Cardiovascular and Cardiorespiratory Interactions – From Physiological Mechanisms to Clinical Applications
Jessenius Faculty of Medicine, Comenius University (Martin, Slovakia), November 2–4, 2026
Project Visegrad Grant No. 22620137

# Dimensional Causality: Revealing Hidden Shared Drivers in Cardiovascular Recordings

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joint work with Zsigmond Benkő[1], András Telcs[1,2], Grzegorz Graff[3], Beata Graff[4], Zoltán Somogyvári[1,5]

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HUN-REN Wigner Research Centre for Physics, Department of Computational Sciences, Budapest, Hungary Dimensional Causality (DC) is a method for revealing causal connections between recorded signals with a focus on identifying hidden common drivers [1]. The state variable of the original system are reconstructed from the recorded signal with time delay embedding. In this reconstructed space our method measures the dimension of individual signals and their joint embedding to infer the probability of each possible causal connection based on the data.

We apply DC to two physiological datasets. The first, featured in the ESGCO challenge [2], consists of beat-to-beat cardiovascular, cerebrovascular, and respiratory signals recorded in healthy controls and individuals prone to postural syncope, during rest, early head-up tilt, and prolonged tilt phases of the head-up tilt test. Our results reveal that hidden common drivers dominate the inferred interaction structure in most cases, highlighting the importance of accounting for latent confounding influences in physiological causality analysis. Orthostatic stress induced substantial reorganization of the interaction network, with stronger bidirectional cardiovascular coupling in healthy subjects. In syncope-prone patients, altered coupling patterns suggested impaired autonomic and cerebrovascular regulation.

The second dataset, recorded at the Medical University of Gdańsk, contains instantaneous blood pressure, beat-to-beat heart rate derived from ECG and respiration. We observe that the dimension of the respiratory dynamics differs significantly between the two groups. The dimension of respiration is lower in individuals with disease, and in parallel, the joint dimension of respiration/blood pressure (BP) and respiration/heart rate (HR) also decreased. In the disease group, these suggest altered causal relationships: instead of a hidden common cause connecting the subsystems their cardiovascular signals (BP, HR) drive respiration more directly. Further analysis requires moving from pairwise causal analysis to describing a network with multiple hidden causes.

Our findings demonstrate the usefulness of dimensional causality analysis for uncovering complex hidden interactions in cardio-respiratory dynamics.


[1] Zsigmond Benkő, Ádám Zlatniczki, Marcell Stippinger, Dániel Fabó, András Sólyom, Loránd Erőss, András Telcs, Zoltán Somogyvári. Bayesian inference of causal relations between dynamical systems. *Chaos, Solitons & Fractals* **185** (2024), 115142. doi:10.1016/j.chaos.2024.115142

[2] Marcell Stippinger, Paweł Pilarczyk, Grzegorz Graff, Beata Graff and Zoltán Somogyvári. Hidden Drivers in the Cardio-Respiratory System. *14th ESGCO Meeting: European Study Group on Cardiovascular Oscillations Erice, Sicily, Italy* (22-26 October 2026), Session "Challenge". Booklet available online at esgco2026.unipa.it.