CARDIOPULSE

Putting (One's) Heart into Music

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On links and similarities between the rhythms of arrhythmia and music, evidence showing prevalence of simple swing ratios in arrhythmia ECGs, and implications for music in medical education and for music informatics in cardiovascular science.

16 December 2020 marked the 250th anniversary of Beethoven's birth, with celebrations extending to September 2021. Apart from being one of the foremost composers of classical music, Beethoven also suffered from a litany of diseases, which some speculate included cardiac arrhythmias. This has led to the informed conjecture that Beethoven set his own ventricular early beats into the dotted rhythms of his 'Les Adieux' Sonata,[1,2] i.e. that his heart rhythm disorders may have been responsible for the distinctive rhythmic motifs in his music. Furthermore, the interoception required to turn arrhythmic heartbeats to music may have been enhanced by his deafness. *Figure 1* shows a possible inspiration for another signature Beethoven motif, one in the opening of his Fifth Symphony. The striking correspondence between the electrocardiographic (ECG) trace and the notated rhythm could be a mere coincidence or an indication of a deeper connection between music and the heart.

Noting the similarity between rhythms of arrhythmia and those found in music, Chew had independently started making music based on transcriptions of arrhythmia ECG traces. These are collage pieces made by merging music excerpts that match contiguous segments of ECG. The result is music that mirrors the arrhythmia sequences.[3,4] Supplementary material online, *Figure S1* shows a transition from normal beats to ventricular tachycardia (VT) in the ECG from the catheterization laboratory and in the matching music collaged from Holst's *The Planets*, 'Mars'. The full ECG excerpt, lasting about 3 min, showed the sequence before, during, and after VT, and formed the basis for the first of the *Arrhythmia Suite* pieces.[5] Such longer pieces were made through a semi-automatic process from ECG signal data.

The fact that arrhythmia music can be made from a collage of existing music suggests that arrhythmias are highly musical, or perhaps that music emulates physiological rhythms including, curiously, cardiac arrhythmic activity. Even when the heart's own natural pacemaker fails and a patient is fitted with an artificial pacemaker, the link between music and the heart persists, as the heart then starts beating like a band playing to a click track.

Why do heartbeats, even abnormal ones, map so well to music? In music with a beat, the rhythms and other musical structures unfold over an underlying grid of regular pulses which can flex with time, but are basically periodic, like a natural pacemaker. Consecutive intervals between rhythm event onsets normally form simple ratios, at least they are notated that way but the reality (performance) is slightly more complex, with respect to the underlying grid. This means that the rational numbers that express their proportional relationships are made of relatively simple numbers. An example of the importance of proportional durations lies in the quantifying of the swing ratio in jazz, where events that may be notated as even and of equal duration are actually performed off-kilter in duration ratios between 1:1 (straight) to 3:1 (hard swing).[5] This swing ratio (the ratio of consecutive RR intervals) is shown for different arrhythmias in *Figure 2* (single Holter recordings of ventricular ectopics and paroxysmal atrial fibrillation) and Supplementary material online, *Figure S2* (collections of recordings of the 1024 beats just before VT and ventricular fibrillation, respectively).

As expected, ratios around 1:1 are most prevalent. Interestingly, there are several narrow peaks showing a preponderance of simple ratios like 1:2, 1:2.5 (i.e. 2:5), 1:1.5 (i.e. 2:3), which are reminiscent musically of a light (3:2 ratio) and medium swing (2:1 ratio). Equally intriguing are the notable gaps surrounding selected peaks, most striking around 2. Distinct peak ratios are marked by vertical red lines (thickness indicating prominence of the peaks) in the histograms. These peak ratios correspond to the radial lines, although their presence is not as obvious, in the Poincaré plots. Example renderings of the duration ratios as music notation are also shown. These peaks mean that certain patterns in arrhythmia lend themselves particularly well to music representation. Why the physiology or geometry of the heart should produce such behaviours around basic ratios is a subject for further investigation.

What does it mean for arrhythmia to map naturally to music? The fact that arrhythmias can be mapped to music suggests that it is possible to describe features of an arrhythmia using musical parlance. The musical

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Figure 1 Opening of Beethoven's Fifth Symphony (CCARH 2008) and 12-lead Holter ECG segments showing short runs of ventricular tachycardia matching the fate motif, normal beats marking time (ECG courtesy Lambiase).
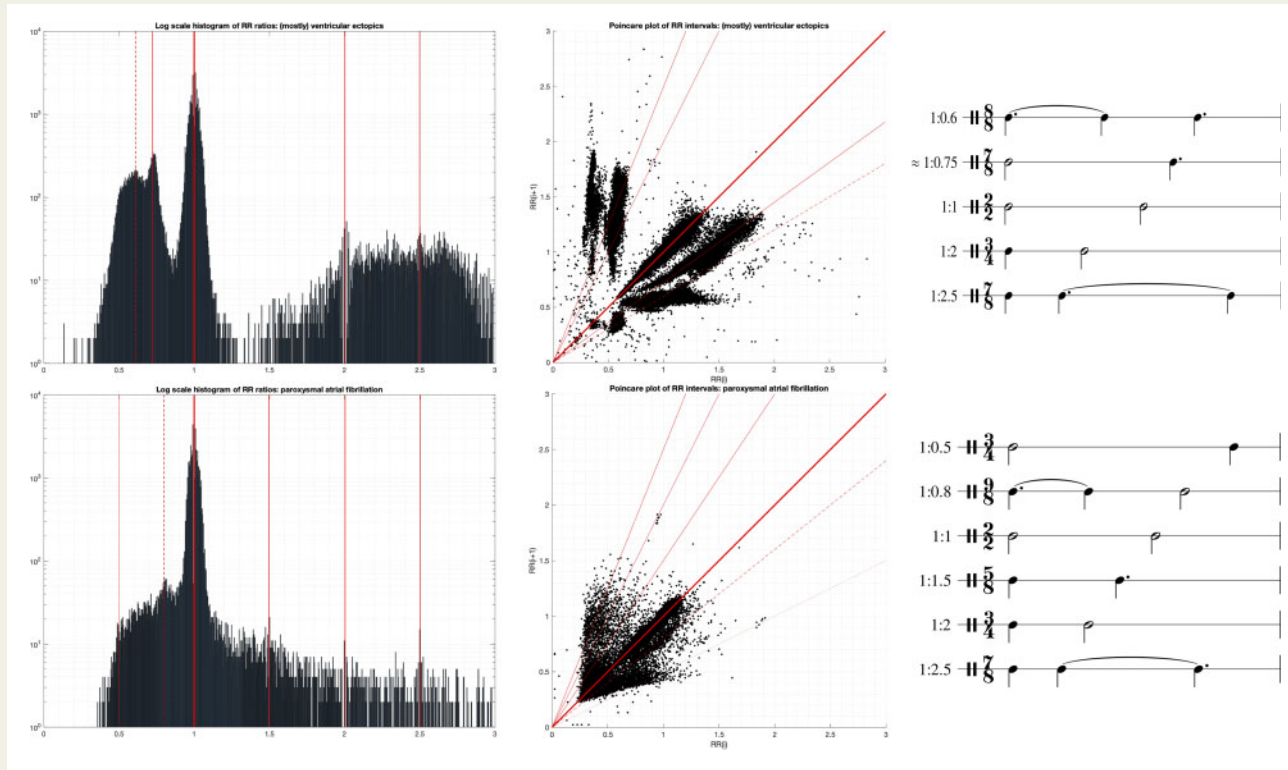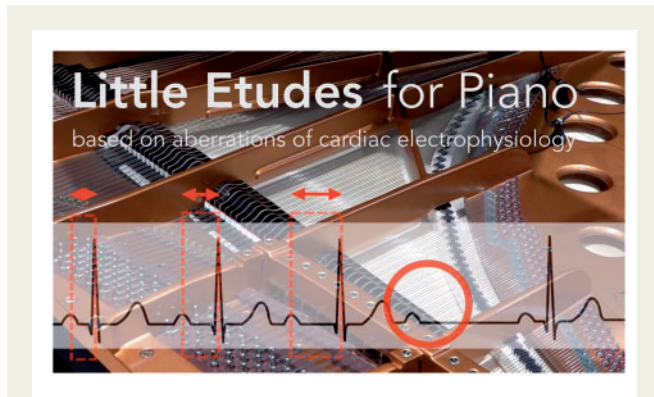

Figure 2 Log-scale histograms of RR ratios, Poincaré plots of RR intervals, and music notation for peak ratios marked (vertical lines in histograms which correspond to lines radiating from origin in Poincaré plots) for ventricular ectopics (top) and of paroxysmal atrial fibrillation (bottom) from single Holter each.

Video I Little Etudes for piano based on aberrations of cardiac electrophysiology–a performance by Elaine Chew of a series of short piano pieces based on cardiac electrical anomalies each described by Pier Lambiase,[10] made initially by Chew, Lambiase, Bedoya for the Ircam AIxMusic Garden at Ars Electronica 2020. The video is available at https://bit.ly/LittleEtudes-video

field has developed over centuries a rich and sophisticated vocabulary for describing time and frequency patterns and variations. Arrhythmias are presently classified physiologically by source, rate, and regularity. To a musician, this is tantamount to describing a piece of music (poorly) as having a fast, irregular beat and in the treble register. Musical nomenclature could offer new ways to describe arrhythmia behaviours. For example, the rhythms of arrhythmia are more than simply irregular; one may be a swing, another a tango. The parallels go well beyond rhythmic patterns. In the frequency domain, the fundamental frequency in musical pitch is like the dominant frequency in atrial fibrillation, and musical vibratos are like fibrillatory waves—they even occupy similar frequency ranges.[8] In music, large-scale (long term) time structures and their evolution are also important and rigorously studied.

Implications for this connection between music and the heart range from medical education to scientific research and communication. For example, the nephrologist Michael Field has meticulously transcribed heart murmurs using music notation for the teaching of cardiac auscultation and the diagnosis of heart valve disorders to medical students.[9] For a lay audience, the authors have created a video illustrating aberrations of cardiac electrophysiology using a set of Little Etudes for piano[10]—see Video 1. Over the past two decades, the explosion of digital music information has given rise to the burgeoning field of music information research, which is concerned with encapsulating music knowledge in computational form. These advances facilitate knowledge transfer between, and interoperability of computer algorithms for, music analysis and computational cardiology, with potential applications to disease stratification and to clinical practices and therapeutics.

Supplementary material

Supplementary material is available at *European Heart Journal* online.

Data availability

The PhysioNet Spontaneous Ventricular Tachyarrhythmia Database used in Supplementary material online, Figure S2 is publicly available at https://physionet.org/content/mvtdb/1.0. Other data provided by permission in this article cannot be shared publicly for ethical and privacy reasons. The data will be shared on reasonable request to the corresponding author with permission of the owner(s).

Acknowledgements

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