Wearable systems for continuous monitoring of physiological parameters

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3rd Joint Workshop
Electronics for Sensors & Biomedical Applications Technologies & Sensors

Outline

- Motivation for designing wearable technologies
- Wearables attributes
- Use Cases requirements and solutions
- Future Directions

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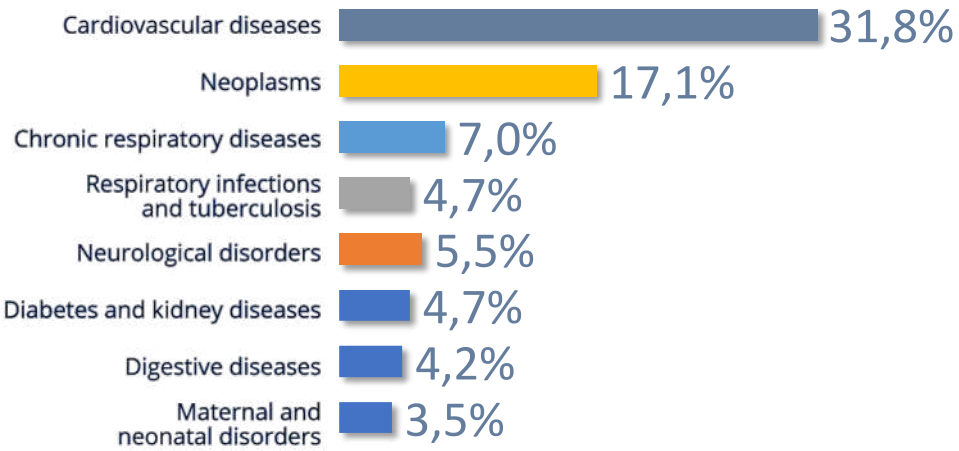
Scenario

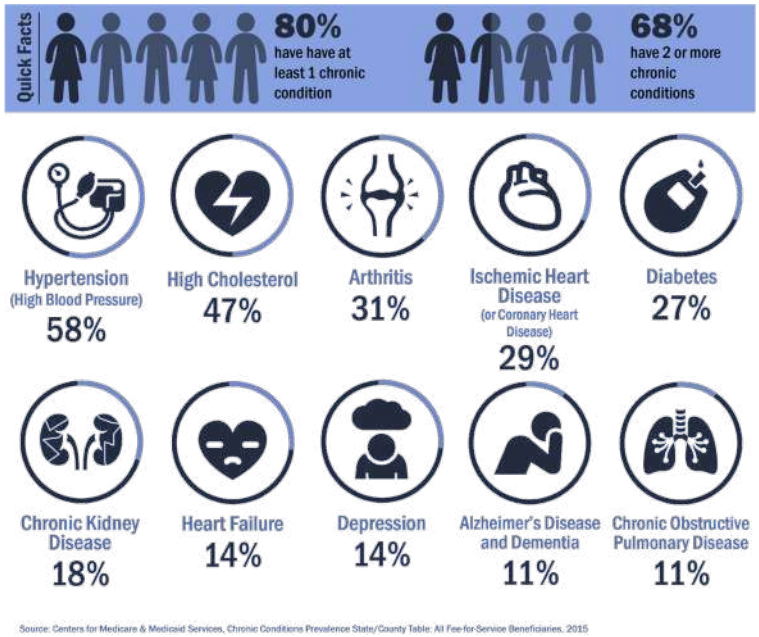
Top Global Causes of Deaths

Share of all global deaths in 2017, by most common causes



Source: World Economic Forum / Institute for Health Metrics and Evaluation

Top Chronic Conditions in Adults 65+



Source: Centers for Medicare & Medicaid Services, Chronic Conditions Prevalence State/County Table: All Fee-for-Service Beneficiaries, 2015

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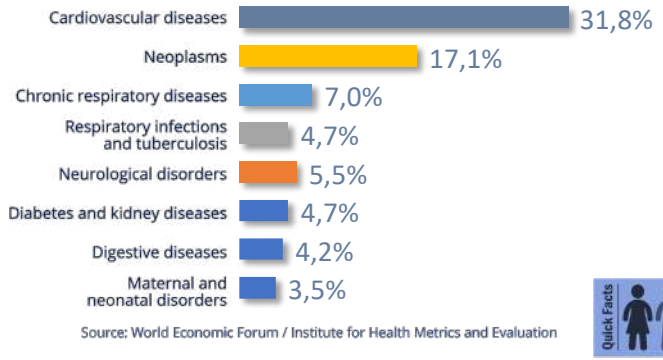
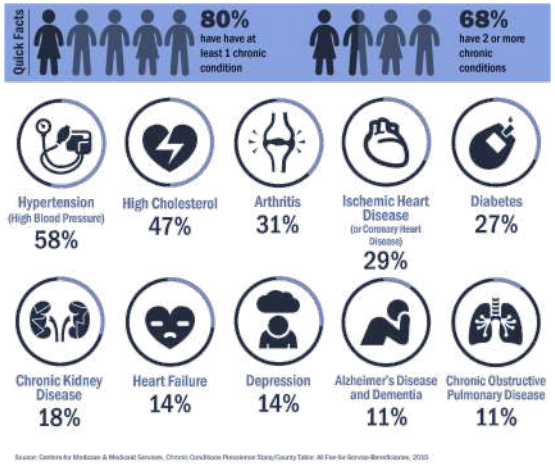
Scenario





Wearables are an opportunity

- Population Health
- Digital Biomarkers/ Signs
  - Explain – influence – predict health outcomes
  - Gain fundamental insight into disease origins
- Personalized Health

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Wearable Devices Market

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Wearable Devices Market

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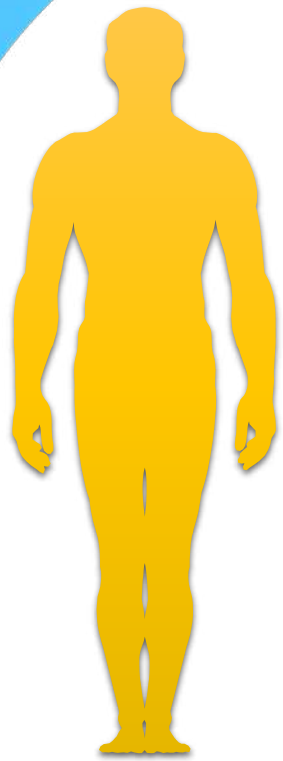
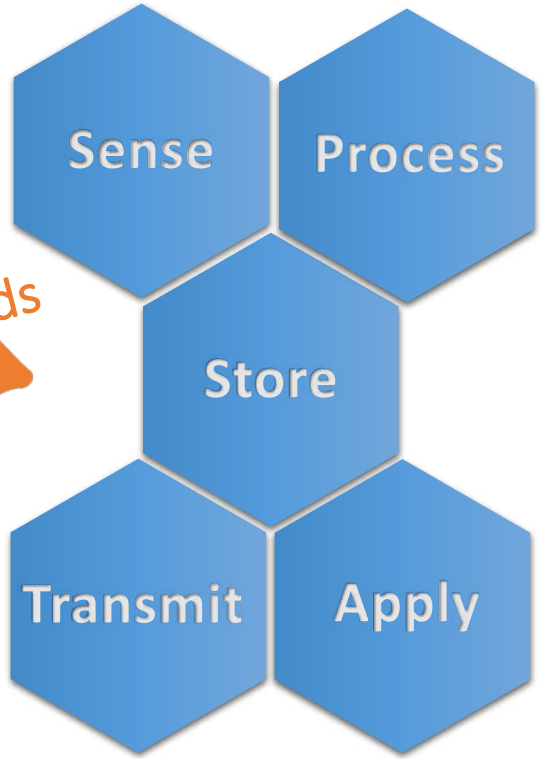
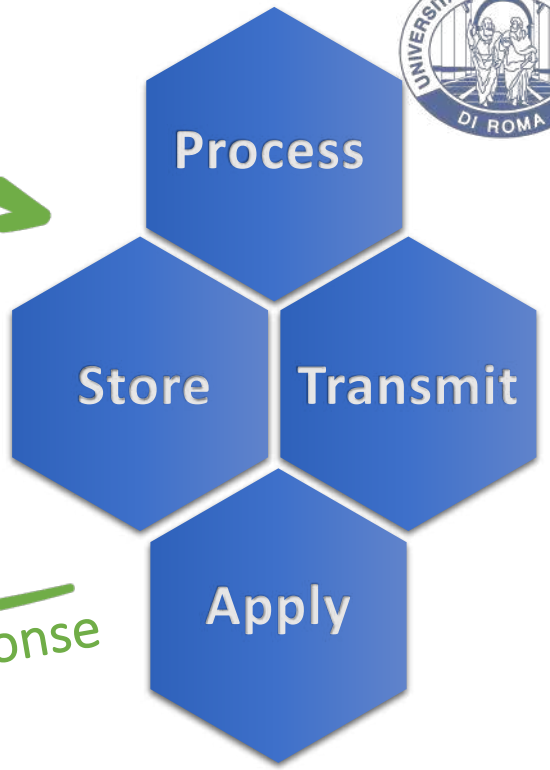


Measurands



Signal



Response

Wearable

Remote location

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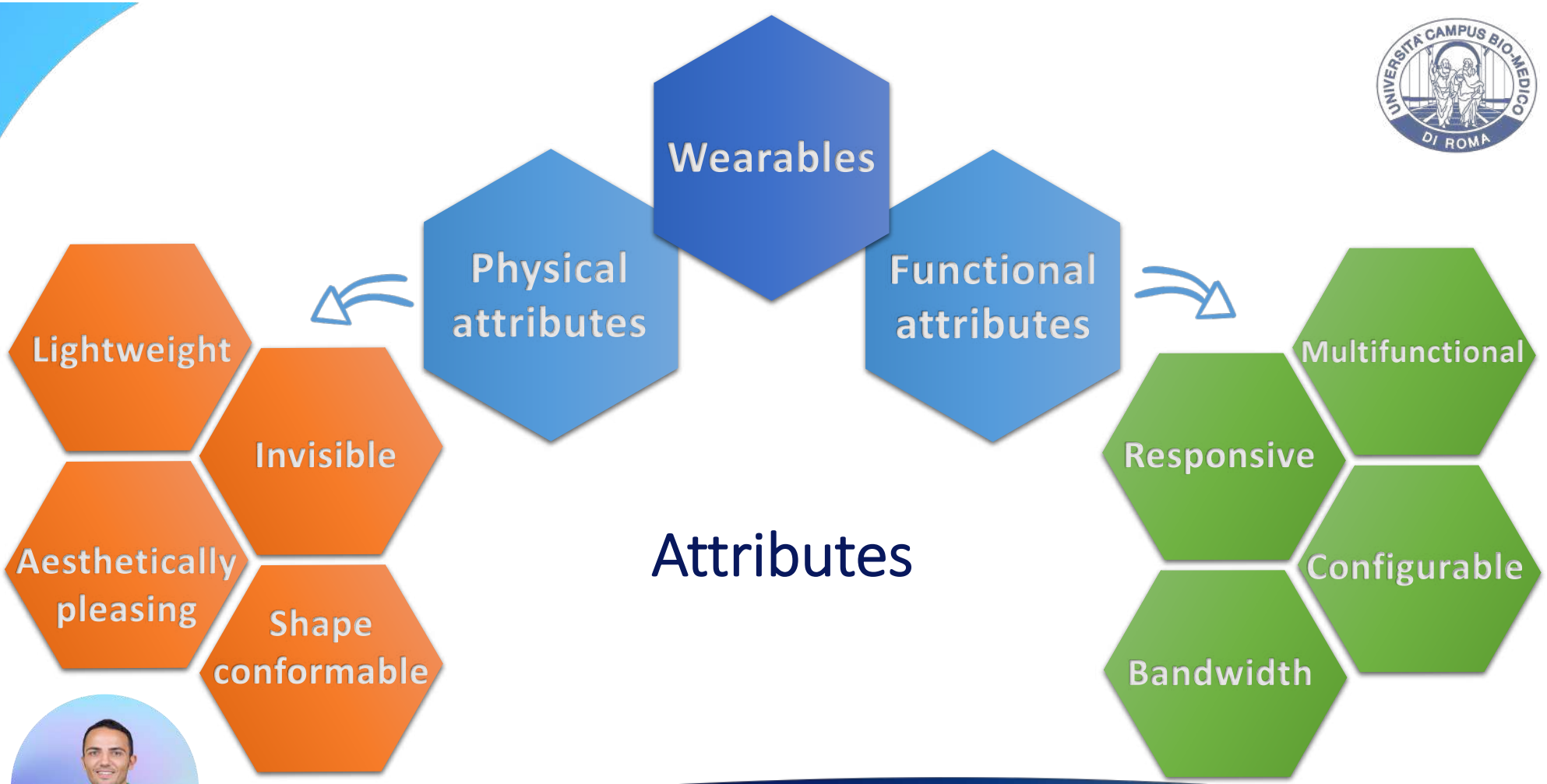
Attributes



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Human activities and vital signs

Hospital setting

Daily activities

Occupational setting

Sports

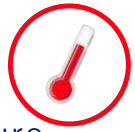
Joint kinematics

Muscle activity

Motion pattern

Heart rate

Respiratory rate



Body temperature

Blood pressure

HUMAN ACTIVITIES

PHYSIOLOGICAL VITAL SIGNS

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Human activities and vital signs

Joint kinematics

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HUMAN ACTIVITIES

PHYSIOLOGICAL VITAL SIGNS

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Data connectivity

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Standard for health data

Problem Statement

- mHealth data encompasses personal health data collected from sensors and mobile applications
- Mobile health data and metadata standards are needed
  - Each device maker / app developer decides how to represent data and metadata
  - Data are poorly specified
- Standardizing mHealth data and metadata will
  - Make data aggregation across multiple sources easier and more accurate
  - Reduce costs of using mHealth data to make biomedical discoveries, improve health, manage disease

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Targeted biomedical use cases

- Remote respiratory monitoring
- Breathing abnormalities
- Athletes performance evaluation
- Accurate cardiac monitoring without electrodes
- Adherence to the rehabilitation program
- Occupational health and Safety

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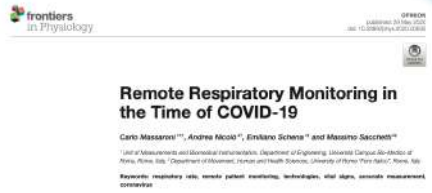
Use Case 1: Remote respiratory monitoring

There is an ever-growing demand for measuring respiratory variables during a variety of applications.

- **RESPIRATORY RATE**
- **predictor** of cardiac arrest
- **prognostic marker** for risk assessment after acute myocardial infarction
- **early detection** of the risk of the occurrence of dangerous conditions such as ***sleep apnea***, ***respiratory depression*** in post-surgical patients



RESPIRATORY RATE is overlooked and under-recorded

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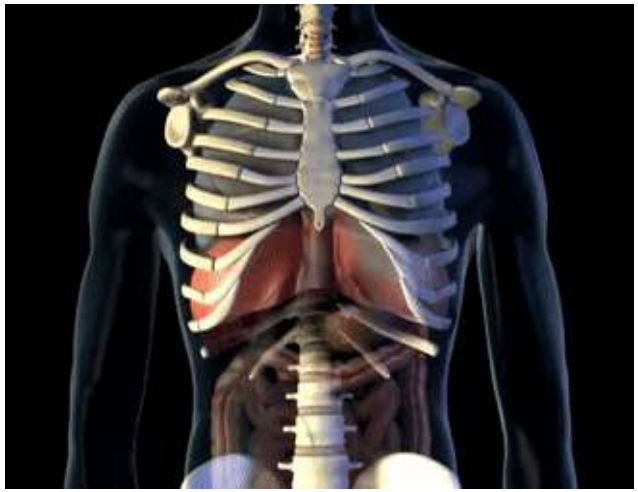
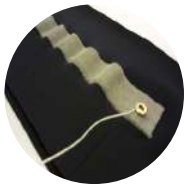
Smart t-shirt proposition

Form factor	→	smart t-shirt embdedding sensors and electronics
Sensors	→	strain sensors at the level of the torso
Sampling	→	continous sampling (at least 30 Hz)
Real-time	→	robust/low power communication



Strain Sensors



Conductive
(resistive sensors)

Fiber Optics
(Fiber Bragg Grating)

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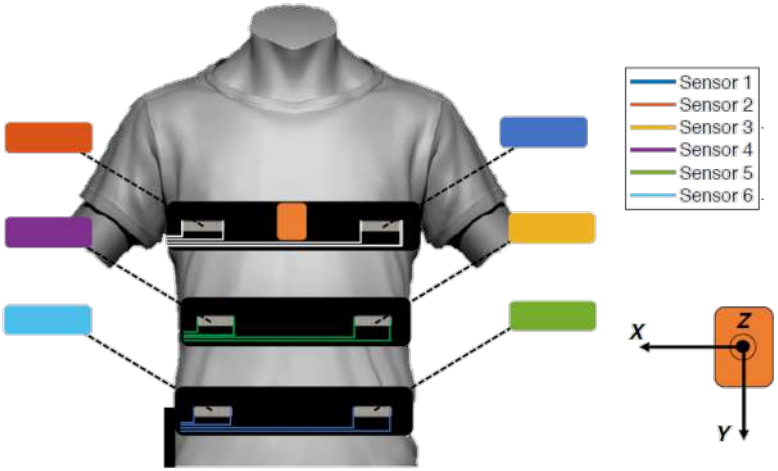
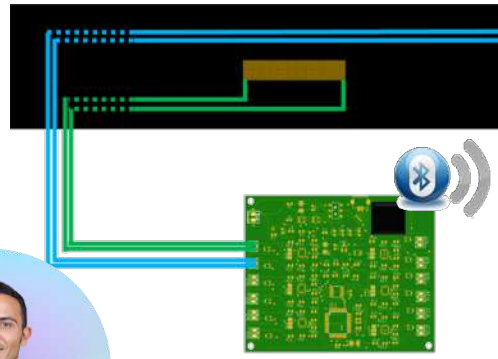
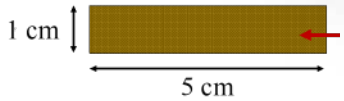
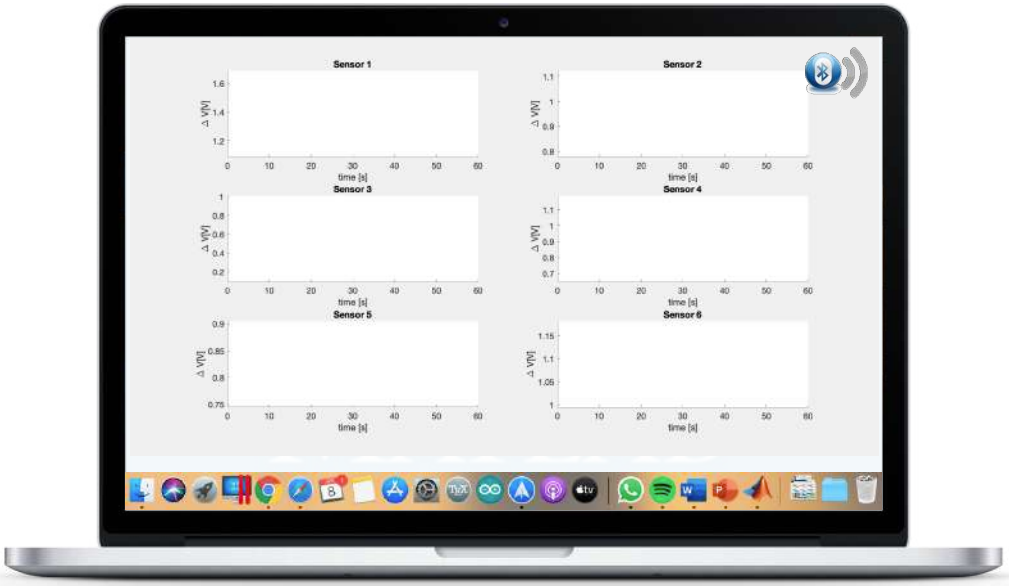
Smart t-shirt









89% silver, 11% spandex

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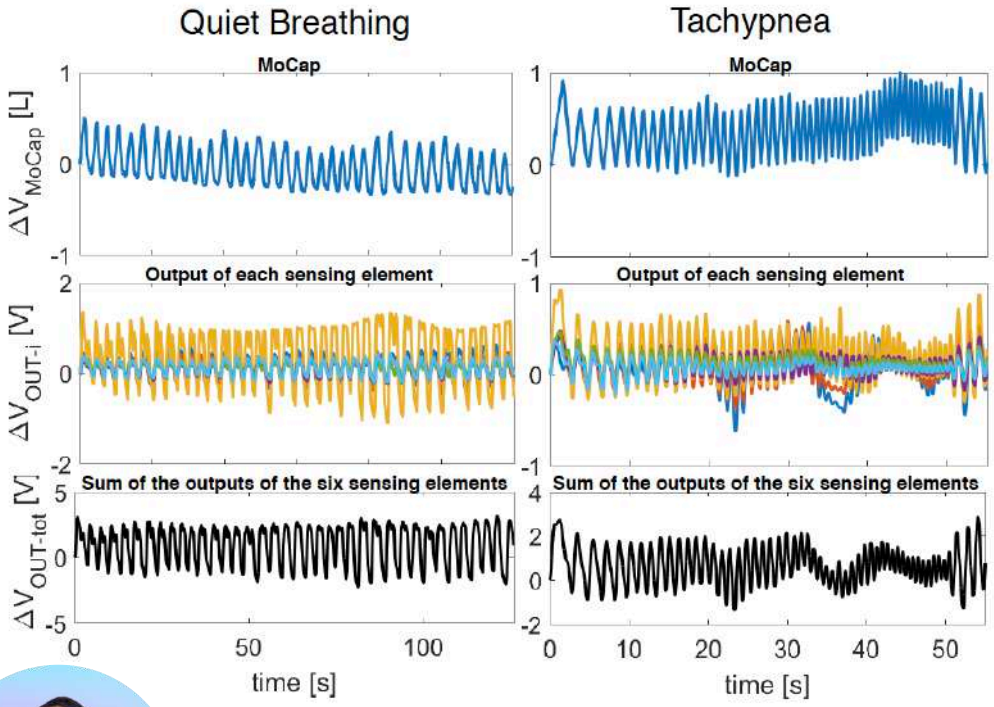
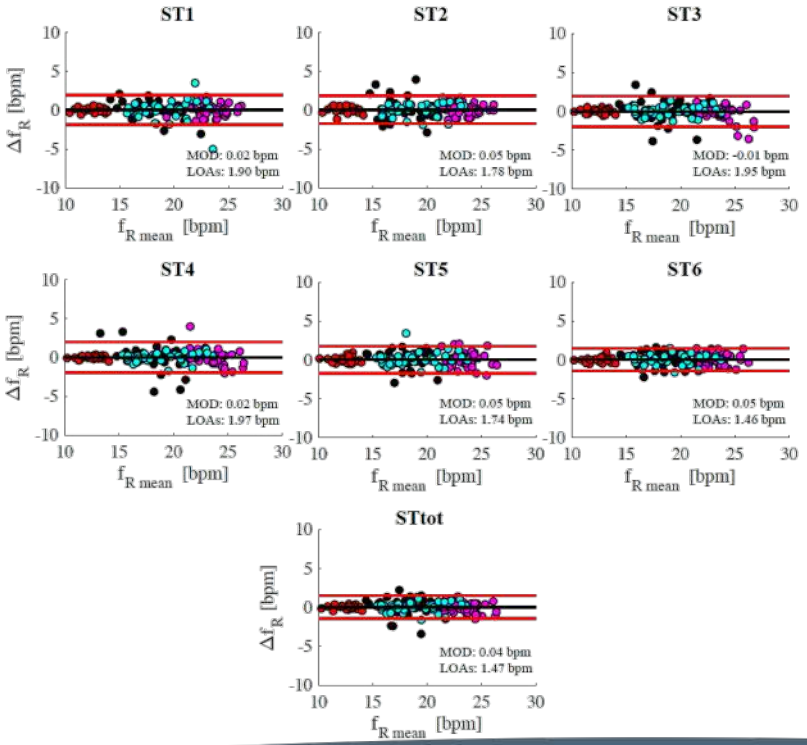
Smart t-shirt – B-by-B analysis





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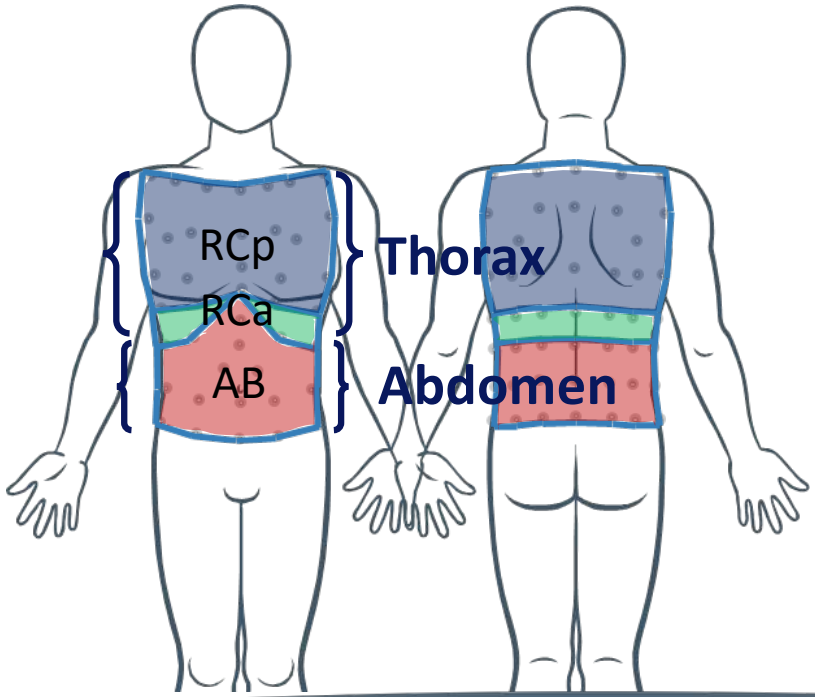
Use Case 2: Breathing abnormalities

Normal breathing involves synchronized motion of the upper rib cage, lower rib cage, and abdomen.

- **ABNORMAL BREATHING**
- No optimal use of muscles
- Desynchronization between upper and lower compartments
- Musculoskeletal pain
- Need for respiratory rehabilitation



BREATHING BIOMECHANICS is difficult to assess with wearables

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Smart garment proposition

Form factor	→	smart t-shirt embedding sensors
Sensors	→	Extremely sensitive strain sensors at the level of the torso
Sensors position	→	Extremely important
Sampling	→	Continuous sampling (at least 30 Hz)
Real-time	→	Robust communication

Strain Sensors

Fiber Optics
(Fiber Bragg Grating)

Multi-sensor measurement chain
12 FBGs in 2 fibers

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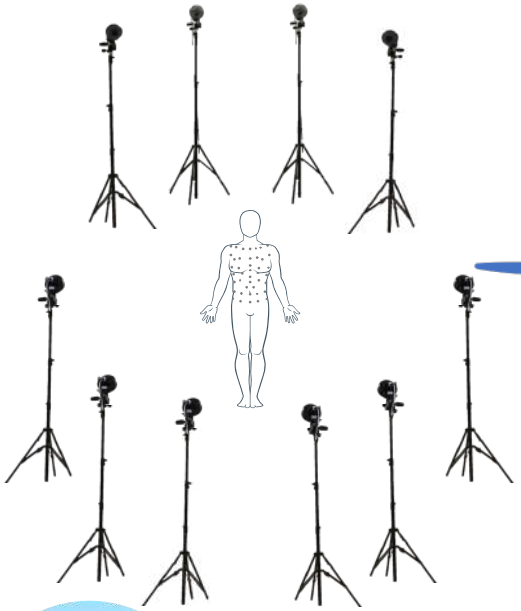
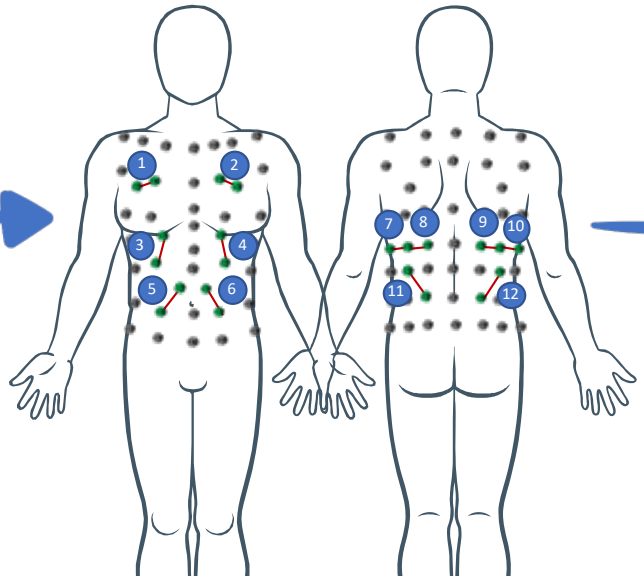
Sensors positions

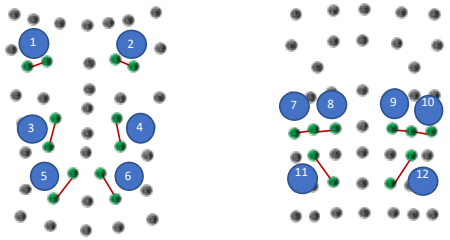
Analysis with cameras and markers



Analysis of chest wall strains



Design of sensors



1 λ_B=1533nm
2 λ_B=1533nm
3 λ_B=1537nm
4 λ_B=1537nm
5 λ_B=1541nm
6 λ_B=1541nm
7 λ_B=1549nm
8 λ_B=1549nm
9 λ_B=1557nm
10 λ_B=1557nm
11 λ_B=1545nm
12 λ_B=1545nm

Minimum distance **4 nm**

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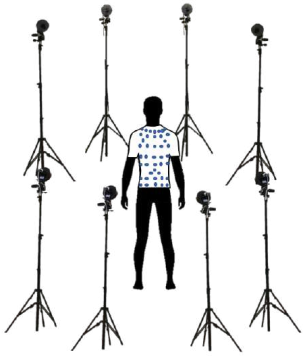
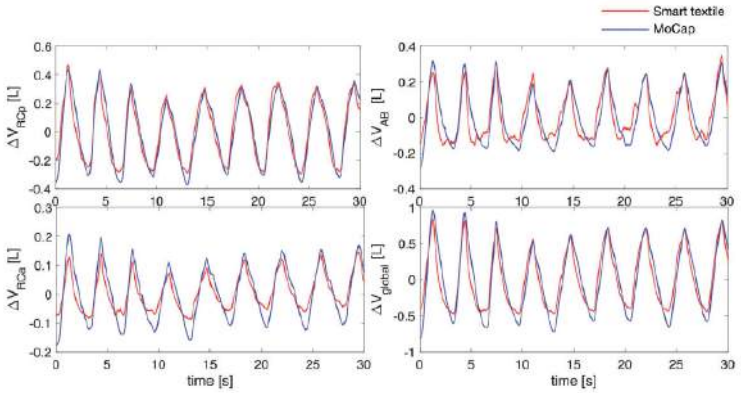
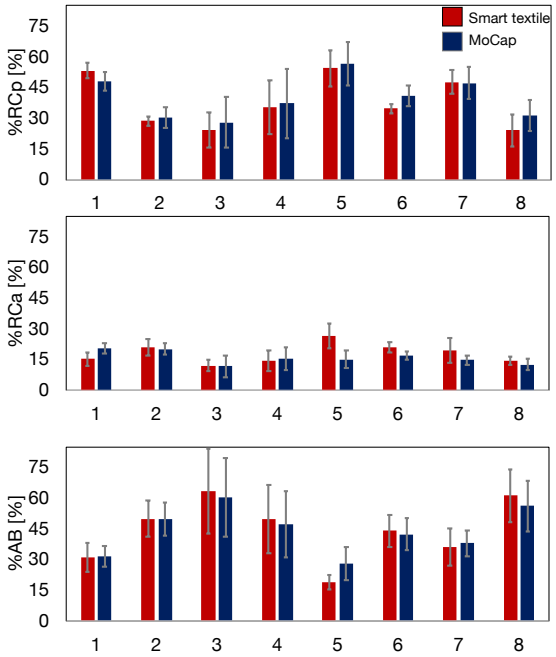
Chest wall compartments

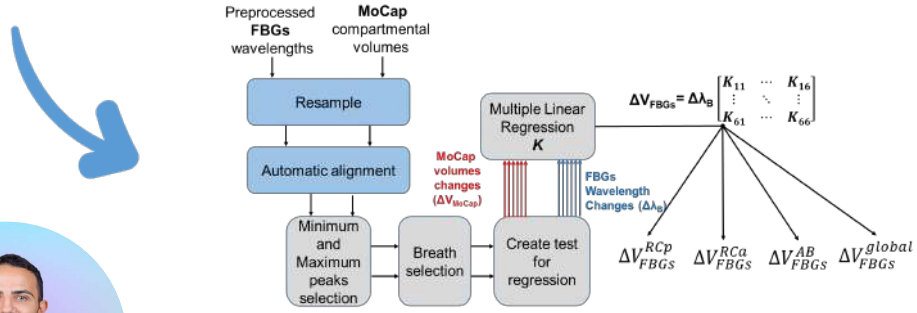
12 FBGs wavelengths changes
(trial 1)



6 MoCap Compartmental volumes
(trial 1)







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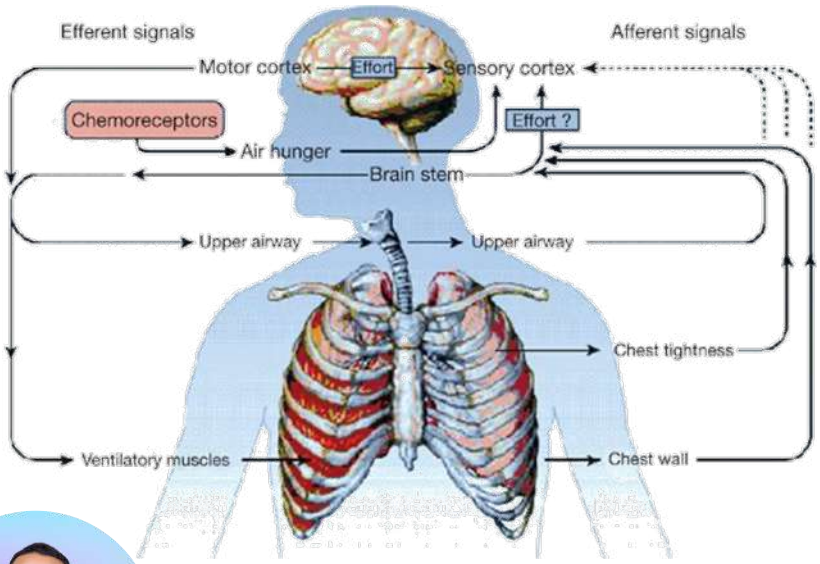
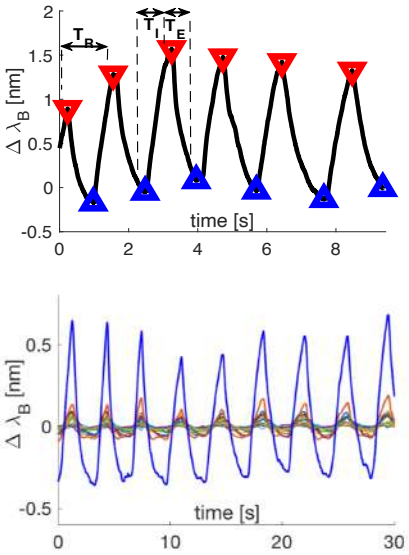
Hemiplegic patients

It has been suggested that hemiplegia caused by a lesion superior to the brain stem will impair diaphragmatic motion.





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Use Case 3: Athletes performance evaluation

Respiratory rate and heart rate are closely associated with perceived exertion in a variety of exercise conditions. They are strongly associated to the intensity of the sport gestures.

- Abrupt changes in work rate
- Physical and physiological attributes have received limited attention in predicting precision sports performance.

Different sports require dedicated hardware and adaptive algorithms for accurate measurement.

- Indoor cycling
- Running
- Archery
- Horse racing

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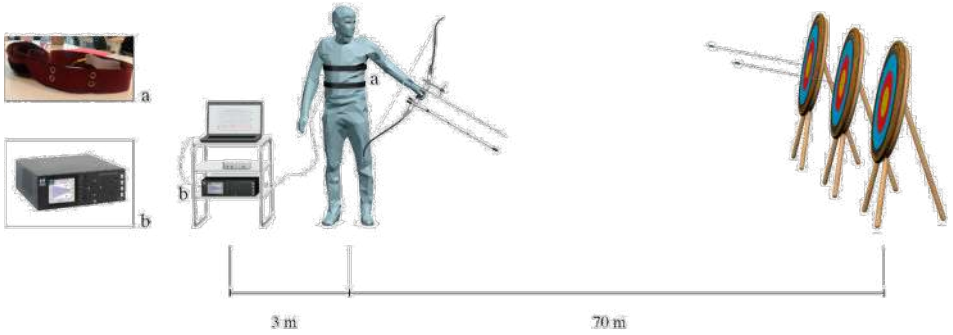
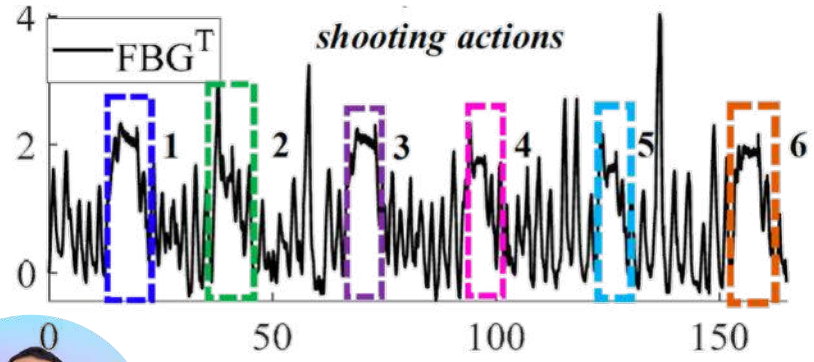
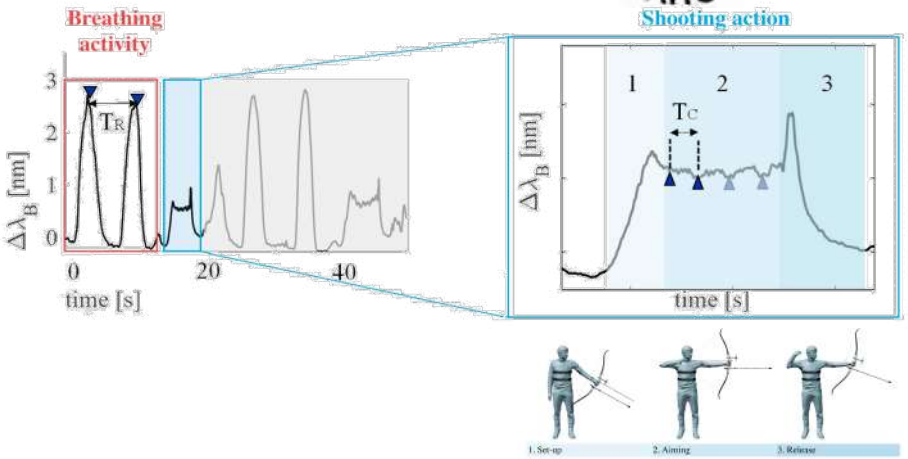
Archery



a. two elastic bands instrumented by flexible FBGs
b. FBG interrogator





Lo Presti, D. et al. Sensors, 2019, 19.16: 3581

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INAIL

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ATLETICOM WE RUN ROME 31.12.2019

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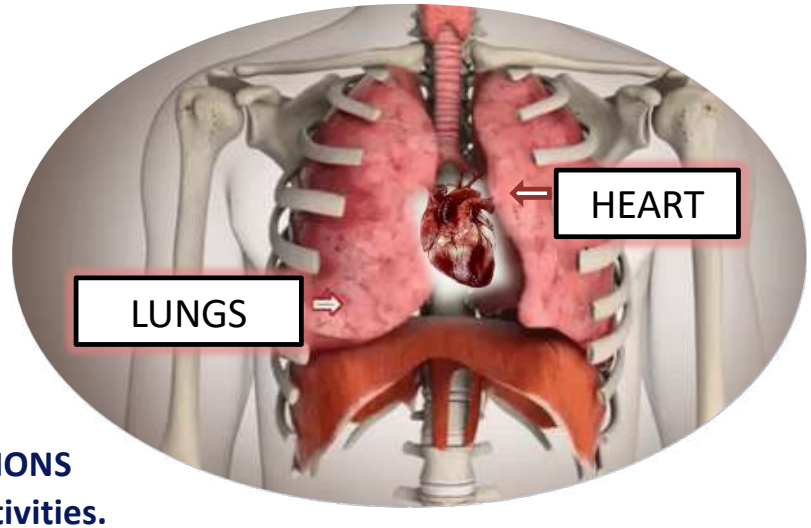
Use Case 4: Continous cardiac monitoring

"Irregular and often rapid heart rate that can increase your risk of stroke, heart failure, and other heart-related complications… and episodes." [Mayo Clinic]

- Detection requires heartbeat detection and accurate R-R interval timing
- Post-diagnosis patients still need continuous monitoring
- The knowledge of the mechanical heart activity cannot be registered with ECG



HEART-INDUCED CHEST VIBRATIONS can be used to retrieve cardiac activities.

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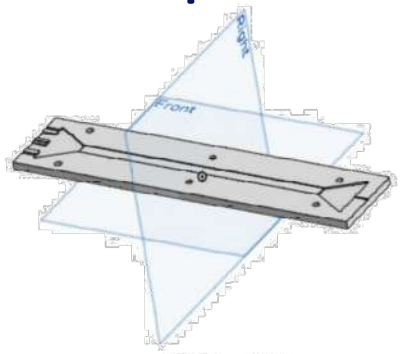
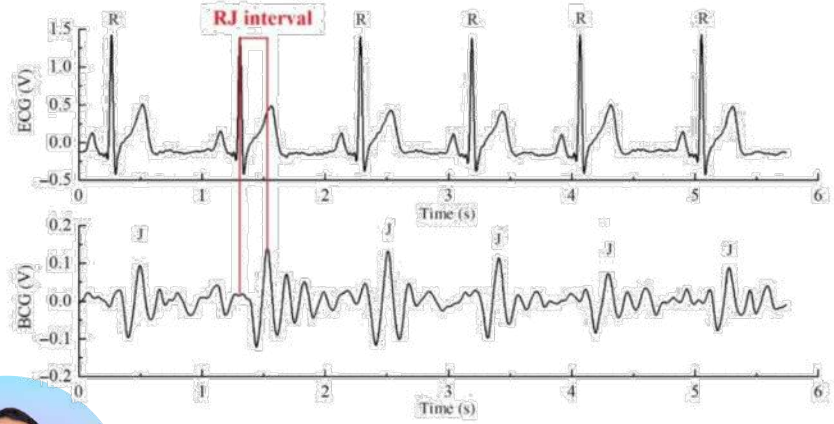
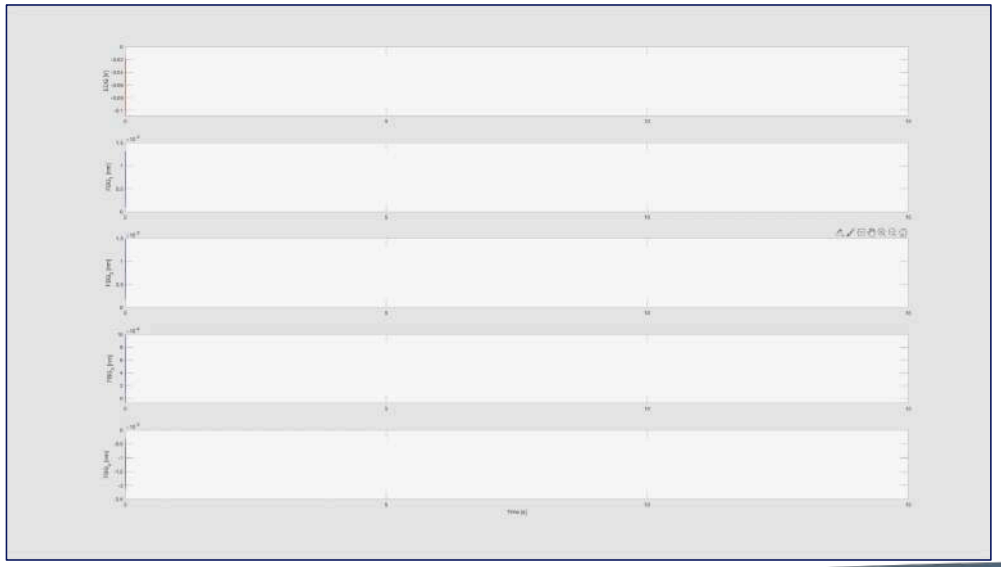
Fiber optic-based solution





Flexible sensors with 4 FBGs

Pilot trials on healthy volunteers



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Use Case 5: Adherence to the rehabilitation program

Home rehabilitation, a chimera or a real need to develop physiotherapy?

- Patients are not monitored continuously during rehabilitation exercises.
- Rehabilitation treatments at home are not patient-specific
- The patient is typically not very engaged at home

A multi-sensor platform may enhance the engadment, provide objective measurements and help physician to tailored the treatment.

MONREAB

FONDAZIONE GIOVAN BATTISTA BARONI

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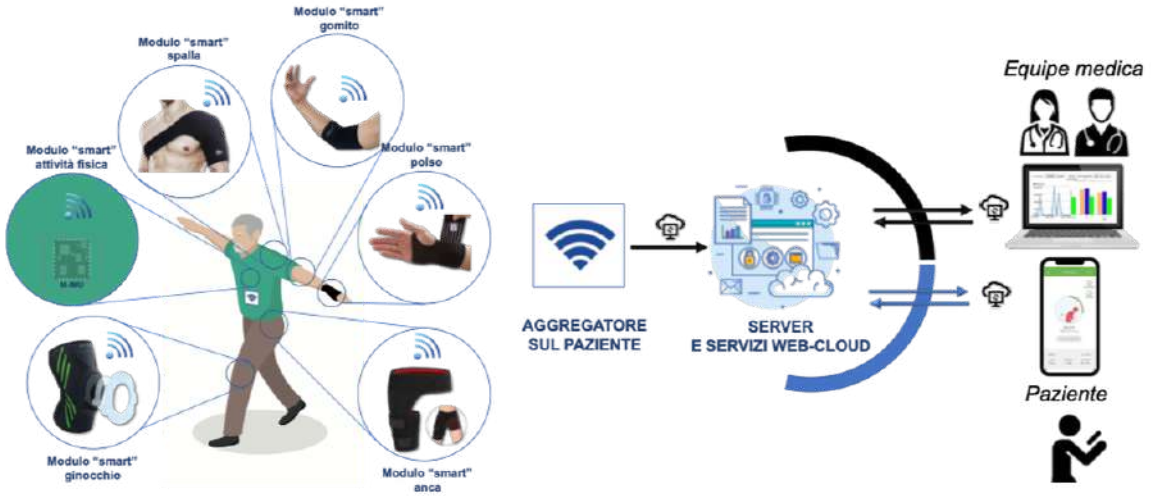
Enabling technology



CARLO MASSARONI

EMILIANO SCHENA

LUCA VOLLERO

DOMENICO FORMICA

SILVIA STERZI

UMILE G. LONGO

MONREAB

FONDAZIONE GIOVAN BATTISTA BARONI

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Use Case 6: Occupational health and Safety

- Workers are not monitored in occupationas settings
- Physiological and psychological stressors may lead to a loss of productivity and an increase of occupational injuries

A monitoring system of the worker's vital parameters can be fundamental to reduce intervention times in at-risk environments

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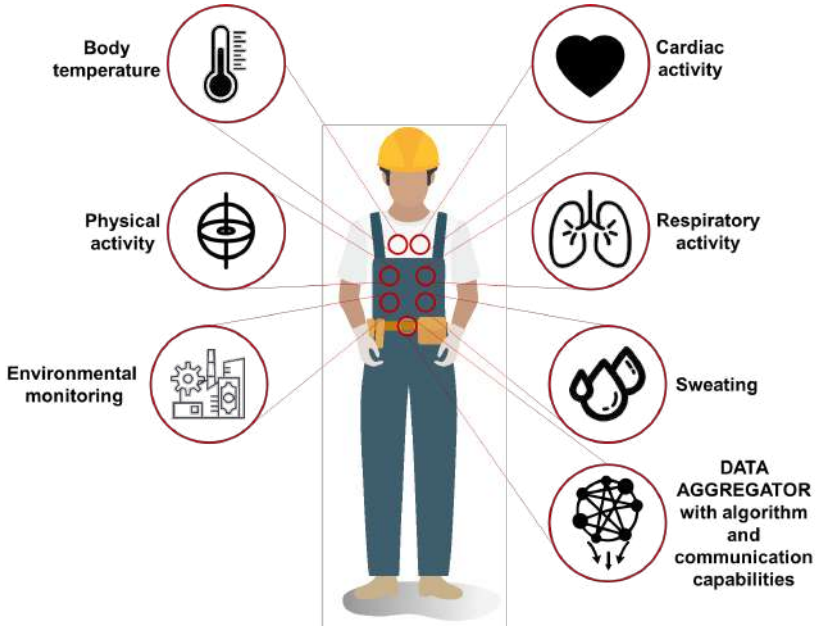

Sense Risc Project

Sviluppo di abiti intelligENti Sensorizzati per prevenzione e mitigazione di RIschi per la SiCurezza dei lavoratori

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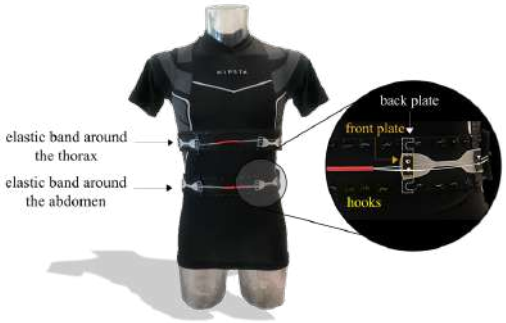

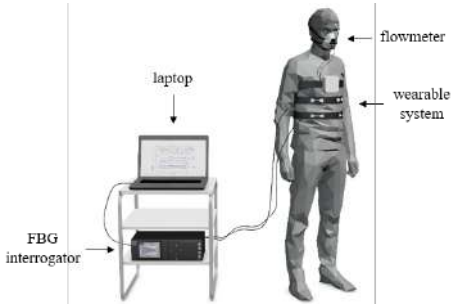

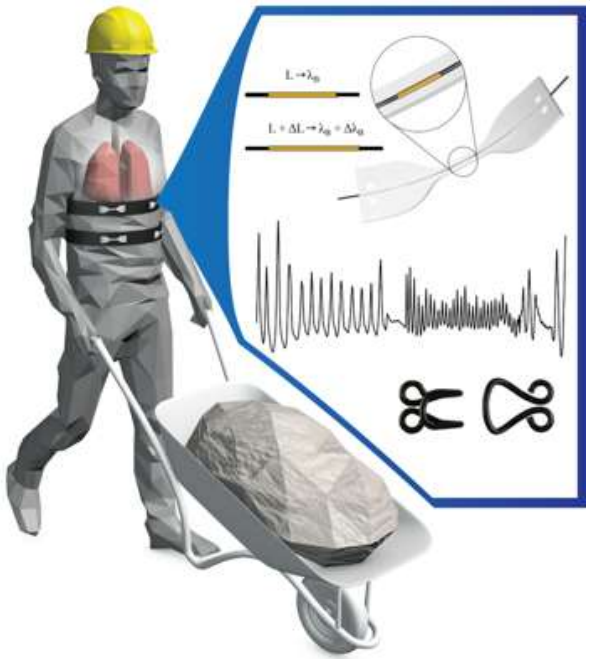

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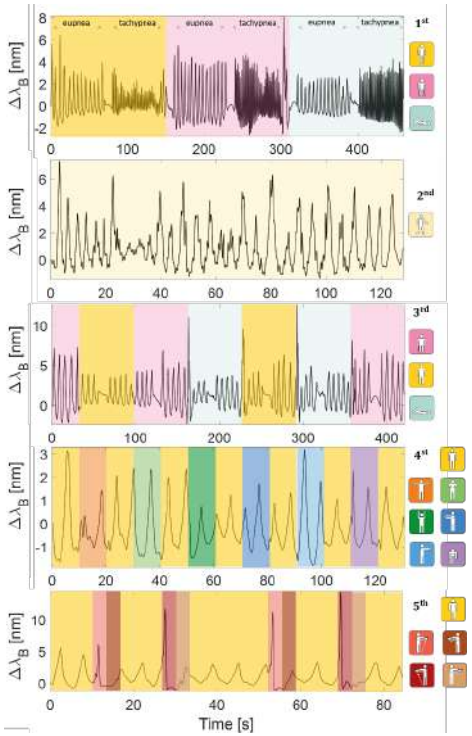

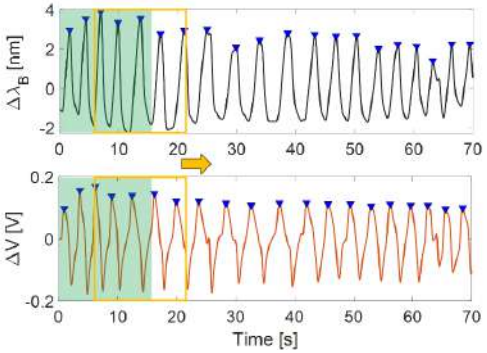

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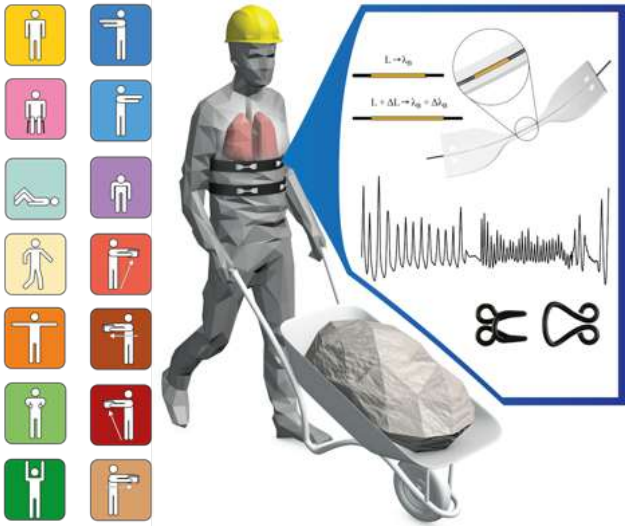

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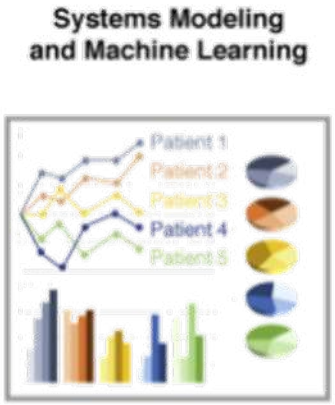
Future opportunities

More information from the patient

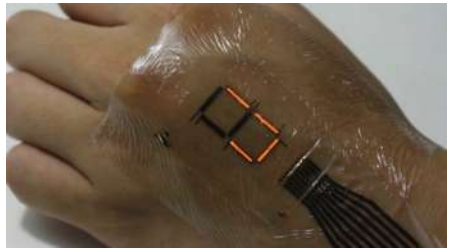
Intelligent analyses and decision support tools



Patient-specific healthcare delivery models

Medical doctors/ caregivers

Wearable technology developers



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FONDAZIONE GIOVAN BATTISTA BARONI

RESEARCH GROUP

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Wearable systems for continuous monitoring of physiological parameters

Thanks for the attention

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