SONIFICATION OF AUTONOMIC RHYTHMS IN THE FREQUENCY SPECTRUM OF HEART RATE VARIABILITY

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ABSTRACT

This poster presents some of the work currently being done at the Paracelsus Clinic in Switzerland on heart rate variability biofeedback with a real time auditory display.

Heart rate variability biofeedback is an important diagnostic and therapeutic tool in the work with a wide variety of chronic disorders. We use a proprietary building-block type laboratory computer program that is linked via MIDI to a software sequencer with a VST virtual instrument library.

Beyond the sonification of RR intervals as discrete numbers, the development of new techniques became necessary in order to be able to sonify the dynamic, wave-like structure of autonomic rhythms in the frequency spectrum of HRV, what we call ”heartmusic”.

The fact that patients can hear their inner autonomic activity as music in real time and so work with elements of their own autonomous rhythmic oscillations, may also add an important new dimension to this field in the future.

INTRODUCTION

Heart rate variability is a measure of the naturally occurring changes in beat-to-beat heart rate.

It is known that all warm-blooded animals require internal, self-regulatory processes in order to maintain homeostasis or what we call health. These regulatory processes are rhythmic in nature and are reflected in psycho-physiological oscillatory activity. Such oscillations are found in almost all regulated physiological systems and appear to reflect autonomically mediated modulatory processes.

The Lacey’s were the first to use HRV as a physiological measurement of change in autonomic lability (Lacey, 1956). Since then, HRV has emerged as an important non-invasive diagnostic tool for quantifying these modulations that reflect neurocardiac functions and autonomic nervous system dynamics. HRV-biofeedback is now emerging as a new technology with broad-based therapeutic applications.

The first effort to use actual rhythms of the heart as a template for musical compositions was the ReyLab Heartsongs project which originated from basic research work by Goldberger et al. (1995) to probe the fractal features common to both music and the complex rhythms of the healthy heart. The Heartsongs project was also implemented in 1995 in a hands on exhibition at the Boston Museum of Science, which allowed museum-goers to record their own ECG’s and, in real time, listen to the music it produces. A real-time example can be heard at: www.polymer.bu.edu/music/.

A CD, ”Heartsongs: Musical Mappings of the Heartbeat”, in which chords and rhythm were added by the composer on top of the melody created from previously recorded and averaged data, was also released in 1995.

Henrik Bettermann et al. (1999) applied the compositional rhythm principles of African music to the analysis of cardiac time series. ECG data were computed and arranged into symbolic sequences of rhythmic patterns. Bettermann concluded that physiological pattern predominance caused by autocorrelations and not by deterministic nonlinearities are inherent in the power spectra of R-R time series. However, this musicality of the heartbeat remains hidden when only the spectral characteristics are analyzed.

Non real-time examples of recordings of a musicians interpretation of these heart rhythms can be heard at www.scientific-african.de/bettermann/research/audiobsp.htm.

In 2000, Marc Ballora published his doctoral thesis on auditory display and HRV and a Poster at the ICAD 2000: Sonification of Heart Rate Variability Data. Using James McCartney’s, in 1996 introduced SuperCollider, Ballora used HRV data sets to generate a variety of data vectors created from statistical and nonlinear dynamical analysis. Each vector was treated as if it were a track in a multi-track music recording. Non real-time audio examples can be heard at:
www. music.psu.edu/Faculty%20Pages/ Ballora/sonification/audiostream.html.

In 2002, Yokoyama et al. used an algorithm to convert heart rate data into real-time pitch and note interval MIDI data. The effects of real-time HRV audio-biofeedback are analyzed for the first time.

In 2004, the authors of this poster started to work with real-time HRV biofeedback as a diagnostic and therapeutic tool.

PROBLEM FORMULATION AND RESEARCH HYPOTHESES

We feel that the sonification of RR intervals as discrete numbers does not represent a complete musical picture of complex biological rhythmic oscillations and that the standard goal of generating cardiac-autonomic coherence at the spectral frequency of 0.1Hz in HRV biofeedback is inadequate to explain and deal with complex autonomic regulatory functions. It was therefore felt that a sonification of the rhythmic structures and dynamics of the HRV frequency spectrum might be the key to help us better understand these autonomically mediated regulatory processes.

The mapping of RR Intervals and their sonification as musical notes are consequential procedures, because RR intervals are time domain based discrete numbers.

This does not however seem to be adequate for the sonification of the HRV frequency spectrum, because of the more dynamic, wave like character of it's spectral behavior.

The fixed trigger rate of MIDI clocks, widely used in sonification of EEG, was not a satisfying solution for an HRV spectrum sonification because artificial technical rhythms are then produced instead of a sonification of the unique biological rhythmic oscillations.

A development of sonification techniques adequate for the character of spectral rhythms, seemed to be necessary.

THE MUSICAL APPROACH

We use a 16 bit J+J Engineering I–330 – C2+, 6-channel device as an A/D converter. It supports the simultaneous mapping of multiple biophysical signals. The sample rate is 256/s.

For real-time biophysical data mapping, recording, processing and data display, we use BioExplorer software, version 1.3, from CyberEvolution Inc. To program a processing algorithm with this software, we have to create "designs" that consist of a signal diagram with sets of instruments for processing and displaying input. Programming is a graphically creative process, adding objects in the signal diagram and "wiring" them together.

From the ECG source signal, the R-wave is detected by a specific design object. The next step is to generate the R-R intervals in milliseconds. This data is "wired" to different bandpass filters, which are assigned to specific frequency areas within the low frequency (LF) band of 0,05 – 0,15 Herz and the high frequency (HF) band: of 0,15 – 0,5 Herz. While the assignment of vagal activity to the HF spectrum is well documented, the assignment of specific autonomic components to the LF spectrum is controversial. Certainly, there is a large sympathetic activity in this area. The signal or signal amplitude is then linked to MIDI objects.

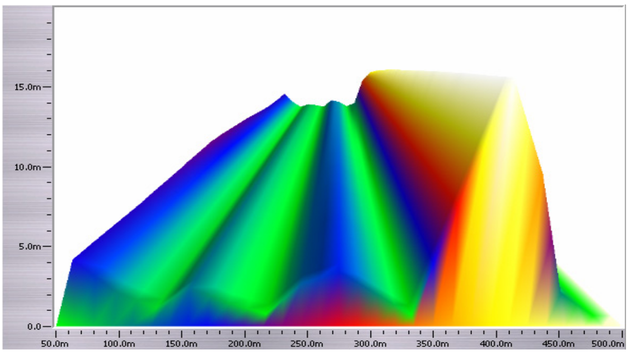

Figure 1. Percent power spectral analysis of the LF & HF bands. Strong parasympathetic activity is shown.

For audio instrumentation, we use the Steinberg Cubase SE3 software sequencer and the virtual instruments and plug-in sample players "Steinberg Halion Player" and "Miroslav Symphonic IK Media", directed to different MIDI tracks.

We have established three different ways of autonomic rhythm sonification:

1. The signal output of a bandpass filter which covers the whole LF-HF frequency range is linked to the MIDI pitch control of a constant sound, for example a virtual singer.

2. The amplitude output of different bandpass filters covering specific frequency areas of the LF and HF ranges are linked to the MIDI volume control of different constant sounds, for example choir samples of different pitch (Fig.2).

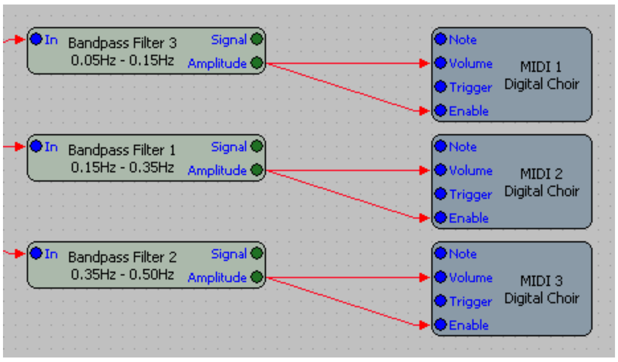

Figure 2. ECG derived RR-values are bandpass filtered and the amplitude output is linked to MIDI volume controllers .

3. The signal output of a bandpass filter which covers the whole LF-HF frequency range, is linked to the MIDI note control. The note range covers three octaves. The internal clock automatically triggers at an "overdriven" frequency of 50 ms. This makes it possible that, with every change from one "note window" to another, a new note is triggered nearly simultaneously because of an accordant change in the bandpass signal frequency. The polyphony of the cello ensemble, used in our audio sample, represents very well the wave-like autonomic dynamics (Fig.3).

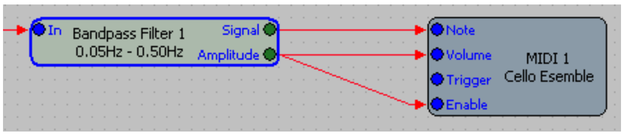

Figure 3. ECG derived RR-values are linked to a bandpass filter which covers the whole LF-HF frequency range and the signal output is linked to MIDI note controllers .

RESULTS

When we choose bandpass filter frequency ranges which cover the whole LF-HF frequency range or specific frequency areas within the low frequency band: (LF) and the high frequency band: (HF) and then link the signal or amplitude-output to a MIDI object, we have observed specific and individual rhythms that are not clearly defined or assigned to other biological oscillators,

Such rhythms in our audio sample are:

1. Oscillations of RR intervals coherent with breathing frequency.
2. A rhythmic variation of loudness, if the MIDI volume control is linked with the overall amplitude of the HRV spectrum.

3. A rhythmic change of MIDI voices, if the amplitude output of bandpass filters representing LF / HF are linked to the MIDI volume control (see also fig.4).
4. A polyphonic MIDI ensemble with a rhythmic modulation of glissando-like notes representing the wave-like signal of the HRV frequency spectrum.

Rhythms 2. – 4. are also heard clearly without forced breathing, while rhythm 1. is then nearly disappearing.

The audio samples can be heard at:
http://www.herzlaut.de/html/musikbeispiele.html

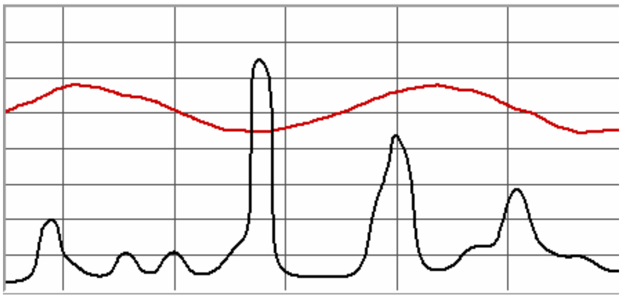

Figure 4. A real time visual display of the trended pulse rate (upper wave) and the LF/HF ratio (lower wave).

CONCLUSION

The sonification of the power frequency spectrum in HRV biofeedback with a real time auditory display, is useful in representing a more complete musical picture of complex biological rhythmic oscillations.

This sonification technique reveals hidden, complex autonomic rhythms and makes them perceptible and modifiable in a therapeutic process.

Most of the mentioned rhythms were detected primarily acoustically. In many cases, a visual detection, even in the real time power- or amplitude spectrum, was not successful.

More work has to be done in detecting and defining the complex biological rhythmic oscillations of autonomic regulatory functions.

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