Manual to bRes\_sp

*Using the batch reservoir fitting program and estimating heart rate variability wave intensity and Pb/Pf with SphygmoCor files*

Alun Hughes

University College London

Manual Version 1.6

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| --- | --- | --- | --- |
| Version number | Date | Changes Made to Matlab Script and manual | Changes made by |
| 1.1 | 24/12/17 | Added information about program upgrade to v9 that includes HRV | ADH |
| 1.2 | 27/12/17 | Incorporated estimates of wave intensity, backward pressure (Pb) and forward pressure (Pf) from central pulse waveform and used sgolayfilt rather than fsg1521 or fsg721 | ADH |
| 1.21 | 22/10/18 | Minor updates to accompany a few bug fixes in v10 (now v11) | ADH |
| 1.3 | 17/03/19 | Improved reservoir algorithm to prevent upturn of pressure at end of diastole (early systole) affecting fit. Also improved HRV algorithm; adding data to excel output, fixing some other bugs in v11 (now v12) | ADH |
| 1.31 | 12/04/19 | Added progress bar (now v13), bug fix to figure output. | ADH |
| 1.4 | 11/01/20 | Restructuring of functions, minor bug fixes | ADH |
| 1.41 | 11/05/20 | More error traps, partially revised to start to use textscan rather than textread, improved peak detection for Wf2 | ADH |
| 1.5 | 23/06/20 | Updated derivative to use 9 frame 3rd order SG filter and renamed program to bRes\_sp. Manual updated to address name change and correct some outdated aspects and errors. | ADH |
| 1.6 | 25/03/21 | Fixed a couple of bugs with findpeaks component | ADH |

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# The script

bRes\_sp runs a Matlab© script that calculates reservoir and excess pressure essentially according to the methods described in Davies et al.1 for Sphygmocor©   
-derived files. A few minor changes have been made since the original description. These include an improved algorithm for fitting the reservoir in diastole – this excludes upstrokes at the end of diastole from the fit presumed to be due to the next cardiac cycle. This results in lower values for P∞ and slightly different values for other reservoir parameters from earlier versions of the software.

# Using the script

Put sphygmocor files to be analysed in the analysis directory

C:\Spdata

If required another folder can be used.

Open matlab and ensure that the working directory is the one that contains the relevant script and function files (in my case this is)

C:\Box Sync\Matlab\work\Reservoir\_batch

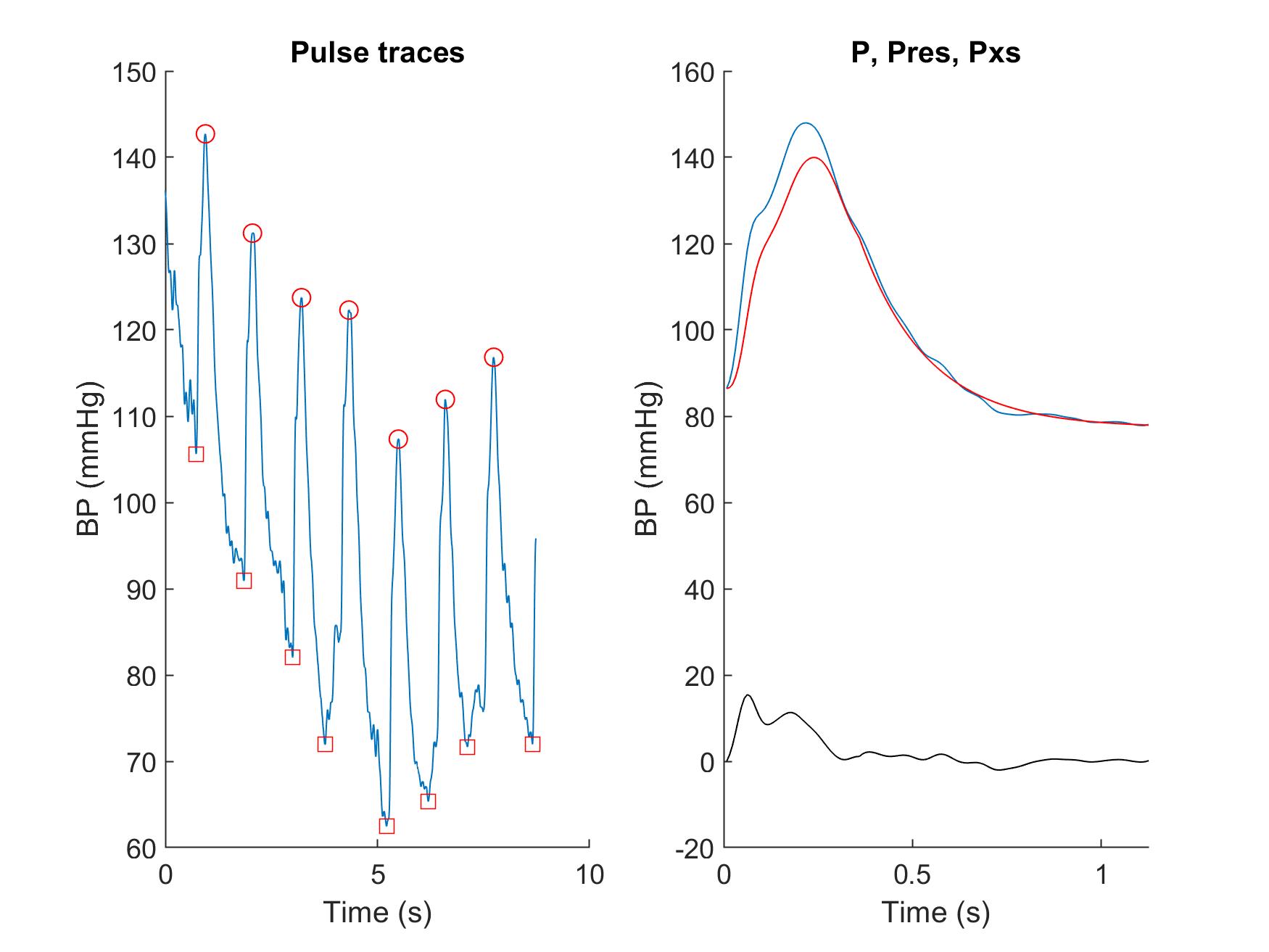
Type into command line:

>>bRes\_sp

After some time (depending on how many files are analysed) the run should complete, returning to command prompt. It will show a progress bar while it is running and inform you when has finished to tell you how many files were processed.

Two new folders should now exist in C:\Spdata - C:\Spdata\figures and C:\Spdata\results.

C:\Spdata\figures contains figures of the signal (all the uncalibrated data) and the pulse (the calibrated ensemble averaged data) with the reservoir pressure shown. These are saved as \*.jpg files. These plots are useful for checking quality and any dubious results (the example shown is not a particularly high quality trace).



*Example of the figure saved by bRes\_sp*

C:\Spdata\results will contain an excel file (resdata.xls) which will contain all the data for each file with its ID. This can then be imported into Stata (or some other stats program) for further analysis.

# Heart rate variability (HRV) and baroreceptor sensitivity measures

NB THESE MEASURES ARE EXPERIMENTAL FOR SPHYGMOCOR DATA

The root mean square of successive differences (RMSSD), the standard deviation of the pulse intervals (SDNN) and baroreflex sensitivity (BRS) are calculated essentially according to Sluyter et al.2[[1]](#footnote-1) The validity of such ultrashort recordings has been studied by Munoz et al.3 Further details on the meaning and interpretation of these measures can be found in Shaffer and Ginsberg.4 It is probably useful to normalise HRV (or adjust it statistically) to mean RR interval due to the correlation between HRV and resting heart rate.5 This can be done as a post-processing step in the statistical package used.

# Wave intensity

NB THESE MEASURES ARE EXPERIMENTAL FOR SPHYGMOCOR DATA

If it is assumed that excess pressure (*Pxs*) is proportional to aortic flow velocity (*U*) (essentially a 3-element Windkessel assumption – see above) then the pattern of aortic wave intensity (*dI*) can be estimated (being proportional to *dP* x *dPxs*). If one of aortic wave speed or *dU* is known then wave intensity can be estimated from the Waterhammer equation. If only pressure has been measured this problem cannot be solved without strong assumptions. In this case, it is assumed that peak aortic flow (*dU)* is 1m/s (based on data from 6) and doesn’t not vary with age, sex etc. While this is not true, it may prove an acceptable approximation, further details can be found in7.

# Backward and forward pressure

NB THESE MEASURES ARE EXPERIMENTAL FOR SPHYGMOCOR DATA

These are calculated based on the assumptions that in the aorta reservoir pressure is 2 x backward pressure (Pb);8 which may be valid if excess pressure is linearly proportional to aortic flow as has been reported in dogs,9 and total aortic flow equals aortic inflow. This approach probably shares similarities with the ARCSOLVER method,10 which uses a 3-element Windkessel assumption[[2]](#footnote-2) to reconstruct forward and backward pressures.

# Data dictionary

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Definition | Example result | Units |
| re\_file | File identifier | xxx\_pwa.txt | No units |
| re\_maxp | Maximum pressure (systolic pressure) | 120 | mmHg |
| re\_tmaxp | Time of maximum (systolic) pressure | 0.1484375 | s |
| re\_minp | Minimum pressure (diastolic pressure) | 76.55 | mmHg |
| re\_intpr | Integral of reservoir pressure | 112.3308474 | mmHg.s |
| re\_maxpr | Maximum reservoir pressure | 108.1486734 | mmHg |
| re\_tmaxpr | Time of maximum reservoir pressure | 0.265625 | s |
| re\_intprlessdias | Integral of reservoir pressure with diastolic pressure subtracted | 16.09752936 | mmHg.s |
| re\_maxprlessdias | Maximum of reservoir pressure with diastolic pressure subtracted | 31.64019694 | mmHg |
| re\_sam\_rate | Sampling rate | 128 | Hz |
| re\_intxsp | Integral excess pressure | 4.169230704 | mmHg.s |
| re\_maxxsp | Maximum excess pressure | 26.3460721 | mmHg |
| re\_tmaxxsp | Time of maximum excess pressure | 0.109375 | s |
| re\_tn | Time of maximum -dp/dt (nominal end of systole) | 0.283007813 | s |
| re\_pinf | Pinfinity | 70.70521706 | mmHg |
| re\_pn | Pressure at start of diastole | 110.95 | mmHg |
| re\_fita | Rate constant systolic fit | 10.45715136 | s-1 |
| re\_fitb | Rate constant diastolic fit | 1.912785514 | s-1 |
| re\_rsq | Coefficient of determination (r2) for fit | 0.992749217 | No units |
| re\_prob | Flag 1 for likely problem[[3]](#footnote-3) | 0 | No units |
| re\_version | kreservoir version (for version tracking | v13 | No units |
| re\_sdsbp\_mmhg | Standard deviation of SBP | 6.1 | mmHg |
| re\_rr\_interval | Pulse to pulse (RR) interval | 900 | Ms |
| re\_rmssd | Root mean square of differences in successive pulse (RR) intervals | 10 | Ms |
| re\_ssdn | Standard deviation of pulse intervals | 6 | Ms |
| re\_brs | Baroreflex sensitivity (BRS) by the sequence method | 22 | ms.mmHg-1 |
| re\_brs\_valid | Number of valid BRS measures | 8 | Count |
| re\_pb\_pf | Central Pb/Pf | 0.65 | No units |
| re\_ri | Central Reflection index | .4 | No units |
| re\_wf1i | Intensity of forward compression wave 1 (W1) |  | W/m2 |
| re\_wf1t | Time of peak of forward compression wave 1 (W1) |  | s |
| re\_wf1a | Area of forward compression wave 1 (W1) |  | J/m2 |
| re\_wfbi | Intensity of backward compression wave (Wb) |  | W/m2 |
| re\_wbt | Time of peak of backward compression wave (Wb) |  | s |
| re\_wba | Area of backward compression wave (Wb) |  | J/m2 |
| re\_wf2i | Intensity of forward compression wave 2 (W2) |  | W/m2 |
| re\_wf2t | Time of peak of forward compression wave 2 (W2) |  | s |
| re\_wf2a | Area of forward compression wave 2 (W2) |  | J/m2 |
| wri | Wave reflection index |  | No units |
| rhoc | Wave speed |  | m/s |

# References

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7. Hughes AD, Park C, Ramakrishnan A, Mayet J, Chaturvedi N, Parker KH. Feasibility of Estimation of Aortic Wave Intensity Using Non-invasive Pressure Recordings in the Absence of Flow Velocity in Man. *Front Physiol* 2020; **11**.

8. Westerhof N, Westerhof BE. The reservoir wave paradigm discussion. *J Hypertens* 2015; **33**(3): 458-60.

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10. Hametner B, Wassertheurer S, Kropf J, et al. Wave reflection quantification based on pressure waveforms alone--methods, comparison, and clinical covariates. *Comput Meth Prog Bio* 2013; **109**(3): 250-9.

1. since Sphygmocor data is cropped at the foot of the waveform, peak systole has been used as the fiducial point of the waveform to calculate beat to beat intervals. [↑](#footnote-ref-1)
2. the details of the procedure used by ARCSOLVER are not in the public domain [↑](#footnote-ref-2)
3. 0 = ok; 1 = Pinf > diastolic pressure; 2 = rate constant b < 0; 3 = time of maximum reservoir pressure > end of systole [↑](#footnote-ref-3)