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The Music of Heart Rate Variability

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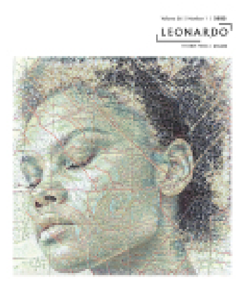

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ARTISTS' NOTE

The Music of Heart Rate Variability

JAN C. SCHULLER AND ULF HENRIK GÖHLE

ABSTRACT

The variability of the heart rate reflects the regulatory status of the autonomous nervous system. For analytic purposes accessible to laypersons, the authors developed methods to transform heart rate variability into acoustical information, through either direct sound synthesis or the production of MIDI files (musical instrument digital interface) to trigger other devices. The authors describe the methods and some results and discuss applications for analytical and artistic purposes, such as music composition and biofeedback. The resulting "music" is complex and rhythmic and often has unexpected and interesting implied harmony.

BACKGROUND AND MOTIVATION

Heart rate and its variability (HR and HRV) are accepted parameters reflecting the internal status of regulation by the autonomous nervous system. HR measurement is a popular feature of mobile devices and can be conducted with acceptable accuracy [1]. Low accuracy in HR measurement has a significant effect on deriving HRV. For scientific purposes, there exists a plethora of analytical approaches for HRV, many of which are rather abstract and not easily accessible to laypersons. The multidimensional sonification of HR data [2] sharpens the senses for features in the data that are less prominent when using traditional analytic approaches (such as univariate statistics, expressed by one number, e.g. mean, or standard deviation, or graphs). Applying this principle to a musical approach, we developed methods to convert interbeat intervals (IBIs) into musical information, using mappings to sine waves or MIDI notes.

In music, 32 beats can make up a musical phrase, and thus the methods are exemplified with a sequence of 32 IBIs from a standard HR measurement of a human subject. Sound examples are provided in the audio supplements, which also include two extended pieces, one played by a live pianist.

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See https://direct.mit.edu/leon/issue/56/1 for supplemental files associated with this issue.

METHODS

HR measurements were taken from a student from the Frankfurt University of Music and Performing Arts (HfMDK), who consented to participate in a pilot study. The study assessed the correlation of HRV and training success during individual lessons in neuro-motoric coordination, which is part of the HfMDK's regular curriculum (Study EM4M-0001). For the present example, 32 IBIs were taken from one subject during a five-minute resting period, using a Suunto Ambit 3 smart watch and a matching wireless sensor that was attached to the chest of the participant.

The required software tools for data processing, R-Studio and Python, are widely available. The R-packages FITfileR and RHRV contain functions for data import and HRV analysis [3]. To produce MIDI files, we used Python's M package.

The raw IBI vectors (lists of numbers, where each element shows number of milliseconds from one heartbeat to the next) were extracted from the mobile device, filtered to eliminate artifacts, and subsequently further processed. All files were generated offline and no sound was played during the measurements.

We employed five methods with increasing complexity beginning with Method a1: Transformation into sine waves: Each IBI (in milliseconds) was transformed into a new frequency f, so that: f=1100 Hz – (IBI * 1 Hz * ms-1). An IBI of, say, 700 ms was mapped to a frequency of 400 Hz. As a result, long IBIs (slow HR) are mapped to low frequencies and vice versa. The choice of the base value (here 1100) determines the average pitch of the resulting tones. The base value can be chosen in such a way that the longest IBI gets the lowest desired tone. Sine tones were filtered to dampen attack and release, using the hyperbolic tangent function.

The sound file (in the *.wav format; sampling rate: 44.1 kHz) was written so that for each IBI a sine tone with the calculated frequency was played, for a duration of 500 ms. An original 5-minute HR recording contains about 300 interbeat intervals. Each of them was transformed into 500 ms of

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sound and thus resulted in a sound file of about 3 minutes in duration and played tones at a rate of 120 per minute.

As a variation of Method a1, we also used an approach where the pauses between successive tone onsets were equivalent to the actual IBI (Method a2). The IBIs were thus represented twofold in the resulting sound file, once by a frequency and once by the pause between tone onsets.

IBIs were used to produce MIDI files containing notations and durations of tones. Method b1: Each pair of subsequent IBIs was compared. If the second IBI was longer, the MIDI note value was decreased by one (one half tone down). If the second IBI was shorter, the MIDI note was increased by one (one half tone up). If both IBIs were identical, the MIDI note did not change. Such an approach yields chromatic tone sequences and responds to the direction of IBI changes (up, down, or constant) but not the amount of change. Consequently, Method b2 "spread" the resulting tones over an entire 88-key piano keyboard, resulting in tone sequences with large intervals, proportional to the IBIs. If there are more than 88 distinct IBIs, each of the 88 tones on a keyboard must map to several IBIs. Therefore, the range of IBIs was divided into 88 equally spaced classes, and the MIDI note assigned to each IBI was determined by the IBI's class. Method b3 also considers IBI note length: The range of IBIs was divided into 6 equal classes, and each class was mapped to a relative note duration from 1/32 to 1/1. Program codes are available upon request from the authors.

RESULTS

Figure 1 depicts 32 IBIs of consecutive heartbeats, which are used for the sound examples 1–4. The IBIs underwent fluctuations and show two peaks in IBI length at 3 s and at 13 s. Overall, the IBIs varied between 635 and 851 ms. Track 1 of the audio example contains the transformation of the IBI sequence into a chromatic tone sequence of 32 tones, using Method b1 (one tone per IBI). Figure 2 shows the transformation of the IBI sequence by Method b2 into a tone sequence where the intervals are derived from a linear transformation of the IBIs over the MIDI notes 21 to 108 (the tone range of a piano). IBIs that are close to each other were mapped to the same MIDI note (e.g. IBIs of 694 and 695 ms were both mapped to MIDI note 84 [C6]).

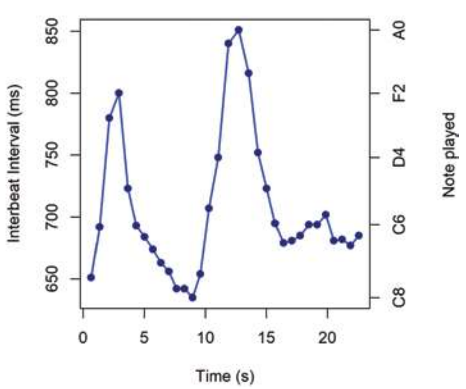

Fig. 1. Interbeat intervals of 32 consecutive heart beats. (© Jan C. Schuller)

Fig. 2. Tone sequence, derived from 32 consecutive Interbeat Intervals (Method b2, Intervals proportional to IBIs). (© Jan C. Schuller)

Audio examples:

- Track 1 (00:00–00:17): A synthesized sound sequence achieved by Method a1, where each IBI was represented by a sine wave with a frequency that was an inverse linear transformation of the IBI (Long IBIs were mapped to sine waves of low frequency and vice versa)
- Track 2 (00:17–00:40): A synthesized sound sequence by Method a2, where each IBI was represented not only by the frequency of the resulting sine wave but also by the time between the onset of successive tones
- Track 3 (00:40–00:50): Example from Method b1, played on a MIDI piano
- Track 4 (00:50–01:00): Example from Fig. 2 by Method b2, played on a MIDI piano
- Track 5 (01:00–05:33): A tonal sequence by Method b3, HRV recording from Aurelijus, 13 years, son to UHG and GG, during 8 minutes of sleep
- Track 6 (05:33–07:40): This example is based on the same HRV data as Track 5 based on Method b2. Title: *Traum Scherzo*, performed by Guoda Gedvilaitė (piano).

SUMMARY AND CONCLUSIONS

Many athletes, and, increasingly, artists, are monitoring their heart rate and HRV. Traditional approaches to quantifying HRV include univariate statistics like the Standard Deviation of the IBIs, or more complex methods like Poincaré Analysis or geometrical methods like the HRV index (HRVi) or the Triangular Index (TINN). Some of them are prone to misinterpretation by laypeople who lately wish to monitor their HRV. Moreover, the sonification of HR data follows an underlying quest that sees epistemological value in the translation of real-world data into symbolic formats that reach beyond language [4].

Method b2 divides continuous IBI-values over musical notes, rather than continuous pitches. A similar principle is realized in statistical histograms, where continuous values are distributed over distinct classes. Our method b2 can be thus described as yielding a "musical histogram" of HR data. Also, our experiment shows that untrained persons cannot tell the difference in two time intervals if it is less than, say, 20 ms, but may easily distinguish two tones that have a pitch difference of 20 Hz (depending on absolute pitch). Thus, transforming time differences into pitch differences sharpens the sense of time (acoustic altimeters in gliders use a similar principle). For our example (Method a1), we chose the transformation such that 1 ms in IBI difference translates into 1 Hz difference in the resulting synthetic sound. One could choose 2 Hz per ms as well, or any other value, and thus adjust the sensitivity of this assay according to need or aesthetic preference. The mapping of IBIs to MIDI notes (Method b) involves a loss of information if close IBIs are mapped to the same note. This imprecision can be valuable in analysis, because recurring variations of musical motifs may point to characteristics in the original data that are less pronounced when using mappings to continuous frequencies. Examples of recurring musical motifs can be heard in tracks 5 and 6 of the audio supplemental material. Beyond the mere analytic approach, this method produces tone sequences with complex structure, tonal rhythmicity, and often interesting and unexpected implied harmony. The potential to map IBIs on tonal scales, sounds, or rhythms is virtually unlimited. Here, we used some rather straightforward linear transformations to achieve either continuous frequencies or tonal results. In many cases it is advisable to use nonlinear transformations or any other mapping procedure. The time dimension of the IBI can be mapped to either or both the tone or time (or to any other parameter) of the resulting sound, which further expands the possibilities of expression. Furthermore, melodies produced by such algorithms are direct reflections of the physical state of a person and are sensitive to changes in the HRV parameters. Moreover, the method presents new possibilities for research, e.g. when recording interacting people synchronously, and assessing the tonal results. The algorithm to produce such highly individualized "music pieces" could be used as a plugin to one of the ubiquitous HR apps that exist for mobile devices or could be directly used as source material for original compositions. Tracks 5 and 6 (the latter played by a live pianist, from a score directly produced from the MIDI file) provide an example of such an approach. Our simple method to produce tone sequences from HR measurements provides a means of intuitively monitoring specific qualities of complex physiological data and, at the same time, invites experimentation with physiological and time-structured data in an acoustical or musical context. The method is not limited to HR data but also applies to other physiological parameters, e.g. from electroencephalograms (EEG) and other biological sources, particularly if they posess periodicity over time.

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