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Measuring physiological parameters through head-micromovements by the VR/AR headset for user bio-feedback and adaptive experience

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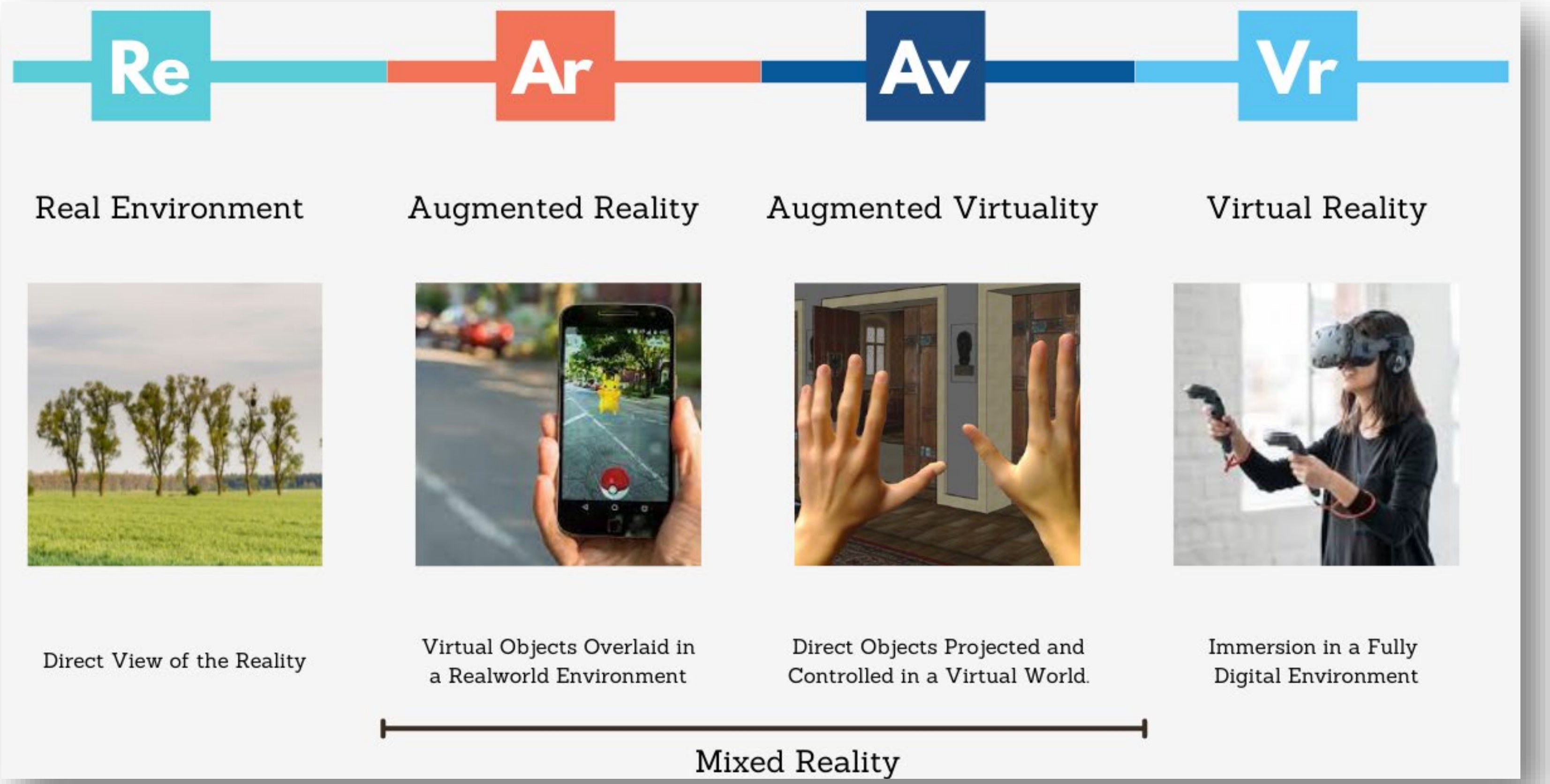
The XR continuum

XR continuum

Extended Reality
Experience Reality



Immersive learning

- Remote learning-by-doing
- Scalability and accessibility
- Immersive Analytics
- Retention and skills transfer

- **4x faster learning**
- **275% more confidence in skills**
- **65% CAPEX reduction**

Immersive healthcare

Mental Health

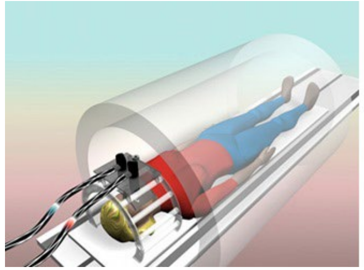
- Cognitive capabilities
- Behaviour

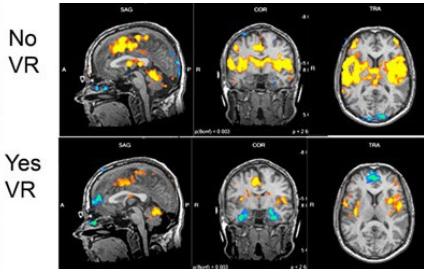
(Banakou et al 2018; Houzangbe et al 2019)

Pain Management

- Routine medical procedures
- Pre/Post surgery

(Ganry et al 2018)

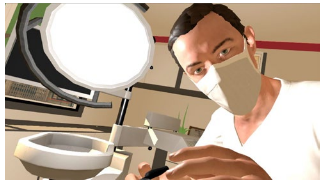




Psychological Therapy

- Anxiety disorders
- Post traumatic stress disorders (PTSD)
- Phobias

(Maples-Keller et al 2017; Cho et al 2017)



Physical Rehabilitation

(Tarr and Warren et al 2002; Gold et al 2005)

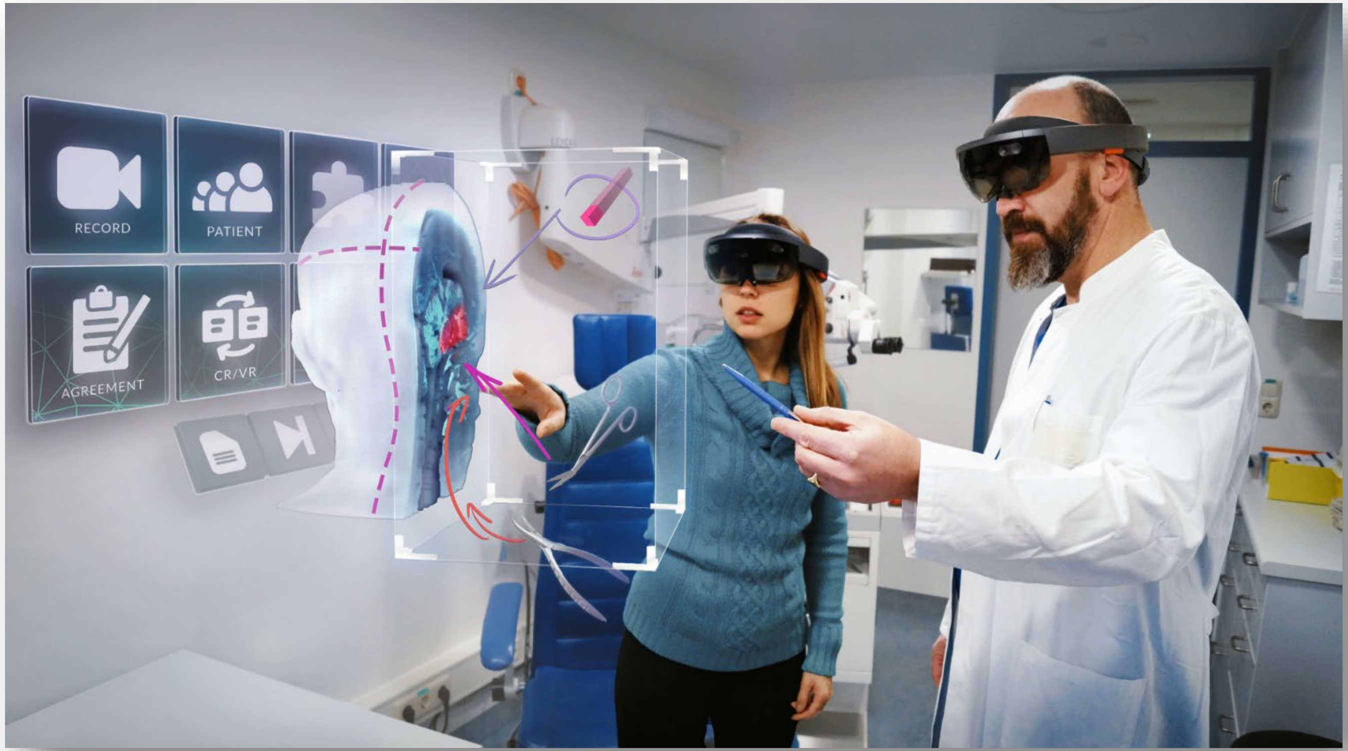
Immersive healthcare

Around **500 startups** in the world.

$ 4.5 Bln the Global Market value in 2022.

Main applications:

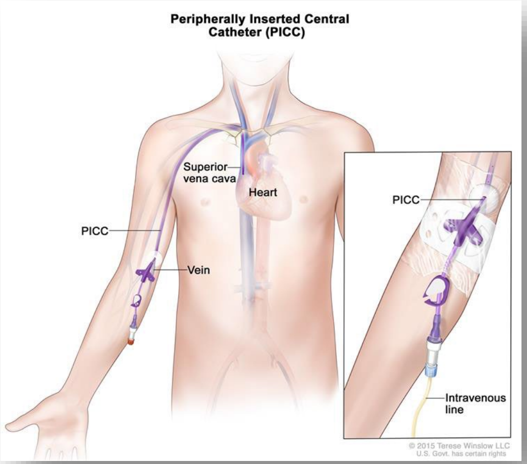
- Digital alternatives to drugs
- Telemedicine
- Neurorehabilitation
- Medical training



Softcare Studios

The company develops virtual reality solutions for pain management of patients and medical training of clinical personnel

- Founded in 2017 in Italy (Rome)
- Active in 20 hospitals
- Partnerships with leading Pharma and MedTech companies



Library of VR experiences designed to support the needs of different **age groups** of patients (paediatrics, adults, elders)

MAIN ADVANTAGES OF VR-BASED EXPOSURE

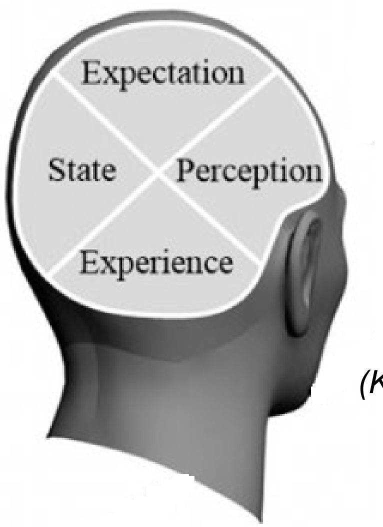
- Graded exposure
- Repeated as often as necessary
- Protected environment

- Yet, although the computer-generated environment is artificial, our mind and body behave as if it was natural

- Abilities learned in VR are transferred to the real world

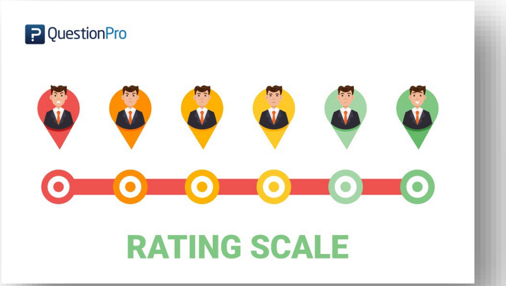
How to quantify the effects of VR-based exposure?

Quality Of Experience (QoE)



Subjective metrics

- Post test questionnaires
- Pre-defined rating scales
- Mean Opinion scores (MOS)
- Differential MOS



(Lee et al 2011)

(Hupont et al 2015)

Objective Metrics

Measurement of physiological signals with external sensors

- EEG *(Kroupi et al 2016)*
- HR *(Egan et al 2016)*
- Respiration

Fitbit HR monitor

PIP biosensor

(Drachen et al 2010)

How to quantify the effects of VR-based exposure?

Laboratory conditions
Pre-flight training

Multiple instrumentation resources

Subject's time resources not critical

Presence of trainers/assistance

⬇

Subject instrumentation with external sensors/wearables to monitor physiological signals and biomarkers during the VR-based exposure

ISS conditions
In-flight utilization

Limited instrumentation resources on-board with possible inter-Agency constraints

Astronaut's time critical and extremely expensive (130k$/hour)

Possible assistance from other crew members

Astronauts' schedule constraint

⬇

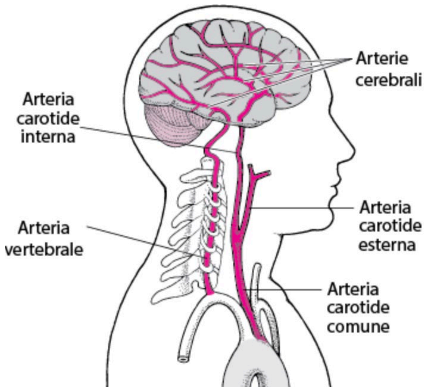
Need to minimize the experimental set-up time
Need to reduce use of consumables

What if….

… we could quantify the physiological response to VR-based exposure by validated biomarkers **without** using any additional **external sensors** ?

… we could **derive** in quasi real-time these **values** and, based on the aim of the VR-exposure, **change** the presented **scenarios** to better tunneling of the experience ?

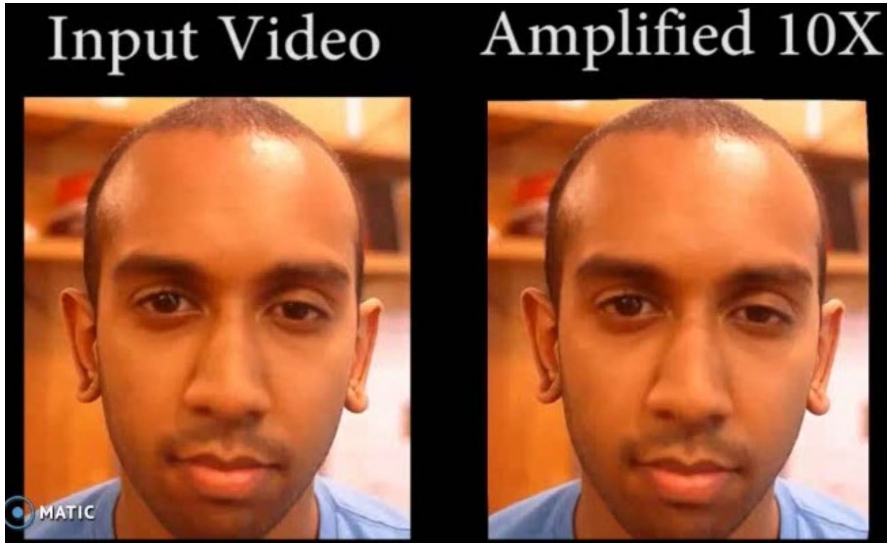
Pulse from head motion



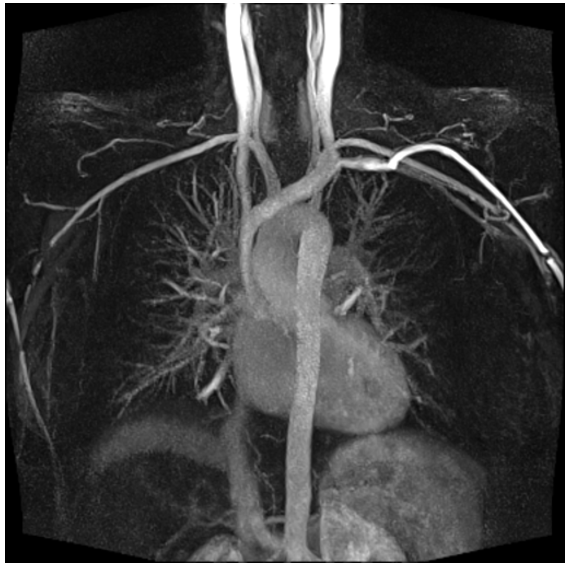
3D

Head motion

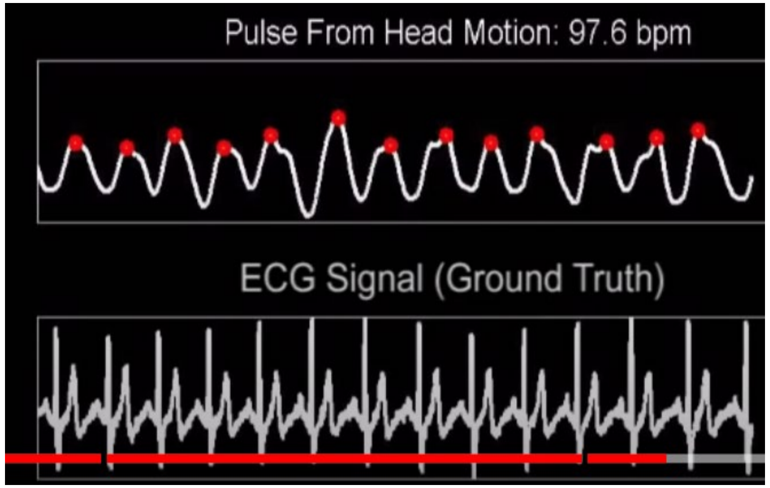
[Balakrishnan G, MIT 2014]



~ 13 grams of blood



- At each cardiac beat, ~13 grams of blood flow towards the head from the aorta through the carotid arteries
- Mechanical recoil caused by the internal movement of blood generates cyclic subtle head motion
- It can be used to derive information about cardiac and respiratory activity



3D Ballistocardiography in microgravity

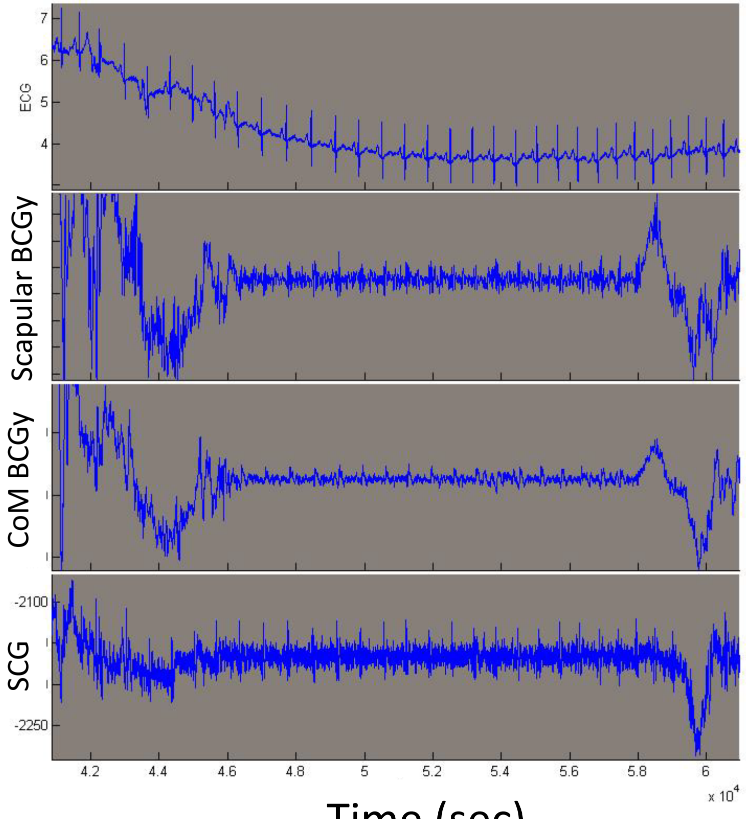
Skylab 4 Crew Observations

EDWARD G. GIBSON II

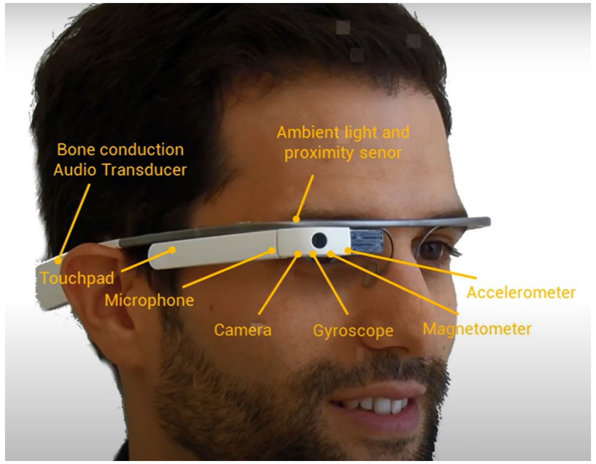
- *"I did notice a* ***ballistocardiographic effect*** *a couple of times when I was trying to take pictures through a window and was just holding on to the adjoining structure rather lightly; I noticed that* ***the whole Skylab cluster was beating at around 60 beats per minute****. This was evidenced several times. It required that I hold myself down rather firmly to get around this."*

3D Ballistocardiography in microgravity

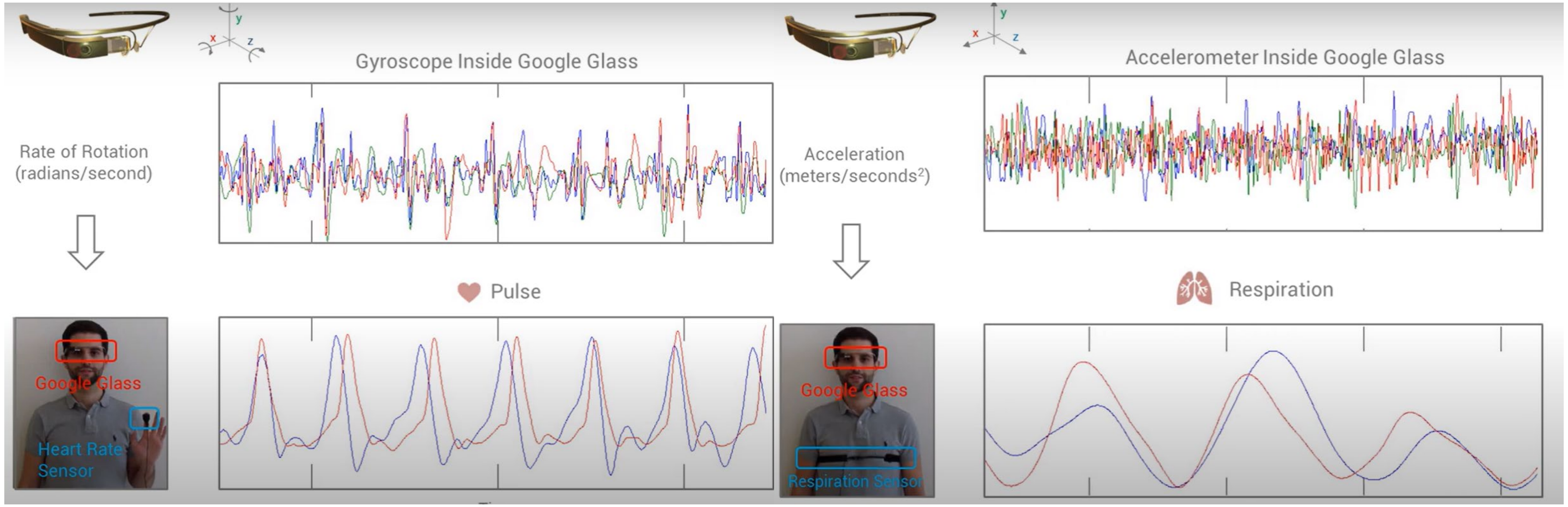
Longest free floating period:
11.5 seconds (18 heart beats)

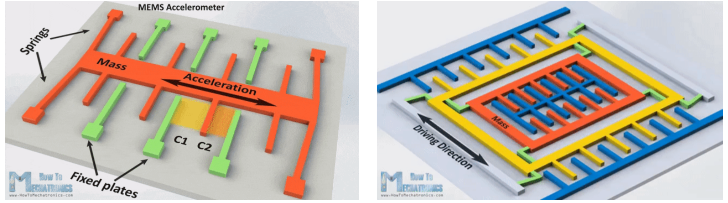


Head-ballistocardiography (BCG)



[Hernandez J et al, Proc. of Wireless Mobile Comm. and Healthcare 2014]

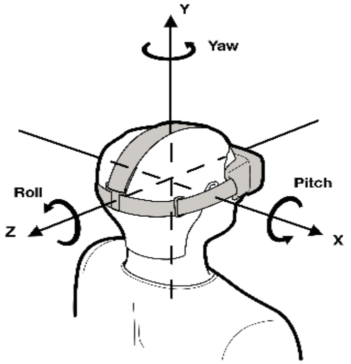




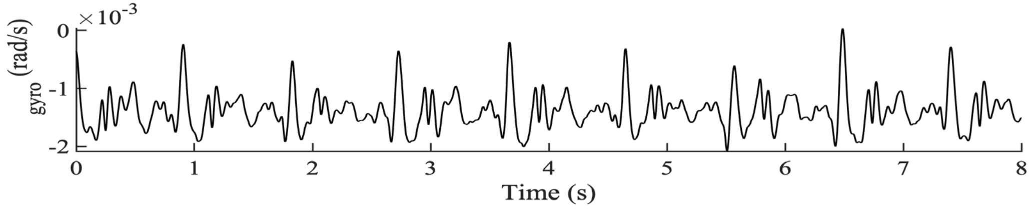
micro-electromechanical systems (MEMS)

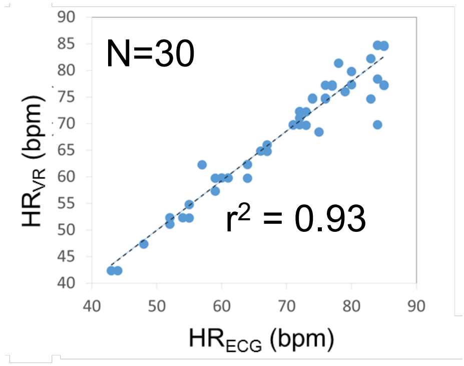
Head BCG from embedded MEMS in VR

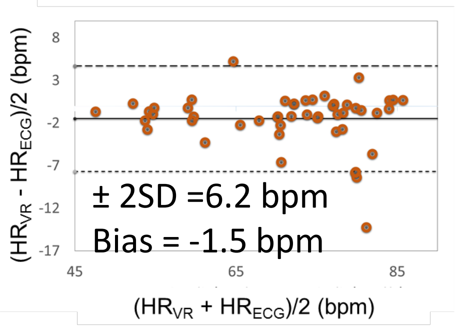
Oculus Go



[Floris et al., Sensors 2020]







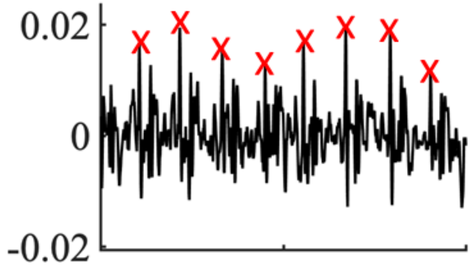
- ➢ f_s = 71[71;77] Hz
- ➢ Ad-hoc recording application (Softcare Studios Srl)
- ➢ 1-lead ECG as reference

Main results

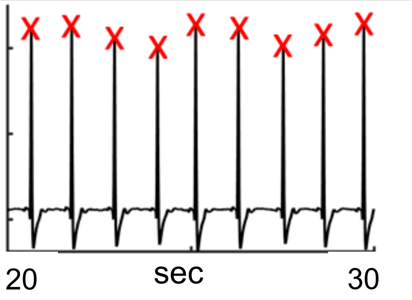
- Using a **VR headset**, it is possible to use the **embedded inertial sensors** to derive physiological parameters in order to **monitor the subject** during a VR experience, in view of providing a bio-feedback.
- Extraction of **mean HR** (30 sec) and **respiratory frequency** (during controlled respiration of 50 sec) is feasible and accurate using **FFT-based method,** with **best results in sitting position** compared to standing and supine.

Head BCG from embedded MEMS in VR

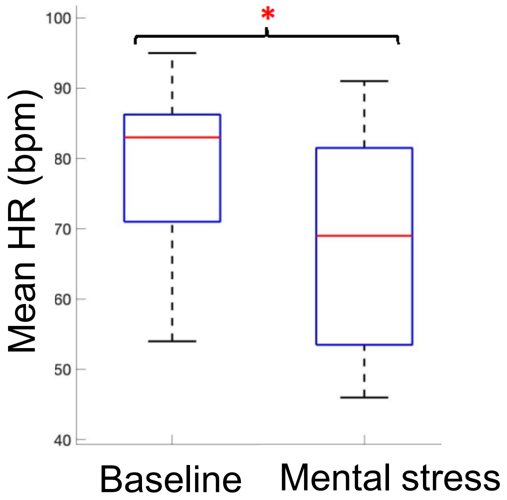
- 9 healthy volunteers (21[21;22.5] years) in supine position
  - Oculus Quest (Meta/ex-Facebook) VR headset
  - fs = 71[71;77] Hz)
  - Ad-hoc recording application (Softcare Studios Srl)



  - 1-lead ECG (f_s = 1024 Hz)
  - 3-axial accelerometer and gyroscope (f_s = 64 Hz)



[Solbiati et al., Proc. IEEE Inertial 2022]



Main results

- **Beat-by-beat analysis of HRV is feasible**, while the subject's head is still, by processing the data acquired from the VR headset with specific software.
- HRV analysis allows extraction of **stress-related parameters** *[Landreani et al, Sensors 2019]*, even from **short-time acquisitions** (30 sec)

Sensor-free biofeedback through a web-based VR application

Aims

- Utilization of this technology **outside a lab setting**
- **Headset** device **indipendent**
- Generation of an **online biofeedback** about the user ability to follow a proposed protocol in **quasi-real-time**
- **Gamification**

Methods

Creation of a **web app** running on an external server to collect and process the data

HTML JS CSS

Sensor-free biofeedback through a web-based VR application

Experimental protocol

- Oculus Quest

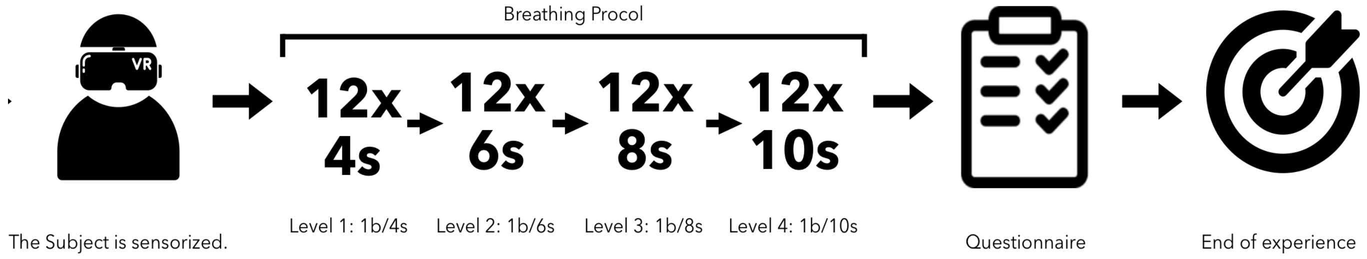
fs = 71.43 Hz

- Movisense EcgMove4

1-lead ECG fs= 1024 Hz

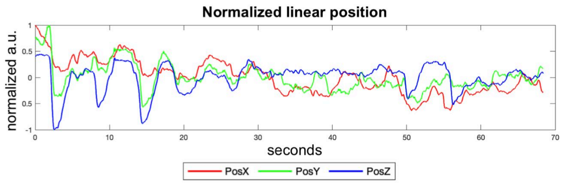
SCG fs=64 Hz

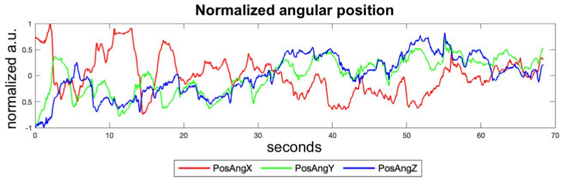
SAM questionnaire

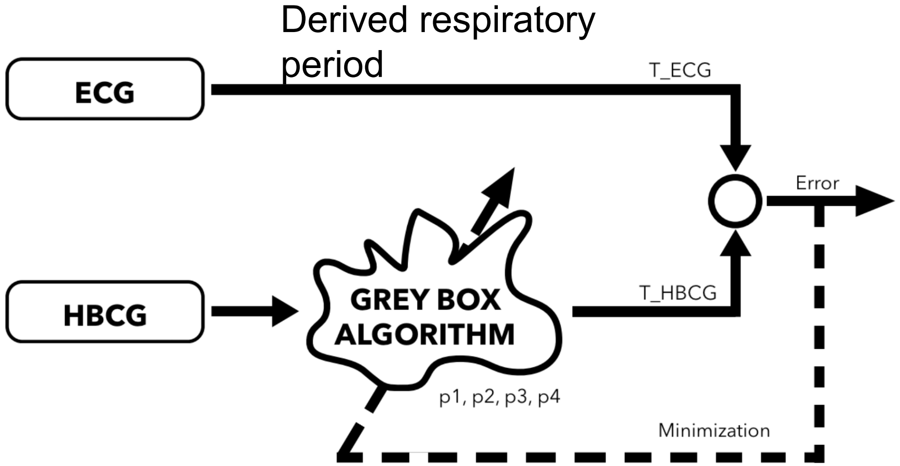


N= 26 volunteers (14M, 12F)

Algorithm training



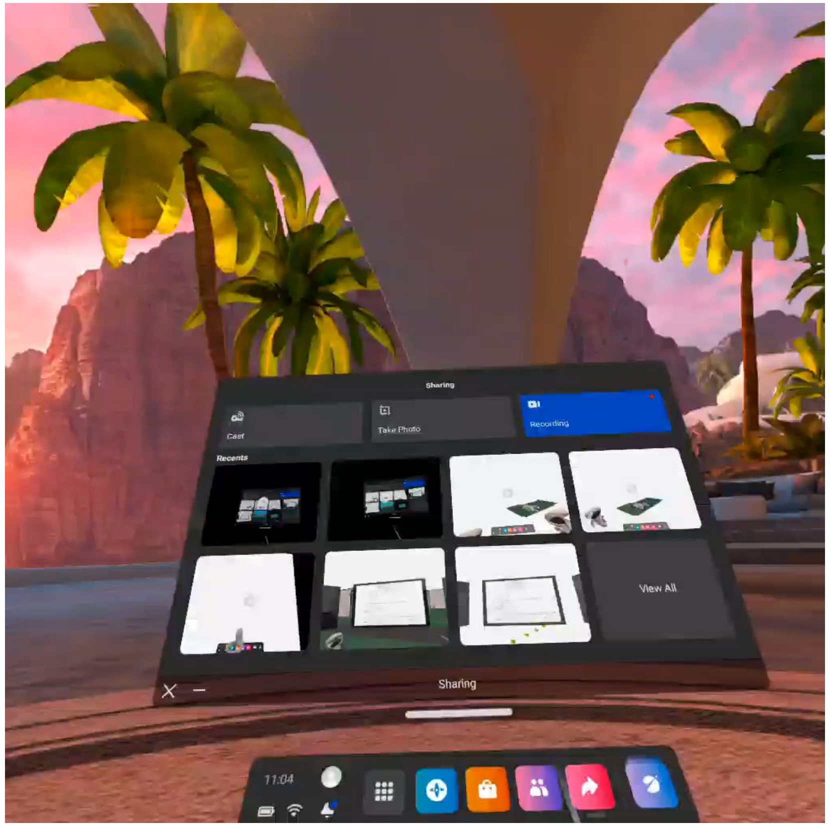




Level	Mean RE	Bias	Std
L1 (4s/b)	2.58%	-0.02s	0.14s
L2 (6s/b)	2.55%	-0.06s	0.21s
L3 (8s/b)	1.93%	-0.11s	0.19s
L4 (10s/b)	1.87%	-0.11s	0.26s

The error for each of the imposed respiratory frequencies was below 3%

Sensor-free biofeedback through a web-based VR application

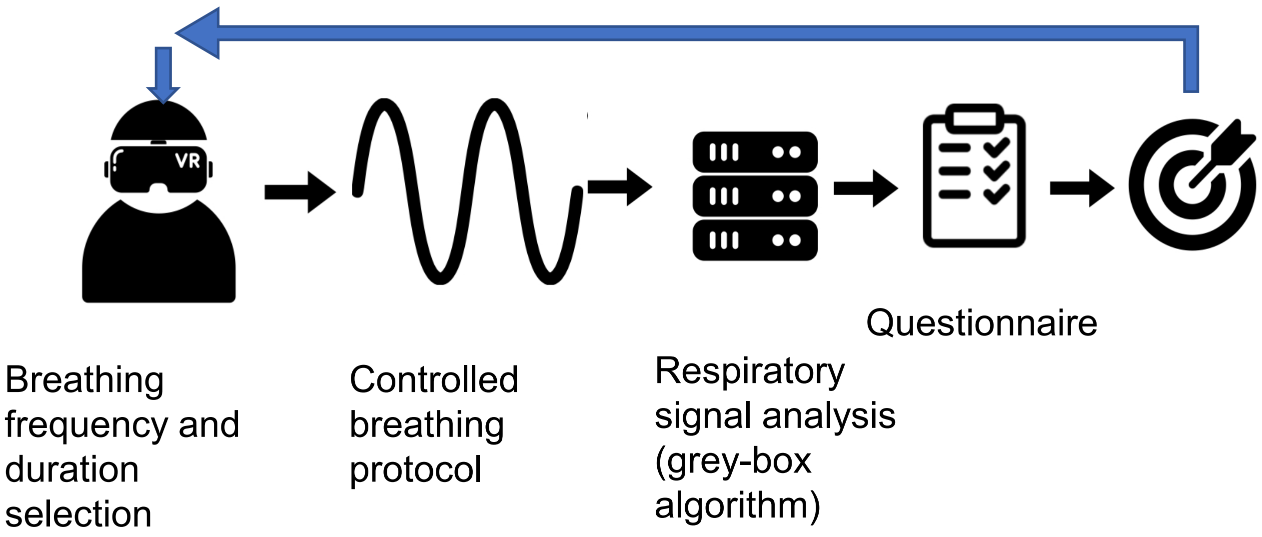


Sensor-free biofeedback through a web-based VR application

Testing protocol

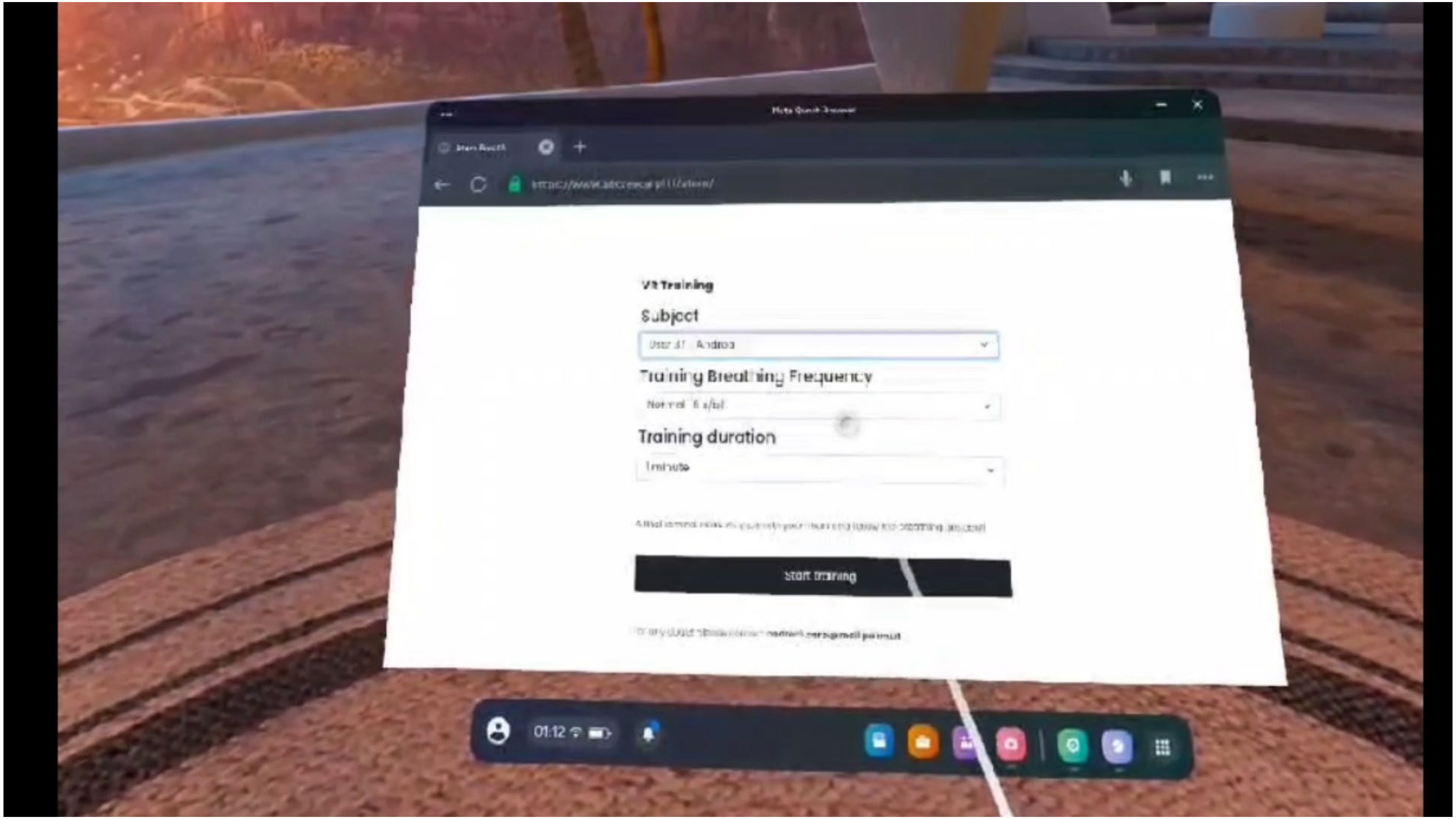
- Oculus Quest
  fs = 71.43 Hz
- Movisense EcgMove4
  1-lead ECG fs= 1024 Hz
  SCG fs=64 Hz

N= 8 volunteers



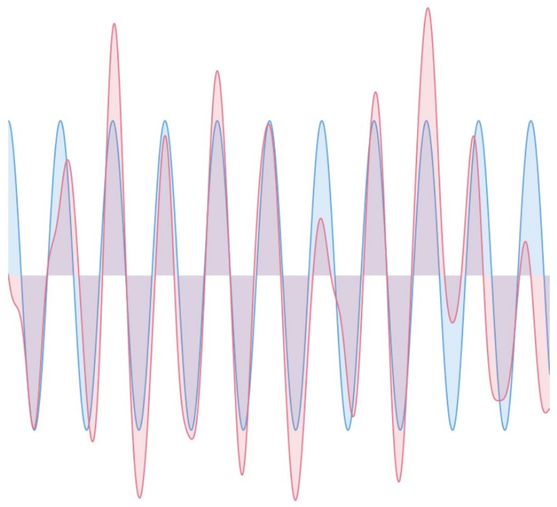
Free choice of the breathing frequency and of the duration of the experience

Sensor-free biofeedback through a web-based VR application



Sensor-free biofeedback through a web-based VR application

User feedback: comparison of measured respiration (in red) with expected respiration (in blue)



Subject	**Duration**	**Imposed [s/b]**	T_{ECG} **[s/b]**	T_{HBCG} **[s/b]**	**Error**
S27	96s	8	7.73	7.65	1.03%
S28	96s	8	7.94	8.09	-1.89%
S29	72s	6	5.81	5.99	-3.09%
S30	96s	10	9.79	9.52	2.76%
S31	120s	8	7.89	7.84	0.63%
S32	96s	8	7.94	8.09	-1.89%
S33	96s	8	8.31	7.82	5.90%
S34	360s	10	10.02	10.19	-1.69%

Respiratory frequency estimated from the VR headset during the imposed respiration experience is accurate compared to the gold standard, and can be used as biofeedback.

Conclusions

Using MEMS embedded into the VR headset, it is possible to indirectly monitor the subject's **heart rate and respiratory activity** by exploiting the **head micro-movements**.

Such approach could also be **embedded in space-related VR experiments** focused on training, physical countermeasures, and mental health of astronauts, in order to derive useful **biomarkers during the experience without using additional sensors**, thus saving **astronaut's time** (and organizational burden)

Such markers could be used to **assess stress and performance** levels, to increase crew safety.

In general, the proposed approach could have a **positive impact** if included in **any VR application** where it is of interest to **evaluate the subject's response** to the induced stimuli without being constrained to a laboratory setting.

Thanks for your attention!

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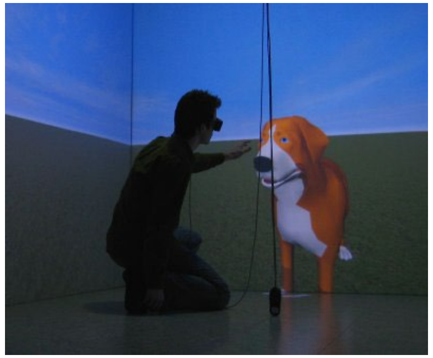
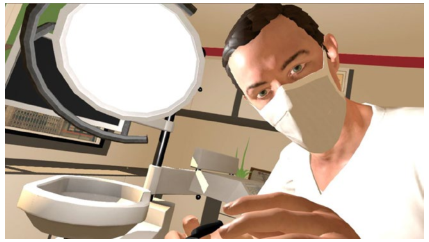
Immersive healthcare

VR to treat phobias

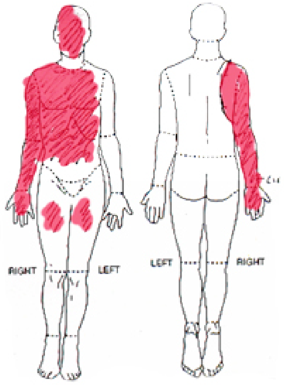




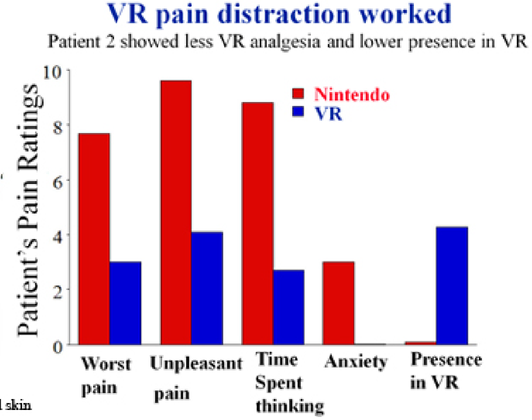
VR to treat PTSD

Immersive healthcare

VR to treat burns

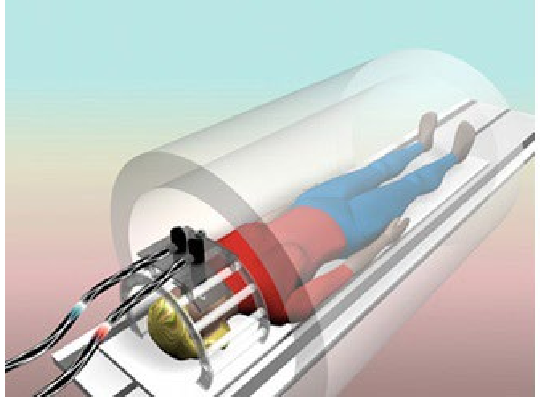


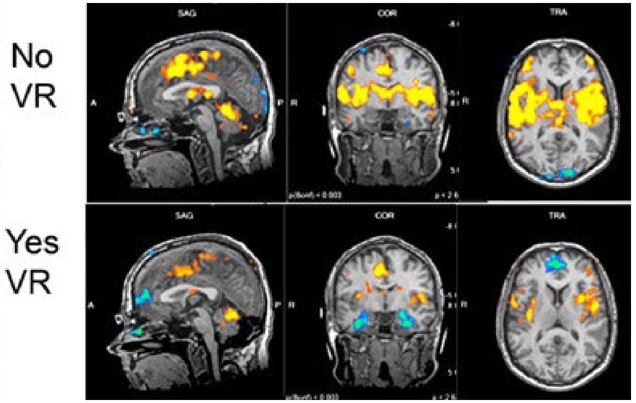
Burned area of patient 2, much the unburned skin was harvested for extensive skin grafts.

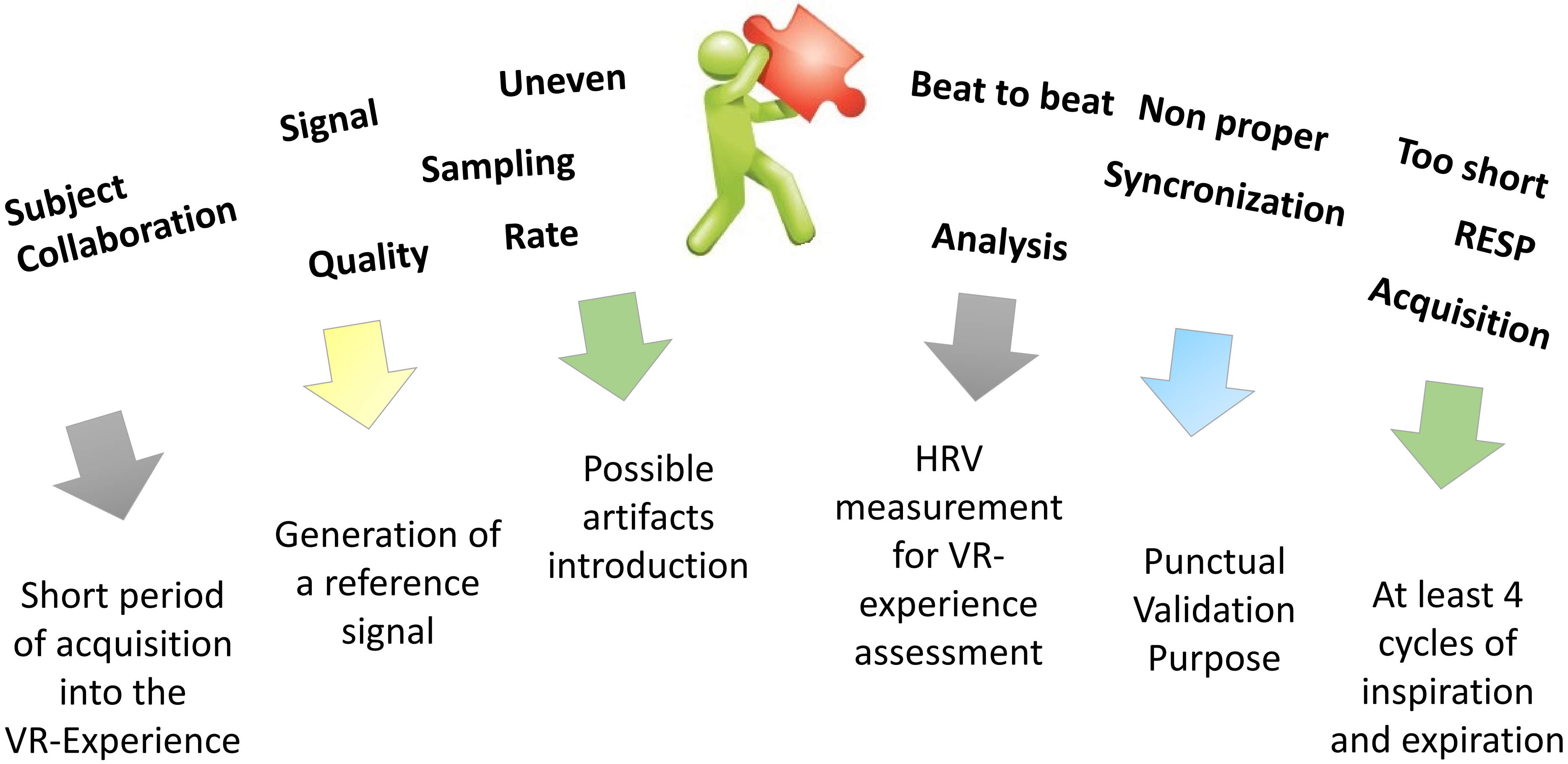


The Snow World

The essence of VR is the illusion that users experience inside a computer-generated environment that KEEP THEIR ATTENTION TO COMPLETELY DIFFERENT STIMULI, and away from pain.

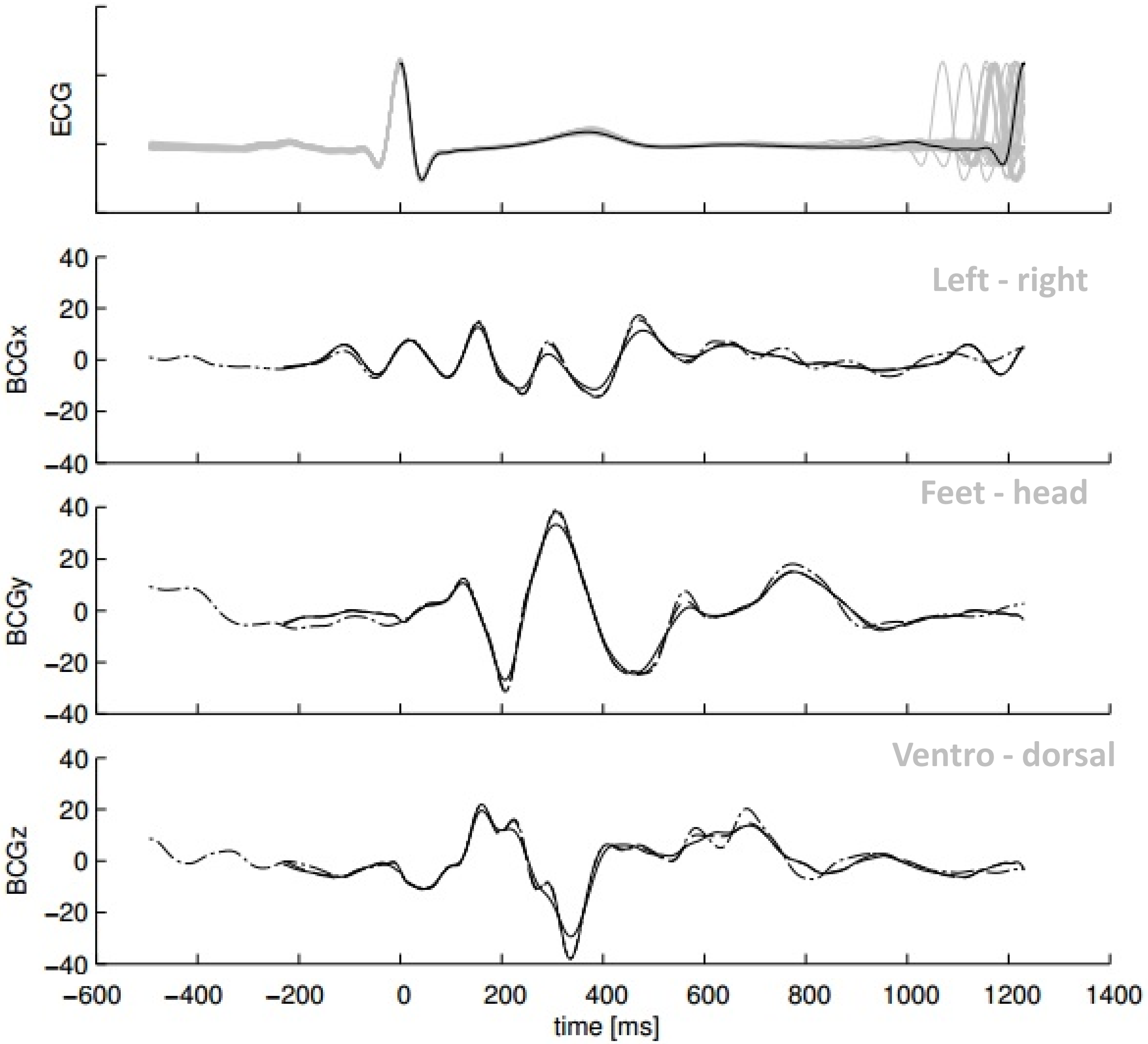





Subject
Collaboration
Signal
Quality
Uneven
Sampling
Rate
Beat to beat
Analysis
Non proper
Syncronization
Too short
RESP
Acquisition
Short period
of acquisition
into the
VR-Experience
Generation of
a reference
signal
Possible
artifacts
introduction
HRV
measurement
for VR-
experience
assessment
Punctual
Validation
Purpose
At least 4
cycles of
inspiration
and expiration

Data from Space Shuttle experiment

STS 55 : Spacelab D2 (1993)



Experiments during parabolic flight

Pneumocard-Ballisto

- 6DOF BCG close to CoM
- 3DOF BCG on the spine between scapulae
- SCG on the apex of the heart
- ICG & ECG standard electrodes placement
- Respiration: nasal thermistor