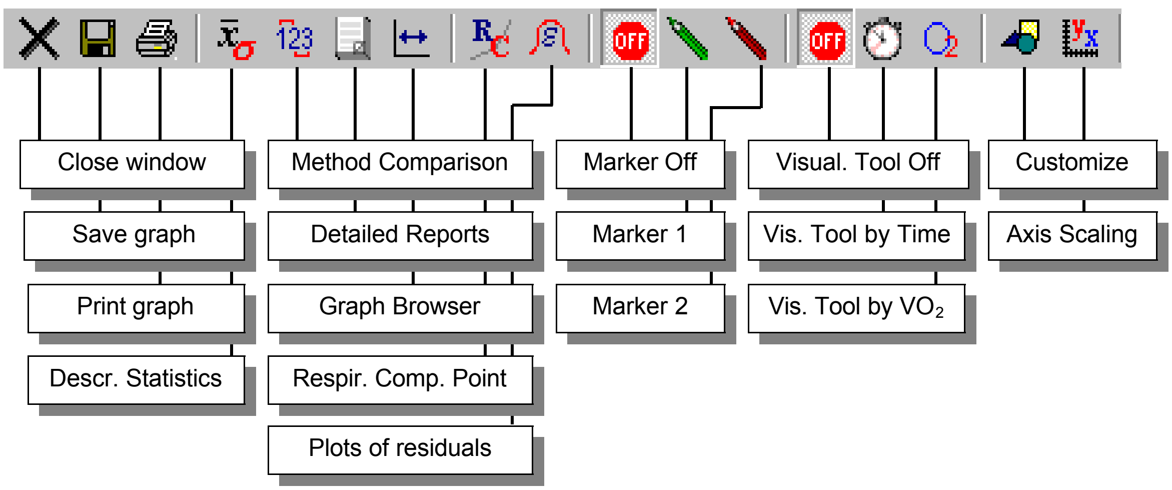
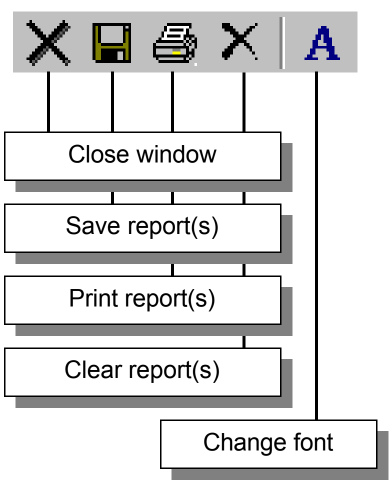


Figure E.3. The taskbar of the "Detailed Reports" window.



E.2 A TYPICAL ANALYSIS SCENARIO

[1] First, make sure that the settings (e.g., how many columns there are in your data set, what the labels for each variable are, etc) are correct. You can either edit the settings to match the format of your data set or load a different configuration file, with different settings. This is useful if you have multiple metabolic analysis systems or use multiple metabolic analysis software packages that export data in different ways.

[2] Before you open a data file, use the control panel next to the spreadsheet (marked "Sampled/Averaged Every") to specify the averaging period that was used to generate the file to be opened. If the data were collected on a breath-by-breath basis, set this value to zero. *WinBreak* will "remember" whatever value you select, so you will not have to repeat this step if the next file you analyze was generated the same way.

[3] Open a data file. *WinBreak* will "remember" both the file extension of the file you opened and the location of the file.

[4] Once your data are loaded, they will appear on the spreadsheet. At this point, you can take a look at the descriptive statistics and, if needed, use *WinBreak*'s Outlier Removal module to quickly remove rows of data that contain aberrant values (a frequent occurrence due to equipment malfunction, shifts of the face mask, etc). If the data in the data set were collected on a breath-by-breath basis, you may also choose to either average or interpolate the data.

[5] Next, you must again use the control panel next to the spreadsheet to set the "Calibration / Warm-up" and "Test Continued Until" times. This will instruct *WinBreak* to ignore any data recorded before the beginning or after the end of the actual exercise test. *WinBreak* will again remember these values, so you will be able to skip this step if these values are the same for subsequent files. Note that you can quickly move around the spreadsheet by clicking on the 4 arrows in the taskbar. These will take you to the top or bottom data row and to the first or last data column. Once you specify these two values, click on "Set". This will activate several *WinBreak* features, including the data smoothing options and all the graphing modules.

[6] You can now take a quick look at your data by using *WinBreak*'s Graph Browser module. You can quickly rotate through 17 different plots, including VO_2, VCO_2, V_E,

RER, V_E/VO_2, V_E/VCO_2, and Excess CO_2 as a function of Time and VO_2.

[7] You can start the search for the gas exchange threshold by opening the VCO_2 by VO_2 (or V-slope) module. Before you can use the Visualization Tool to ask *WinBreak* to identify the breakpoint for you, you must locate the Respiratory Compensation (RC) point, which will subsequently serve as the upper boundary in the analyses for the determination of the gas exchange threshold. To do this, click on the button marked "RC" on the taskbar. This will open a window containing a graph of V_E by VCO_2. Following Beaver et al.'s (1986) suggestion, you should decide on a percentage by which the slope of the regression line through the top part of the data is higher compared to the slope of the regression line through the bottom part. A value of 15% is a reasonable number suggested by Beaver et al. but *WinBreak* allows you to select any number you want. When you click on the button marked "Find RC Point", *WinBreak* will get to work, computing all possible pairs of regressions through the data. It will then search through all the results to find the first pair, for which the value of the second slope exceeded the value of the first by the percentage that you specified. It will also display the value and the position of the highest slope difference found. You are then free to select a different percentage and ask *WinBreak* to search again, or you may choose to locate the RC at any point you see fit. When you are satisfied with the results, click on "Transfer" and *WinBreak* will transfer the RC point to the Visualization Tool of the VCO_2 by VO_2 module (as well as any other module you subsequently open), to be used as the upper boundary in the analyses for the determination of the gas exchange threshold.

[8] You are now ready to use the Visualization Tool for the first time. Click on the button marked "O_2" on the taskbar. This will activate the Visualization Tool in "VCO_2 as a Function of VO_2" mode. This is the only mode available in the VCO_2 by VO_2 module, but, in the other two modules, you can use the Visualization Tool in either "as a Function of Time" or "as a Function of VO_2" mode. You can now also specify the lower boundary to be used in the analyses for the determination of the gas exchange threshold. Typically, this is set to 1 or 2 minutes after the beginning of the exercise test. *WinBreak* will again "remember" this value, so you will not have to set it again when you use the other modules. The next step is to choose an algorithm. It is important to read the *WinBreak* user guide, to develop an understanding of the logic

behind each of the 5 algorithms that *WinBreak* uses in the VCO_2 by VO_2 module (only one algorithm is offered in the other 2 modules). By default, *WinBreak* uses the Jones and Molitoris (1984) algorithm, but you may have reasons to use any one of the other options available. When you click on the button marked "Algorithm", the window that will appear will contain brief descriptions of the five algorithms, to assist you in making a decision. Of course, you can also experiment with more than one algorithm and, in fact, in most cases, it would be advisable to do so (this is one of the strengths of *WinBreak*; you do not have to rely on a single method of determination). With both the lower and upper boundaries set and an algorithm selected, click on "Find Breakpoint".

[9] *WinBreak* will perform the necessary calculations (exactly what it does and how long it will take to do it will vary, depending on the algorithm that you chose) and will display the results. It will show you the point at which a breakpoint was found (in terms of the absolute VO_2, the percentage of VO_2peak, and the time). Furthermore, to help you visualize the breakpoint, it will re-plot the VCO_2 by VO_2 graph, this time with a regression line through the data points below the breakpoint and another regression line above the breakpoint. You can also have the data points below and above the breakpoint appear with different markers, sizes, and colors.

[10] Every time you ask the Visualization Tool to identify a breakpoint, *WinBreak* records the complete computational details, so you can check the calculations, if you are so inclined. You can do this by clicking on the "notepad" button on the taskbar.

[11] An extremely helpful feature offered by *WinBreak* is the plot of residuals. You can access this by clicking on the button marked with the Greek letter "epsilon". This module has three tabs. On the first tab, you see the residuals resulting from fitting a single straight line through the data. On the second tab, you see the residuals resulting from fitting two lines through the data, separated at the breakpoint that you have identified (automatically or manually). On the third tab, you can see a complete listing of the calculations that resulted in the derivation of these residuals. What you want to see when examining the second tab is a completely random pattern, with the residuals equally divided above and below the "zero" line. If there is a clear, systematic departure from the "zero" line, this means that the solution was not a good fit to the data. This could mean that the breakpoint

was not located at the appropriate position or it could mean that there were multiple breakpoints in the data set; for example, in many cases what you have to do is shift the position of the Respiratory Compensation (RC) point.

[12] By clicking on "Manual Override", you can manually shift the breakpoint lower or higher or to any point in the data set you wish. *WinBreak* will re-draw the graph to let you visualize the effects of your selection. It will also compute the slopes that result from this change, as well as the new estimate of the absolute VO_2, the percentage of VO_2peak, and the time corresponding to the new breakpoint. By clicking on "Automatic", *WinBreak* will revert to the automatically determined breakpoint.

[13] If you wish, you can print or save the graph. If you choose to print the graph, the printout will contain all the essential information, including the lower and upper boundaries used in the calculations, the location of the breakpoint, etc. This is a good way to keep a permanent record of the analyses that you perform.

[14] You can now switch to one of the other 2 graphical methods for the determination of the gas exchange threshold, namely the method of the ventilatory equivalents or the Excess CO_2 method. Most of the tools are the same. You can activate the Visualization Tool, examine the Respiratory Compensation (RC) point, ask for a breakpoint, and look at the plots of residuals using the same procedures as in the VCO_2 by VO_2 module.

[15] *WinBreak* offers a "marker" feature, which enables users to compare the location of breakpoints identified from other modules. For example, in the Excess CO_2 module, you can "mark" the position of the breakpoint identified in the VCO_2 by VO_2 or in the ventilatory equivalents module. The "marker" is a vertical line, the thickness, pattern, and color of which you can specify. When you activate the "marker" feature, *WinBreak* actually displays two markers, one corresponding to the position of the automatically determined breakpoint and one corresponding to the position of a manually set breakpoint (if different). You can shift the position of the "manual" marker; *WinBreak* will show the absolute VO_2, the percentage of VO_2peak, and the time corresponding to the new position.

E.3
AN INCOMPLETE BIBLIOGRAPHY OF METHODOLOGICAL PAPERS ON THE DETERMINATION OF THE GAS EXCHANGE THRESHOLD

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