Fluctuation-Dissipation Theorem (FDT) Provides a Simple Analytical Relationship between Post-Stress Heart Rate Recovery (HRR) and Heart Rate Variability (HRV) During the Stress

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Objectives

The autonomic nervous system modulates both the dynamics of heart rate (HR) recovery (HRR) after a cardiac stress test (e.g. treadmill exercise test) as well as HR variability (HRV) under steady-state ("free-running") conditions. Also, both reduced HRV as well as prolonged HRR are believed to be predictors of mortality. Thus, we hypothesized that there is a relationship between post-stress HRR time constant (T_{off}) and a HRV measure.

Methods

While all previous studies have employed conventional statistical tools (such as correlation coefficients) to explore empirical correlations between HRR time constant and different HRV indices during the exercise, we adopted an alternative strategy, deriving such a relationship theoretically rather than empirically (statistically) infering it from the data. We applied the fluctuation-dissipation theorem (FDT), which relates the system response to a relatively small perturbation to the fluctuations in the stationary state of the system.

We test our theoretical results with 20 HR datasets recorded during and after the spontaneous breathing trial (SBT), considered as a stressor, from 16 mechanically ventilated critically ill patients in an intensive care unit (ICU).

Results

The FDT predicts the exponential shape of HRR and provides a simple analytical relationship linking post-stress HRR time constant with a standard HRV measure, namely the correlation coefficient of the Poincare plot of the HR dynamics during the stress (SBT). For 17/20 datasets FDT correctly predicts the values of post-SBT HRR time constant using HRV during the SBT. The cases when the FDT-based relationship fails correspond to non-exponential shapes of HRR.

Conclusion

The relationship between the *microscopic fluctuations* (HRV) during the stress and the *macroscopic response* (HRR) after the stress was terminated can be interpreted as an example of FDT or, equivalently, Onsager Regression Hypothesis, which states that the same time constant characterizes both the decay of *spontaneous microscopic fluctuations* (HRV) at steady-state, and the *macroscopic relaxation* (HRR) to a new steady-state after a relatively small external perturbation (stress) was withdrawn.

The approach is specific neither to cardiac physiology nor to transitions between mechanical and spontaneous ventilation as a specific stress. It may therefore have wider applicability (both in ICU and elsewhere) to many physiologic systems subjected to modest stresses.