Brain, Respiration & Cardiac Causalities in Anaesthesia

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Anaesthesia

"...the anaesthetist is still unable to measure the depth of anaesthesia in order to prevent inadvertent awakening during anaesthesia."

Author	Date	Sample	Awareness %
Hutchinson	1960	656	1.2
Harris	1971	120	1.6
McKenna	1973	200	1.5
Wilson	1975	490	0.8
Liu et al	1990	1000	0.2

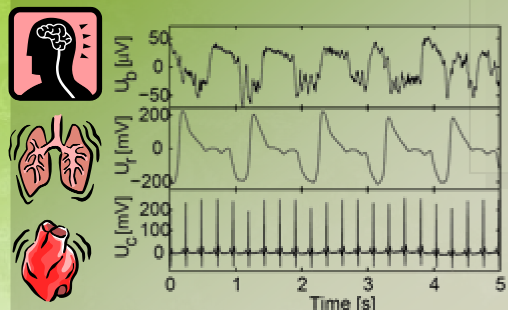
In anaesthesia a chemical perturbation of the organism leads to a temporary loss of consciousness, but just how this happens remains to a large extent of mystery. Perhaps on account of this lack of deep understanding, there are not yet any reliable markers for depth of anaesthesia.

It is perhaps not surprising, therefore, that the incidence of awareness among patients undergoing surgery is nonzero. The problem can be particularly severe in cases where for clinical reasons the anaesthesia is kept as light as possible, and where a patient is unable to give any voluntary indication of awareness.

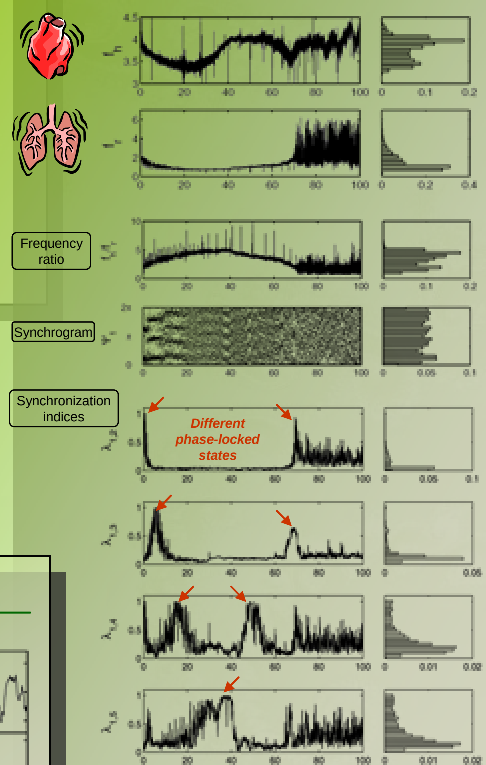
A well advertised approach to assessment of depth of anaesthesia is the bispectral index technique known as BIS. But Its use is controversial and it is certainly not 100% accurate.

So, a reliable approach is needed!!

Measurement



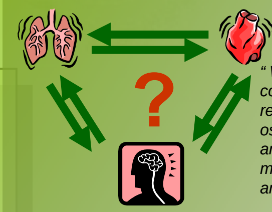
Cardiac and Respiratory systems



There is abundant evidence favoring the perception of the cardio-respiratory system as a noisy dynamical system that behaves like a collection of coupled oscillators. These oscillators synchronize in a hierarchy of different phase-locked states. During the course of anaesthesia, transitions between different phase-locked states are found to occur in a reproducible sequence, suggesting that the state of synchronization may provide a potentially useful measure of the depth of anaesthesia at any moment .

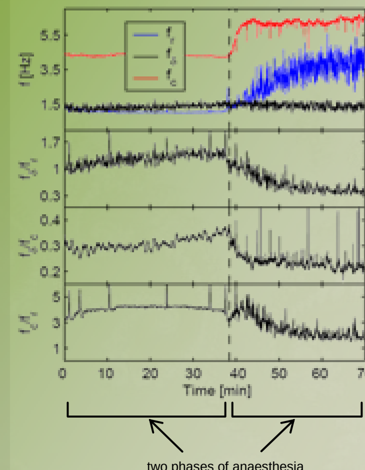
These results have been obtained from measurements on rats. Given the similarities in cardio-respiratory dynamics and in other characteristic frequency ratios between humans and rats, it seems plausible that similar results may also apply to humans.

Cardio-Respiratory-Cerebral System



" We want to know how the couplings between cardiac, respiratory and cerebral oscillators change during anaesthesia in order to measure the depth of anaesthesia. "

• Frequency analysis



In order to reduce the effects of noise and artifacts by concentrating on the information of primary interest, the resultant time-series were preprocessed prior to analysis by selecting out the frequency bands of interest.

The EEG power spectrum is conventionally divided into several frequency bands: δ(0.5–3.5 Hz), θ(3.5–7.5 Hz), α(7.5–12.5 Hz), β(12.5–25 Hz), γ(25–100 Hz).

The frequency ratios all underwent changes at the transition.

During the deep phase of anæsthesia, the δ/respiration ratio fδ/fr remained close to unity, suggesting some possibility of synchronization.

But it was impossible to reveal any synchronization between waves and respiration, despite their closeness in frequency. This conclusion was tested and confirmed.

Therefore the analysis was extended to seek evidence of interactions and causal relationships between them.

For inferring the directionality of coupling we used two independent methods, based on: (i) phase dynamics; and (ii) information theory.

To effect the latter, we consider phase increments, and define the conditional mutual information. And then define a directionality index.

d1,2 should be positive if the driving from system 1 to system 2 prevails, and negative for the opposite case.

These results have also been obtained from measurements on rats.

• Interaction analysis

- Phase increments:

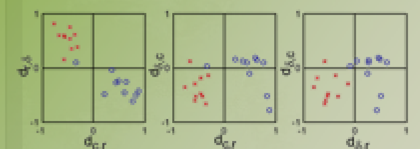
$$\Delta_\tau \phi_{1,2} = \phi_{1,2}(t+\tau) - \phi_{1,2}(t)$$

- Conditional mutual information:

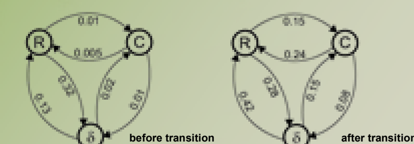
$$I(\phi_1(t);\Delta_\tau\phi_2 \,|\phi_2(t)) \quad and \quad I(\phi_2(t);\Delta_\tau\phi_1 \,|\phi_1(t))$$

- Directional index

$$d_{1,2} = \frac{i(1\to 2) - i(2\to 1)}{i(1\to 2) + i(2\to 1)} = \frac{I(\phi_1(t);\Delta_\tau\phi_2|\phi_2(t)) - I(\phi_2(t);\Delta_\tau\phi_1|\phi_1(t))}{I(\phi_1(t);\Delta_\tau\phi_2|\phi_2(t)) + I(\phi_2(t);\Delta_\tau\phi_1|\phi_1(t))}$$



Averaged directionality indices calculated before(X) and after(O) the deep/light transition



Schematic diagram of 3-oscillator model of mutual interactions

Project Goal

The synchronization indices of cardio-respiratory system can be also seen when cardiac and respiratory activity interact in a similarly causal way during the forced ventilation often employed during surgery. Therefore, combining the brain system, we consider a network of three oscillators. In this poster, frequency analysis and one way of interaction analysis are shown.

The aim of this project is to find out other methods to analyze these interactions between three oscillators and find out some other indices to define the depth of anaesthesia in order to create a reliable measure of depth of anaesthesia by combining several such indices.

Results on this poster are obtained by *Group of Nonlinear Dynamics and Synergetics, University of Ljubljana, Slovenia*