A Wearable Technology Revisited for Cardio-Respiratory Functional Exploration: Stroke Volume Estimation From Respiratory Inductive Plethysmography

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INTRODUCTION

✓ Continous monitoring of vital and behavioral signs is an emerging concept of healthcare
✓ Wearable technology should provide a new way for non invasive and performing functional exploration tools
✓ The indirect nature of measurements generates a complexity in the signal due to multiple physiological interactions
⇒ **We aim to extract new information from these physiological interferences**

✓ Respiratory Inductive Plethysmography (RIP) already tested for respiratory rate monitoring and also used for ventilatory function assessment
⇒ **We aim to assess the estimation of cardiac parameters from the respiratory signal**

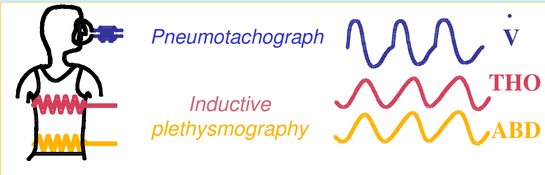
⇒ **We propose an integrated physiological tool to study cardio-respiratory (CR) interactions**

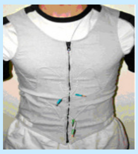
MATERIAL

Subjects : 4 healthy volunteers (with informed consent)

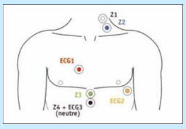
Protocol : Spontaneous calm respiration (10 min) while sitting

Simultaneous recorded signals (Sampling rate : 100 Hz)
✓ Electrocardiogram
✓ Airflow with pneumotachograph (2 last minutes of recording)
✓ Thorax and Abdomen cross sectional area changes with a computer-assisted RIP vest (Visuresp®, RBI, France)





✓ Stroke volume values (SV_{ICG}) estimated from a thoracic electrical bioimpedance signal (PhysioFlow™, Manatec Biomedical, France)

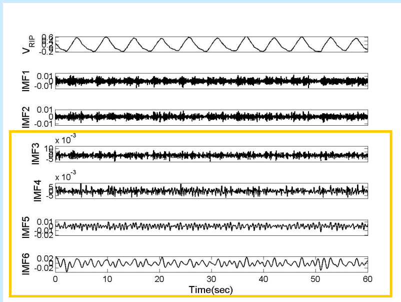


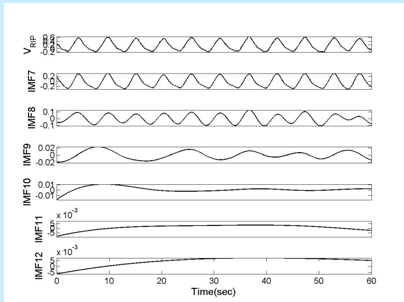
METHODS

✓ Reconstruction and calibration of a CR signal V_{RIP} from the airflow and the abdomen and thorax cross sectional area changes, using a least square method (Eberhard, 2001) $V_{RIP} = \alpha.ABD + \tau.THO$

✓ Low-pass filtering of V_{RIP} (F_c = 10 Hz) to remove high-frequency noise

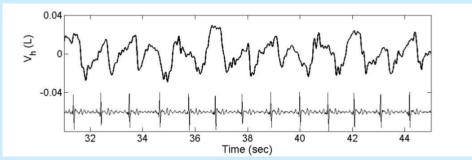
✓ **C**omplementary **E**nsemble **E**mpirical **M**ode **D**ecomposition (Yeh, 2008) on V_{RIP}
Time-scale method derived from **E**mpirical **M**odel **D**ecomposition (Huang, 1998)
EMD : Local adaptive technique without any requirement of stationarity or linearity
Extraction of all the oscillatory modes embedded in a signal
Signal decomposition into a definite number of HF and LF components : **I**ntrinsic **M**ode **F**unctions
CEEMD : Addition of white noise before performing EMD (for uniform distribution of the scales) and average of the resulted IMF to converge towards the true IMF

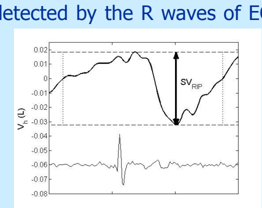




✓ Extracted cardiac signal V_h = sum of the cardiac IMF (3 to 6)

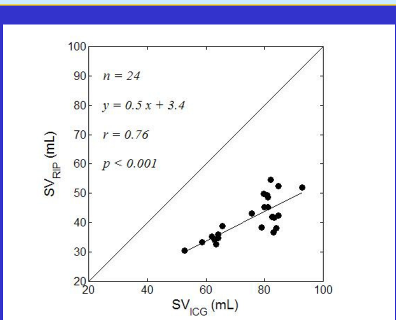
✓ Estimations of beat-to-beat stroke volumes (SV_{RIP}) = difference between maximum and minimum of each cardiogenic oscillation, detected by the R waves of ECG (Bloch, 1998)





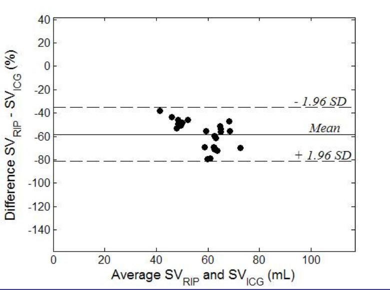
RESULTS : Comparison between SV_{RIP} and SV_{ICG}

24 sequences of 5-beats (all subjects taken together): averaged values of SV
Sequence choice: EMD efficient separation of cardiac and respiratory modes
No ambiguity to decide which IMF are cardiac



✓ **Linear regression**
Correlation satisfactory compared to other values reported in the literature

Bias (under-estimation of SV_{RIP}) due to :
- THO and ABD measures location
- Conversion into airflow of a part of the cardiac contraction



✓ **Statistical test of Bland and Altman**
Limits of agreement (**±23%**) consistent with Critchley (1999) recommending ±30% for acceptance of a new cardiac output measurement technique

CONCLUSION

✓ This validates the use of RIP for following stroke volume variations
✓ It suggests that one simple transducer can provide a quantitative exploration of both ventilatory and cardiac volumes
✓ This study is also a proof of the concept that wearable solution can bring multi-dimensional and complex information and can be used for CR functional exploration.

FURTHER STEPS

✓ Validation with more subjects and various recording protocols
✓ Validation of the beat-to-beat SV variation estimation
✓ Improvements in RIP signal processing algorithm in terms of robustness and definition of an automatic criterion for the IMF choice

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