Detection of Obstructive Sleep Apnea through Auditory Display of Heart Rate Variability

M Ballora[1], B Pennycook[2], P Ch Ivanov[3], A Goldberger[4], L Glass[5]

[1] School of Music, The Pennsylvania State University, University Park, USA
[2] Faculty of Music, McGill University, Montréal, Canada
[3] Center for Polymer Studies and Department of Physics, Boston University, Boston, USA
[4] Cardiovascular Division, Harvard Medical School, Beth Israel Hospital, Boston, USA
[5] Department of Physiology, McGill University, Montréal, Canada

Abstract

A data set of interbeat interval times is read into a music software synthesis program to become the basis of a "soundtrack" or auditory display. Here we present examples of the sonifications, and discuss potential advantages in listening to, as opposed to viewing, heart rate variability data. This method treats the diagnosis of obstructive sleep apnea as a problem of orchestration and melody.

1. Introduction

The auditory system has been shown as being particularly well-suited for following simultaneous streams of information [1,2]. It has thus been suggested that an auditory display is an effective representation of high-dimensional data sets [3].

While heart rate variability (HRV) is thought to be associated with a variety of cardiopulmonary and systemic disorders, analyses of variability patterns remain difficult to interpret and there is not consensus on their utility.

With an auditory display, a variety of representations of an HRV data set may be displayed simultaneously. In this way, the one-dimensional HRV vector is transformed into a multi-dimensional representation, with each dimension based on a different signal processing operation. Such a sonification has the potential to reveal correlations among various operations that may not be attainable with a visualization.

Sonification also allows long time series records to be screened quickly by compressing the playback rate. Our implementation sonifies data points at a default rate of sixty per second. The resulting pointillistic "sound cloud" of extremely short events is an example of granular synthesis, a compositional methodology explored by composers such as Iannis Xenakis, Barry Truax and Curtis Roads [4]. While the focus of the sonifications discussed here is diagnostic rather than aesthetic, we are also eager to explore the artistic possibilities that our implementation suggests.

2. Components of the sonification

We selected the software synthesis programming language SuperCollider (http://www.audiosynth.com) because of its computational efficiency and its capability for creating flexible and interactive listening environments. SuperCollider runs on the Macintosh platform. In addition to its synthesis algorithms, SuperCollider also has an extensive set of list and array processing operations, as well as a method for generating ("spawning") musical events based on a programmer's instructions.

We have written a set of routines in the C programming language that performs a series of basic statistical operations on the data. The routines output four files, all of which are formatted to be read into SuperCollider as arrays:

1) the interbeat intervals, unchanged;
2) the mean of a window of 15 beats, with the current data point at the center;
3) the mean of a window of 5 beats, with the current data point at the center—values are rounded to a significantly coarser degree than the values in the 15-point window;
4) the standard deviation of a window of 300 beats, with the current data point at the center;

Our implementation of SuperCollider iterates through the four arrays concurrently, spawning musical events based on each data point. In addition to the four dimensions listed above, interbeat intervals that differ from the last interval by more than 50ms are given an additional timbral annotation (the total number of these intervals is known as the NN50 count [5]).

The listener uses a graphical user interface (GUI) to adjust the overall playback rate as well as the relative volumes of the five sound dimensions. Thus, the data set is treated as a multi-track recording, and the cardiologist or researcher plays the role of audio engineer in creating an optimal mix of the various tracks. All tracks are based on the same pitch mapping to avoid tonal cacophony, but are meant to be distinct timbrally.

3. Hearing a diagnosis

This method gives distinctive signatures for healthy, congestive heart failure and atrial fibrillation cardiac states [6]. We have found it particularly useful in detecting episodes of obstructive sleep apnea characterized by relatively low-frequency heart rate oscillations associated with periodic breathing [7]. However, different patients display different cardiac dynamics, making the flexibility of our listening environment essential for identifying apneic episodes.

In the most straightforward examples, the running mean with a window of 15 data points creates a distinct siren-like sound.

In noisier examples, the oscillations are more difficult to detect, either with a visualization or by listening to the running window of 15 points. In these cases, the coarser values of the 5 point window may produce a clear alternation between a high and a low pitch.

The larger (> 50ms) interbeat interval differences, with their additional timbral annotation, can often be heard to oscillate regularly in density during apneic episodes. They are therefore often useful as a supporting cue, particularly in cases where the oscillations in the mean do not cover a wide pitch range.

Thus, the listener may choose which version of the data to listen to, depending on its particular characteristics; or may choose to "fine tune" the volume controls to listen to multiple tracks in combination, or at a slowed or accelerated playback rate. The sonification may be paused and the user may "fast forward" or "rewind" to another point in time. This feature is particularly useful for listening while viewing a visualization of the data set: if a part of the visual graph looks interesting, the sonification can easily be set to play from that point. A listener may also create a list on the fly of notable time points by pressing the "a" key on the computer keyboard, causing the current hour:minute:second to print out on the computer monitor.

4. Conclusions

This sonification model is open-ended in that any other signal processing operation may easily be added to it and compared to any other signal processing operation.

Since listening training via stethoscope is an essential component of a physician's training, an advantage of sonification is that it draws on a skill into which cardiologist has already put significant effort: learning to hear diagnostically significant nuances in a changing sound pattern. The only difference here is the type of information being presented.

HRV analysis remains an exploratory area in the field of cardiology, into which we are proposing a sonification methodology that we are still at the early stages of learning to interpret. However, based on the results of this work to date, it can be stated that an auditory display represents a potentially valuable diagnostic component and is a compelling avenue for further development.

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References

[1] Bregman, A.S. *Auditory Scene Analysis*. Cambridge: MIT Press, 1990.

[2] Fitch, T. & Kramer, G. Sonifying the body electric: superiority of an auditory over a visual display in a complex, multivariate system. In *Auditory Display: Sonification, Audification, and Auditory Interfaces*, Kramer, G. ed. Reading, MA: Addison-Wesley, 1994.

[3] McCabe, K. & Rangwalla, A. Auditory Display of Computational Fluid Dynamics Data. In *Auditory Display: Sonification, Audification, and Auditory Interfaces*, Kramer, G. ed.. Reading, MA: Addison-Wesley, 1994.

[4] Roads, C. *The Computer Music Tutorial*. Cambridge: MIT Press, 1996.

[5] Task Force of the European Society of Cardiology and NASPE. Heart rate variability, standards of measurement, physiological interpretation and clinical use. *Circulation* 1996; 93:1043-1065.

[6] Ballora, M. *Data Analysis through Auditory Display: Applications in Heart Rate Variability*. Ph.D Thesis, McGill University, 2000.

[7] Guilleminault, C, Connolly, S, Winkle, R, Melvin, K & Tilkian, A. Cyclical variation of the heart rate in sleep apnoea syndrome. Mechanisms and usefulness of 24 hour electrocardiography as a screening technique. *Lancet* 1984; i:126-131.

Address for correspondence:

Mark Ballora
School of Music
The Pennsylvania State University
University Park, PA 16802-1901
ballora@psu.edu