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Generalized multifractal analysis of heart rate variability recordings with a large number of arrhythmia

The regulation of human heart rate is the result of many inputs e.g. the activity of the sympathetic and parasympathetic nervous system, respiration and its control or such pathologies as ectopic activity or delayed conduction of cardiac tissue - each having its own characteristic time scale and magnitude. The MF-DFA (MultiFractal Detrended Fluctuation Analysis) method used by us allows to assess the effect of the different controls systems and pathologies. Because it requires stationarity the method is applied in the literature to heart rate variability recordings with less than 5% of arrhythmia.

We analyzed the published MF-DFA method, using synthetic data and chosen RR intervals series. We developed an original, generalized version of the MF-DFA method - multiscale multifractal analysis MMA. We found that the calculation of the $f(\alpha)$ curve is a major source of artifacts. We thus focused on the dependence of the local Hurst exponent h on the multifractal parameter q: $h(q)$ and we allowed it to depend on the scale s. In the standard MF-DFA the time scale s is fixed, somewhat arbitrarily (usually from 50 intervals up to 500). Thus, we obtained the $h(q, s)$ dependence - a surface - the shape of which tells us what is the magnitude of the fluctuations the RR intervals have in different time scales (different frequency bands). MMA was found to be immune to noise contamination of the data (we tested up to 50% of noise). It also allows to study heart rate variability with an arbitrary level of arrhythmia required for clinical applications.

We analyzed 51 24-hour recordings of heart rate variability (36 males age 16-64, 15 females age 11-57: 42 healthy persons, 9 cardiac arrest cases including 5 without organic heart disease). We did not remove arrhythmia from the recordings. We limited the study to the night hours to avoid arbitrary daytime activity. Our mathematical criterion was able to distinguish, in a blind test, healthy subjects from the high risk cardiac arrest cases including those without organic disease. The different peculiarities of each recording have a unique effect on the results of the multiscale MF-DFA analysis e.g. the occurrence of arrhythmia may readily be identified from the results. Thus, the new method allows to recognize and assign a complexity measure to features of the heart rate variability which hitherto went unnoticed when using standard, linear diagnostic methods and MF-DFA.

References

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