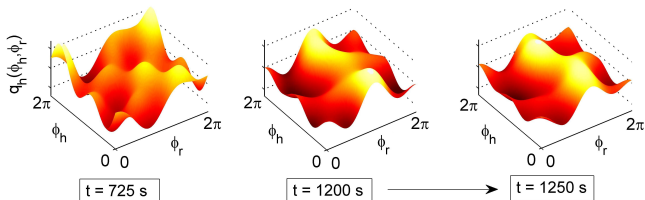


Interactions of Biomedical Oscillations

Tomislav Stankovski

Faculty of Medicine, Ss Cyril and Methodius University, Skopje, Macedonia
Department of Physics, Lancaster University, UK

September 18, 2015



Outline

- Oscillations

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- Methods

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Outline

- Oscillations
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- Ongoing projects

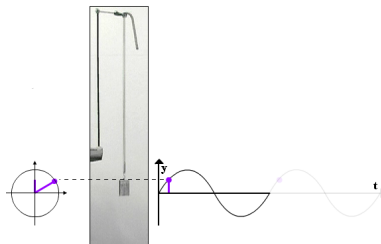
Oscillations

- Oscillation – repetitive, rhythmic and **periodic** dynamics

Oscillations

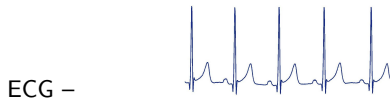
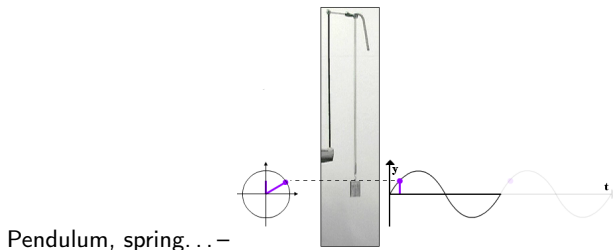
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Pendulum, spring... –



Oscillations

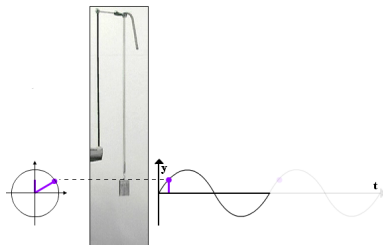
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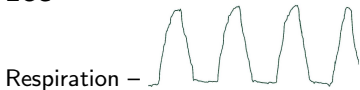
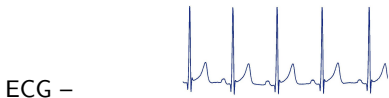


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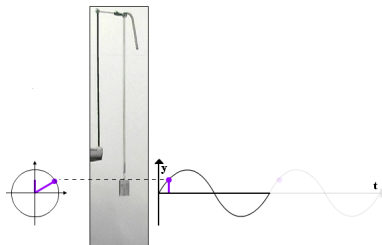


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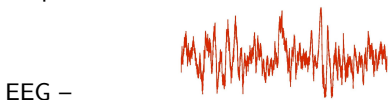
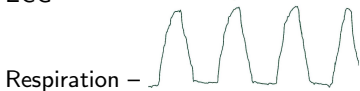
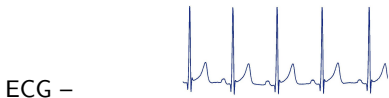


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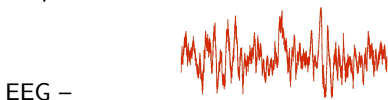
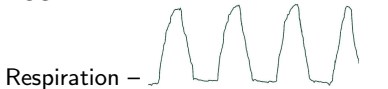
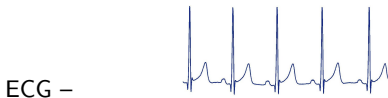
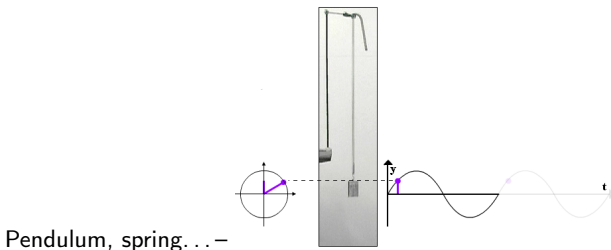


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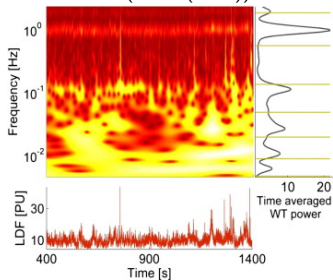


Oscillations

- Oscillation – repetitive, rhythmic and **periodic** dynamics



Blood flow (MVR (2011))



Short theory

- Ideal harmonic oscillator

$$\ddot{x} = -\frac{k}{m}x = -\omega^2 x; \quad x(t) = A \cos(\omega t + \phi)$$

- Amplitude A , frequency ω и phase ϕ

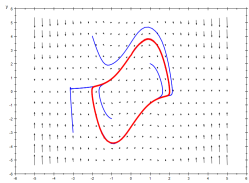
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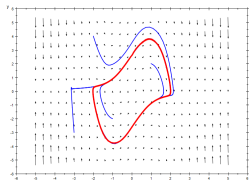
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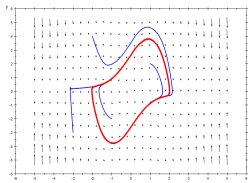
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Kuramoto, Springer 1984

- Interactions $\mathbf{q}_i(\phi_i, \phi_j)$ – Synchronization, Directionality, Coupling Function

Coupling Function

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Coupling Function

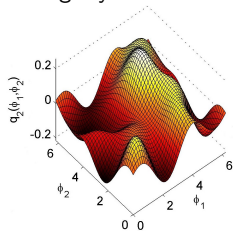
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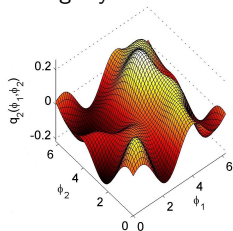
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- *Unified and systematic* way of describing mechanisms

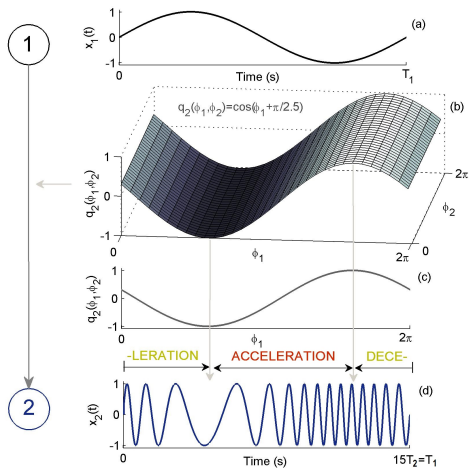


Coupling Function II

- Schematic example

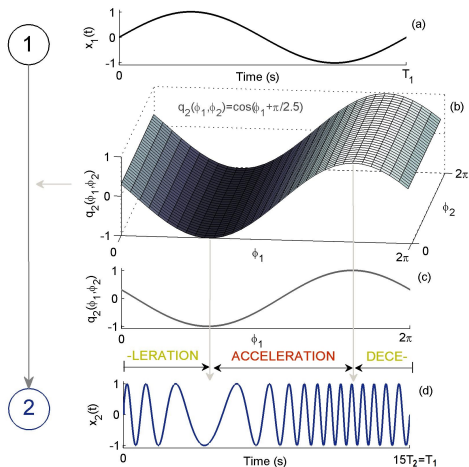
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- Increasing interest: chemistry, biomedicine, mechanics, encryption

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- How to treat biomedical oscillations?

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- Three types of connectivity - **structural, functional and effective**

Dynamical Bayesian Inference

- *Dynamical inference* – reconstructing a model in terms of differential equations from an analysis of time-series

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Time-series from noisy interacting systems



Bayesian inferential framework



Time-varying parameters



Synchronization

Directionality

Coupling function

Dynamical Bayesian Inference II

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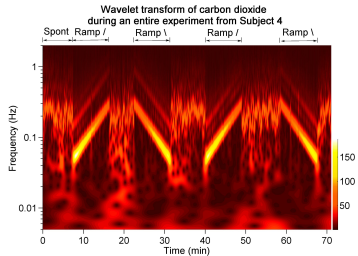
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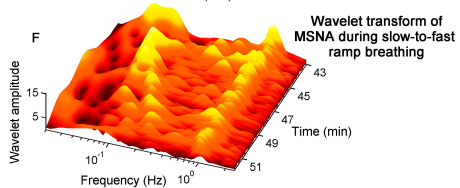
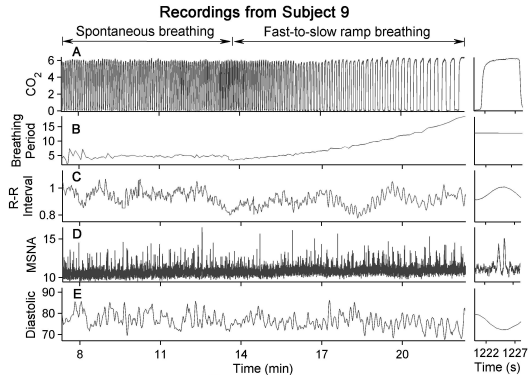
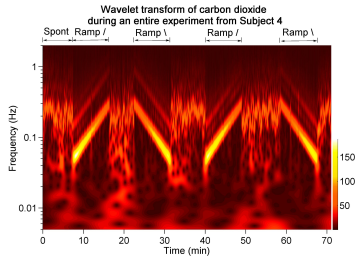
Details in:

Stankovski et al, PRL (2012)
 Smelyanskiy et al, PRL (2005)
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Ramp-breathing protocol



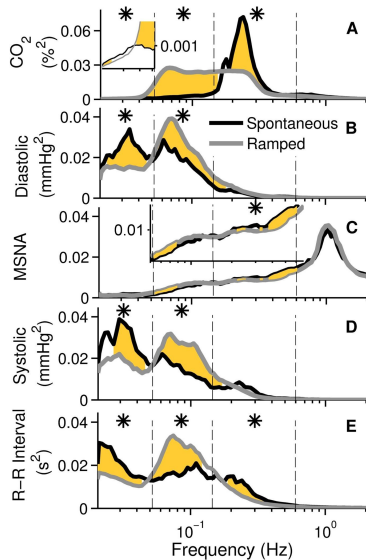
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Wavelet power

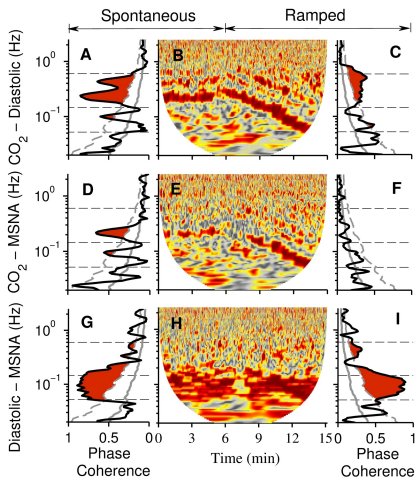
- spontaneous vs. ramp
- significant differences across broad frequency intervals
- large differences at *very-low frequencies (bellow the ramps)*
- cardiovascular coupled oscillators – possible reason

Median wavelet power for all subjects

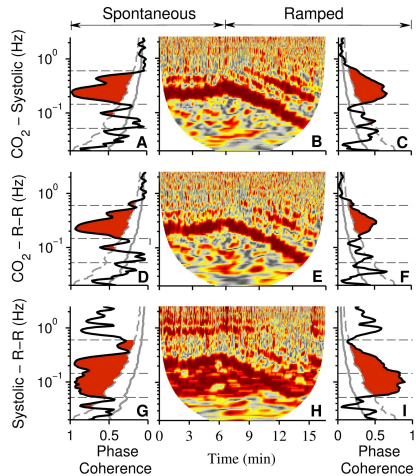


Wavelet phase coherence

Wavelet phase coherence from Subject 9



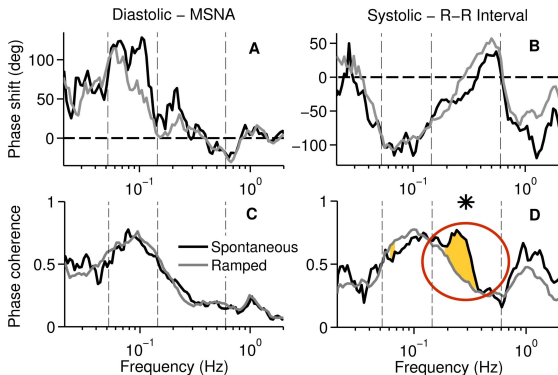
Wavelet phase coherence from Subject 9



Wavelet phase coherence – group results

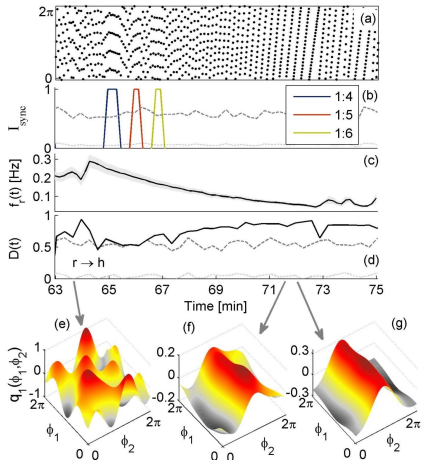
- MSNA-Diastolic *high* and not changed
- Systolic-RR changed around the breathing frequencies

Median wavelet phase shift and phase coherence for all subjects



Cardiorespiratory interactions

- Human CR measurements with ramped breathing
- inferred ramped respiration frequency
- time-varying respiration-to-heart directionality
- intermittent synchronization transitions
- complex *time-varying* form of the coupling functions



Cardiorespiratory interactions II

Video available on:

<http://journals.aps.org/prl/supplemental/10.1103/PhysRevLett.109.024101>

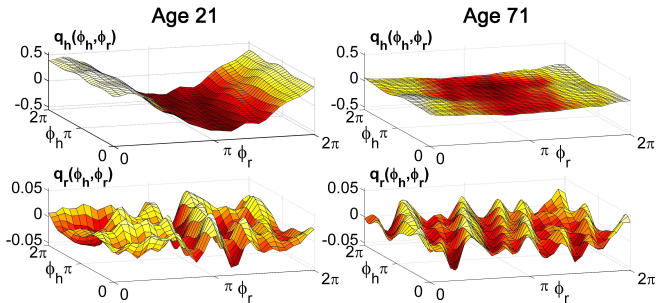
Stankovski et al, PRL (2012)

Cardiorespiratory interactions and ageing

- Evolution of cardiorespiratory interactions with age

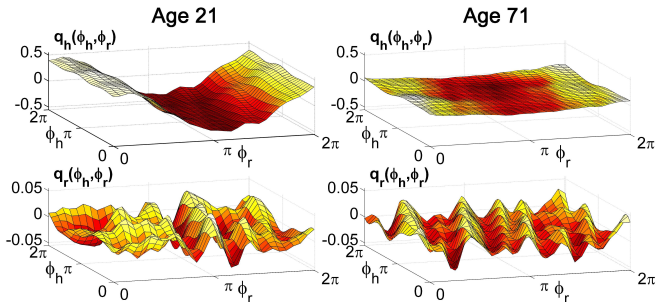
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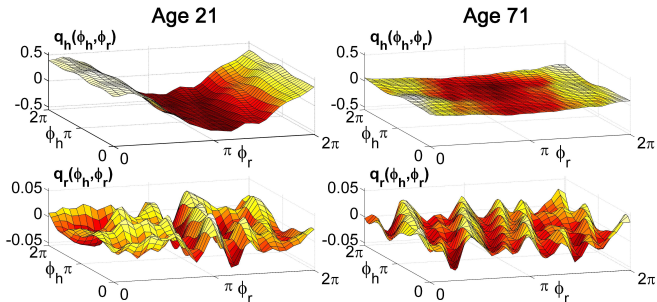
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Neuronal cross-frequency coupling functions

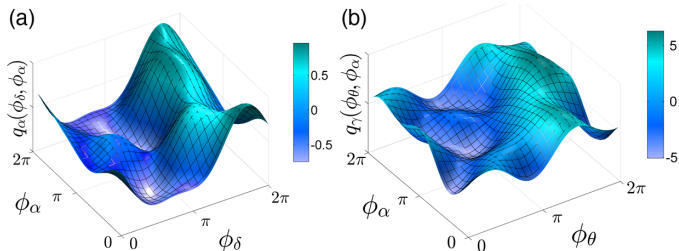
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- Coupling functions and brain dynamics
- Inference of multivariate 5-oscillator network including $\delta, \theta, \alpha, \beta, \gamma$ EEG brain waves (anaesthesia)

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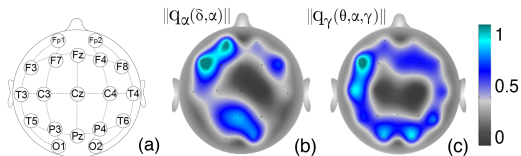
δ - α coupling function; θ - α - γ triplet coupling function;

Neuronal cross-frequency coupling functions II

- Analysis of coupling function from multi-channel EEG (autism)
- International EEG 10-20 system

Neuronal cross-frequency coupling functions II

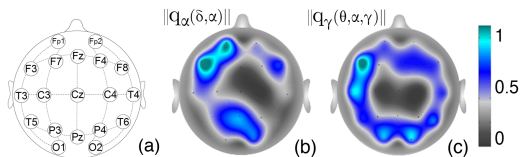
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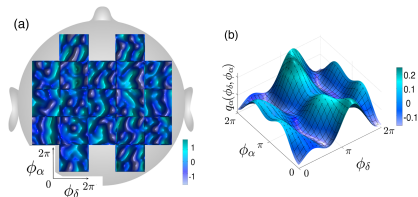
Coupling strength

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Coupling strength



Group and average coupling function

Other (more purely physical) applications

- Theory and methods for coupled oscillators

Stankovski et al, PRE (2014)

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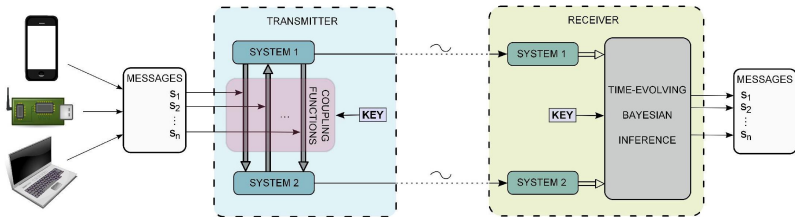
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- Example - from cardiorespiratory interactions to secure communications



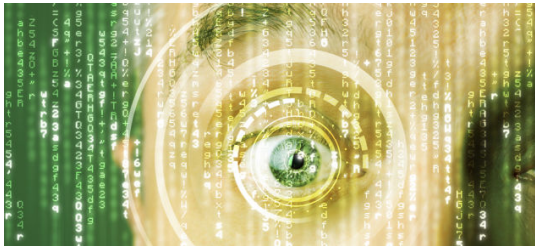
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Secure communications

- Subject to patent application GB1314114.8, WO2015019054A1

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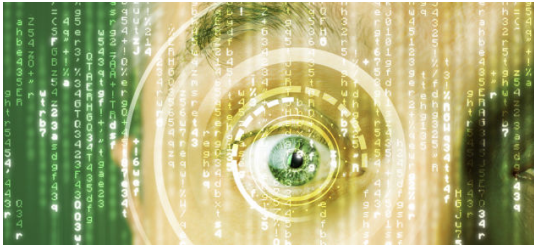
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New "Unbreakable" Encryption Is Inspired By Your Insides

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- Two small UK-EPRSC projects for implementation of hardware and software prototypes

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- Plans to link the work with *images from nuclear medicine* – exploiting dynamical changes e.g. of the heart

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Toolbox download from: <http://py-biomedical.lancaster.ac.uk> or email: t.stankovski@ukim.edu.mk

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Thank you for the attention!