CARDIOVASCULAR VARIABILITY SIGNALS : TOWARDS A QUANTITATIVE ASSESSMENT OF THE COMPLEXITY OF AUTONOMIC CONTROLLING SYSTEMS WITH NOVEL APPLICATION TOOLS

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Biological signals carry *information* about the physiological systems under studying. The processing of signals allow: i) to *quantify* and ii) to *qualify* such information (for validating *physiological modelling*) mainly through mathematical tools







Modeling of cardiovascular signal interactions



from **Baselli G et a**l, IEEE Trans BME, 1988



Sympathetic (red lines) and parasympathetic (blue line) nervous systems

A PROBE TO ANS ASSESSMENT

Cardiovascular Signals







Variability Signals



Pathology of organs

 \mathcal{VS} .

Pathology of controlling systems

Dynamical diseases

What are these HRV signals telling us?



Healthy

Congestive heart failure

Atrial fibrillation



HEART RATE VARIABILITY DISSEMINATION

- About 12000 papers in MedLine
- The 3rd most-frequently-cited paper in *Circulation*: Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology:" Heart Rate Variability : Standards of Measurement, Physiological Interpretation, and Clinical Use, Circulation, 1996 93: 1043-1065
- The 6th most-frequently cited paper in *Circulation Research*: M Pagani, F Lombardi, S Guzzetti, O Rimoldi, R Furlan, P Pizzinelli, G Sandrone, G Malfatto, S Dell"Orto, E Piccaluga, G. Baselli, S.Cerutti, A.Malliani, Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog, Circ Res, 1986 59: 178-193

INTEGRATION

INTEGRATION BETWEEN PHYSIOLOGICAL MODELS AND DATA & SIGNALS TREATMENT
INTEGRATION OF INFORMATION FROM SIGNALS AND IMAGES FROM ≠ SYSTEMS, WITH ≠ MODALITIES, ON ≠ SCALES.... (COMPLEMENTARY) TO IMPROVE:
i) PHYSIOLOGICAL KNOWLEDGE OF SYSTEM/S
ii) CLINICAL PROCEDURES (diagnosis, therapy and rehabilitation)

Next step: Transesophageal RT3DE



3D Point- tracking technique



3D Papillary muscles Analysis



3D manual navigation of the dataset, with recognition of papillary muscle tips and computation of distances and angles

COMPLETE GEOMETRICAL MODEL



Characteristics

- Leaflet inclinations: anterior=8°,posterior=7°
- 82 insertions on free margin, 42 insertions behind leaflet borders, 13 insertions of 3° order.
- Transversal section of cordae from literature
- Commissural zone with intermediate width in repect to the two leaflets.

• Every papillary muscle is indicated by one single point and the leaflet amplitude may be changed according to the clinical observations

Results: map of main strains



Results: map of main strains



Example (Memo3D - Sorin)



Analysis of dynamic matching between aorthic and mitral annuli



[Veronesi et al.: Circulation, Cardiovasc. Imaging 2008

SLEEP INTENDED AS AN EXAMPLE OF MULTIORGAN INVOLVEMENT

Sleep is classically segmented in stages on the basis of the EEG signal and also of EMG and EOG (macrostructure of sleep)

• REM sleep (rapid eye movement)

• NREM sleep (stages 1-4 according to the sleep depth) Rechschaffen A and Kales A. A manual of standardized terminology, techniques and scoring system of sleep stages of human subjects. US Government Printing Office: Washington Public Health Service, 1968.

➢Also the autonomic control on heart rate was found to be correlated to the sleep stages

Background - sleep stages



Background - sleep

> Obstructive Sleep Apnoea pathologies



Collapse and total occlusion of the ainway during apnea The ainway in people who have obstructive skeep apnea collapses during skeep.

Insonnia



- ➤ nasal flow
- Abdominal efforts
- ➢ Heart rate
- ➤ oxymetry

- ➢ hypnogram
- Central Arousal

SLEEP FRAGMENTATION

- restorative effects
- Physiologic changes
- Sympathetic hyperactivity



Hypertension/Ischemia/Heart Falure

overwork of the heart
 low adaptability to
 endogenous stimulus



Diurnal Consequences

STAGE 2 CAP MC



More complex physiological phenomena still to be completely explained

Sleep Apnoea



Somers 1995





An important challenge:

 Is it possible to properly detect Sleep Parameters and classify Sleep Properties (important for the neurophysiological and clinical aspects) on the basis of ECG & derived signals only (mainly RR intervals) ? Cyclic recurrence of peak sympathetic activation during REM sleep, increasing from the second non-REM/REM cycle towards the early morning hours.







Parameter extraction

Classification stage



7 Beat-to-beat features Mean over 30 sec Classificator HMM (REM/nonREM/awake)



24 subjects HSE (San Raffaele Hospital Sleep Centre, Milano):

Accuracy 80%, SP 85%, SE 71%

MO Mendez et al.,. Int J Biom Engin & Tech, 2010

Automatic classification (R&K) Mean accuracy (70 - 90% in normal subjects, 65 - 87% in sleep disturbances Mean agreement among different examiners (87,5%)

The Society of Information



Wearable system

It detects and monitors data and signals with an improved comfort degree for the user in respect to portable monitoring systems
Goal: to realize non-intrusive systems which do not interfere with the daily activities of monitored subject



Wearable vs portable







Examples of textile electrodes





- Textile fibers with electroconductive properties
- Conductive fibers mixed to natural or synthetic yarns
- Electroconductive yarns



ECG monitoring



- Contemporaneous acquisition of 5 ECG leads:
- Pseudo Einthoven Leads: I, II, III
- Precordial leads: V2, V5



Respiration through impedenzometric sensors



4 thorax electrodes: injection of 50kHz current into the external electrodes. The ratio between the potential difference from the internal electrodes and the current provides the modulus of impedance.

Measurement of respiration through piezoresistive electrodes



Thoracic and abdominal respiration signals

Electrode-skin contact improvement



Electrode-skin contact

My-Heart EU VI Framework Programme Advanced ICT tools

- User interfaces
- Textiles
- Electronics
- Algorithms
- System integration







Wake up 07:00 Activity index 45 (75) Coffee max 3 cups



• Testing

TakeCare: Risk Management modules

•Focus area @ home

Sleep quality improvement

Stress management

Daily activity management

Weight management



Smartex —

Sleep Signal Acquisition

• Bed Foil (VTT)



Bed Sensor with 8 channel piezo foils

SLEEP STUDIES









Bodily accellerometer



Sleep fragmentation index



Sleep Fragmentation Index (SFI)

SFI = 3^* (No. Arousals in TST 1/3) + (No. Arousals in TST 2/3) + 0.33^* (No. Arousals in TST 3/3).

| SFI < 70 | 70 < SFI < 100 | SFI > 100 |
|----------|----------------|-----------|
| GOOD | MODERATE | BAD |



Application: behavioural therapy for insomnia



Energy expenditure (black-box O₂ consumption)



With classification information

Without classification information

- Signal magnitude and Pressure Gradient are the model inputs.
- Oxygen Uptake $(mlO_2/(Kg*min))$ is the model output.
- The classification information is used to improve the model performance.

Energy expenditure Using Triaxial Accelerometers and Barometric Measurements, Voleno M. et al., IEEE-EMBS Conference, Buenos Aires, 2010

PSYCHOPHYSICAL STRESS







Relaxation



HeartCycle (HF and CAD) (2008-2011)



Psyche (Bipolar Disorder) (2010-2013)



BIOSIP Lab, Bioengineering Deptm, Milano None of us is as good as all of us !!



Baselli



Caiani



Cerutti



Mainardi



Bianchi



Signorini

