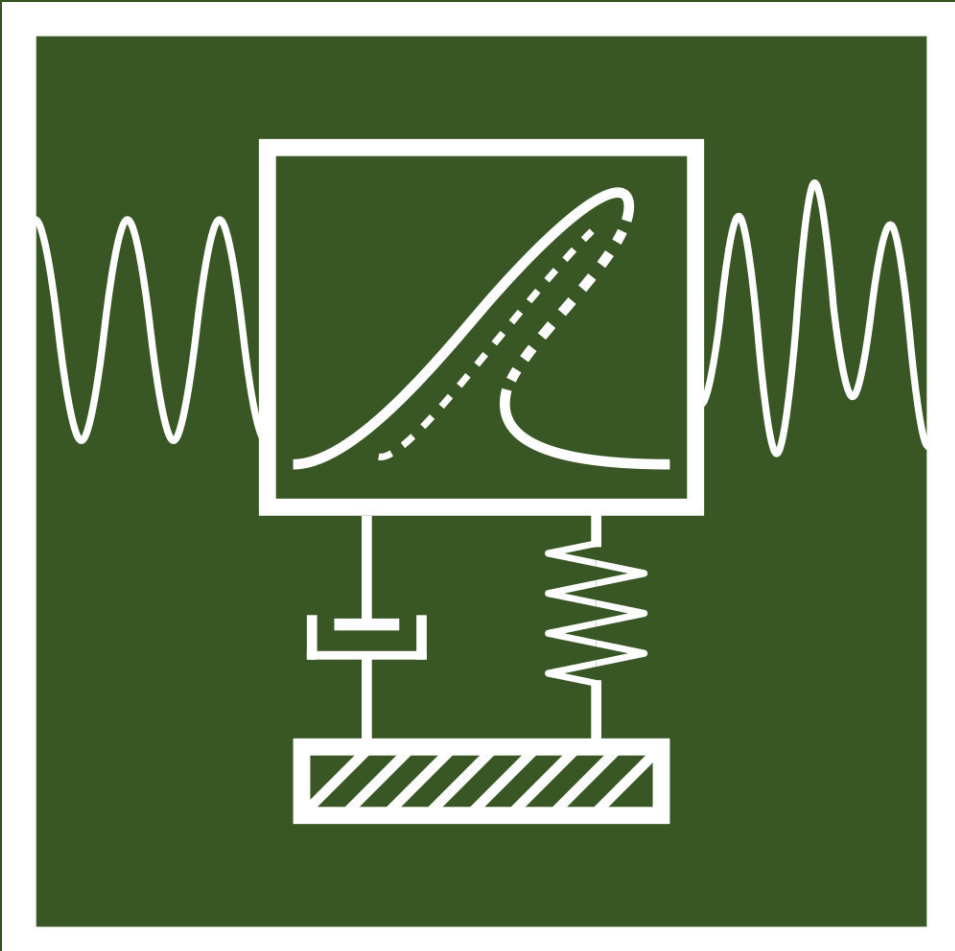


The Heart as a Complex System: Insights from Nonlinear Dynamics in ECG Analysis

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A Abstract

The heart is a complex dynamical system. Nonlinear analysis of relationships among ECG parameters can reveal adaptive changes not captured by single-parameter assessment. This work examines RR-DQRS, JT-ST, and phase-plane dynamics in relation to the anaerobic threshold, ischemic alterations, and cardiovascular self-organization.

01 Methods

ECG intervals were analysed as interacting dynamical variables rather than isolated measurements. Second-order Lagrange difference matrices quantified RR-DQRS and JT-ST algebraic relationships. Smoothing and delay-coordinate phase-plane reconstruction were used to identify changes in dynamics during exercise, recovery, and auricular vagus nerve stimulation (aVNS).

02 Results

Anaerobic threshold (Fig. 1). RR-DQRS dynamics and reconstructed attractors changed around the anaerobic threshold during increasing exercise load.

JT-ST dynamics (Fig. 2). Changes in the algebraic relationship during exercise and recovery were examined; two consecutive declines were investigated for detecting ischemic episodes.

aVNS (Fig. 3). RR/JT and JT/QRS phase-plane trajectories revealed individualized changes in cardiovascular dynamics during stimulation compared with placebo.

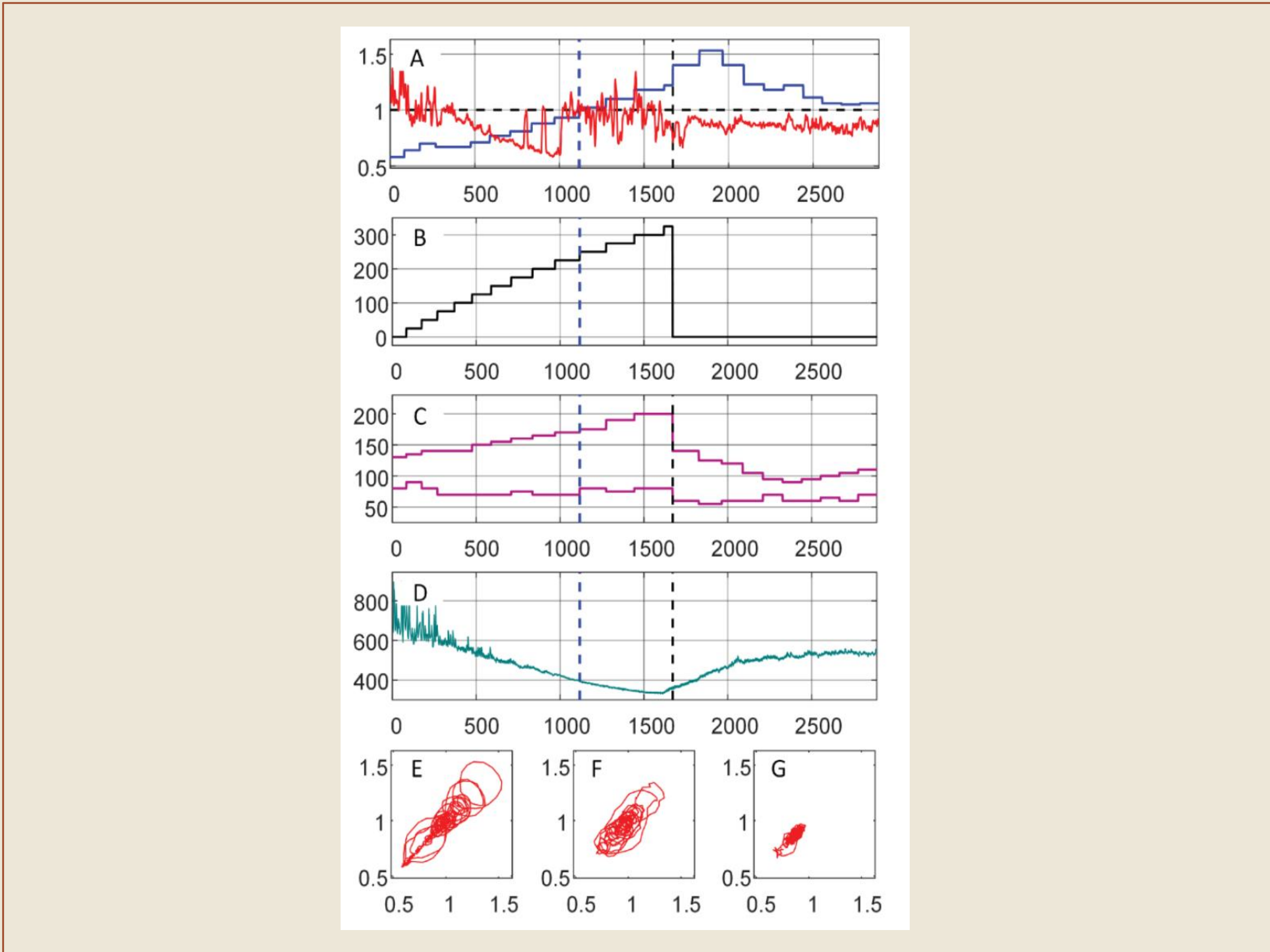


Fig. 1. RR-DQRS dynamics and reconstructed attractors around the anaerobic threshold (dissertation Fig. 10).

03 Discussion

Changes in relationships between ECG parameters provide information that is not evident from absolute values alone. Transitions in coupling and phase-space organization reflect cardiovascular adaptation under changing physiological conditions and support interpretation of the heart as a complex adaptive system.

04 Conclusions

- RR-DQRS dynamics indicate the anaerobic threshold.
- JT-ST dynamics characterize early ischemic alterations.
- Phase-plane analysis visualizes cardiovascular self-organization during aVNS.

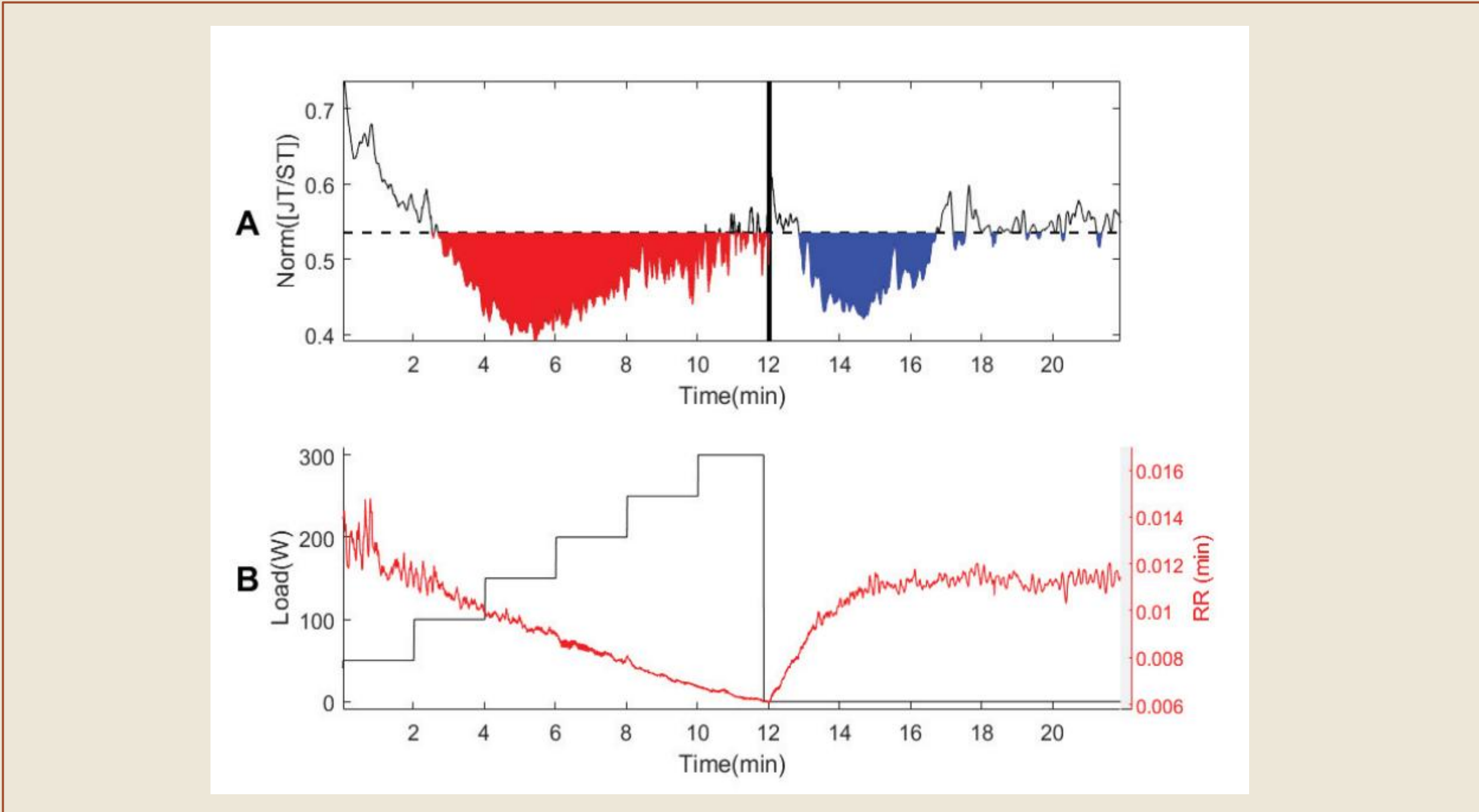


Fig. 2. JT-ST dynamics during exercise and recovery in a healthy participant (dissertation Fig. 13).

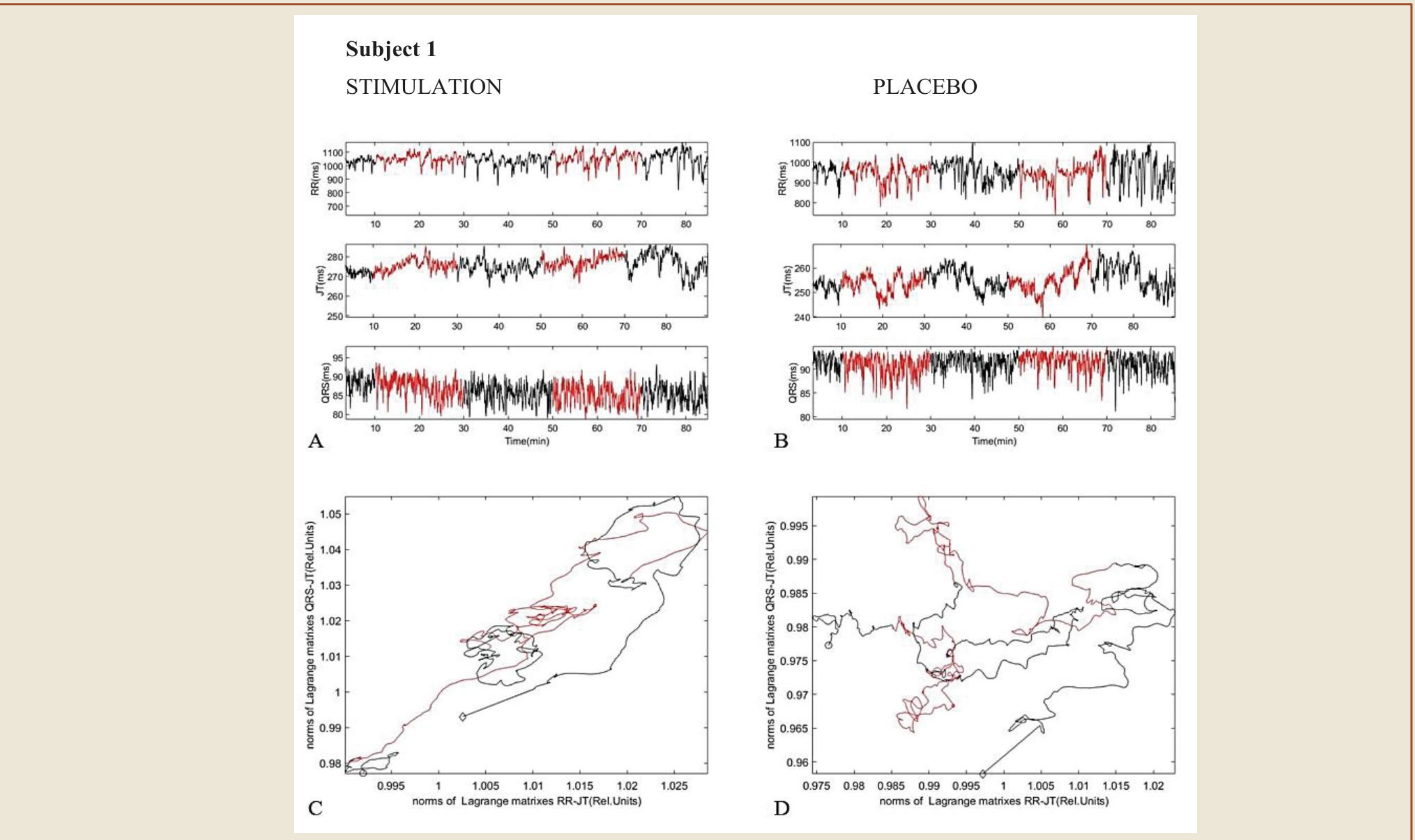


Fig. 3. ECG dynamics and phase-plane trajectories during aVNS and placebo (dissertation Fig. 25).

Acknowledgements

The author gratefully acknowledges her scientific supervisor, Prof. Minvydas Ragulskis, and scientific consultant, Prof. Alfonsas Vainoras, for their valuable guidance, support, and expertise throughout this research.



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