Decoding the ATCO's brain for augmented Human-Machine Interaction

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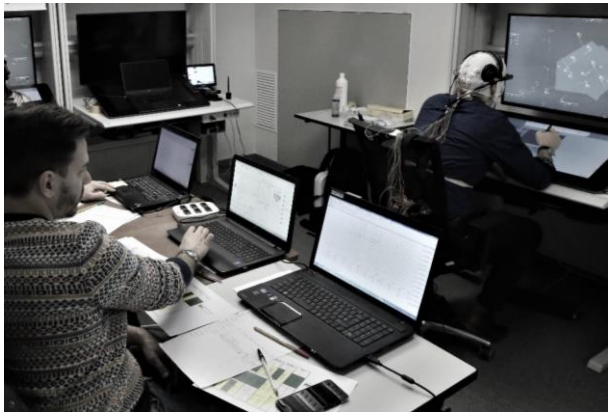
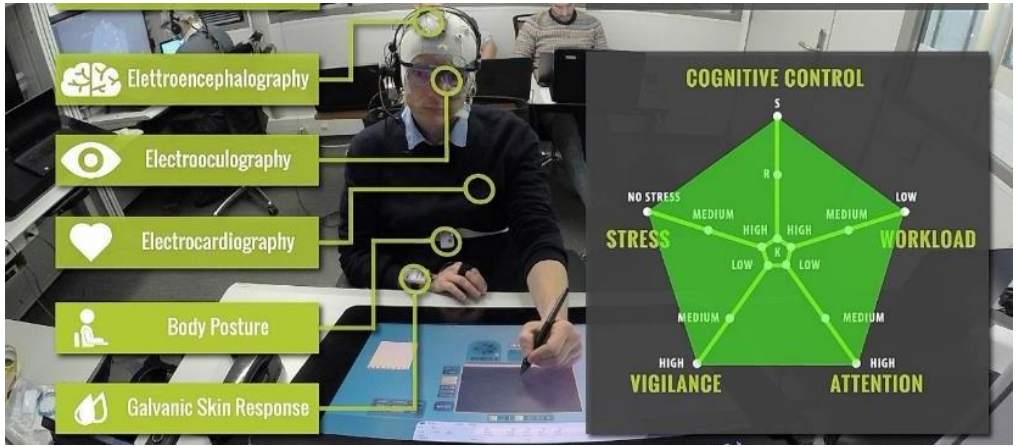


Preliminary concepts

Biometrics is the technical term for **body measurements** and calculations. Biometric identifiers are the distinctive, **measurable characteristics used to label and describe individuals**. Examples include, but are not limited to body measurements, fingerprint, face recognition, DNA, palmprint, iris-recognition, etc.

Preliminary concepts

Neurometrics is a technical term developed in the last decade within the field of neuroscience and stands for **measures of human mental states** (thus the prefix *neuro-* because of the relation with human neurophysiological activities)**, such as the level of workload, attention or stress while performing a task.**

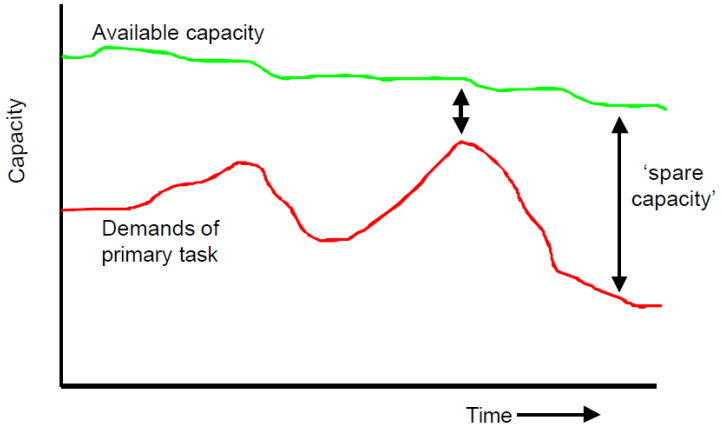


Credit to:
STRESS project, H2020 SJU GA n. 699381,
http://www.stressproject.eu/

Why is it important to measure the mental states of a user?

Introduction

The human brain cognitive resources are not unlimited!



The **greater the mental workload** required by the primary task is, the **less the cognitive resources available** are (***spare capacity***).

Spare capacity decreasing → **lower surveillance** on the surroundings and **lower capacity to react** to unexpected events.

Introduction

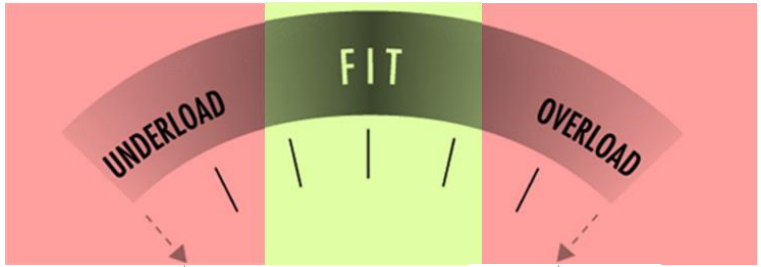
Mental Workload is not a unitary concept, because is the **result of different aspects that interact** each other
(C.D. Wickens, 1984).

Mental Workload is not an inherent property, but rather it emerges from the **interaction between** the requirements of a **task**, the **circumstances** under which it is performed, and the **skills**, **behaviours**, and **perceptions** of the operator
(S.G. Hart and L.E. Staveland, 1988).

The aim of **evaluating the mental workload** is to quantify the mental resources involved during task performance in order **to predict operator and system performance**
(B. Cain, 2007).

Introduction

Human Factor (HF) research has indicated that **performance declines at either extremes of the workload** demand continuum, **increasing the probability of human errors** (Calabrese, 2008; Aricò et al., 2017).



QUALITATIVE	QUANTITATIVE
Sufficiently frequent, but simple, narrow requirements	Mental requirements are too seldom

QUALITATIVE	QUANTITATIVE
No time pressure but mental require-ments are too complex and/or complicated	Time pressure, mental requirements are too frequent

Human performance are not constants but they **depend on the actual psychophysical state of the operator**.

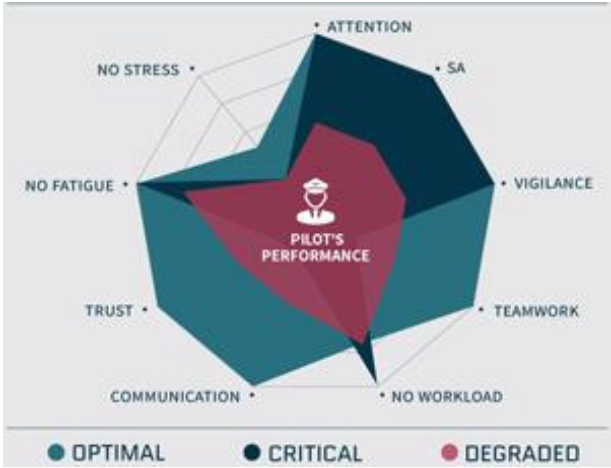
Human Factor & Safety

- More than **70% of aviation accidents are due to human errors**.
- Over **1.2 million people die each year on the world's roads**, millions more sustain serious injuries affecting their whole life. **Human error is the main cause** of the 57 % of road accidents and contributing factor in over 90 % of them.
- In general, human error is consistently identified as one of the main causes of incidents and tragedies in most of workplace's accidents. **Its main cause is a sudden mental impairment (overload, stress, distraction, etc.)**.

(WHO Report, 2015; Boeing Report, 2011; AviationSafetyNetwork reports)

The Human Performance Envelope

Human performance degradation results from the interaction of multiple HFs and this interaction is still mostly underexplored.



The concept of **Human Performance Envelope (HPE)**, a function defined by relevant HFs and associated scales, aims **to predict operator's performance** defining a region where performance will be tolerable, and where it starts to become hazardous *(H2020 Future Sky Safety program).*

One of the **current limitations** is the **lack of objective information about the operator's psychophysiological status** while dealing with operative activities.

Human Factor assessment

Lack of objective information about the operator's psychophysiological status while dealing with operative activities.

- ! Self-assessed measures are subjective and "a-posteriori" or require additional tasks. Also, the user could be not aware of an incoming impairment.
- ! Supervisor assessment could have a certain subjective bias. Also, mental state degradation could be covert (i.e. not perceivable from user's behaviour).
- ! System data (performance metrics) often highlight risky behaviours "after the fact".

Neurometrics could provide objective information about human mental states.

(Parasuraman et al., 2008; Borghini et al., 2017)

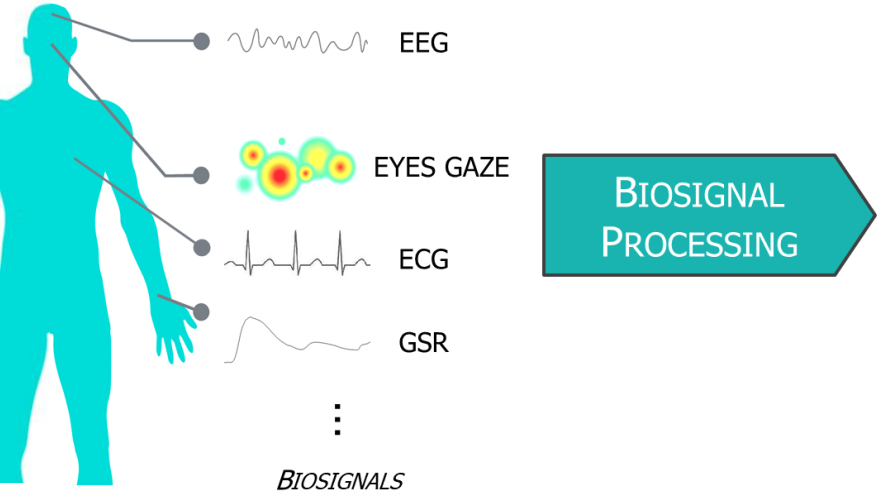
Human Factor assessment

Neurometrics could provide objective information about human mental states.

- ✓ **Objective** and based on **instantaneous neurophysiological activities**.
- ✓ Even **online**, without requiring any additional task.
- ✓ Potentially able to even **predict** incoming impairments.
- ✓ They can be used as a **communication channel to enhance Human-Machine Interaction.**

(R. Parasuraman, 2003; Aricò, Di Flumeri et al., 2017; Di Flumeri et al., 2019)

Concept



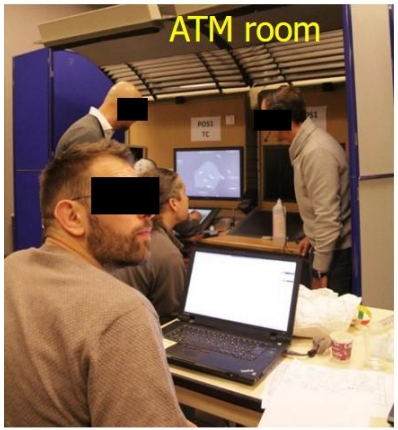
CROSS - DOMAIN

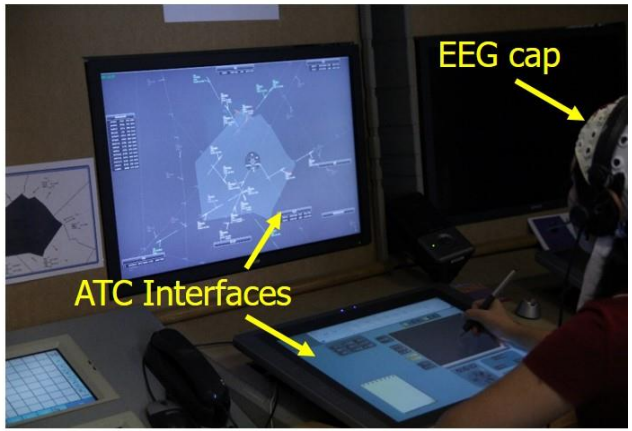
Cognitive Neuroscience applied to operational environments

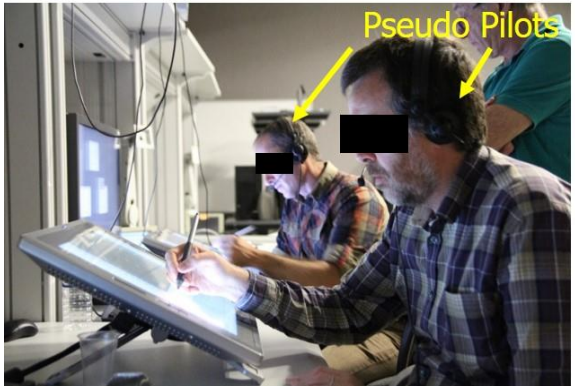
Mental Workload assessment

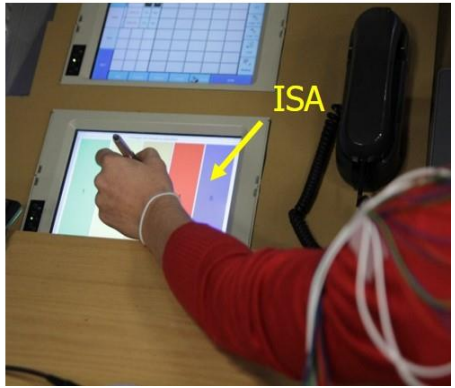
- 15 experts ATCOs (40.4 ± 5.5 ys),
  22 students ATCOs (23 ±1.95 years old)
- EEG Data acquisition with 12 electrodes (FPz, AF3, AF4, F3, Fz, F4, P3, P7, Pz, P4, P8 and P8) in the following conditions
  - 60 seconds Open Eyes
  - 60 seconds Closed Eyes
  - 3 minutes of Baseline (automatic scenario)
  - Simulated real-scenario in a workstation (a).
- The difficulty during the whole task (45-minute long) varied continuously (15 mins Hard, 15 mins Medium, 15 mins Easy).
- Collection of the ATCO's experienced mental workload (**behavioural measures**) by using the Instantaneous Self-Assessment (ISA) technique, assessed each 3 minutes by a **Subject Matter Expert observer (SME-ISA)** and by the **operator himself (SELF-ISA)**.

Mental Workload assessment





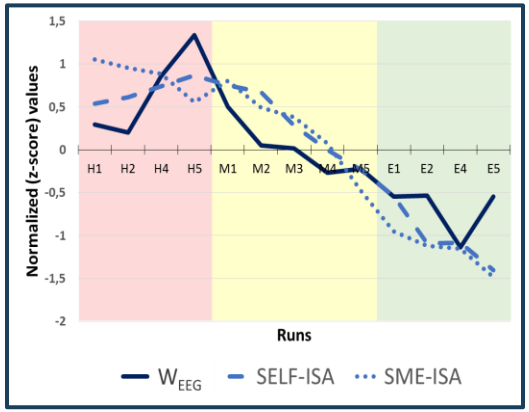




High realistic settings:

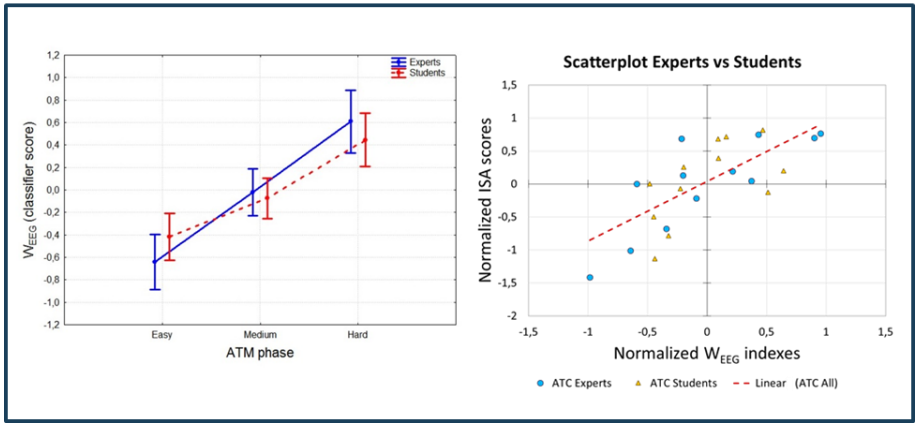
- Real workstation;
- Realistic simulation scenario (45 minutes) normally used for training;
- 2 aircraft pseudo-pilots in a different room to simulate radio communications coherently with the scenario conditions.

Mental Workload assessment



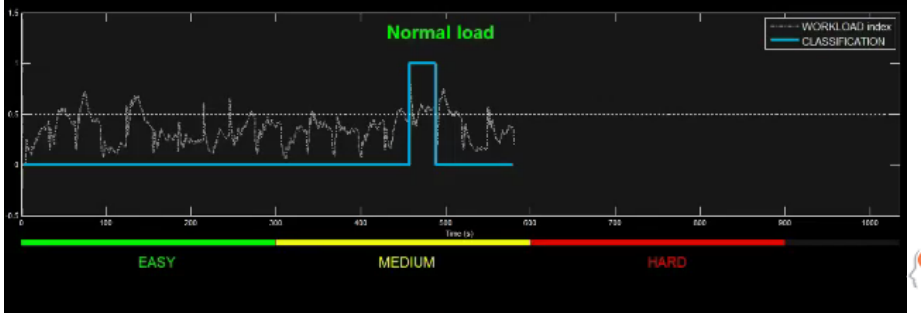
The EEG-based MW index **(W_{EEG}) showed high positive and significant correlations** both with SELF-assessed (R=0.86, p=0.0002) and SME-assessed (R=0.80, p=0.001) MW measures.

https://doi.org/10.1016/bs.pbr.2016.04.021



The algorithm was able to **discriminate significantly the three workload demand** of the ATM scenario (all p<0.01) for both the ATC Experts (blue line) and Students (red line).

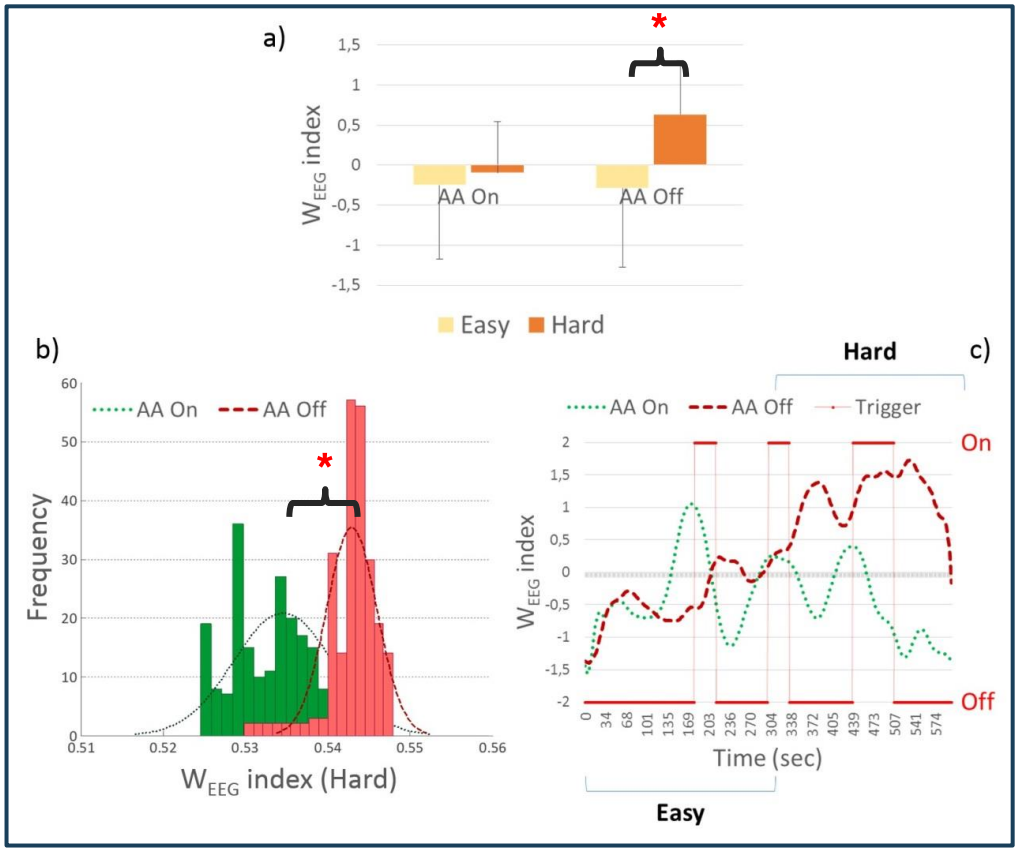
Online MW and Adaptive Automation



12 student ATCOs (23 ± 2 years old).

- ✓ EEG with 9 electrodes
- ✓ 2 testing scenarios of 15 minutes (5 mins EASY, 5 mins MEDIUM, 5 mins HARD):
  1. Adaptive Automation off (AA off);
  2. Adaptive Automation on (AA on) → **online testing**
- ✓ High realistic settings:
  - Real workstation, realistic simulation scenario normally used for training, 2 aircraft pseudo-pilots.

Online MW and Adaptive Automation



a) The t-tests showed a **significant increasing** ($p = 0.03$) of the W_{EEG} indexes distribution between the Easy and the Hard periods **only for the AA Off condition**.

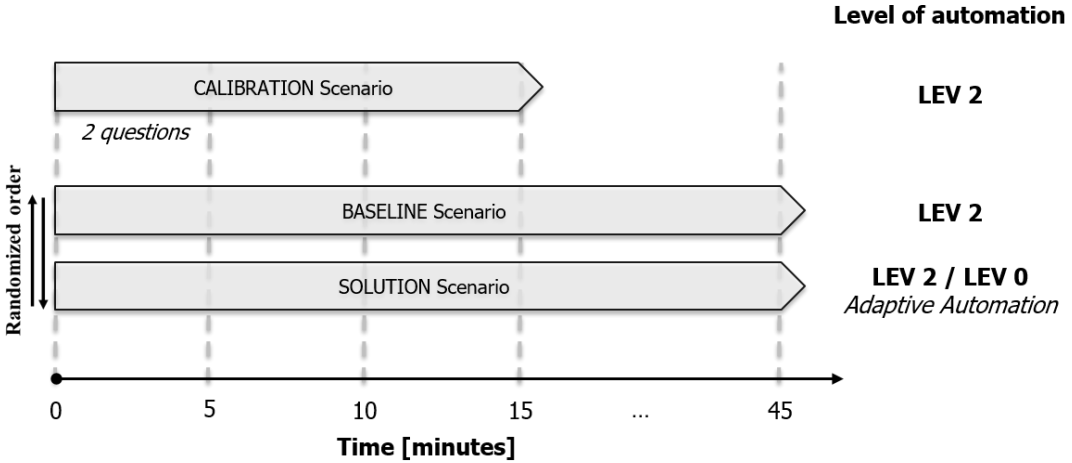
b) The shape of the W_{EEG} distributions related to the Hard slot, for both the two conditions (AA On/Off). **The *AA On* indexes were significantly ($p = 0.04$) lower than during the *AA Off* scenario.** No differences between the Easy condition.

c) Time course of the W_{EEG} index, during both the two scenarios (AA On/Off), with the AA activation segments (Trigger) for a representative subject.

https://doi.org/10.3389/fnhum.2016.00539

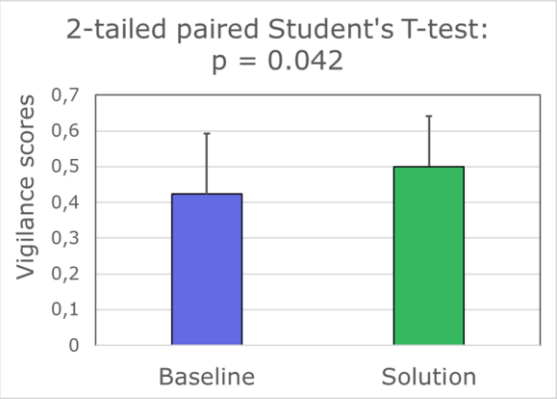
Vigilance and Adaptive Automation

- 14 male pro Air Traffic Controllers (Age: 45.0 ± 7.5 years)
- 15 EEG channels

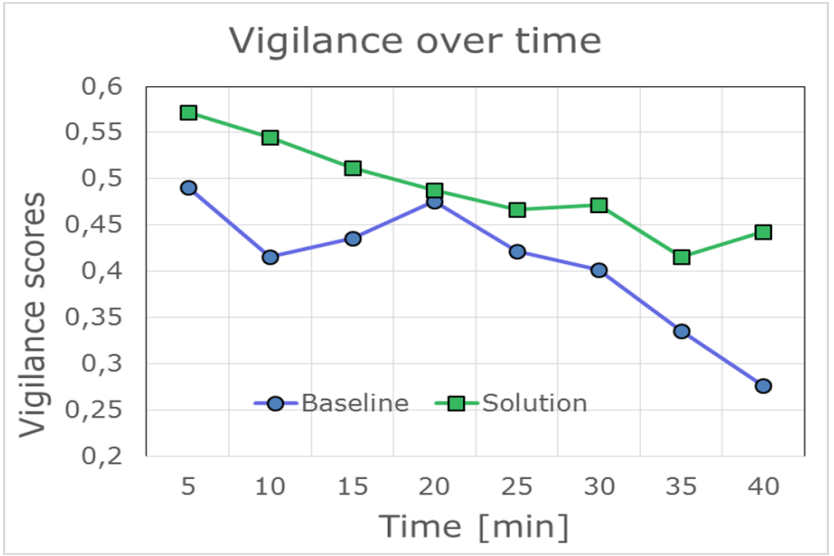


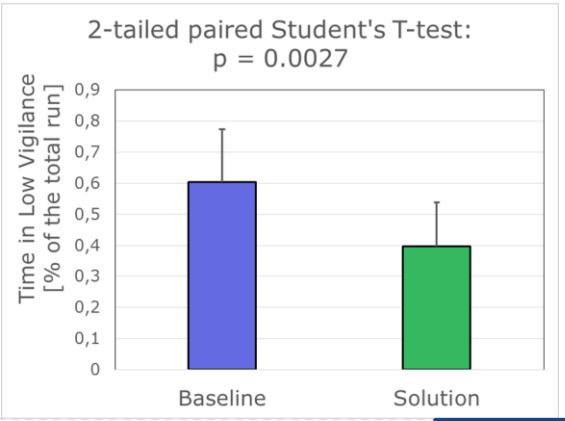
- Eye-tracking device also for measurements
- NASA-TLX after each experimental scenario

Vigilance and Adaptive Automation



The averaged EEG-based **vigilance scores were significantly higher** during Solution than Baseline scenario.





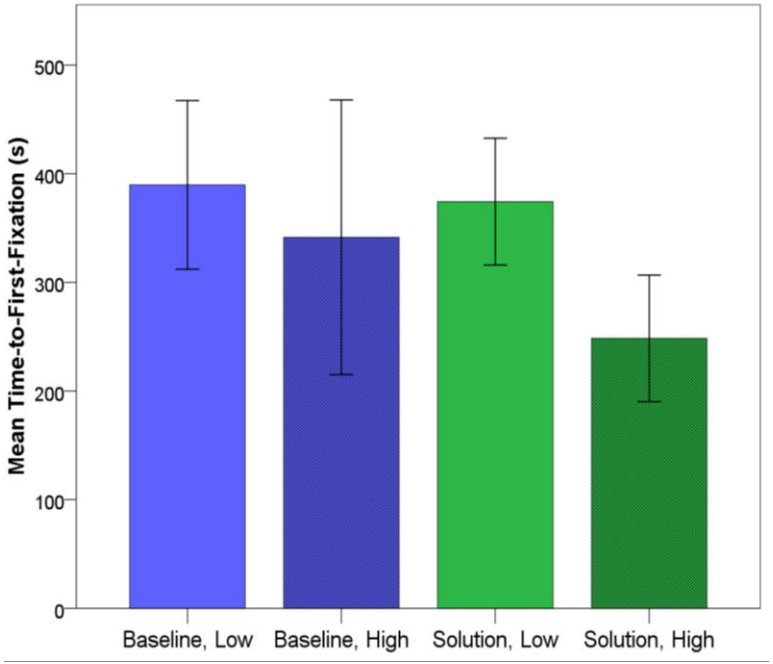
The time spent in a **"Low Vigilance condition" was significantly lower** during Solution than Baseline scenario.

✗ Controller vigilance decreased when they were not actively involved with the task but only acted as a mere monitor.

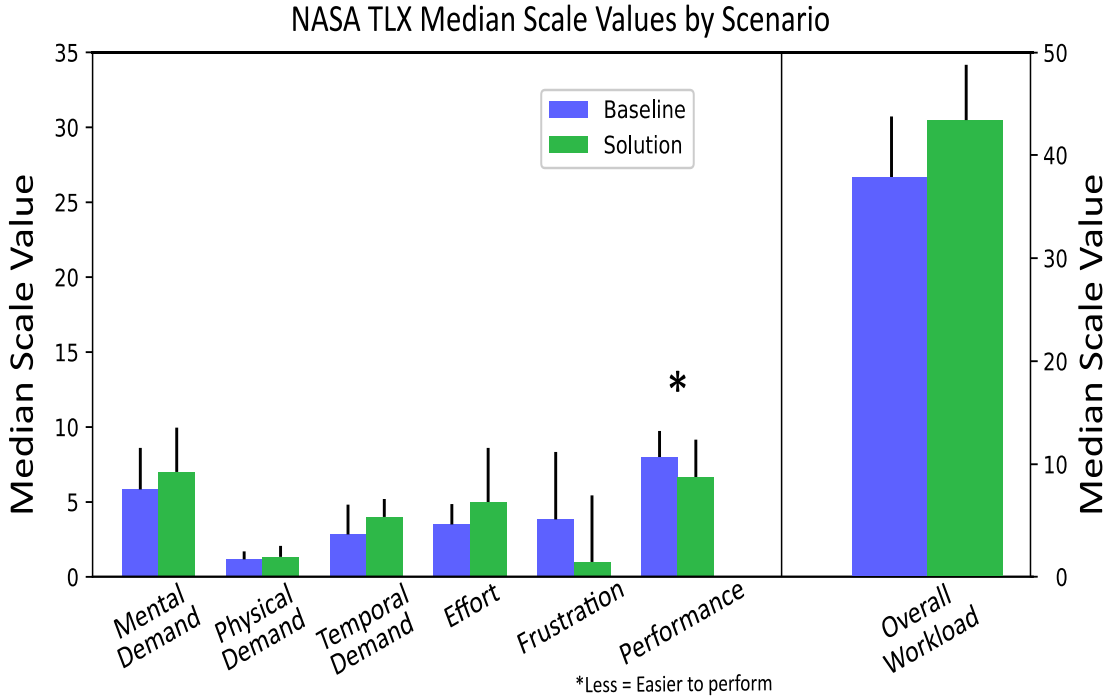
✓ The vigilance decreasing was mitigated through the Adaptive Automation solutions triggered by the EEG Vigilance Observer.

https://doi.org/10.3389/fnhum.2019.00296

Vigilance and Adaptive Automation

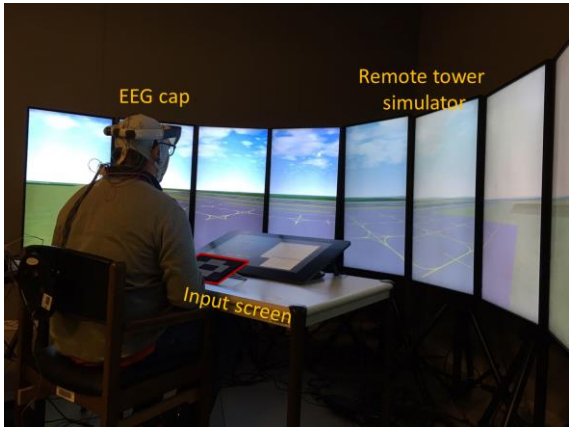


Oculometric measures confirmed that the **performance have been significantly better during the Solution scenario**, in particular during High Vigilance condition.



Subjective measures confirmed that the ATCOs felt **more involved** (higher but not excessive workload), **less frustrated and better performing during the Solution scenario**.

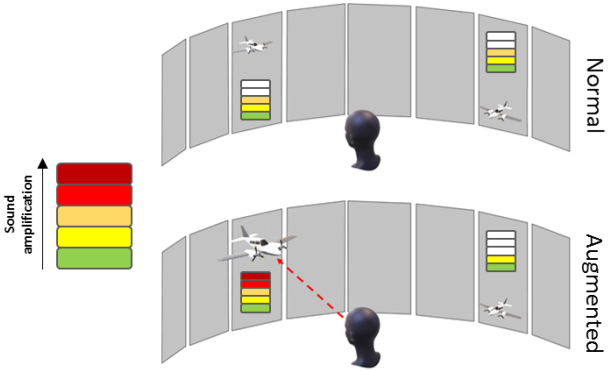
HMI evaluation



www.moto-project.eu

In the MOTO project, **Workload Neurometric** has been used **to compare different HMI modalities of Remote Towers:**

- Normal;
- Augmented (Visual, Acoustic and Vibrotactile spatial cues of aircrafts in movement)



Augmented modality significantly decresead ATCO's mental workload and improved its performance.

RECENT FINDINGS:
- VV and VAV modalities are equivalent → audio is not necessary

HMI evaluation

- ✓ Multiple concurrent biosignals.
- ✓ Neurometrics of 5 different Human Factors.
- ✓ Evaluation of different Interfaces and eventual malfunctioning

www.stressproject.eu

CONCLUSIONS

Conclusions

- Neurometrics allow to obtain **objective insights about human mind** while dealing with tasks **that are difficult or even impossible to obtain by using traditional approaches**.

- Neurometrics allow to obtain information about **the intrinsic causes** (mental overload, stress, loss of situation awareness, etc.) **of abnormal human behaviours**, in order to mitigate and eventually prevent them.

- Neurometrics allow to monitor online human mental states, in order to develop **BCI-based systems able to adapt their behaviour** (adaptive automation) on the basis of the operator's state.

New enablers

Innovative wearable devices for biosignals recordings

https://www.brainsigns.com/en/company/c2/blog/mindtooth-project-kicked-off

Artificial Intelligences
&
Internet-of-Things

Applications and Future trends

Research

Obtain insights about covert and/or unconscious reasons of human behaviour.

Industry

Human-centred design of workstations/dashboards /cockpits.

It is not science fiction, it is reality!

BCI to support operators and improve Human-Machine Interaction.

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> 30 high-impact scientific publications,
1 patent, 1 book, various awards

Thank you for the attention!

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