Exploring Neural Data

Final Project

Exploratory Investigation of Cardiorespiratory System during Meditation

David Trowbridge, Dec 9, 2014

Abstract

Data analysis and programming skills learned in Brown University's, *Exploring Neural Data* course were applied to an informal investigation of heart and breathing rhythms during meditation. Eight subjects participated in the study. Electrocardiogram and respiration data were collected for meditative (counting or following the breath) and non-meditative (reading) conditions. Data were analyzed using spike-finding and waveform display algorithms adapted from Problem Set 1 and subsequent programming assignments from the *Exploring Neural Data* course. A Cardiorespiratory Viewer program with a graphical user interface was developed using the Python programming language. Results included the observation that breath rhythms are slower and deeper, with longer exhalations during specific meditation practices than during reading. While heart rates were independent of activity, breathing rates were much reduced during meditation compared to reading. Typically, the amplitude of the EKG R-wave during meditation grows steadily during each exhalation and falls during the following inhalation. Among inexperienced meditators, the change in amplitude is typically about 5% while among highly experienced meditators the change can be as high as 50% during a single inhalation.

Introduction

The author is a Zen practitioner who uses meditation techniques of counting exhalations or following his breath. Increasingly he has become attentive to his heartbeat as well as his breath during meditation and has developed a practice of consciously synchronizing his breathing rhythm with heartbeat. This sparked an interest in recording cardiorespiratory data during his own meditation sessions as well as examining those of friends and family members. Enrollment in the course, *Exploring Neural Data* came at an opportune time for learning a new programming language and applying it to the analysis of these data. Questions that motivated the investigation included:

- How shall we characterize the cardiorespiratory system during zazen meditation? How does functioning during meditation compare with non-meditative activities such as reading or other daily activities?
- Is synchronization between heart and breathing rhythms typical of meditation practice?
- Are there observable differences in cardiorespiratory functioning between novice and experienced practitioners of meditation?

Methods

Subjects and experimental procedure

Eight subjects (5 female, 3 male) ranging in age from 26-70 participated in the study. Estimated lifetime meditation experience ranged from 170 to 17,900 hours (the two most experienced subjects were monks at the Tahoma Zen Monastery in Freeland, Washington).

Each subject participated in three different 15-minute sessions: (1) Seated meditation while counting exhalations, (2) Seated meditation while following the breath but not counting, (3) Seated while reading a recent article in *The Atlantic* magazine.[1]

Data acquisition

EKG and respiration signals were recorded at 200 samples/second using a Vernier LabQuest[2] data recorder equipped with a 3-lead EKG sensor and a respiration belt monitor incorporating a gas pressure sensor. The LabQuest was connected to a laptop computer during the recording sessions. Data was saved using Logger Pro 3 software and exported as tab-delimited text files.

Analysis

A new GUI application, Cardiorespiratory Viewer was developed in IPython, using the Anaconda Spyder programming environment, with the Tkinter, numpy, scipy and matplotlib libraries. The application reads the data files generated by the LabQuest recorder and displays simultaneous plots of EKG voltage and breath pressure.

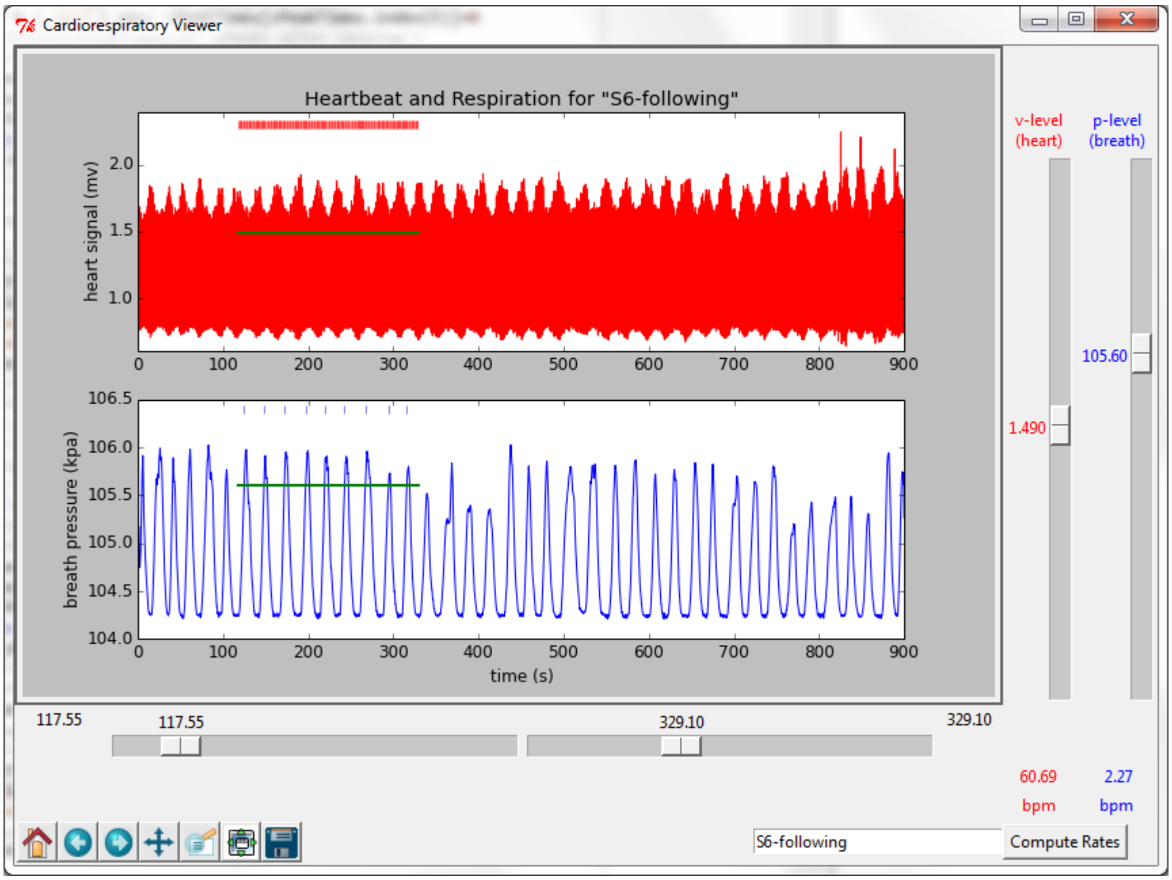

Figure 1 - Cardiorespiratory Viewer for Subject 6 during Meditation

The purpose of the Viewer is to assist in locating intervals of interest in the time series and setting threshold levels for counting spikes (R-wave peaks in the case of the EKG heart signal and inhalation maxima in the breath signal).

Vertical sliders on the right are used to set threshold levels (indicated by the green horizontal lines) for heart and respiration signals. The horizontal sliders below the graphs are used to adjust the left and right ends of the green line and to select a time interval of interest. Heart rate and breath rate are calculated when one clicks on the Compute Rates button. Pressing this button invokes a function to identify peaks of the heart (R spike voltage) and breath inhalation (gas pressure) signals and then computes rates for the indicated time interval.

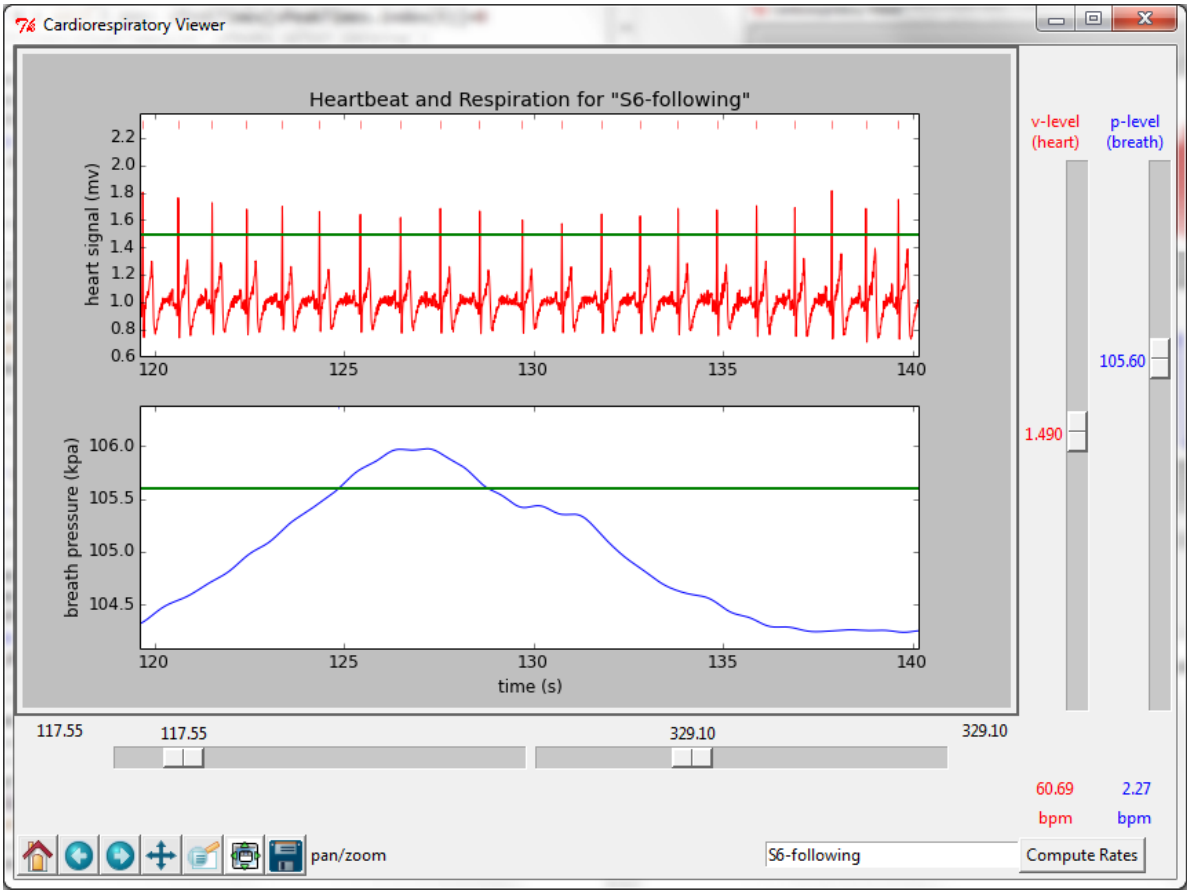

Figure 2 - Zoomed-in view of heartbeat and respiration graphs for Subject 6

The navigation panel in the lower left corner can be used to zoom in on a region of interest. The image above shows the result of zooming in to a 20-second segment of this 15-minute recording. Red tick marks indicate peaks found in the EKG of the upper plot and blue tick marks indicate peaks found in the respiration record in the lower plot. An FFT algorithm is used to filter out low frequency variations in the breath signal and smooth the curve.

Results

Breathing and heart rate during meditation

For all eight subjects, breath rate was significantly slower during meditation than during reading. Breath rate showed no apparent difference between the two meditation conditions: counting the breath vs. following the breath. Heart rate did not differ significantly among the two meditation conditions and non-meditative reading.

The synchronization of breath and heartbeat has not yet been analyzed in detail, but given that the Cardiorespiratory Viewer is now working, it should be relatively easy to start doing a quantitative analysis of synchronization. The first step is to understand the algorithms that have been published and settle on an operational definition of synchronization.

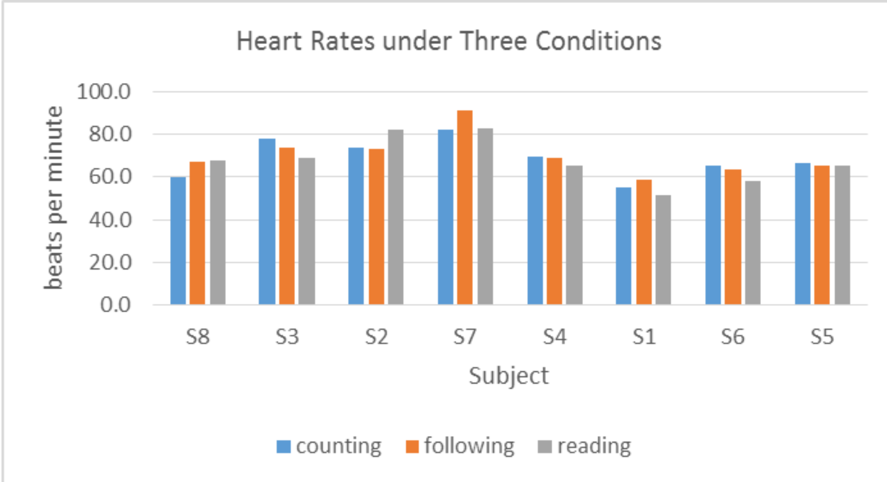

Figure 3 - Heart rate among eight subjects under three different condition. Rates were not significantly different during counting, following the breath or reading.

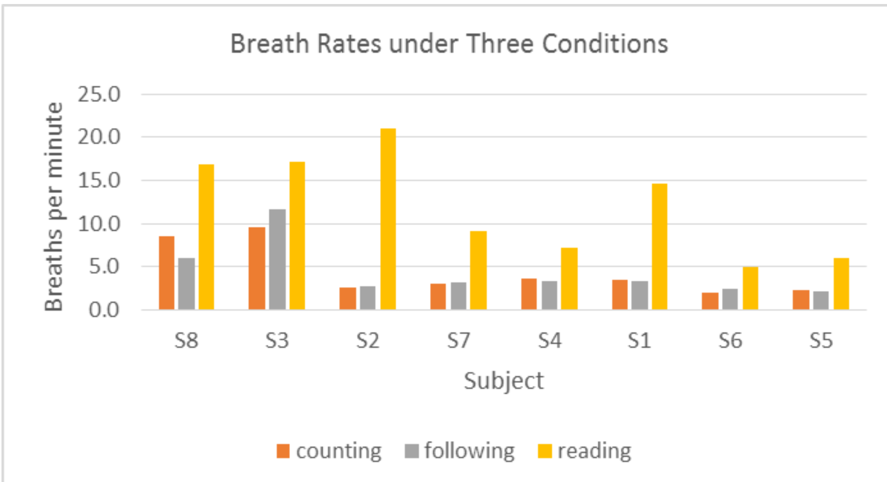

Figure 4 - Breathing rate among eight subjects under three different conditions. Rates during reading were typically double or greater compared to meditation.

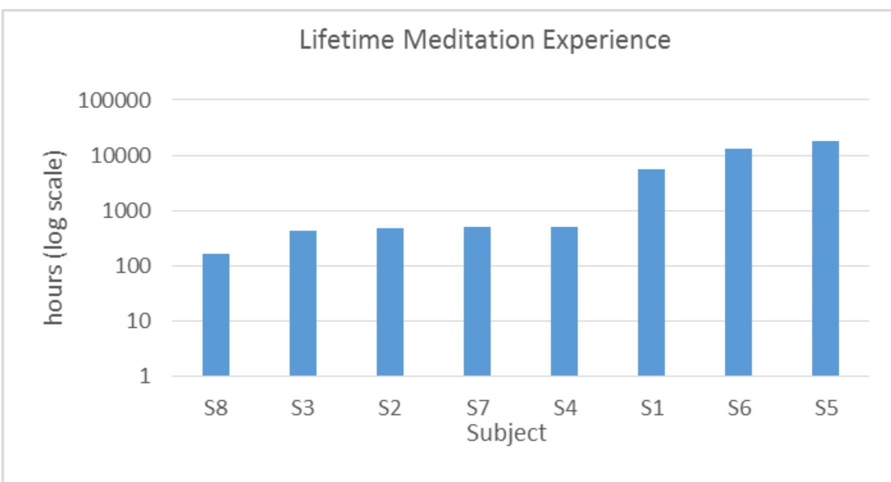

Figure 5 - Lifetime meditation experience of subjects. Vertical scale is logarithmic. Subjects S1, S6 and S5 each had over 5,000 hours of experience.

Heart amplitude increases during exhalation

One striking observation was that during meditation sessions the amplitude of the R-peak in the heart signal grows steadily during the exhalation, diminishes during inhalation and grows again during the next exhalation. The graphs below compare two subjects over roughly 100s intervals.

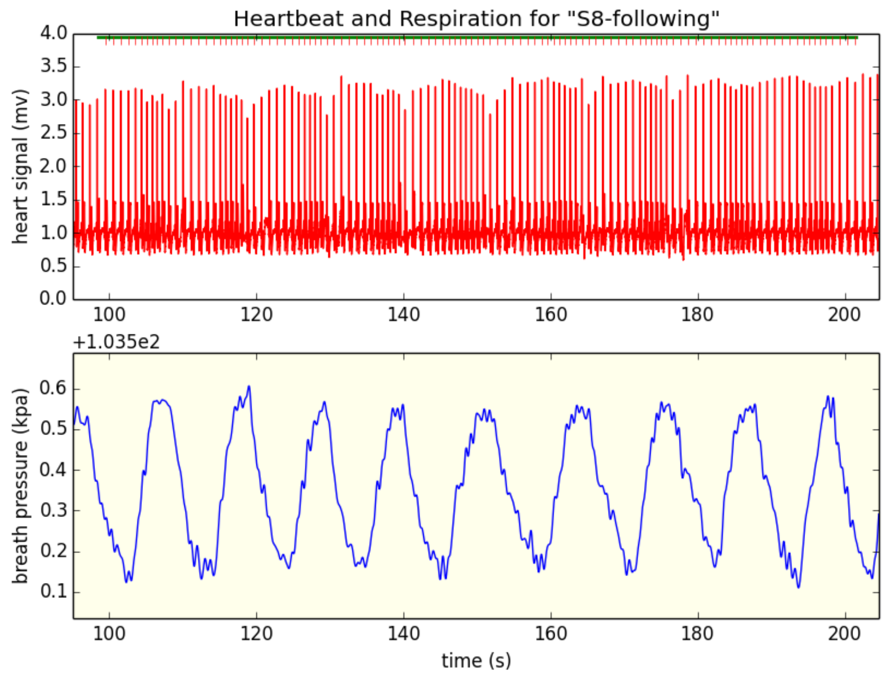

Figure 6 - Heartbeat and respiration for Subject 8, a relatively inexperienced meditator. Heart rate is 66.4 beats/min; breath rate is 5.8 breaths/min.

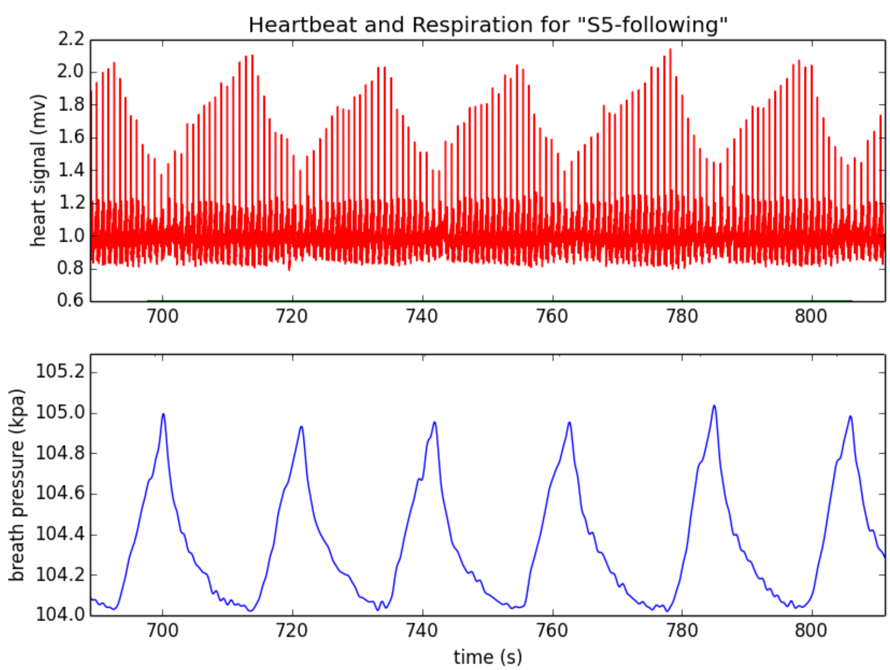

Figure 7 = Heartbeat and respiration for a highly trained meditator. Heart rate is 63.8 beats/min; breath rate is 2.8 breaths/min.

For novice meditators (fewer than 500 hours of meditation experience), this effect was small but observable (upper figure, above). For highly trained meditators (greater than 5000 hours of experience) the effect was quite pronounced (lower figure, above). After consulting with a cardiorespiratory expert (anesthesiologist), I have concluded that this dramatic change in R-wave magnitude reflects the deeper breathing of the trained meditator—as the intrathoracic cavity collapses during exhalation, the gap between the heart and the outer surface of the body (where the EKG signal is measured) shrinks, thereby reducing electrical resistance and resulting in an increased amplitude of the R-wave.

Discussion

Follow-up and new questions

The Cardiorespiratory Viewer application opens up a number of avenues of further investigation, such as examining heart rate variability and cardiorespiratory synchronization, for which there has been considerable research in recent years.[3] [4] [5] In addition, it should be possible to expand the research to include electroencephalography measures, especially given the availability of low-cost EEG recording devices such as those modeled in the *Exploring Neural Data* course.

Programming Trick

I faced many challenges developing the Cardiorespiratory Viewer: learning Python and becoming familiar with the vocabularies of matplotlib, numpy and Tkinter. Nevertheless, the experience was rewarding and I discovered helpful online communities: the Coursera forums, and stackoverflow.

One programming trick I learned is that to reverse the sort order of an array one must use a different strategy from reversing the order of a list [since there is no mylist.reverse() for arrays]. Instead, an array PeakTimes can be reversed using the statement, PeakTimes = PeakTimes[::-1].

Problems encountered

In Problem Set #1, my algorithm for finding action potential spikes was successful, but not efficient. My routine took ~12 seconds to complete for the test data, while the peak_finder function provided in the problem solution took only about 0.01 second. The trick I learned was to use construct a Boolean array icross using np.logical_and to find the threshold-crossing times and then set the array PTimes = time[icross]. This was an efficient way to reduce an array of over a hundred thousand items to an array of crossing times consisting of just a few hundred items.

Conclusion

The Exploring Neural Data course has been a great introduction to Python programming in the context of neuroscience data and opens up a host of new opportunities for investigation of breathing, EKG and EEG datasets. I look forward to continuing the investigation.

References

[1] "Why I Hope to Die at 75" by Ezekiel J. Emanuel, The Atlantic, October 2014, www.theatlantic.com/features/archive/2014/09/why-i-hope-to-die-at-75/379329/

[2] Vernier LabQuest, www.vernier.com/products/interfaces/labq/

[3] Heart Rate Variability: Standards of Measurement, Physiological Interpretation, and Clinical Use, circ.ahajournals.org/content/93/5/1043.full

[4] Zazen and Cardiac Variability, Lehrer, Sasaki and Saito, Psychosomatic Medicine 61:812-821 (1999)

[5] Cardiorespiratory synchronization during Zen meditation, D. Cysarz, A. Bussing, Eur J Appl Physiol (2005) 95:88-95