

ATM training and workload estimation by neurophysiological signals

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WHAT WE DO

Researches for:

- Neurometric quantitative training evaluation
- Neurometric real-time workload estimation
- Avionic technology testing
- BCI communication systems

Tested ON:

- Professional commercial (Alitalia) and military (Italian Air Force) pilots
(total sample size 45)
- Military helicopters pilots
(total sample 3)
- ATCos professional and students
(total sample size 30)
- Car drivers
(total sample size 30)

In Cooperation with:



PAST EXPERIENCE IN MENTAL STATES RECOGNITION



BCI demonstration at the Posters and Exhibits Session 2 at 4.30 PM

LIMITATIONS:

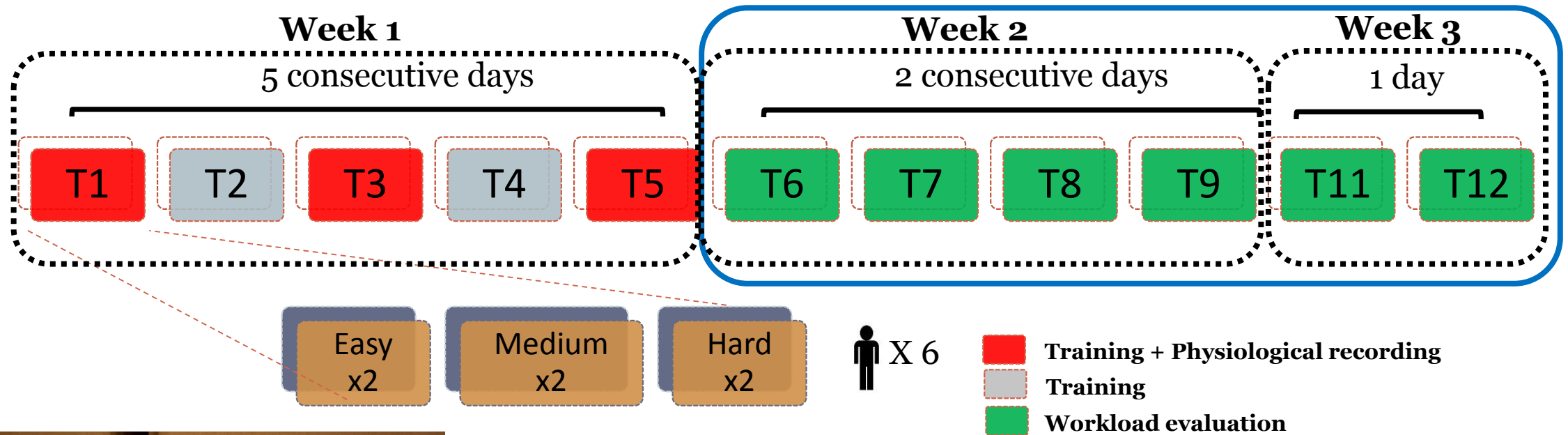
- ❑ No quantitative methodologies in terms of cognitive evaluation of the mental efforts performed by the subjects.
- ❑ Such mental effort and the related performance are generally evaluated by the supervision of experts and it is easy to understand how this approach is highly operator–dependent.

AIMS:

- ✓ Evaluate the training improvement and the level of cognitive workload of ATM operators in a realistic context, through a combination of neuro-physiological signals.

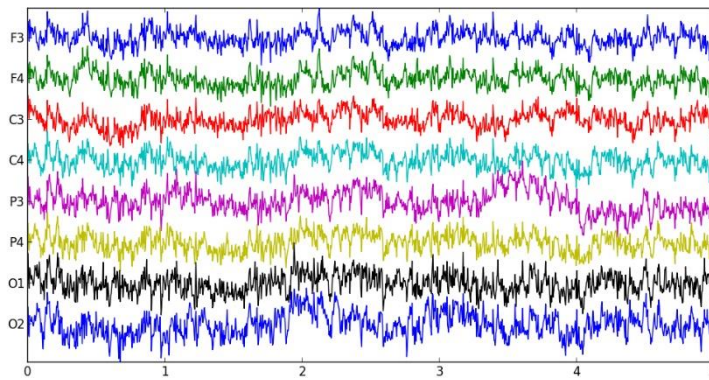


EXPERIMENTAL PROTOCOL

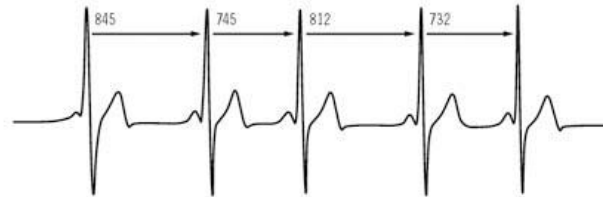


LABY: Participants must input numerical values such as heading, flight level, speed, etc., in order to direct flight around the trajectory and to avoid any conflicts or obstacles which may occur during the flight-route. Penalties are applied if the aircrafts deviate off the route or if other constraints are not met.

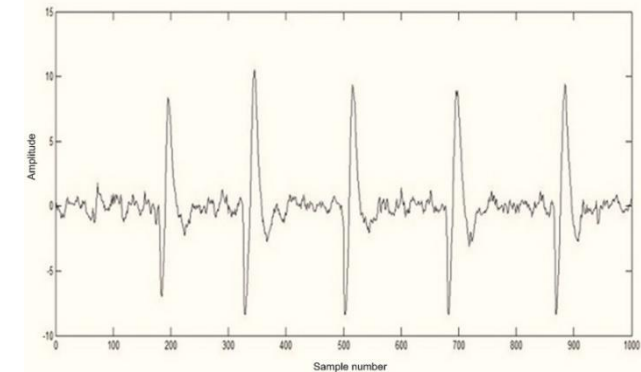
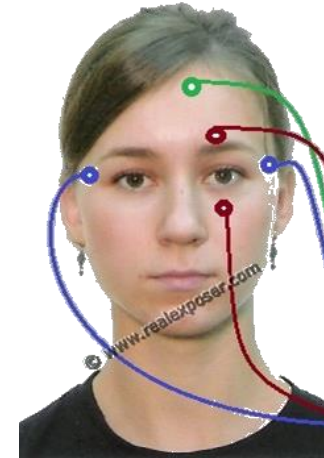
Electroencephalogram (EEG)



Electrocardiogram (ECG)



Electrooculogram (EOG)



TRAINING EVALUATION

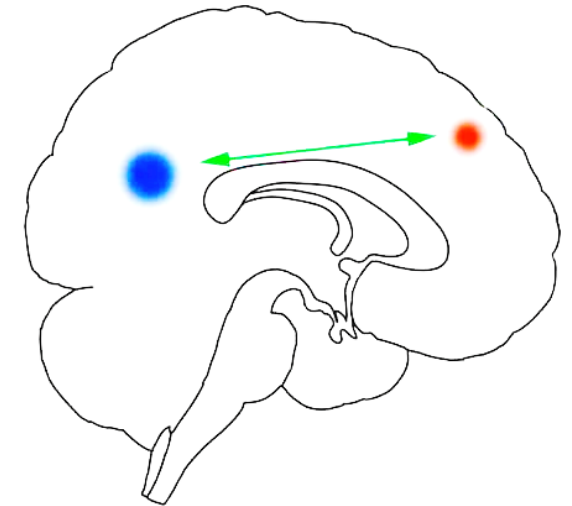


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Training Cognitive Processes: Literature Review

- ❑ Activations seen earlier in practice involve generic attentional and control areas: **prefrontal cortex (PFC)**, **anterior cingulate cortex (ACC)** and **posterior parietal cortex (PPC)**.
- ❑ With practice, the **task-related processes fall away and there is a shift toward the attentional brain areas** (in particular, toward the parietal brain area).
- ❑ Practice-related reorganization of the functional anatomy of task performance may be distinguished into two types, one constituting a *redistribution*, the other a *'true' reorganization*:
 - **Redistribution.** The brain activation map generally contains the same areas at the end as at the beginning of practice, but the levels of activation within those areas have changed.
 - **Reorganization.** It is observed as a change in the location of activations and is associated with a shift in the cognitive processes underlying task performance.

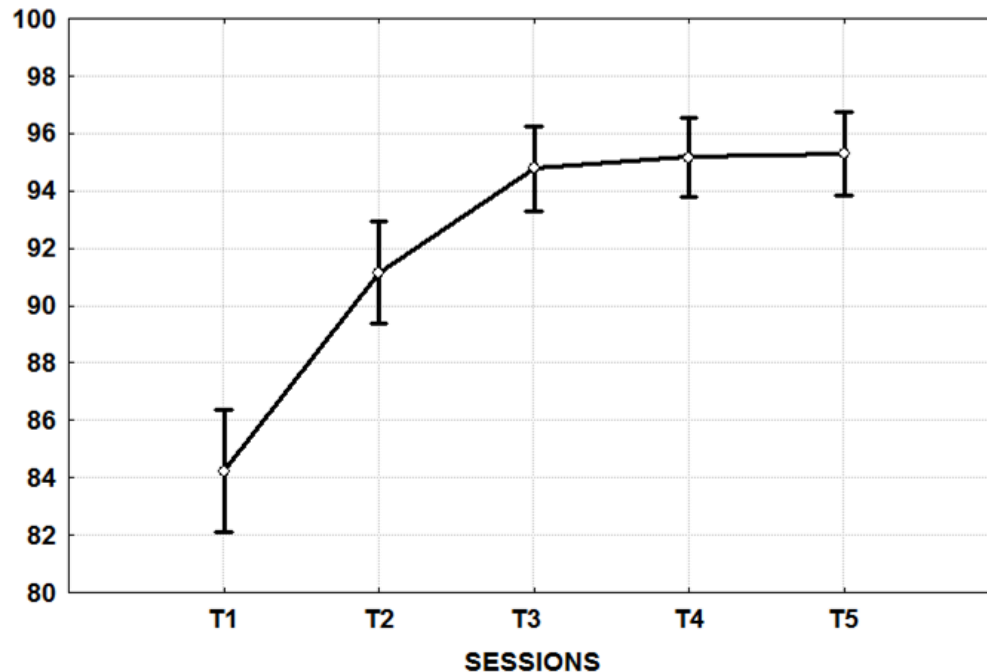


TRAINING

- ❑ The training implies the acquisition of physical and cognitive automatic processes that allow the improvement of the performance and accuracy.
- ❑ 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.



LABY PERFORMANCE (%)



Across the training sessions the performance of the tasks increases following the “*Learning curve*” trend.

Duncan test: T1 and T2 statistically different from all the others ($p < 10^{-4}$) while T3, T4 and T5 were not statistically different to each other.



Task performance saturation

Borghini et al., 2013 (EMBS-IEEE)

Borghini et al., 2014 (EMBS-IEEE)

Borghini et al., 2014 (GNB conference)

Borghini et al., 2014 (Brain Topography, in press)

Borghini et al., 2014 (Italian Journal of Aerospace Medicine, in press)

PHYSIOLOGICAL ANALYSIS STEPS

EEG ANALYSIS

Artifact rejection

PSD ESTIMATION

Welch's Periodogram: 2-sec epochs, shifted of 125 msec

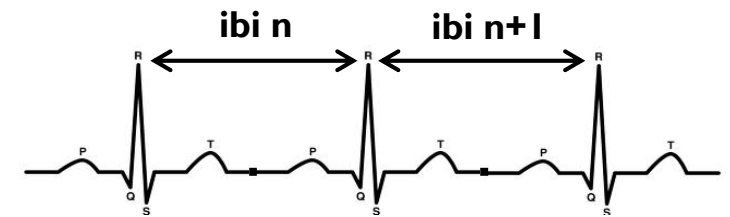
F-P NETWORK

Frontal Theta PSD
Parietal Alpha PSD

NORMALIZATION

r-square with respect to the *Baseline* condition

ECG & EOG analysis

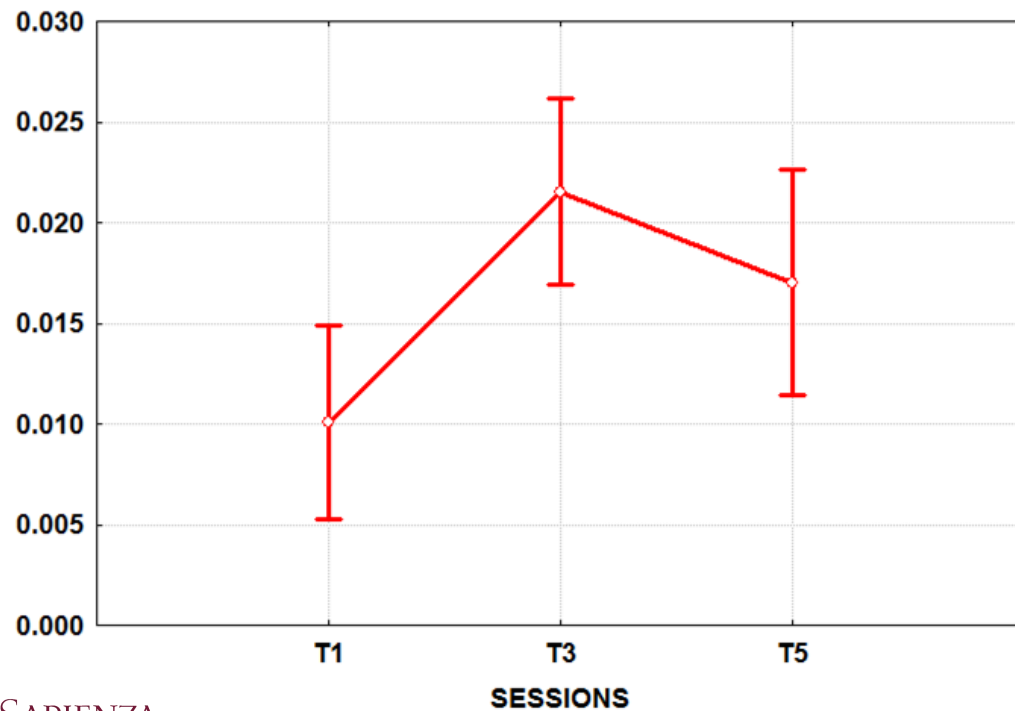


$$\text{Rate} = fs / ibi * 60 \text{ [bspm]}$$

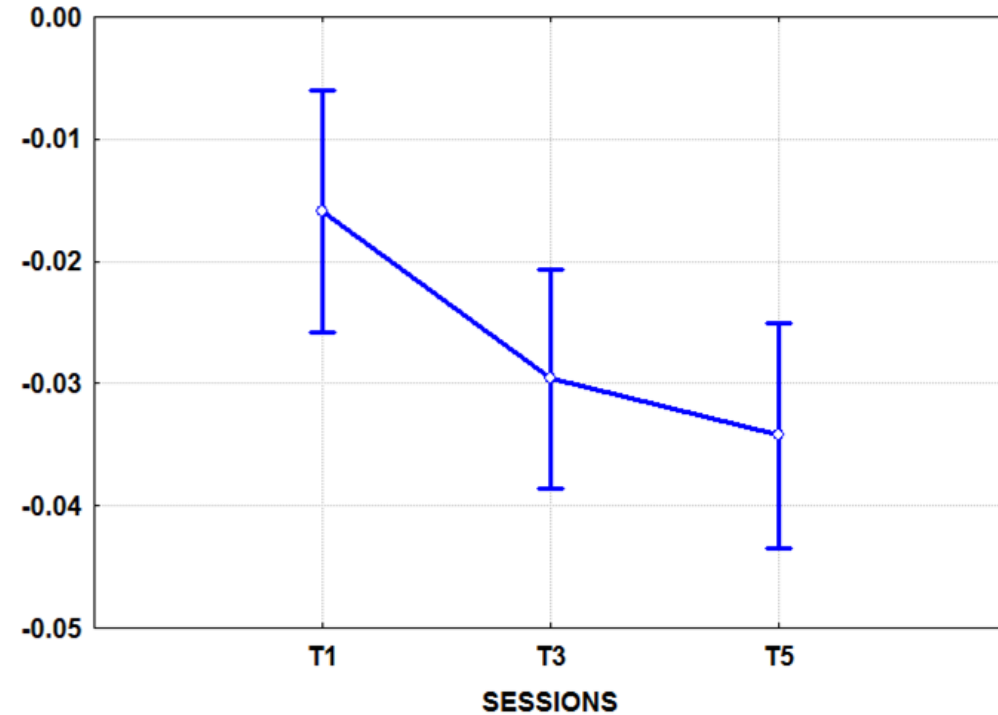
FRONTAL AND PARIETAL PSDs

- **T1:** the subjects did not know how to complete the tasks properly and they had to practice and to take confidence.
- **T3:** the frontal theta and parietal alpha PSD reflect an increased effort respect to the session T1.
- **T5:** the subjects perceived less workload (lower theta) and to the task (alpha decreasing).

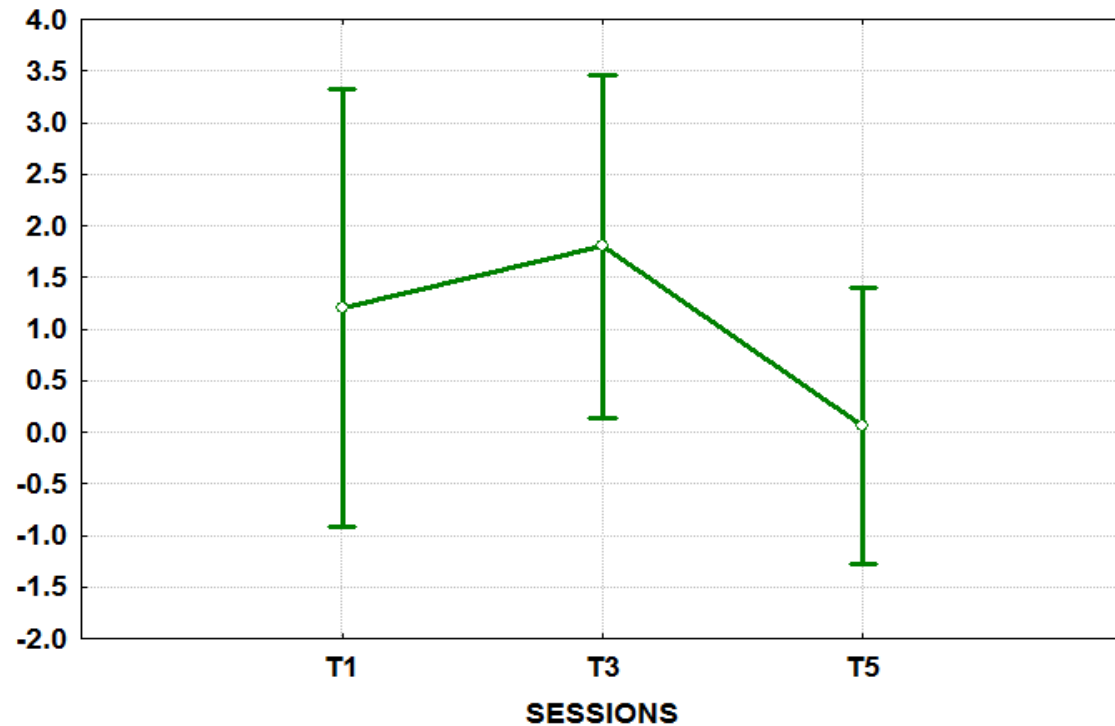
FRONTAL THETA PSD (r-square)



PARIETAL ALPHA PSD (r-square)

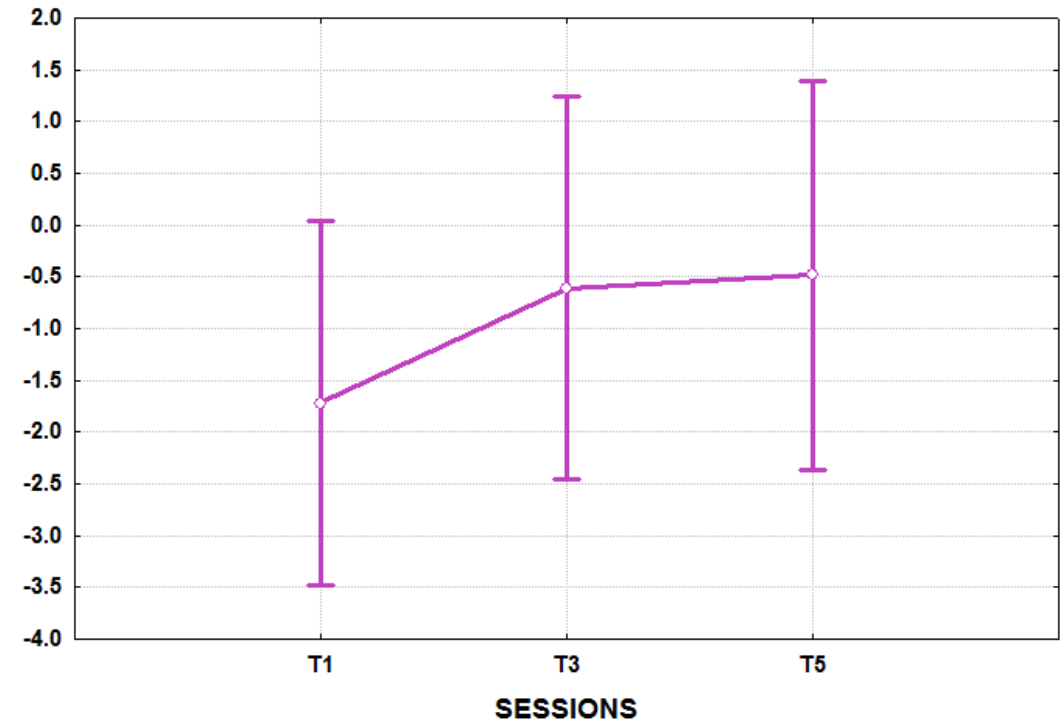


HEART RATE (z-score)



The **HR** reflects the level of cognitive and emotive engagment in the central training session (T3) and of the familiarization at the end of the training period (T5).

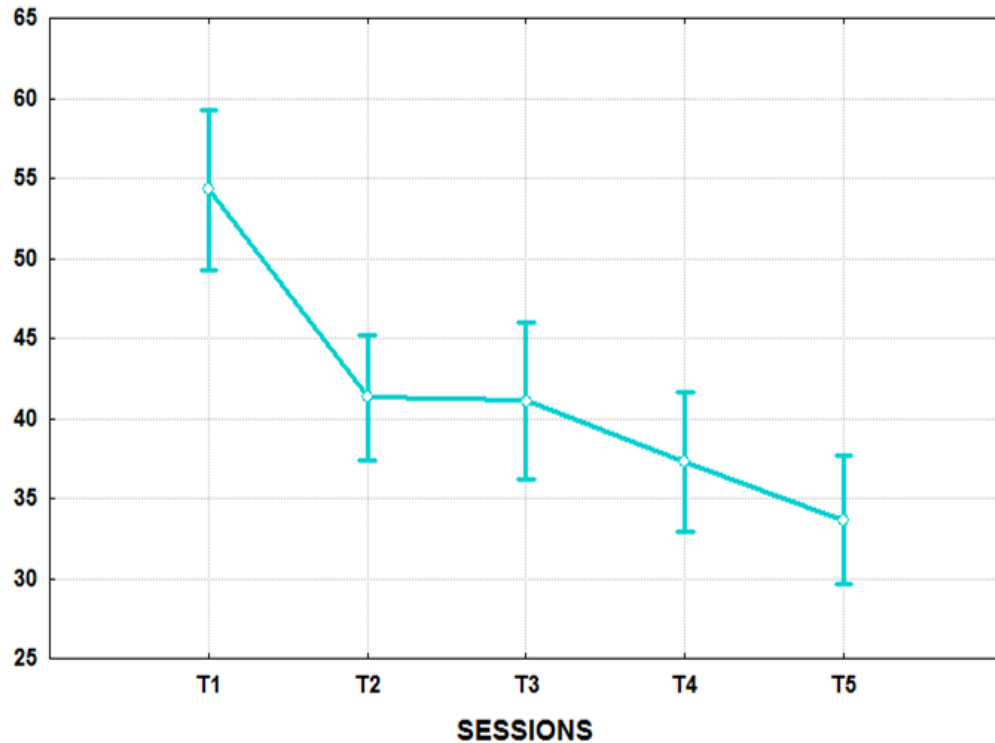
EYESBLINK (z-score)



The **EBR** trend shows how the subjects kept paying attention to the task (as it is possible to see on the performance trend) and how they got more confident with it than at the beginning (T1).

PERCEIVED WORKLOAD: NASA-TLX

NASA-TLX (score)



All the subjects gained familiarization with the task after any training session and perceived the task workload easier throughout the training period.

WORKLOAD EVALUATION



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MENTAL WORKLOAD

The mental workload is a measure of the resources required to process information during a specific task

Three modalities

Subjective **Direct**

- **Questionnaires**

- The user rates his perceived workload at the end of the task (NASA-TLX).

Objective **Indirect**

- **Performances evaluation**

- Correlation between performances and workload (Multiple-Attribute Task Battery, MATB).

Objective **Direct**

- **Neurophysiologic measures**

- Variation of biosignals with the workload (EEG, HR, HRV).

The amount of cognitive resources required for the correct execution of tasks can be evaluated by the variation of specific EEG and HR features.

Activity in the EEG frequency bands



- Theta band increment 4-8 [Hz]
- Alpha band decrement 8-12 [Hz]

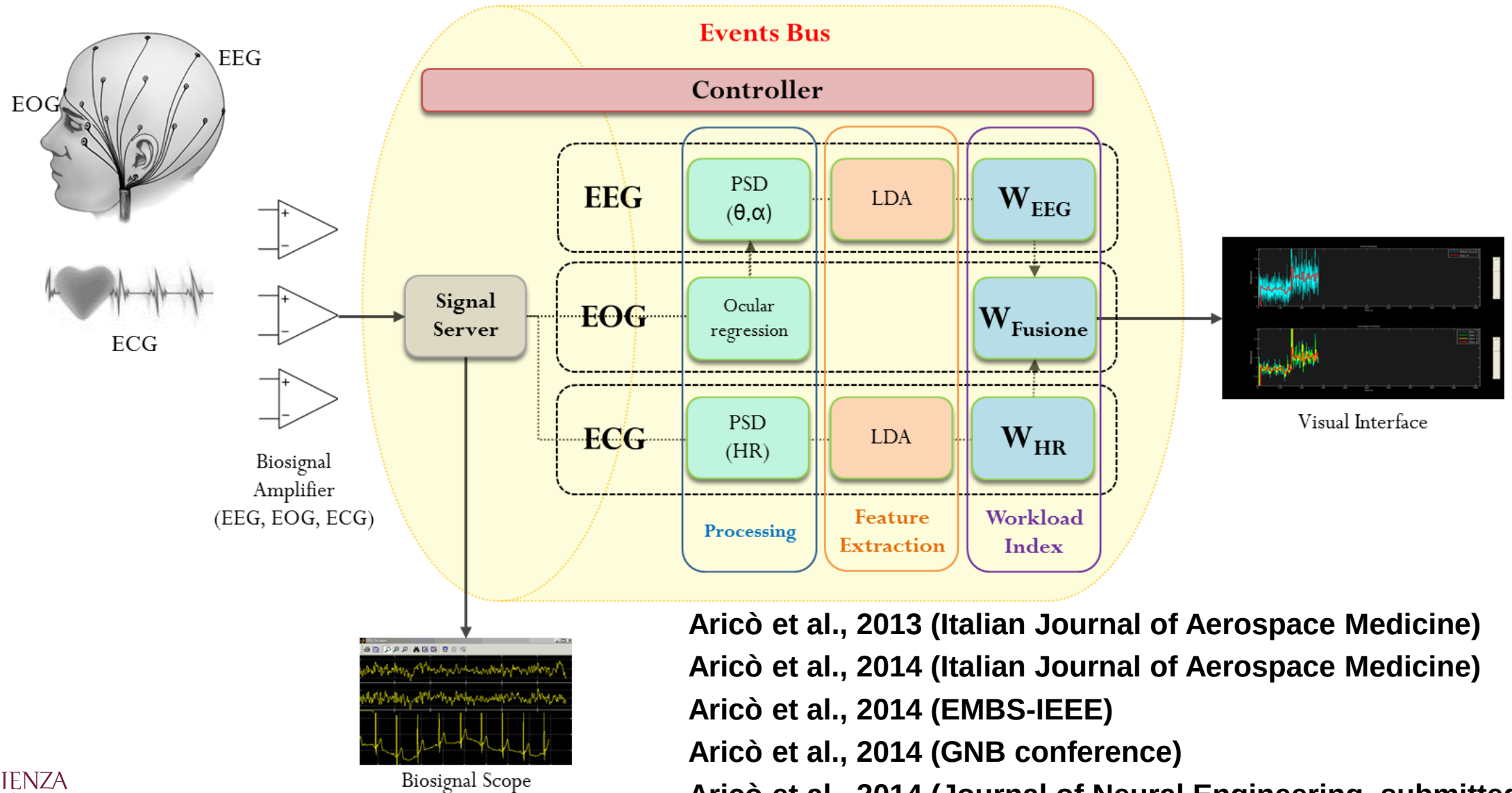


Heart Rate (HR)

- Enhancement of the heartbeat frequency [bpm]

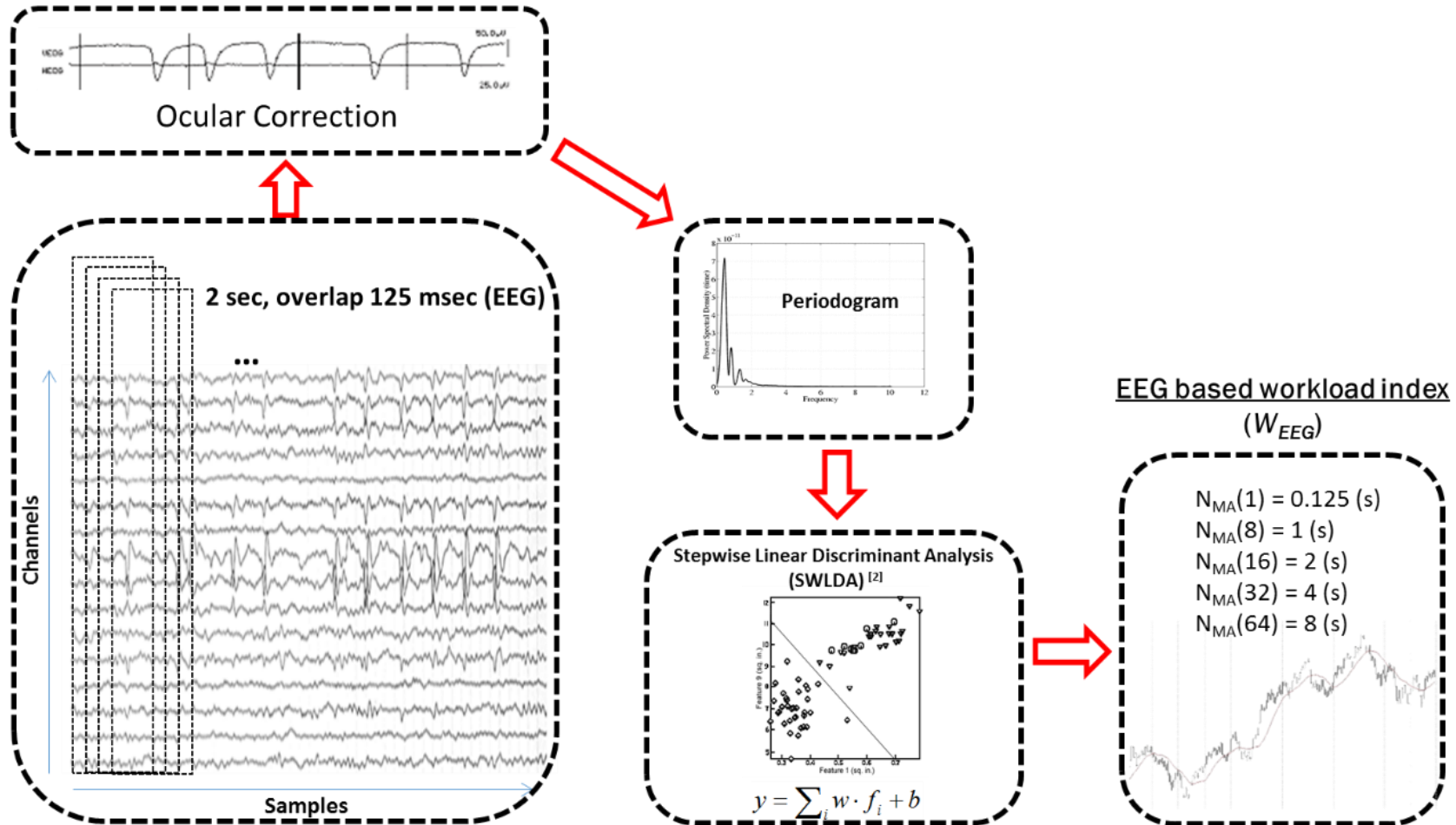


SYSTEM ARCHITETTURE

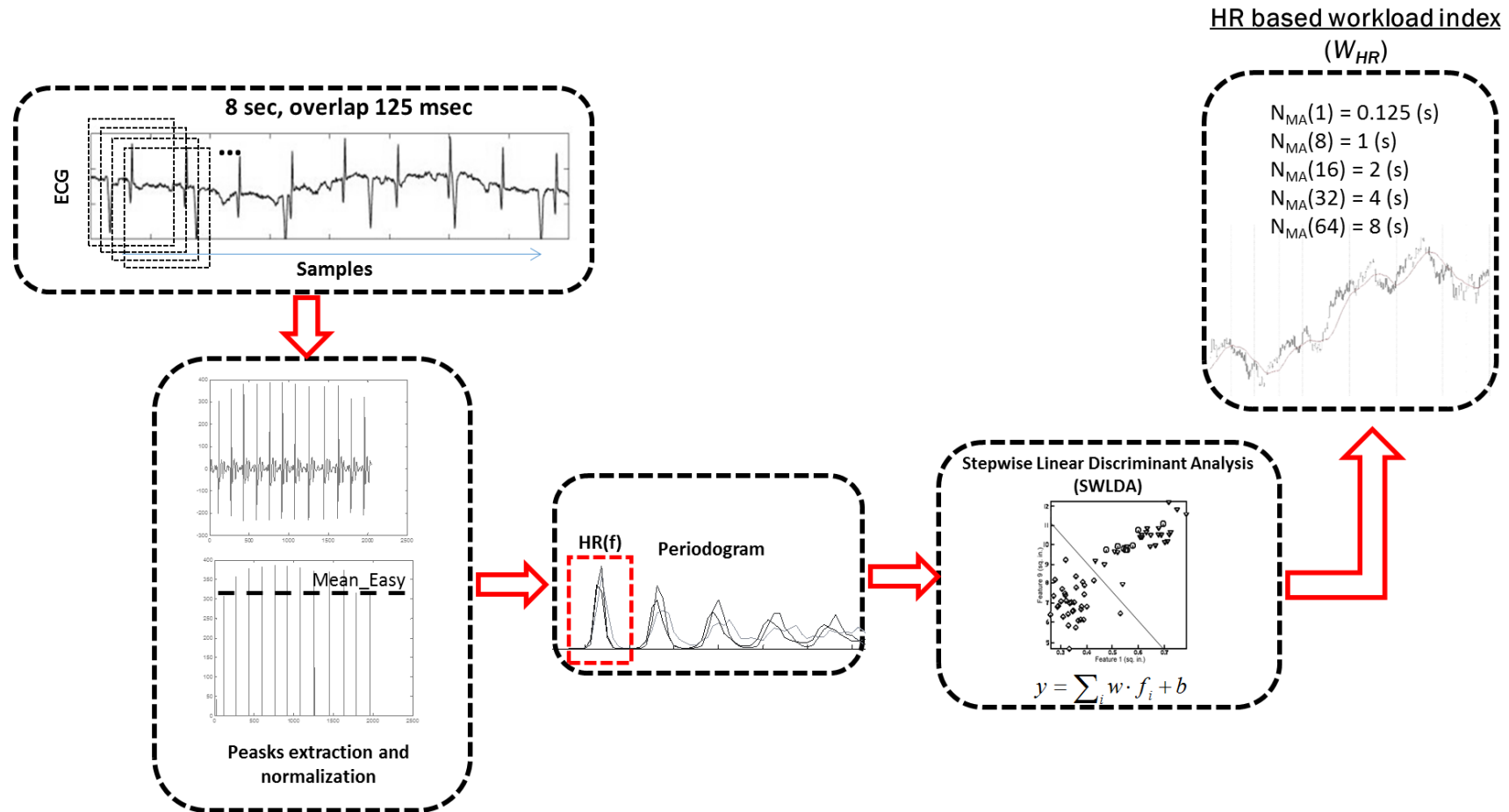


Aricò et al., 2013 (Italian Journal of Aerospace Medicine)
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 Aricò et al., 2014 (GNB conference)
 Aricò et al., 2014 (Journal of Neural Engineering, submitted)

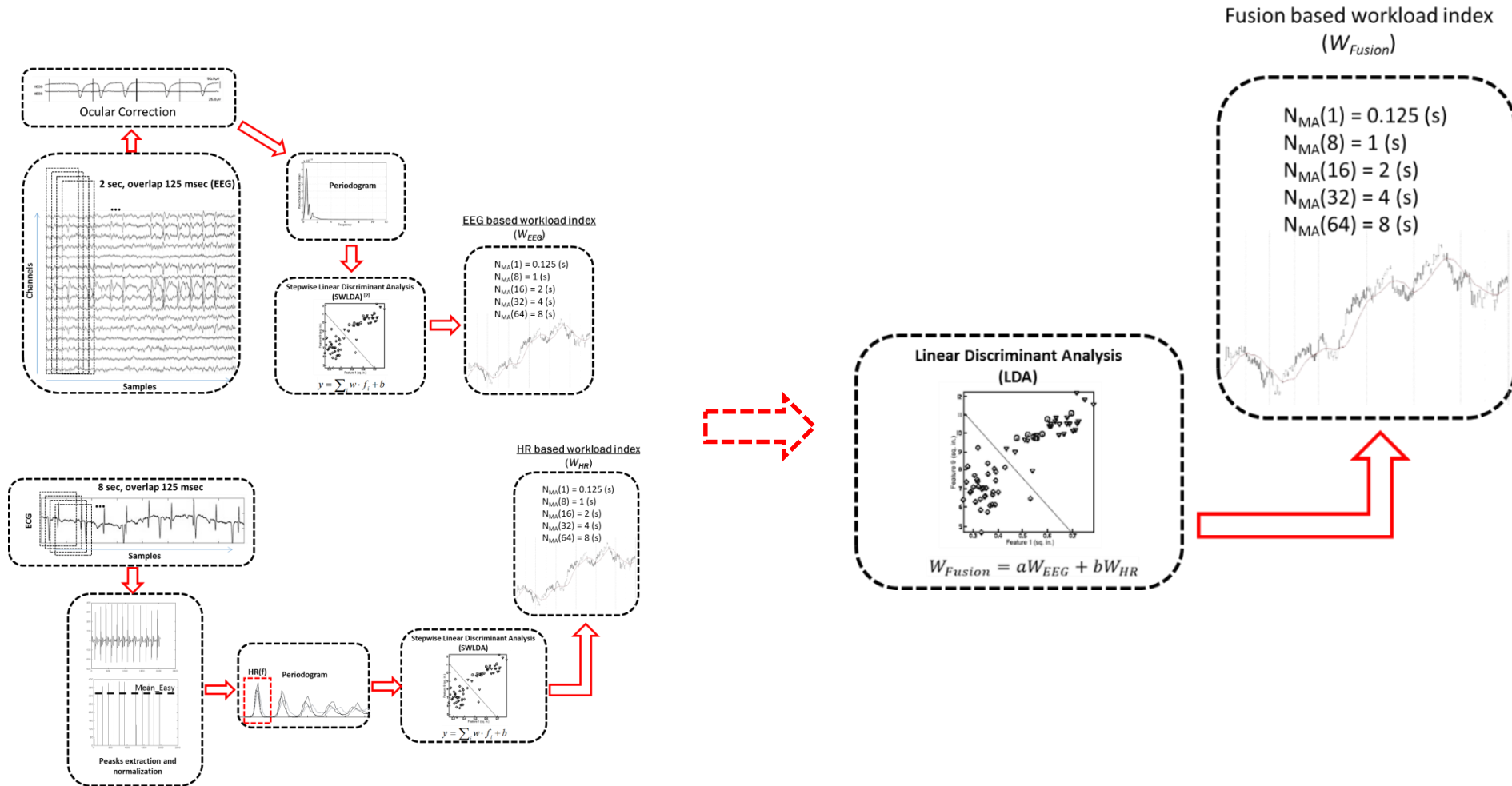
WORKLOAD EVALUATION ALGORITHM



WORKLOAD EVALUATION ALGORITHM

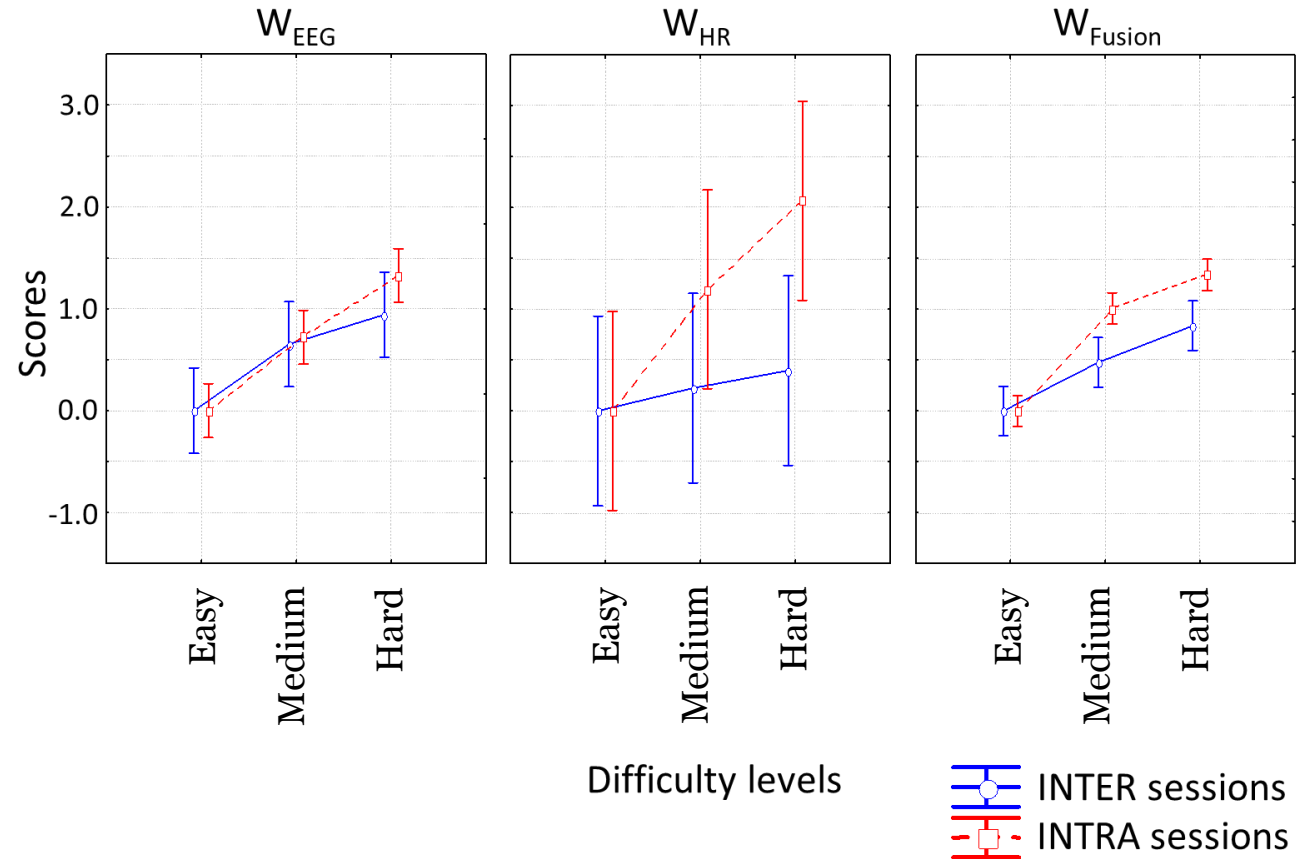
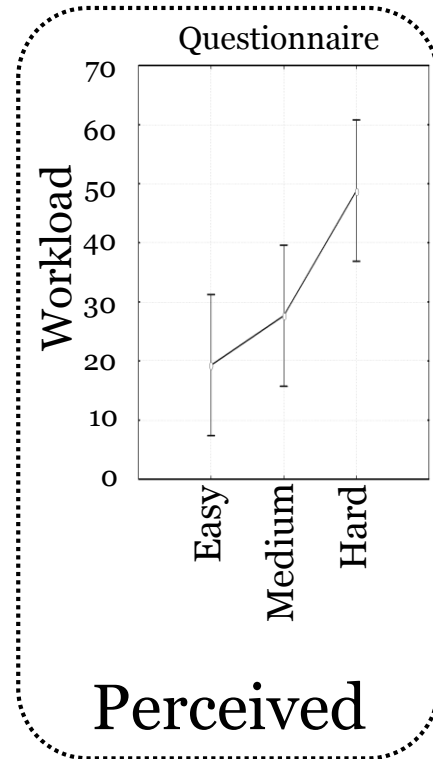


WORKLOAD EVALUATION ALGORITHM



WORKLOAD SCORE DISTRIBUTIONS

- ✓ NASA-TLX ($p < .05$)
- ✓ High separability between the distributions ($p < .05$)
- ✓ Recalibration needed for W_{HR} index
- ✓ Increasing of the reliability by using the W_{Fusion} index



CONCLUSIONS

- ✓ Cognitive training assessment
- ✓ Evaluation of the mental workload
- ✓ Reliability of the system over the time
- ✓ Independence on the proposed task



Usage in general operative contexts
(e.g. ATCOs, Pilots, Industrial surveillance, Car drivers, etc...)

THANKS FOR YOUR ATTENTION

BCI demonstration at the Posters and Exhibits Session 2 at 4.30 PM



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