SAFEMODE

Strengthening synergies between Aviation and Maritime in the area of Human Factors towards achieving more efficient and resilient MODES of transportation.

SAPIENZA UNIVERSITÀ DI ROMA

# Training Package

## *Human Factors Assessment*

*SAFEMODE-CBHF-M1*

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.

# Presentation contents

# Operator's HFs assessment

In the modern world, humans work in **increasingly complex environments** that place high demands on our mental capabilities.

Operator's mental states can be negatively affected by **inadequate training**, **unrealistic schedules**, etc. so then contributing to accidents.

**Human performance** is not constant but it **depends on the actual psychophysical state of the operator**.

Investigate the cognitive and physiological factors underlying the operator's states would pave the way for **adaptive interventions** and **enhanced human-machine interaction**.

**The capability of characterising and measuring the Human Factors would provide great benefit for improving Human-Machine Interaction and Safety, especially in operational environments.**

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.

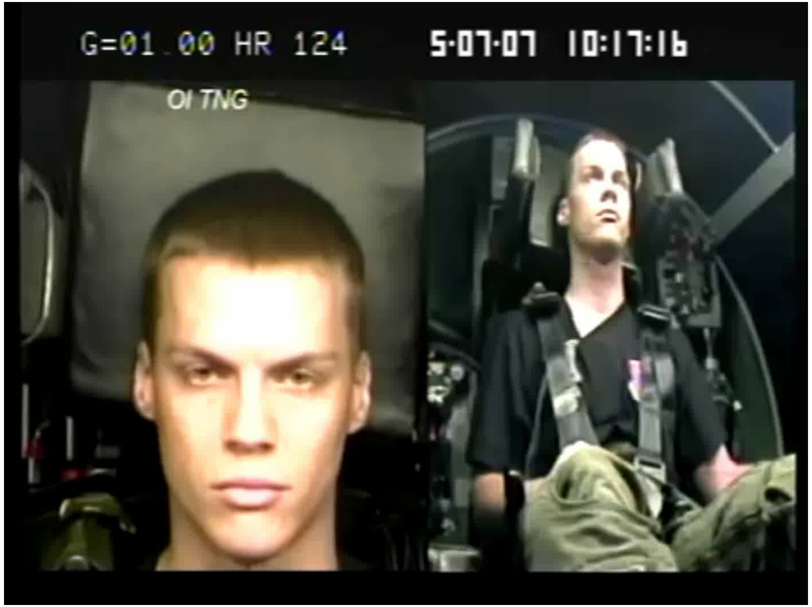
# Presentation contents

# Attention (Visual) Tunnelling

The Pilot Flying became **too focused** on the landing and started to **do not paying attention** to the surrounding environments and other information (e.g. Second Pilot warning about the landing gear).

(Source: youtube.com)

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.




Most of the people will face changes in vision such as **grayout** or **blackout** at 4.1Gz~4.8Gz, and without any equipment or techniques to handle rapid acceleration from 1Gz to 6Gz, or constant exposure to over 6Gz, they will go under a G-LOC state within 5 seconds.

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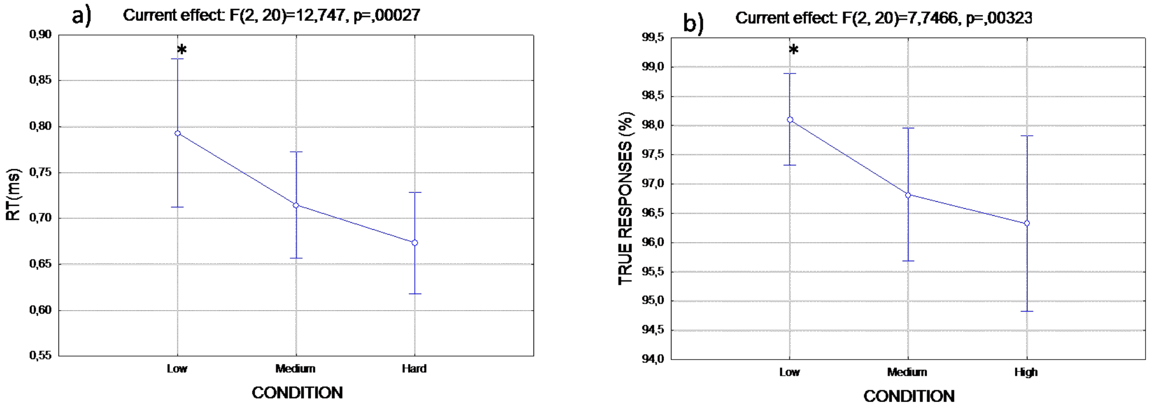
# Stress

**Stress** is a physiological response to mental, emotional, or physical challenges, determined by the **balance between the perceived demands** from the environment and the **individual's resources** to meet those demands.

| (some) **STRESSORS** | |
|---|---|
| *Work Environment* | Time pressure |
| *Task Demand* | Unpredictable events |
| *Operating Procedures* | Conflicting Information |

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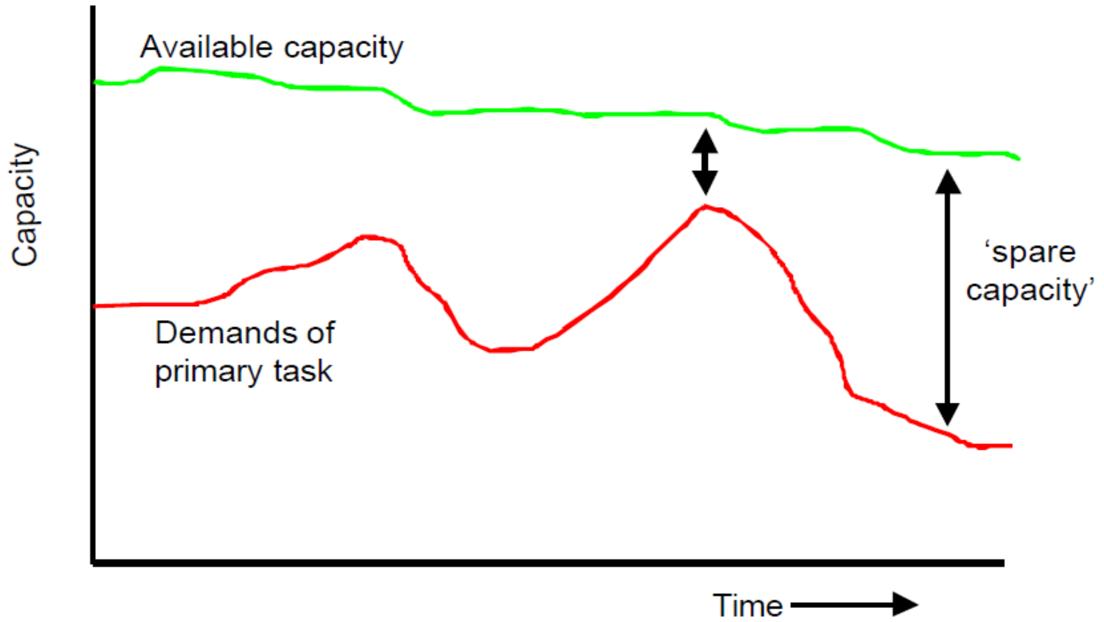
# Spare Cognitive Capacity

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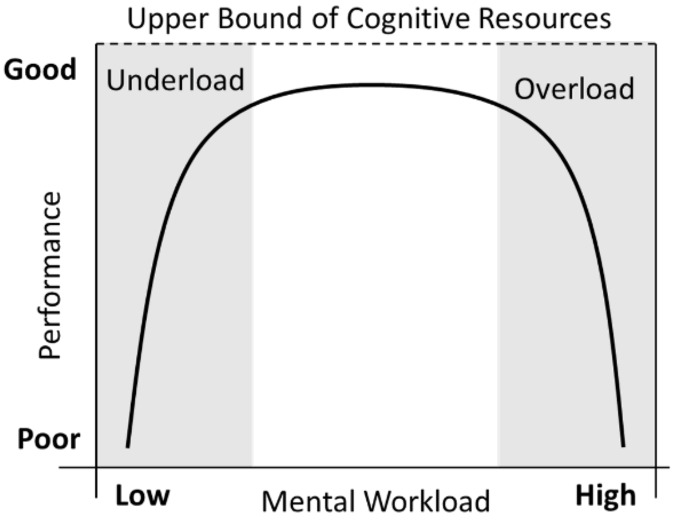
# Mental Workload

## Reversed U-shaped relationship

Mental workload reflects the **amount of cognitive capacity needed to fulfil task performance** and it is one of the **most ubiquitous constructs** in cognitive ergonomics, as it has a direct impact on how humans perform in all types of tasks.




This drives the need to **better understand the factors and mechanisms of mental workload.**

(Borghini et al., 2014, Neurosci Biobeh Rev)
(Seet, 2020, Hand of NeuroEng)

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# Different Theories

Theoretical frameworks posit that cognitive performance relies on a **central cognitive architecture,** which can be flexibly utilised to do a variety of tasks.

This relates to a psychological concept known as ***executive control*****—a core system** that manages broad abilities to focus attention, ignore distractions, maintain and manipulate complex information in mind (i.e. working memory), and to coordinate performance between multiple tasks: **fronto-parietal control network** comprising the prefrontal cortex interacting with the posterior parietal cortex.

**General-capacity** theories assume that there is a single undifferentiated capacity from which all cognitive processes compete for resources.

On the contrary, the **Multiple Resource model** argues that there are separate sub-pools of resources for different domains of mental processing (e.g. ‘visual resources’ for visuospatial processing, ‘verbal resources’ for verbal processing).

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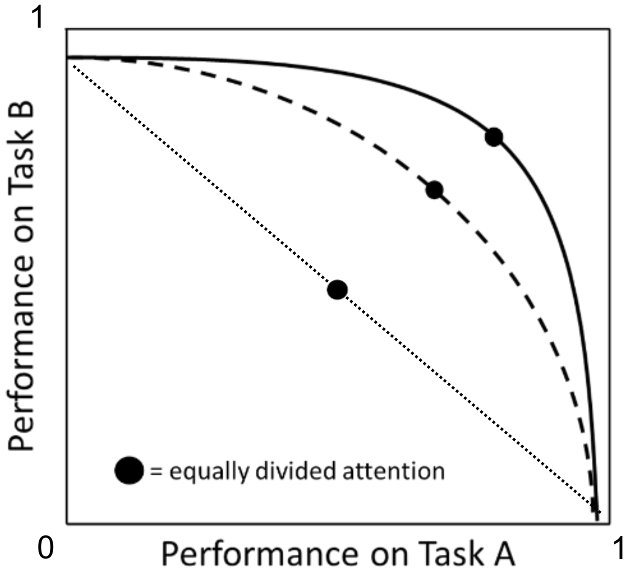
# Hybrid Model

There appears to be support for a **hybrid viewpoint**: instead of a linear trade-off that would indicate a common resource pool, the curvilinear relation suggests that the **two tasks share some but not all resources.**

**Greater domain overlap** between the tasks (e.g. both being visual-based tasks) would produce higher dual-task interference, translating to a **more linear** AOC curve.




(Sperling and Melchner, 1978, Science)
(Wickens, 2002, Theor issues Ergon Sci)

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# Mitigate Mental Workload

Apart from **task demands**, mental workload is also affected by various secondary factors.

**First** are external supports such as **task aides and automated tools** (e.g. unreliable system vs. manual control). This highlights that having external supports are not necessarily beneficial, and may miscarry and place additional mental burdens if found to be ineffective.

**Second** is subjective **appraisals of performance and motivation**. People experience greater workload after an instance of failing to meet task demand, in turn causing performance to decline further. Positive feedback can have the reverse effect of reducing perceived workload and improving performance.

**Third** are user **experience and skills**. Expertise with a task can reduce the workload required to perform a given task (‘proceduralisation’). Nonetheless, too much experience can be disadvantageous too. Working on the same tasks without increasing task demands can induce underload.

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# Optimise Mental Workload vs. Performance

Mental workload depends on both individual and task factors. From this theoretical perspective, we can identify **two simultaneous approaches** to optimise human productivity hence manage the Mental Workload:

**(i)** **Tailoring** task demands to individual capability.

**(ii)** **Training** individuals to handle complex demands.

The **first approach** is an **objective measure of mental workload** is useful to **track changes** in mental workload as the task progresses, so that task requirements can be adjusted to optimal levels.

The **second approach** is to improve individuals' cognitive facilities to **tolerate greater task demands**. Pre-task training be made more effective if the **training environment and practice tasks are similar** to those at the actual workplace, such as using immersive virtual reality training.

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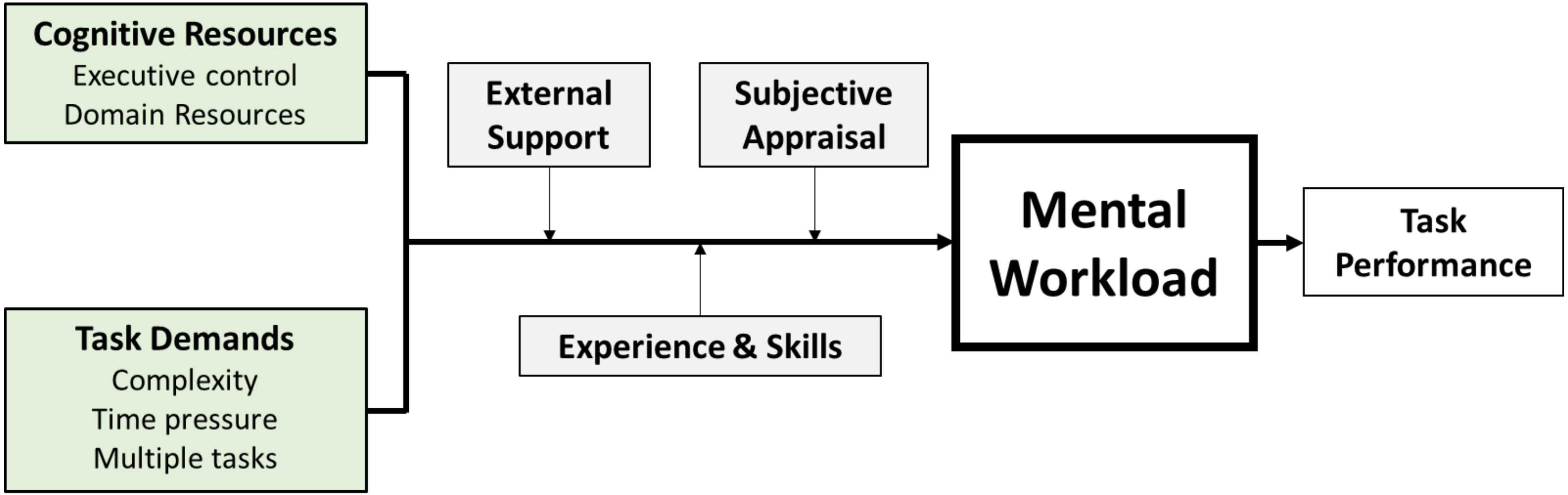
# Framework

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# Presentation contents

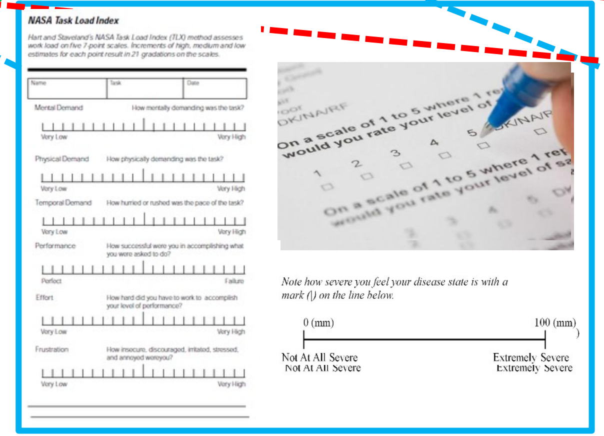
# Measurements

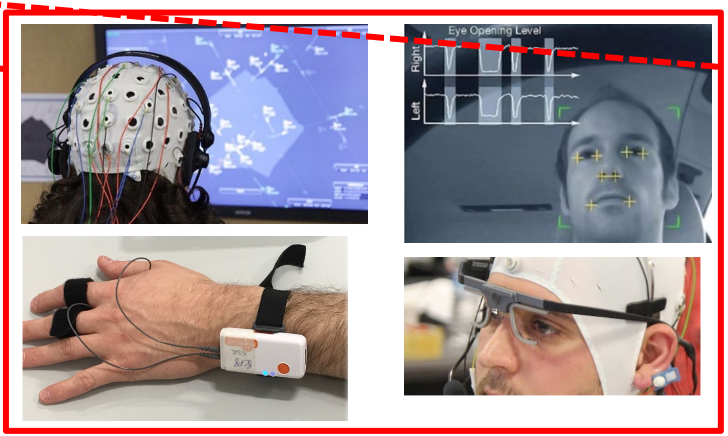
The following measures are widely used for monitoring operator's mental state:

(1) **System- and Behavioural-based measures** - Deviations from the declared Flight Plan (FP) position, Reaction Time, detected and solved conflicts.

(2) **Subjective-based measures** - Questionnaires about perceptions and feelings of the Operator before, during, and\or after the execution of the tasks.

(3) **Neurophysiological measures** - Biosignals are recorded and analyzed in order to highlight variations in human mental states.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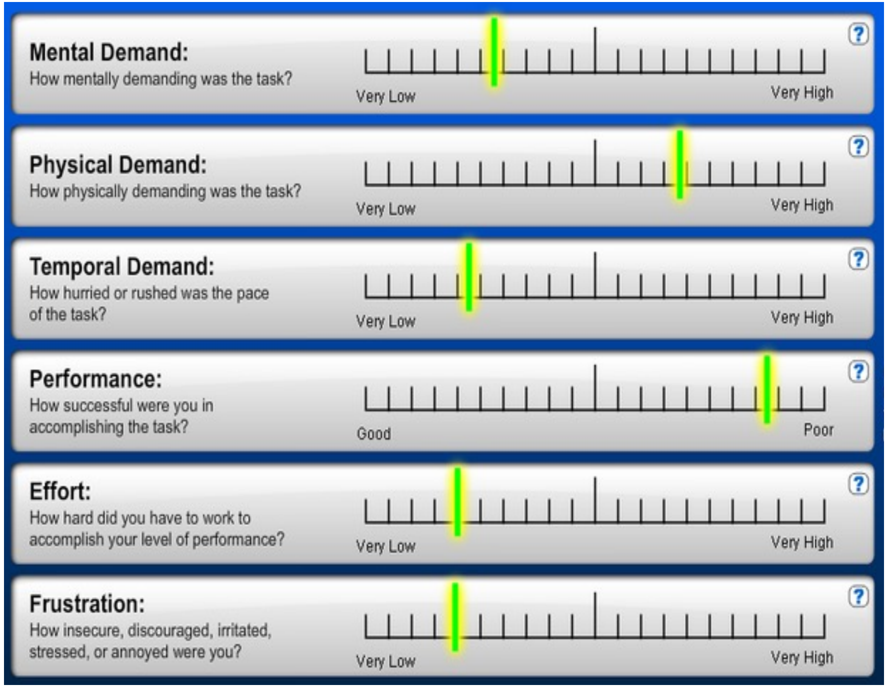
# NASA - TLX

NASA-Task Load Index (TLX) is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales:

- Mental Demands
- Physical Demands
- Temporal Demands
- Own Performance
- Effort
- Frustration.




This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.

# Why Neurometrics?

| | BEHAVIOURAL | SYSTEM LOG | SUBJECTIVE | NEUROPHYSIOLOGICAL |
|---|---|---|---|---|
| Temporal resolution | ! | ! | ✗ | ✓ |
| Operator-dependent | ✓ | ✓ | ✗ | ✓ |
| Easy to use | ✗ | ✗ | ✓ | ✗ |
| Objective measure | ✓ | ✓ | ✗ | ✓ |
| Time for setting-up | ! | ! | ✓ | ! |
| Real-time tracking | ! | ! | ✗ | ✓ |
| Interruptive | ✓ | ✓ | ✗ | ✓ |
| Comfortable | ✓ | ✓ | ✓ | ! |
| Insight information | ✗ | ✗ | ✗ | ✓ |

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.

# The Rationale

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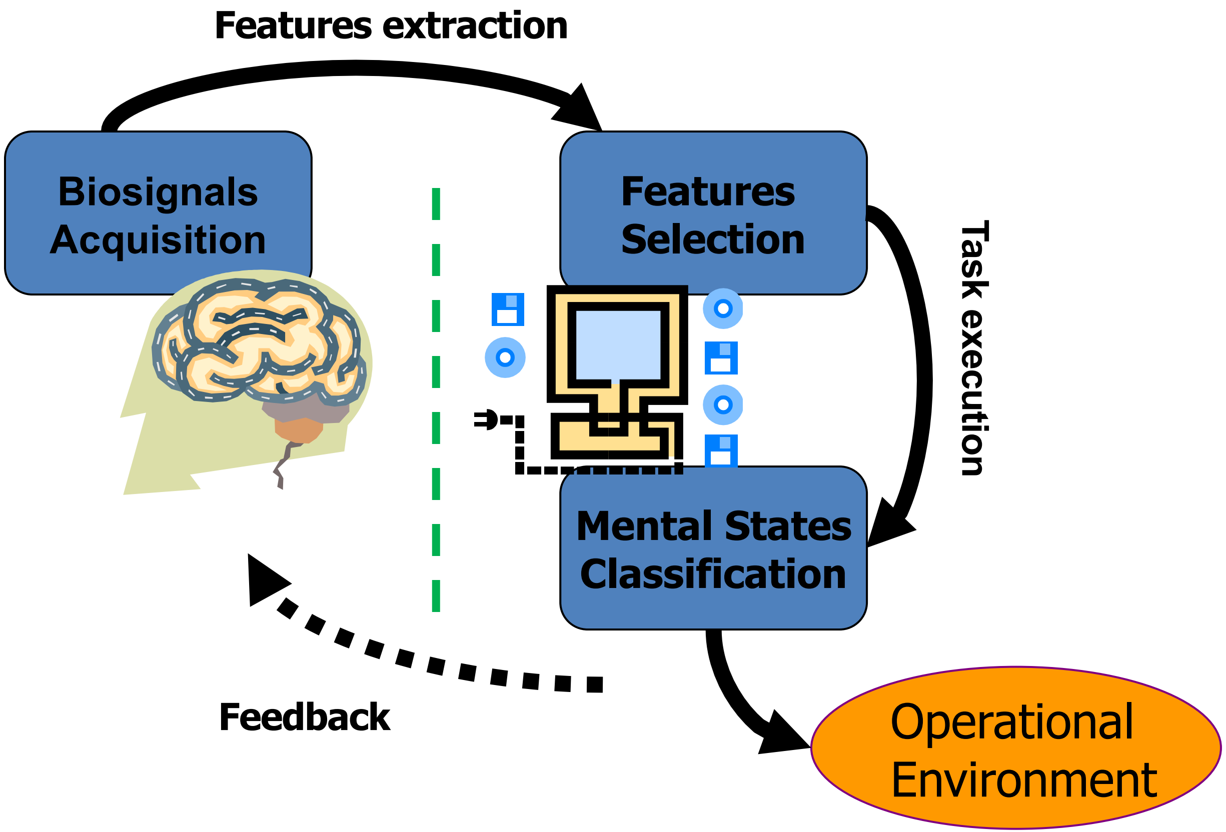
# Passive-BCI

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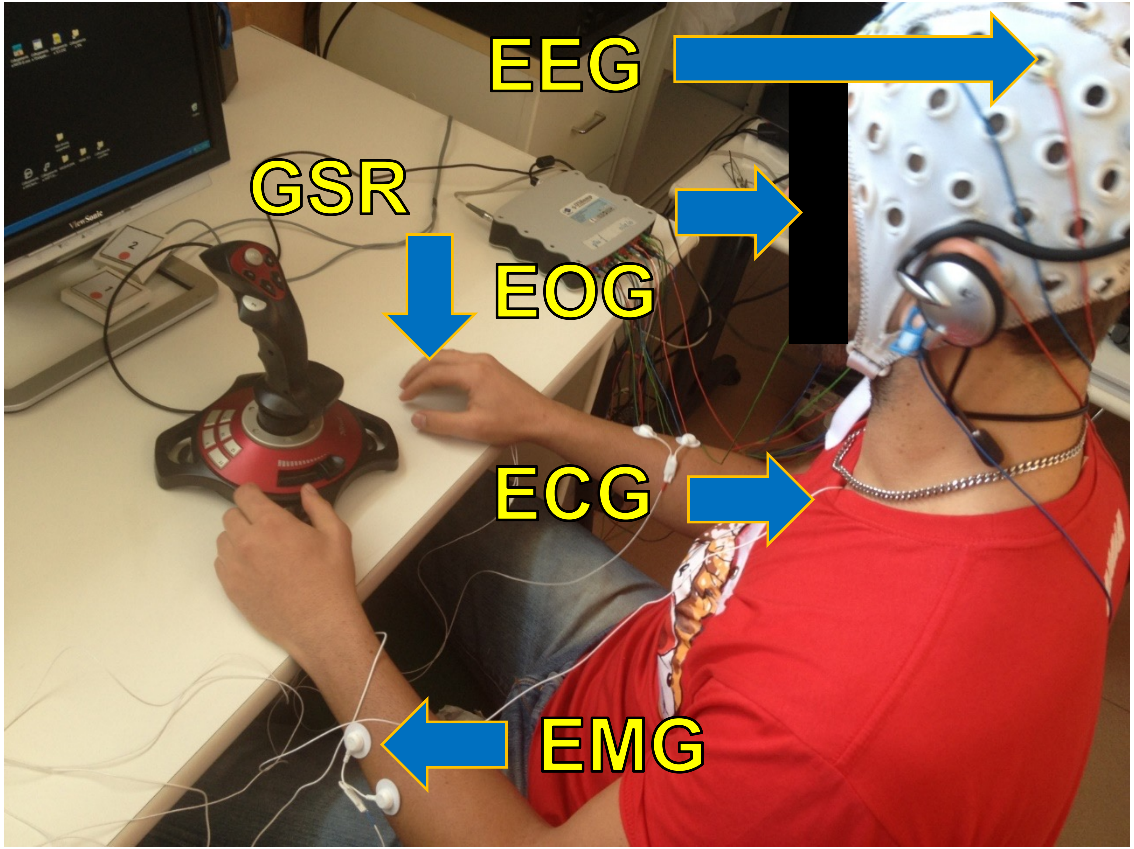
# Experimental Setting: Example

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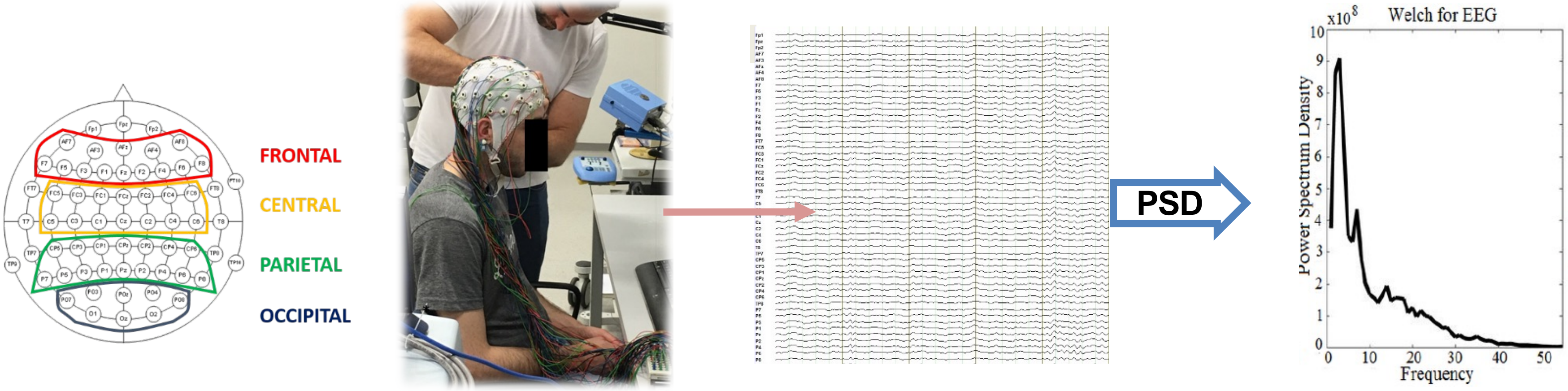
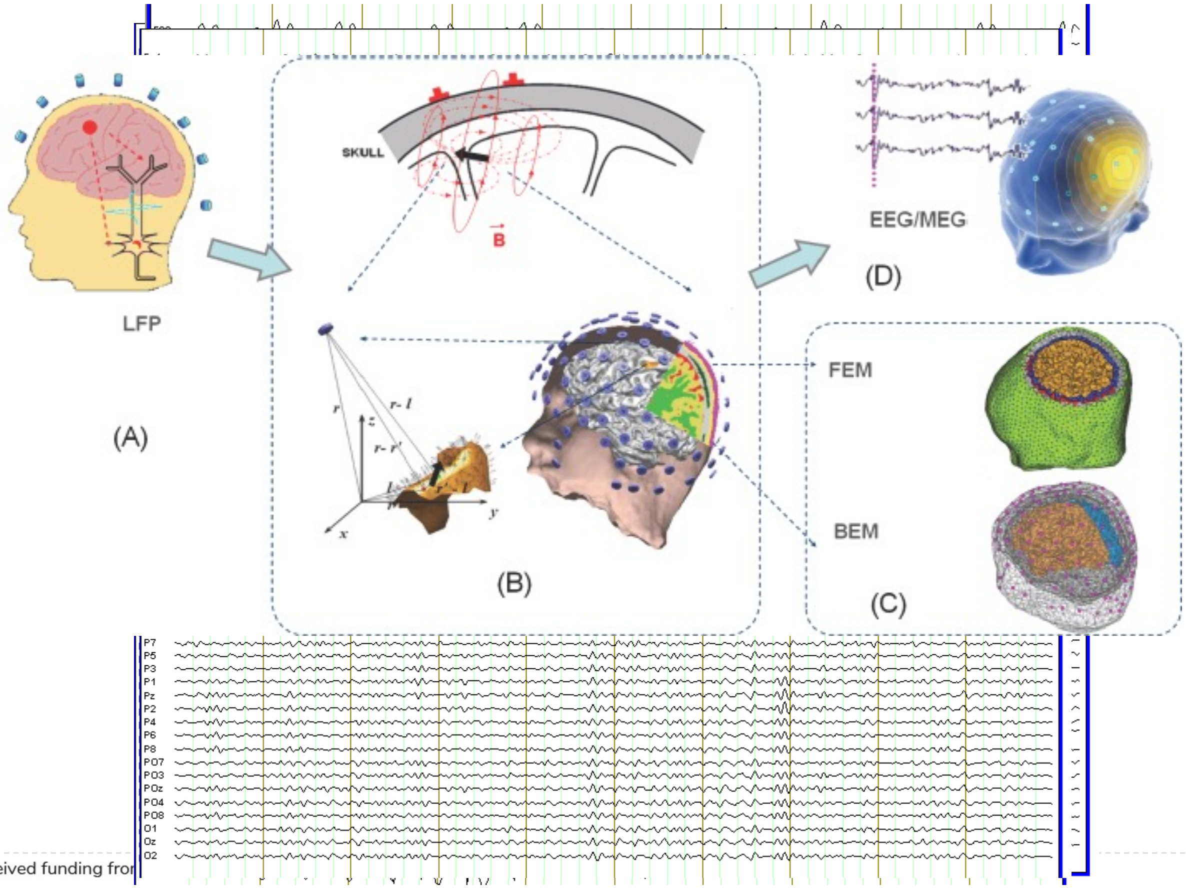
# Electroencephalogram

- ***Electroencephalography* (EEG)** refers to the recording of the brain's spontaneous electrical activity over a period of time, as recorded from multiple electrodes placed on the scalp.
- Applications generally focus on the spectral content of EEG, that is, the type of neural oscillations (popularly called "brain waves or rhythms") that can be observed in EEG signals.




This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.

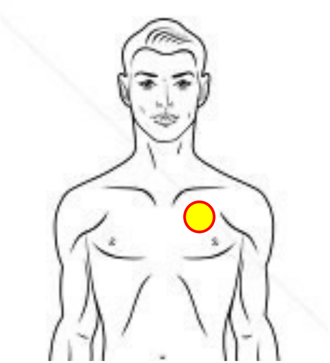
# EEG pre-processing: Example

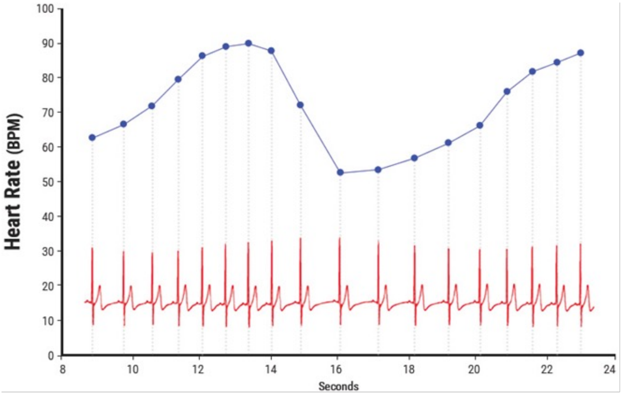


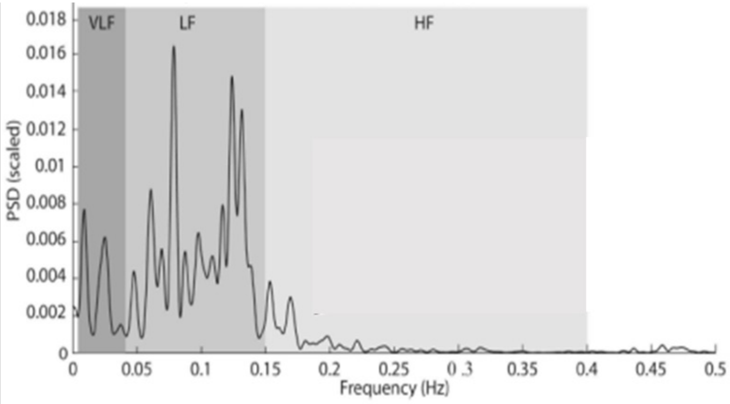

This project has received funding fro

# Electrocardiogram

- ***Electrocardiography*** **(ECG)** is the process of recording the **electrical activity of the heart**. The electrodes detect electrical changes on the skin that arise from the **heart muscle's electrophysiological pattern** of depolarizing and repolarizing **during each heartbeat**.






- **2 INDICATORS: HR mean LF/HF ratio (HRV)**

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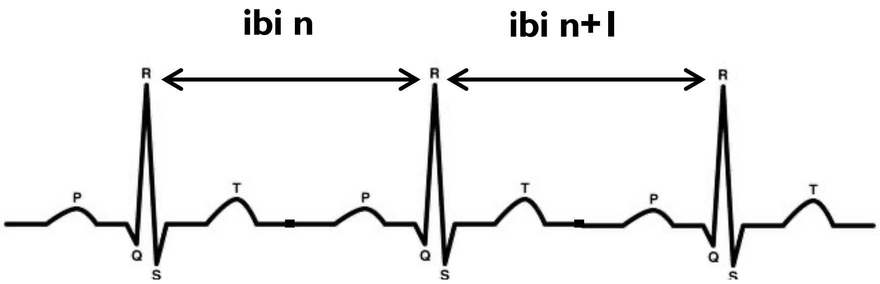
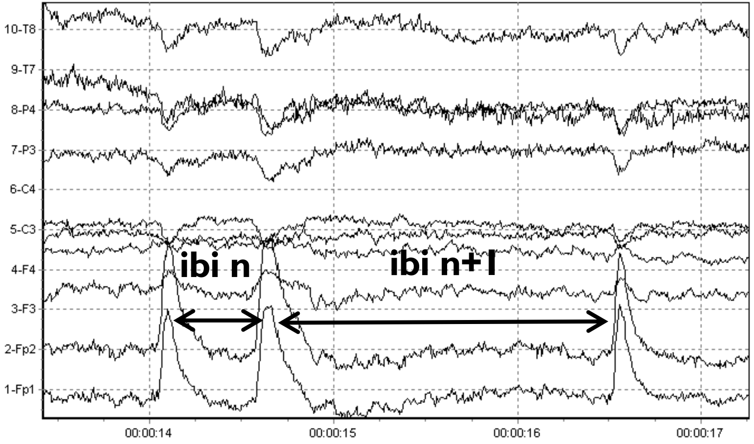
# ECG pre-processing: Example

ECG




EOG




Rate = fs / ibi * 60 [bpm]

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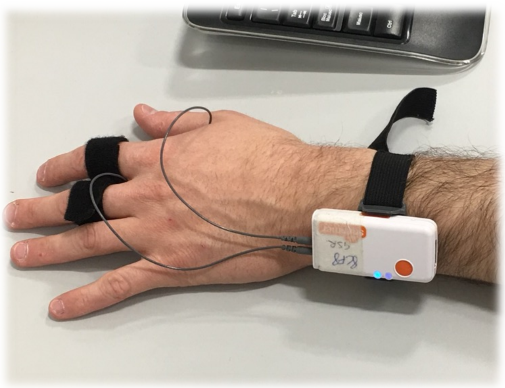
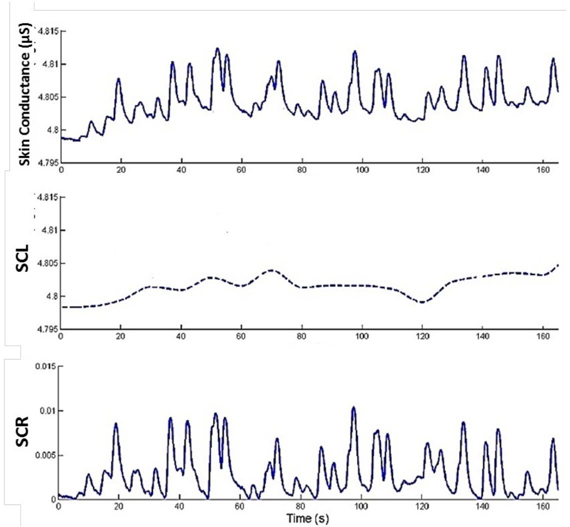
# Galvanic Skin Response

- ***Galvanic Skin Response* (GSR)** is the electrical measurement of the **Skin Conductance (SC)**. Skin resistance varies with the state of sweat glands. Sweating is controlled by the sympathetic nervous system. If the sympathetic branch of the **autonomic nervous system is highly aroused**, then **sweat gland activity also increases**, which in turn **increases SC**.






**2 INDICATORS:**

**SCL mean**
**Epidermis Sweat Diffusion**
**(Tonic – Slow)**

**SCR peaks amplitude**
**O\C Pores**
**(Phasic – Fast)**

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# Presentation contents

# Real-Time MWL Assessment



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SANTA LUCIA NEUROSCIENZE E RIABILITAZIONE

nina

DEEPBLUE consulting&research

AleniaAermacchi A Finmeccanica Company

ENAC La référence aéronautique

EUROCONTROL

(Borghini, 2011, IJASM)
(Aricò et al., 2016, Frontiers)

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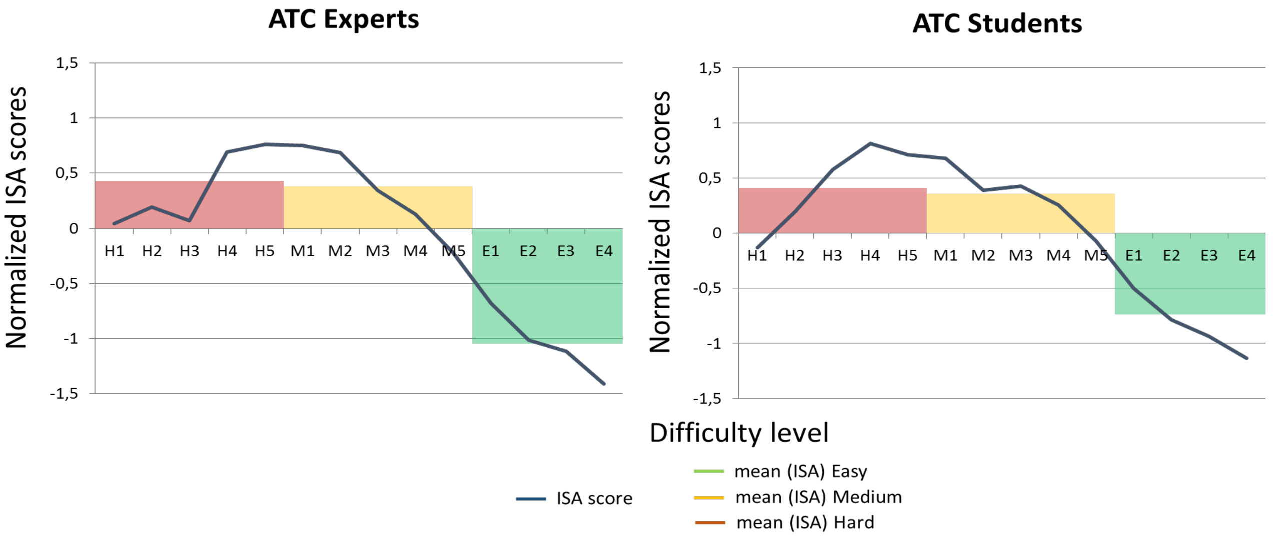
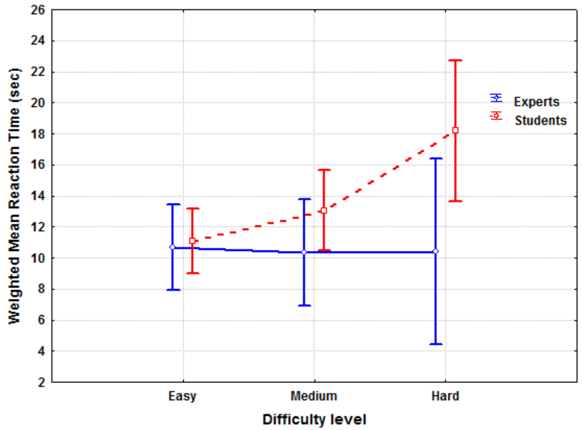
# Example: ATM Case Study (1/2)




| | Easy vs Medium | Medium vs Hard | Easy vs Hard |
|---|---|---|---|
| **ATC Experts** | **$5.2*10^{-9}$** | 0.854 | **$8.9*10^{-5}$** |
| **ATC Students** | **$2.6*10^{-5}$** | 0.593 | **$7.5*10^{-5}$** |

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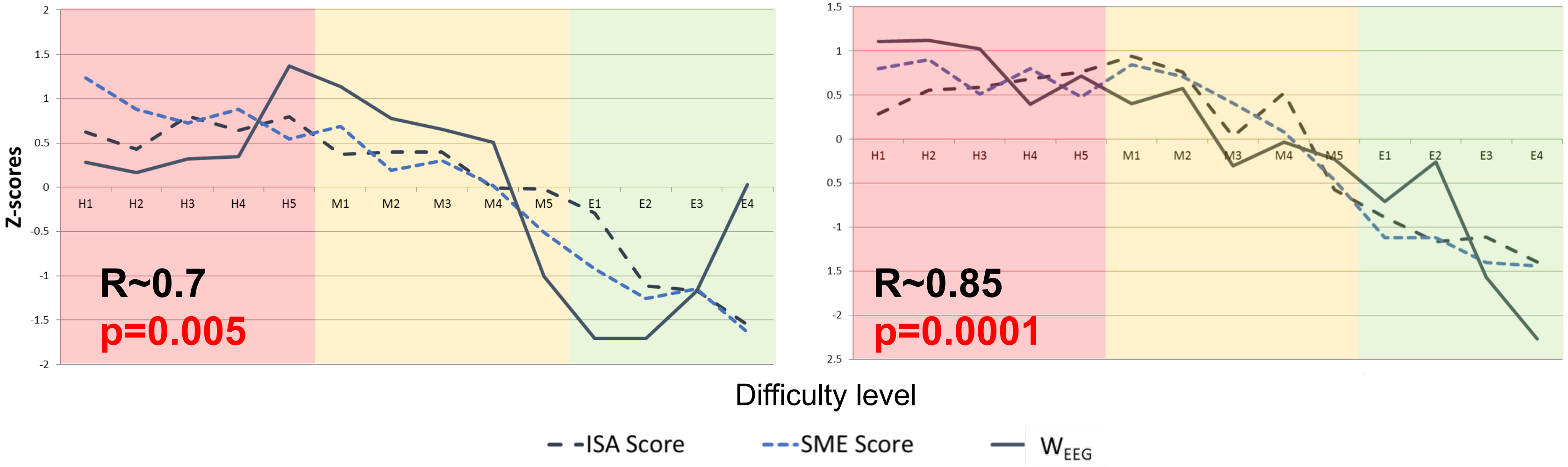
# Example: ATM Case Study (2/2)

## ATC Experts | ATC Students




| | Easy vs Medium | Medium vs Hard | Easy vs Hard |
|---|---|---|---|
| **ATC Experts** | 0.02 | 0.01 | 0.003 |
| **ATC Students** | 0.04 | 0.04 | 0.003 |

(Aricò, Borghini et al., 2016 Prog Brain Res)

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# Expertise Evaluation

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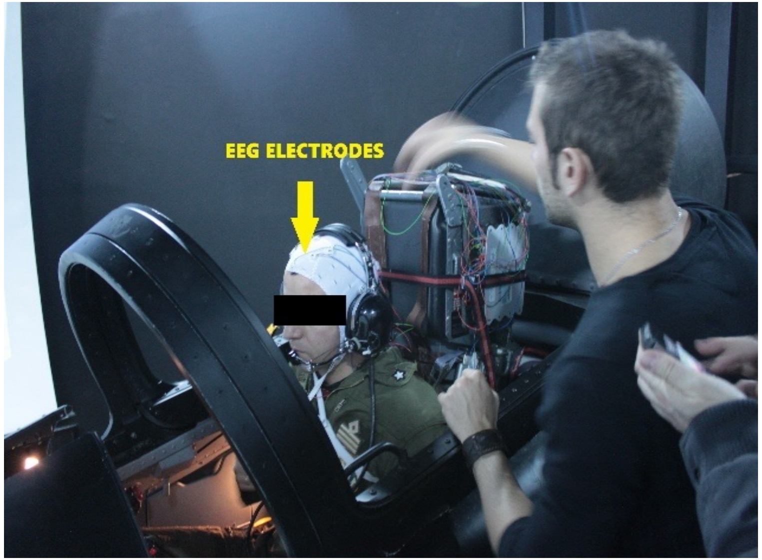
# Air Force: Experts vs. Students



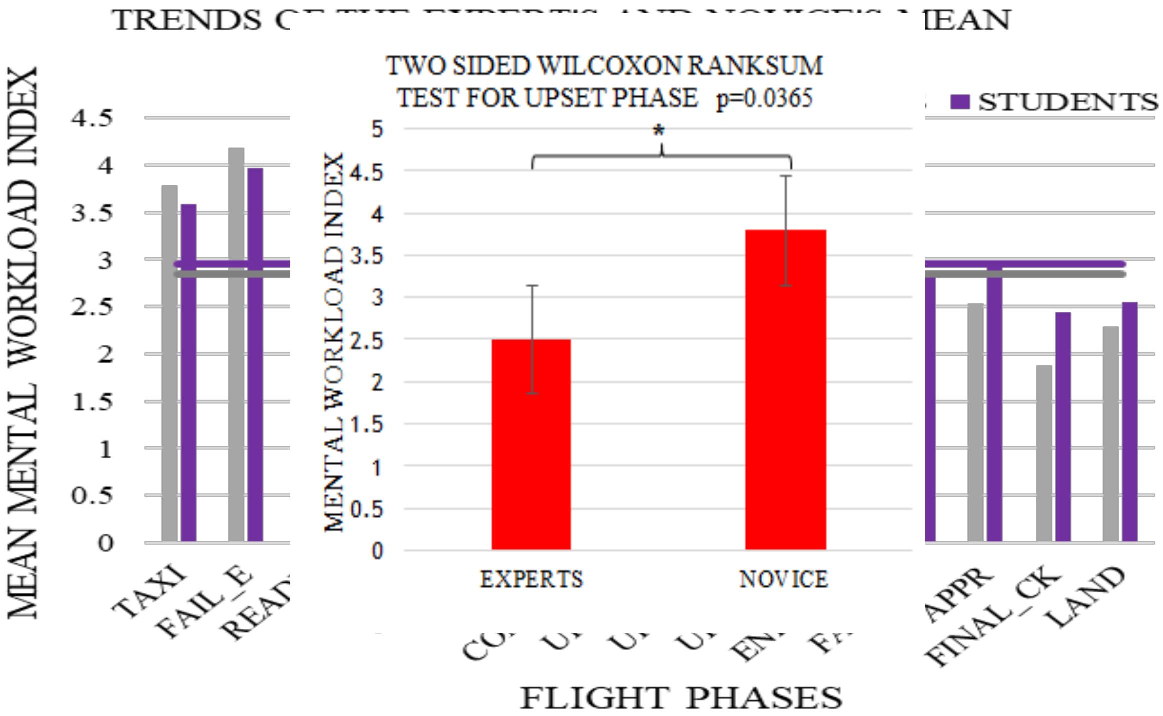

The Placing of the EEG electrodes on the pilot scalp


During the entire flight simulation, the pilots monitoring has been done from the outside by the remote-control station

(Borghini 2012 – IJASM)

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.

# Experts vs. Students: Results



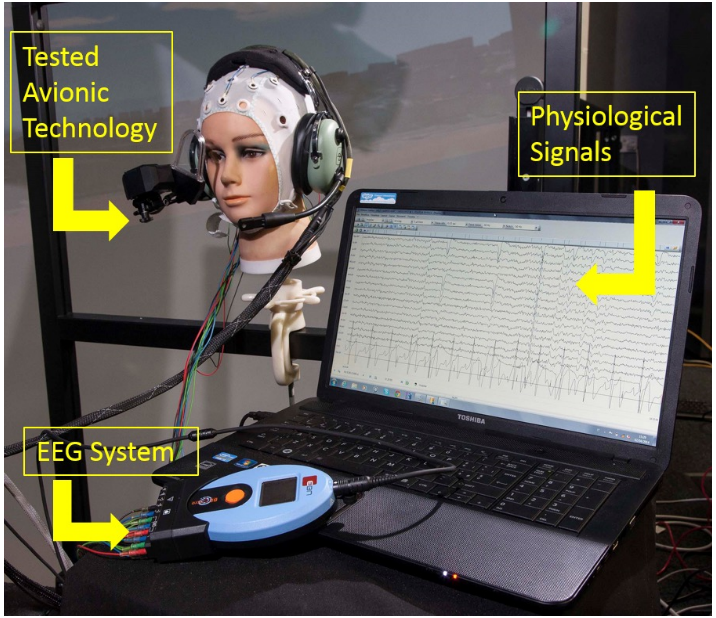

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.

# Technology Comparison

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N°814961.

# Avionic Technology Testing

Cognitive neurometrics can be used as a reliable measure of the user's mental workload, being a valid indicator for the comparison and testing of different avionic technologies.





(Borghini et al., 2015, IEEE EMBC)

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DEEPBLUE consulting&research
AgustaWestland

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# CRM Estimation

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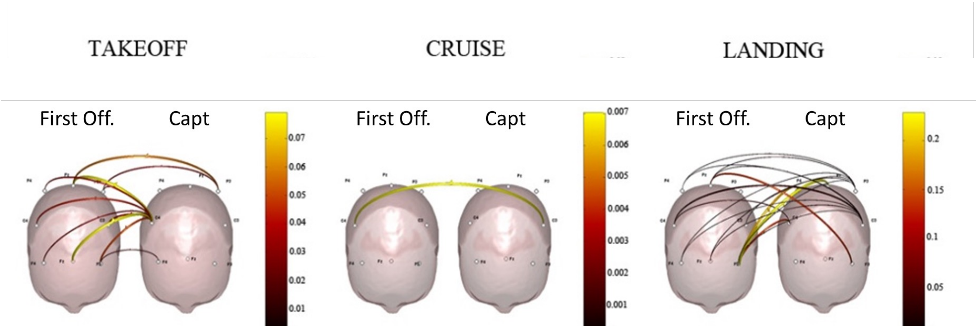
# CRM\TRM Assessment

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Alitalia

SANTA LUCIA NEUROSCIENZE E RIABILITAZIONE

For the purpose of optimizing the Crew Resource Management (CRM), the interaction has been investigated by simultaneous recordings of brain signals during flight simulations and real jumps.

(Toppi, Borghini et al., 2016, PlosONE)

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# Presentation contents

# Motivation

**LIMITATIONS**

- **Standardised training schedules** that do not accommodate individual differences.
- The training is generally evaluated by the supervision of experts and it is easy to understand how this approach is **highly operator–dependent**.
- **No quantitative training assessment** in terms of cognitive resources.

**AIMS**

- **Tailoring and objective and information** are needed, especially regarding the amount of available cognitive resources (Spare Capacity) and workload level reached during the specific operative conditions.

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# Example: ATPL / CBT Comparison

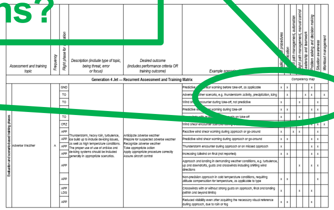
## ATPL
## (Integrated Air Transport Pilot Licence )
## Tasks/ Maneuvers Assessment

## CBT
## (Competency Based Training )
## Competencies Acquisitions Assessment

**What if we could be able to characterize and objectively measure how the competences change throughout the training sessions?**

Tasks/ Maneuvers #1
Tasks/ Maneuvers #2
.
.
.
Tasks/ Maneuvers #N

Flight situations by which assess competencies acquisitions based on the K-S-A model (*Knowledge*, *Skill*, *Attitude*).



**Debriefing**

**Debriefing + Assessment and Theory Matrix**

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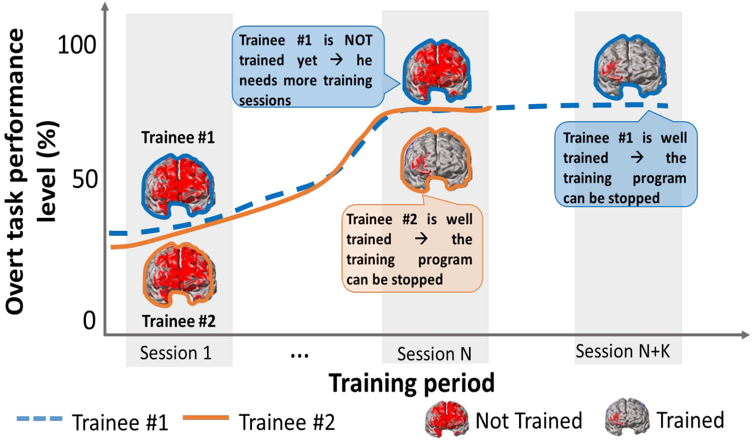
# Training Scenario

A subject can be defined “**Trained**” when his/her correct execution of the task requires less physical and cognitive resources and effort.

As consequence, the **available spare capacity** for emergencies and unexpected events will be greater and the safety level higher.

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(Borghini, et al. 2015 Brain Topo)

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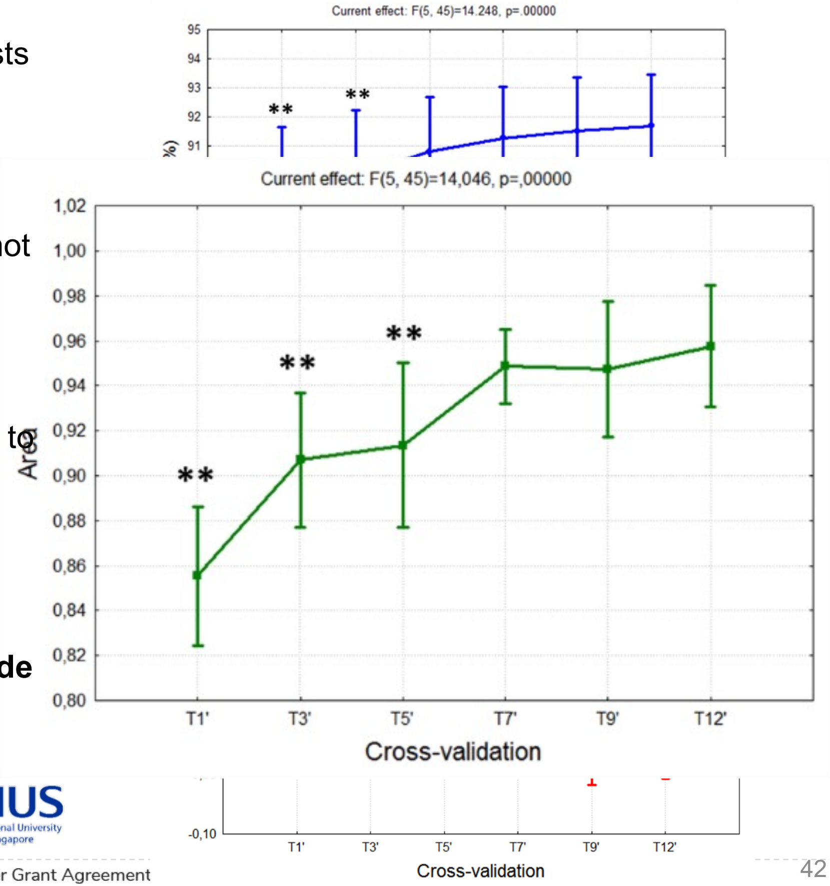
# Training Assessment: Lab study

**Inappropriate training assessment** might have either high social costs and economic impacts, especially in high risks categories, such as Pilots, Air Traffic Controllers, or Surgeons.

In fact, even if the task is accomplished achieving the maximum performance, by the standard training assessment methods, it would not be possible to **gather and evaluate information about cognitive resources available for dealing with unexpected events or emergency conditions**.

We proposed a **neurometric** based on a **machine learning** algorithm to **quantify the user's training level** within each session by combining **both the behavioral and cognitive** abilities between consecutive sessions.

The results demonstrated that the proposed methodology and neurometric could quantify and track the users' progresses, and **provide the Instructor information for a more objective evaluation and better tailoring of training programs.**




(Borghini et al., 2017, Frontiers Neuro)

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NUS National University of Singapore

This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement

# What are your takeaways up to now?

- The Human Factors are crucial for Safety: **direct relation between operator’s mental states and performance**.

- Neuroscience and technology progress can provide useful tools to mitigate risky conditions: **operator’s mental states monitoring to allow support\intervention by adaptive automations.**

- We can estimate objective information from the operator’s neurophysiological signals: **the combination of different data can provide a more accurate characterization of the phenomenon under investigation**.

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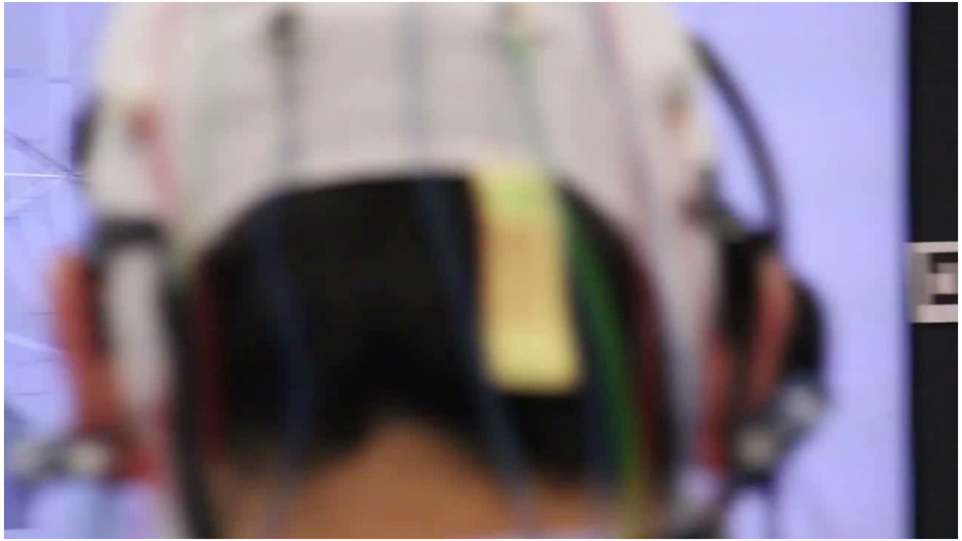
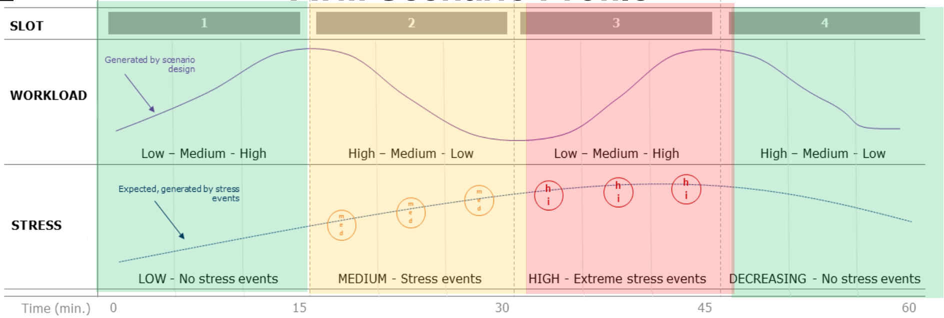
# ATCO's Stress Assessment



16 ATC students
60-min realistic ATM scenario
2 Subject Matter Experts (SMEs)
2 Pseudo-Pilots
Neurophysiological data (EEG, ECG, GSR)
Self-report (Every 5-min)

(Borghini et al., 2020, Sci Rep)

**ATM Scenario Profile**

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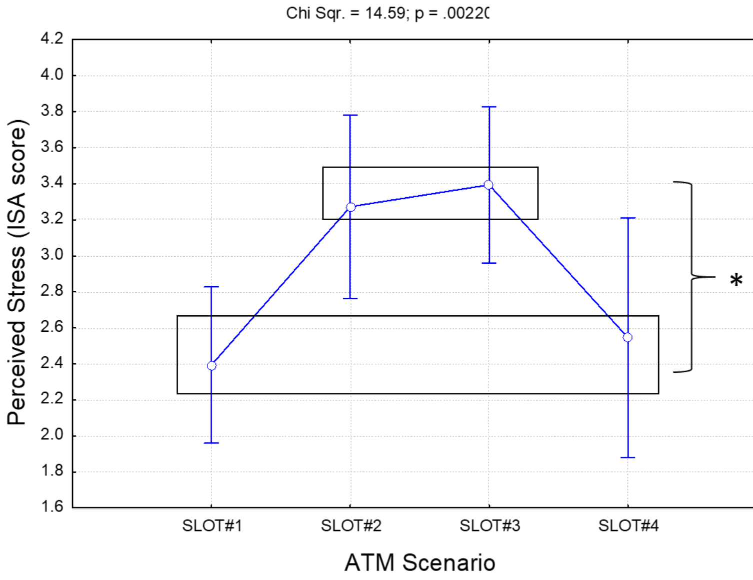
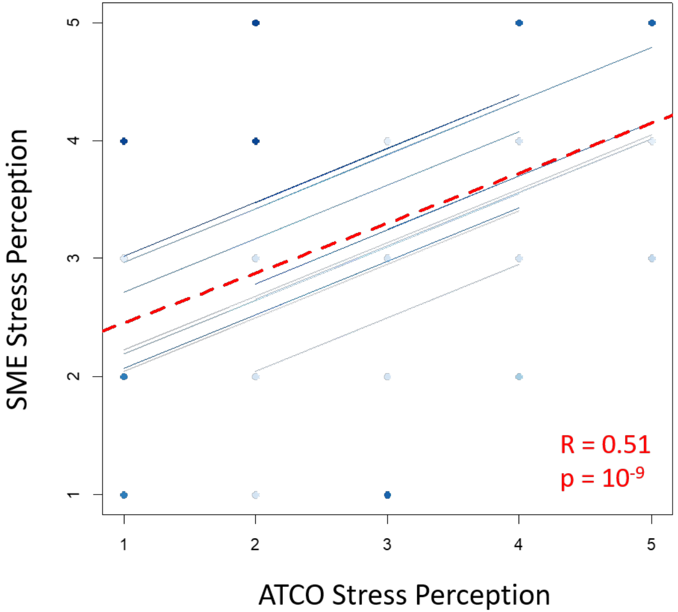
# Subjective Measures – Stress Perception

The overall stress perception **decreased significantly** (p<0.0001) between the beginning and the end of the ATM scenario both for the ATC Students and SMEs

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# But…

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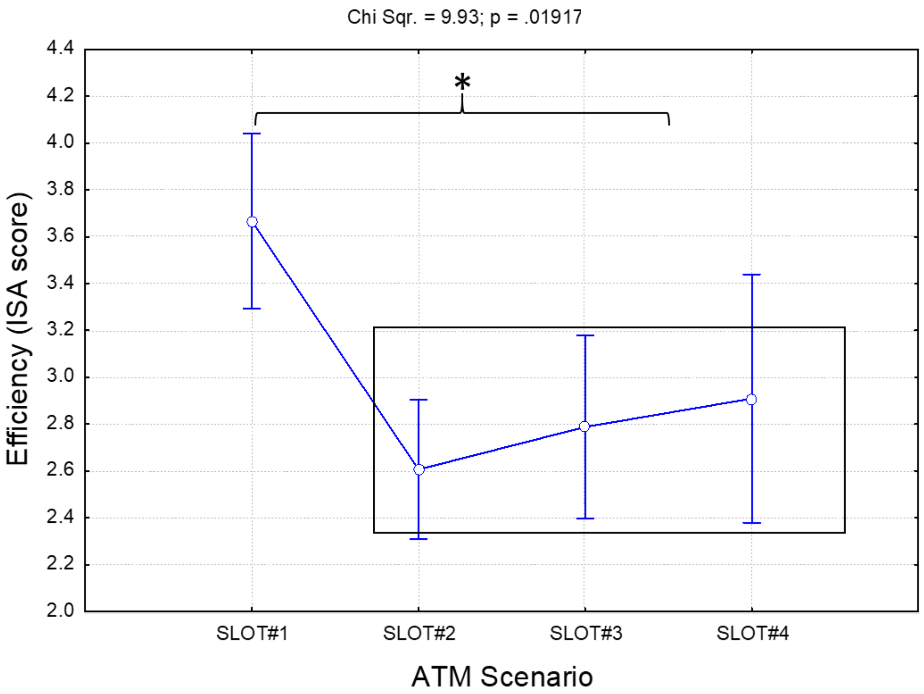
# Subjective Measures - Efficiency

The SMEs' assessment regarding the ATCOs' Efficiency (p=0.0008) reported **significant decrement** when the stressful events started to the end of the ATM scenario.

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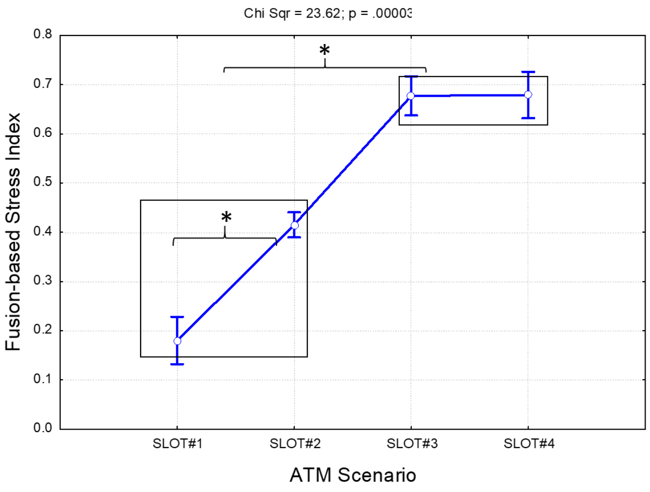
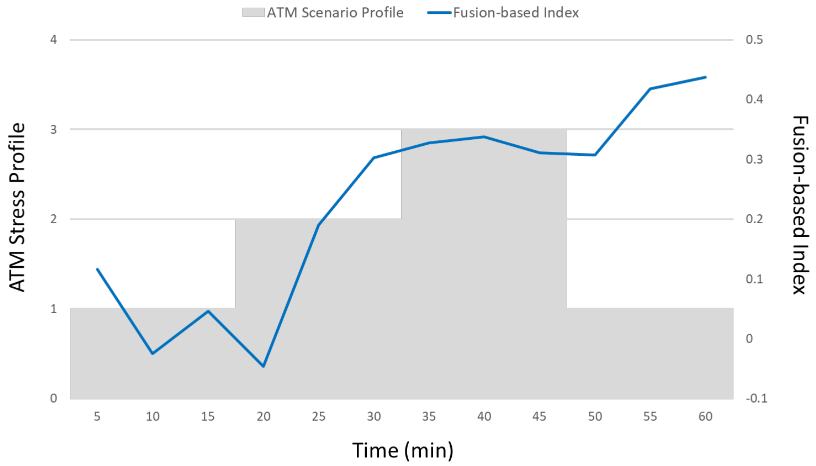
# Fusion-based Stress Index

The Fusion-based Stress Index **reported significant effect** (p=0.00009) across the ATM scenario.

The stress level **kept increasing after the highest stressful phase** (SLOT#3) rather than decreasing as the subjective stress perception.

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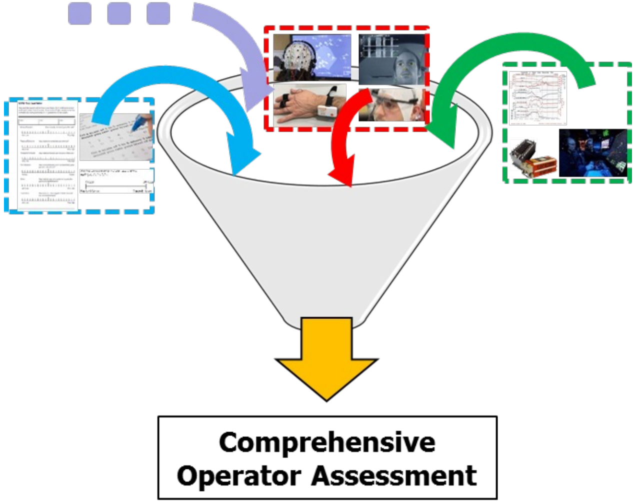
# Take Home Message

- A **multimodal approach** would overcome the current limitations in assessing the operator's **internal state** and **provide a more accurate characterization and assessment** of the operator's Human Factors.

- **Closed-Loop between Humans and Machines** in order to improve the interactions and feedbacks to better manage the control system(s) and enhance the safety under all conditions.





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# Thank you for your attention

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SAFEMODE

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