E.02.22-D08/M015-Final Project Report

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Abstract

The final report of the NINA project provides a publishable summary of the results. In addition it lists all deliverables, dissemination activities, eligible costs, bills and lessons learned.

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Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground.

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Publishable Summary

The future ATM scenarios describe a system where **high levels of automation** have been deployed to support humans [1]. However, automation brings a range of new challenges, including those related to the human role and its interaction with the automated systems and tools. Advances in automation and technology may bring about drastic changes, questioning the allocation of activities and direct control of front-end operators.

A series of problems concerning the interaction between human and automation has been reported in the specialized Human Factors literature: deficiencies in human operator states, including vigilance decrements, complacency, loss of situation awareness and out-of-the-loop problems. Among others, one of the possible causes is that **the automated system has no information about the "internal" attentive and cognitive state of the user,** i.e. if he/she is in a low or high vigilance state, or he/she is experiencing a high cognitive workload state. Information about this "internal" state of the ATC personnel would improve dramatically the capability of the ATM system to interact with them, by flexibly adapting the type of automated support and increasing the 'requisite variety' [2] of support tools.

The NINA project addressed this research gap, developing the capability to analyse brain waves to asses controllers' cognitive state.

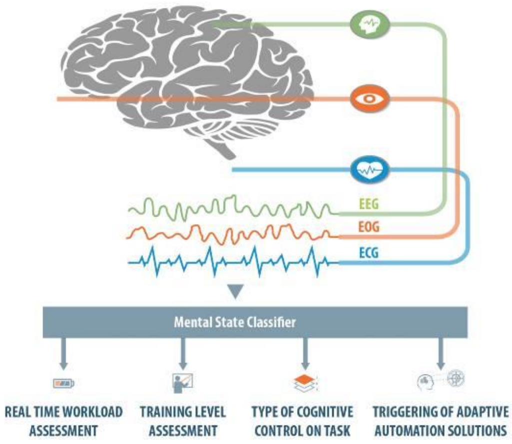

Figure 1: NINA project concept image

Project objectives and phases

The project was divided into two phases, corresponding to the two main objectives of the project:

- Investigate the use of neurophysiological indicators (i.e. brain activity, eye blink, heart rate) to assess air traffic controllers' mental state, **measuring in real time mental workload, level of training and type of cognitive control on tasks.**
- Generate a set of automation solutions that use the information on the air traffic controller's mental state to **automatically adapt their behaviour**, with the end goal of enhancing system performance and safety.

The first activity of the first phase was the selection of the **Human Factors concepts to be measured via neurophysiological indicators.** The selection was driven by their relevance and use in the ATM domain:

- Mental Workload (real-time monitoring)
- Level of training
- Level of cognitive control on tasks (Skill, Rule, Knowledge based [3])

Approach

A **literature review** has been performed to understand the current state of the art on the measurement of these concepts through the use of neurophysiological indicators. On the basis of this review the following indicators have been considered suitable for reaching the project objectives:

- EEG: Electroencephalography
- EOG: Electrooculography
- ECG: Electrocardiography

For each HF concept, specific brain areas and EEG frequency bands have so been identified. Combining EEG with EOG and ECG data, **a state classifier algorithm has been developed** to measure each one of the identified concepts.

Operationally realistic human-in-the-loop experiments have been designed to simulate the concept to be assessed (e.g. different levels of mental workload) and have been used to validate the state classifier ability to measure the target concept.

Cross validation was performed with methods such as:

- NASA-TLX questionnaires,

- ISA questionnaires [4] (collected from the subjects and from Subject Matter Experts sitting behind controllers),
- system logs analysis,
- performance indicators,
- direct observations by experts controllers and
- interviews with the subjects.

Figure 2: One of the NINA simulation sessions at ENAC

37 subjects (air traffic controller students and experts) executed 45 minutes scenarios with different levels of difficulty (easy, medium, hard) and specific events designed to trigger different levels of cognitive control (Skill, Rule or Knowledge based). The scenarios presented an en-route sector and were based on realistic traffic samples.

Figure 3 summarises the approach used in the first phase of the project. It brings together the knowledge coming from the Human Factors field, the latest techniques and methods in neurometrics and a deep understanding of ATM working methods and needs.

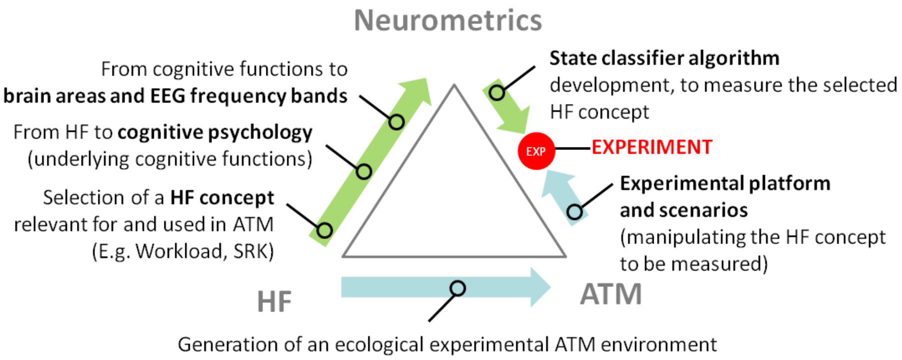

Figure 3: the approach followed in the first phase of the NINA project, to develop algorithms, based on neurophysiological indicators, able to assess selected Human Factors concepts.

In the second phase, the **real time data coming from the neurophysiological monitoring of mental workload has been used as a trigger for adaptive automations**. 4 ad-hoc adaptive solutions have been developed (out of an initial number of 8 design ideas), with the input of operational experts and interaction design experts. The feasibility and acceptability of the solutions have been tested in one human in the loop simulation, in a realistic ATM environment.

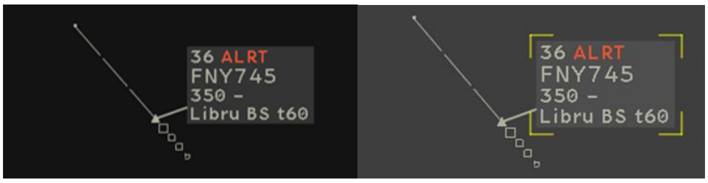

Figure 4: example of one of the adaptive automations tested: the saliency of alerts is modified according to the ATCO current level of mental workload. I.e. a moving yellow rectangle appears to draw attention on relevant alerts during peak workload situations.

Other 12 advanced adaptive solutions concepts have been developed in the form of proof of concepts (video demos) to **show the potentiality for systems that adapt their behaviour according to the**

operators' internal state, not only taking into consideration mental workload but also all the other relevant factors, as described by the Human Performance Envelope concept [5].

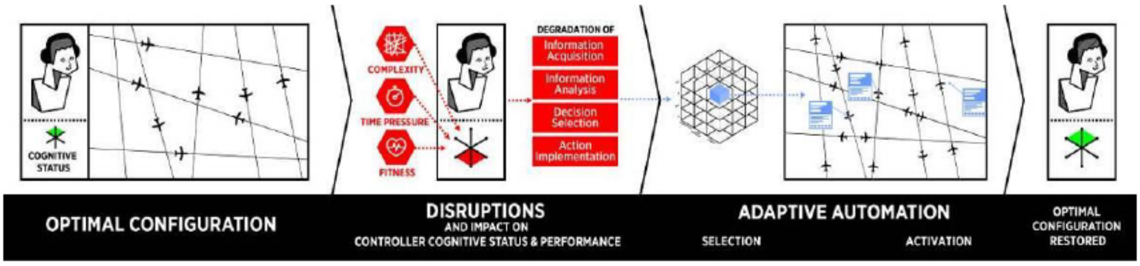

Figure 5: hi-level conceptual description of how the 12 advanced adaptive solutions could work in a future scenario.

Highlights and key results

The NINA project achieved the following results:

- **Mental workload measurement:** An algorithm able to estimate the mental workload of an operator by using the combination of EEG rhythms and HR signals has been proposed. It has been demonstrated that: i) the method was able to significantly differentiate three workload levels related to the three difficulty level tasks employed with a high reliability; ii) the subjective features used for the evaluation of the mental workload remained stable over one week only by using the EEG-based classifier. The combination between the information derived from the EEG and the HR signals allowed increasing the performance of the system with respect to the only EEG signal. Successively, because the HR has been demonstrated to be too much prone to movement artefacts, a state classifier based only on EEG signal (WEEG) has been proposed. In particular, the original algorithm has been improved in order to increase the reliability over time (up to a month). The results confirmed that the state classifier algorithm (WEEG) was able to track the mental workload of the ATCOs (both ATC Experts and Students) along the experimental sessions, and to differentiate significantly the three difficulty levels proposed in the ATM scenario (easy, medium, hard). The EEG features used were: parietal theta and frontal alpha. [6], [7], [8], [9], [10], [11].

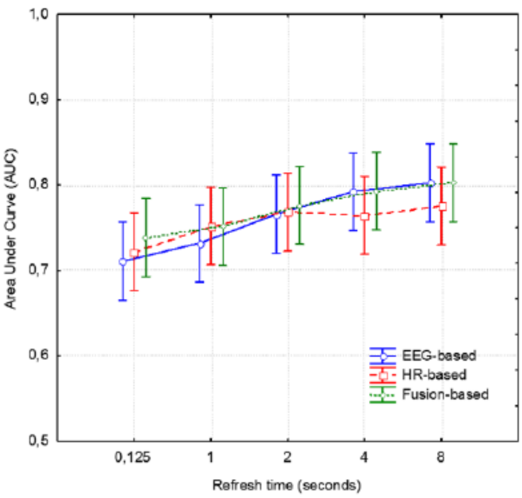

Figure 6: Mean values and related standard errors (CI = .95) of the AUC values of the three classifiers (EEG, HR and Fusion-based) over the different refresh time values.

- **Level of cognitive control assessment:** The state classifier was able to discriminate significantly the Skill-Rule-Knowledge conditions for the ATC Experts, and the S-R conditions for the ATC Students. The Knowledge level was not discriminated for students, as one of the Knowledge events was missed by most of them. The EEG features used were: Theta band over the frontal and parietal sites and the Alpha band over the frontal EEG channels [12]. It has to be noted that it could be possible to assess at the same time the SRK conditions and the mental workload experienced by the user by using different brain features (i.e. frontal theta and parietal alpha for the mental workload and parietal theta and frontal alpha for SRK).

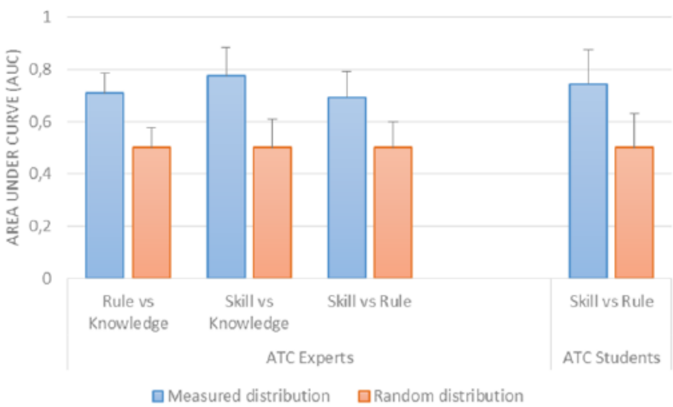

Figure 7: error bars (CI=.95) related to the discrimination accuracy between the three conditions (i.e. Rule vs Knowledge, Skill vs Knowledge, Skill vs Rule) for the Experts ATCOs and Skill vs Rule for the Students. Accuracy measured by comparing Measured AUC distributions and Random AUC distributions.

- **Training assessment:** the state classifier was able to track the training level of ATC Students in performing a new operative task. In addition, the system was able to assess the skill level of ATC Experts in using a new prototypal ATM interface [13], [14], [8].

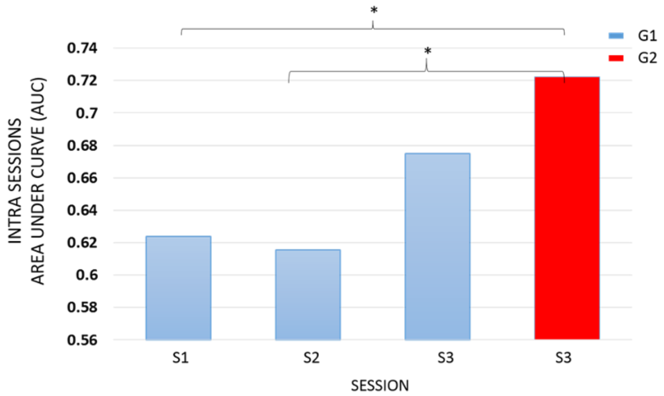

Figure 8: Intra cross-validations have been calculated in order to compare the two ATC Experts groups: G1, blue bar, performed a six weeks training program to use the prototypal ATM interface; G2, red, already knew how to use the interface.

The state classifier detected different training levels, showing no significant differences between the two groups only during the last session, when the G1 reached the same level of G2.

- **Development of adaptive automation solutions:** the state classifier was able to classify the mental workload of the student controllers in real time (every 30 seconds), and to trigger the adaptive automations. Adaptive automation was activated more often during the Hard slots than the Easy ones. The overall ATCOs' feedback was positive, but the adaptive automations decreased the workload level experienced by the ATCOs only during one of the two scenarios. This behaviour was caused by the lower overall difficulty of one of the scenarios, and by the adaptive solution used. Feedback from controllers highlighted how only one solution was perceived as strongly impacting the mental workload level (i.e. "Highlight of station calling" solution).

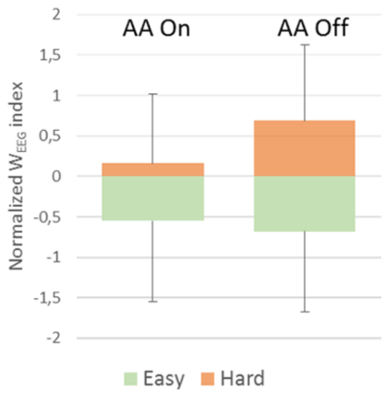

Figure 9: normalized WEEG index related to the Easy and the Hard runs, both during the Adaptive Automation activated (AA On) and the Adaptive Automation deactivated (AA Off) conditions.

Future steps based on the outcomes of the project

The results achieved so far are very encouraging, and represent opportunities for future research. More data on the level of cognitive control could be collected in more controlled settings. It would be beneficial to test the proposed neurometrics on “pure” Skill, Rule, Knowledge events, i.e. events where controllers perform at only one level of cognitive control. The need for a more controlled experiment will probably decrease the realism of the performed tasks.

The topic of adaptive automation is really promising but very sensitive, as it implies deep changes in technological systems, workflows and responsibility sharing between humans and machines. Experiments should be performed to collect more data on the impact of adaptive automations on controllers' workload during ATM tasks. Experiments should also control and neutralise inter-individual variations on the acceptance level of Adaptive Automations.

More information and publications available at: **www.nina-wpe.eu**

Some of the NINA research topics will be investigated during the **STRESS and MOTO projects**, funded by SJU (within the SESAR 2020 programme), to be run in the 2016-2018 period.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities (past and in progress). Where appropriate, provide feedback from presentations. Describe exploitation plans.
- Provide a complete overview of the billing status, eligible costs, planned and actual effort (incl. an explanation of the discrepancies).
- Analyse the lessons learnt at project level.

1.2 Intended readership

The document is intent to be used by the NINA Project Officer, the SESAR JU and EUROCONTROL organizations to have an overview of the NINA project, the project results and lessons learnt. The document also contains a summary of the project deliverables, dissemination activities, eligible costs and bills and provides a picture of the project activities in the past 24 months.

1.3 Inputs from other projects

P16.5.1 Identification and integration of Automation Related Good Practices: The NINA coordinator (Deep Blue) played a primary role in the former, coordinating the activities and delivering an ATM specific refinement of Parasuraman's guidance to select the best automation level.

BrainShield project: UniSap was involved, demonstrating that brain activity measurements can be used both in simulated environment (commercial and military flight simulators) and real flights to i) evaluate the mental workload of pilots; ii) to improve the learning processes by means of electrical stimulation (i.e. tDCS); iii) to assess the expertise of pilot students with respect to expert pilots; and iv) to quantify the degree of cooperation of the flight crew.

1.4 Glossary of terms

Term	Definition
ANSA	Agenzia Nazionale Stampa Associata
ATC	Air Traffic Control
ATM	Air Traffic Management
ATCO	Air Traffic Controller
BCI	Brain Computer Interface
DBL	Deep Blue
e-DEP	Early Demonstration & Evaluation Platform

Term	Definition
EEG	Electroencephalogram
ENAC	École Nationale de l'Aviation Civile
ENAV	Ente Nazional di Assistenza al Volo
ISA	Instantaneous Self Assessment
MWL	Mental Workload
NASA-TLX	NASA Task Load Index
NINA	Neurometrics Indicators for ATM
SESAR	Single European Sky ATM Research Programme
SID	SESAR Innovation Days
SJU	SESAR Joint Undertaking (Agency of the European Commission)
UniSap	University “Sapienza” of Rome
WP	Work Package

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D0.8-0.9	Progress reports	Activity and Financial Reports	Approved
D.10	Final Report	Project final report	Submitted
D1.1	Draft of Report Baseline Measurement in Laboratory Setting	This deliverable presents the current results of the first part of the NINA project. The activities were dedicated to three main areas: workload literature review, experimental ATM task development and testing, neurophysiological signals recording during the experiments with students at the University "Sapienza" of Rome's Laboratory.	Approved
D1.2	Baseline Measurement in ATM Setting and in Laboratory Setting	This deliverable presents the results of the experiments made at ENAC with ATC students. The activities were dedicated to the testing and the comparison of the neurometric indicators used previously in Lab settings with students from the University "Sapienza" of Rome and professional Controllers from ENAV with those obtained in the ENAC setting with ATC trainees.	Approved
D1.3	State Classifier	This deliverable presents the results of the literature review and the calibration/verification of the state classifier when used during realistic ATM tasks. Four professional ATCOs from ENAV (Ente Nazionale Assistenza al Volo, Italy) have been involved in the experimentation before the validation measures with professional ATCOs from ENAC (Toulouse, France). The activities were dedicated to the testing of the neurometric indicators used previously in Lab settings in a real scenario. For this purpose we used the eDeep simulation environment.	Approved
D2.1	Report on Adaptive Solutions	This document presents a report on adaptive interface solutions. The aim of this document is to describe and detailed the preparatory activities held to identify possible adaptive solutions to be implemented, the design process followed and the selection of final adaptive solutions that will be evaluated during the second validation activity.	Approved
D2.2	Report on Advanced Interface Solutions	This document presents a report on advanced adaptive interface solutions. This document aims at describing the main strand of activities carried out to develop a high level concept on advanced adaptive automations based on neurophysiologic measurements in future ATM scenarios. A description of the motivation, the methodology, the design process and the concept development have been presented.	Submitted
D3.1	Validation Plan	This deliverable presents the NINA validation plan, detailing the objectives, the planned exercises, and the interactions between the Work Packages.	Approved
D3.2	First Validation Report	This document presents the description of the first NINA validation activity, detailing the objectives, the simulation exercise preparation, execution and results. The aim of this document	Approved

		is to describe and provide the results achieved during the three validation sessions. Results about the reliability of the State Classifier algorithm in realistic ATM tasks and environments and the assessment of identifiable neurophysiological condition associated with the levels of cognitive controls have been provided.	
D3.3	Second Validation Report	This deliverable describes the second validation activity detailing the objectives, strategies, approaches and results achieved. Results about the feasibility to discriminate between the different levels of cognitive control and to trigger adaptive solutions by the means of neurophysiologic measures is provided.	Approved
D4.1, D4.2	Contributions Reviews	Preparation and participation of contributions at SESAR Innovation Days and with the HALA network, and related scientific dissemination	Approved
D4.3	Dissemination Report	This document reports all the scientific dissemination activities accomplished within the project. Conference papers and presentations are enclosed.	Submitted

Table 1 - List of Project Deliverables

3 Dissemination Activities

The work done during the NINA project has regularly been submitted to various conferences and events associated to various communities. Articles presenting the work done in the NINA project have been submitted each year to the SESAR innovation days. Also, the project periodically updates its news and outcomes sections of the website to disseminate the results achieved towards the general public.

3.1 Presentations/publications at ATM conferences/journals

3.1.1 Presentations at SESAR Innovation Days (SESAR community)

SESAR innovation days have been an opportunity to present to the SESAR community the work carried out and the main achievements of the NINA project.

3.1.1.1 SESAR Innovation Days, Bologna, Italy, December 1st- 3rd, 2015

For SID 2015, the NINA project members submitted a paper entitled: "Skill, Rule and Knowledge-based Behaviours Detection during Realistic ATM Simulations by Means of ATCOs' Brain Activity" [12]. This paper aims at describing the results came out from the first validation activity. In particular, the paper reports the activity carried out to test the neuro-physiological methodology able to discriminate the Skill (S), Rule (R) and Knowledge (K) based cognitive control levels of Air-Traffic Controllers' while performing realistic traffic management tasks.

Figure 10: SESAR Innovation Days, 2015.

3.1.1.2 SESAR Innovation Days, Madrid, Spain, November 25-27, 2014

For SID 2014, the NINA project members submitted a paper entitled: "Analysis of neurophysiological signals for the training and mental workload assessment of ATCOs" [13]. The aim of the paper was to present an extensive neurophysiological study of the Air-Traffic-Controllers (ATCOs) during en route ATC simulations. The purpose was to extract neurophysiological features suitable for evaluating the learning progress and for estimating in real-time the user's workload level.

3.2 Presentations/publications at other conferences/journals

3.2.1 Conference of the IEEE Engineering in Medicine and Biology Society

3.2.1.1 A neurophysiological training evaluation metric for Air Traffic Management, 2014

For the IEEE Engineering in Medicine and Biology Society, NINA partners submitted a paper entitled: "A neurophysiological training evaluation metric for Air Traffic Management" [14]. The aim of this paper was to analyse the possibility to apply a neurophysiological cognitive metrics for the evaluation of the training level of subjects during the learning of a task employed by Air Traffic Controllers (ATCOs). It is referred to the first strand of activities of NINA project.

3.2.1.2 Reliability over time of EEG-based mental workload evaluation during Air Traffic Management (ATM) tasks, 2015

For the IEEE Engineering in Medicine and Biology Society, NINA partners submitted a paper entitled: "Reliability over time of EEG-based mental workload evaluation during Air Traffic Management (ATM) tasks" [7]. This paper presents the machine-learning approaches for mental workload (MWL) estimation by using the user brain activity. These techniques allow now to measure the MWL with a high time resolution (e.g. few seconds). However, one of the outstanding problems of these techniques regards their ability to maintain a high reliability over time. In order to overcome this issue, this work reports that the reliability of a classifier can be improved by using a low number of brain spectral features, between those ones strictly related to the MWL (i.e. Frontal and Occipital Theta and Parietal Alpha rhythms).

3.2.2 Italian Journal of Aerospace Medicine

3.2.2.1 Air-traffic-controllers (ATCO): neurophysiological analysis of training and workload ATCO, 2015

NINA project members submitted a paper for the Journal of Aerospace Medicine, entitled: "Air Traffic Controllers: neurophysiological analysis of training and workload" [8]. The aim of this paper is to present an extensive neurophysiological study of the Air-Traffic Controllers
(ATCOs) during en route Air Traffic Control (ATC) simulations. In other words, the purpose was to extract neurophysiological features suitable for the evaluation of the learning progress and for the real-time estimation of the user's workload level.

3.2.2.2 Mental workload evaluation of ATCOs during ecological ATM scenarios, Italian Journal of Aerospace Medicine, 2015

For the Journal of Aerospace Medicine, NINA partners submitted a paper entitled: "Mental workload evaluation of ATCOs during ecological ATM scenarios" [15].
In this study, a system able to estimate the user's mental workload by using the electroencephalographic (EEG) activity has been tested on four professional Air Traffic Controllers (ATCOs) from ENAV while performing an ecological Air-Traffic-Management (ATM) task under different difficulty levels. The results showed i) a high positive and significant correlation between the two indexes and ii) despite the low sample size, the EEG-based workload indexes along the different difficulty levels were significantly different, according to the ISA results.

3.2.3 Symbiotic interaction, Springer International publishing

3.2.3.1 On the use of cognitive neurometric indexes in aeronautic and air traffic management environments, 2015

For the Symbiotic Interaction NINA project members submitted a paper entitled: “On the use of cognitive neurometric indexes in aeronautic and air traffic management environments” [11].
This paper presents the use of neurophysiological indexes for an objective evaluation of mental workload, during an ecological Air Traffic Management task. Six professional ATCOs from ENAV were asked to perform an ecological ATM task by using the e-DEP simulation platform. Electroencephalographic signals were recorded in order to compute the neuro-physiological workload index, and simultaneously the subjective perception of the mental workload by using the ISA technique. The results showed the reliability of the neurophysiological index to assess the mental workload of expert controllers.

3.2.4 Chapter to the volume: Progress in Brain Research: Brain-Computer Interfaces: Lab Experiments to Real-World Applications

3.2.4.1 A passive Brain-Computer Interface (p-BCI) application for the mental workload assessment on professional Air Traffic Controllers during realistic ATC tasks:

NINA project members wrote a chapter for the volume: Progress in Brain Research: Brain-Computer Interfaces: Lab Experiments to Real-World Applications. The chapter is entitled: “A passive Brain-Computer Interface (p-BCI) application for the mental workload assessment on professional Air Traffic Controllers during realistic ATC tasks” [10]. The objective of the proposed study was to provide an example of a passive BCI methodology used for the evaluation of the users’ mental workload in an operative environment. For this purpose, through the facilities provided by the École Nationale de l’Aviation Civile (ENAC) of Toulouse (France), twelve professional Air Traffic Controllers (ATCOs) have been asked to perform a high ecological scenario of Air Traffic Management (ATM). The results showed i) a high significant correlation between the neurophysiological and the subjective workload assessment and ii) a high reliability over time (up to a month) of the proposed algorithm, that was also able to maintain a high discrimination accuracy by using a low number of EEG electrodes (~ 3 EEG channels). In conclusion, the proposed methodology demonstrated the suitability of passive BCI systems in operative environments and the advantages of neurophysiological measures with respect to the subjective ones.

3.3 Web presence

The NINA project web site is available at the following address: http://www.nina-wpe.eu/

NINA web site is composed of seven main sections:

- **Overview**: this section provides with a short introduction to the project and describes its main objectives.
- **Context:** the context page aims at describing the general context and the most important research areas within the SESAR programme that NINA aims to address and overcome.
- **Outcomes**: this section is divided into two subsections: the first “NINA main tools and technologies” describes the three main outcomes of the project, the second “List of references” presents all the articles and papers submitted at conferences during the project.

- **Consortium:** the consortium section provides information about NINA partners' and their role inside the project.
- **Dissemination**: the dissemination section contains and collects all the dissemination material produced during the project: posters, articles and papers, image gallery, brochure and video.
- **Contacts:** the contact section contains a form to be completed to gain additional information about the project.
- **News:** the news section aims at presenting the updated activities carried out during the project (e.g. the First and Second Validation activity held at ENAC, the presentation of NINA paper at SID 2015). This page had been updated according with the most important project' activities.

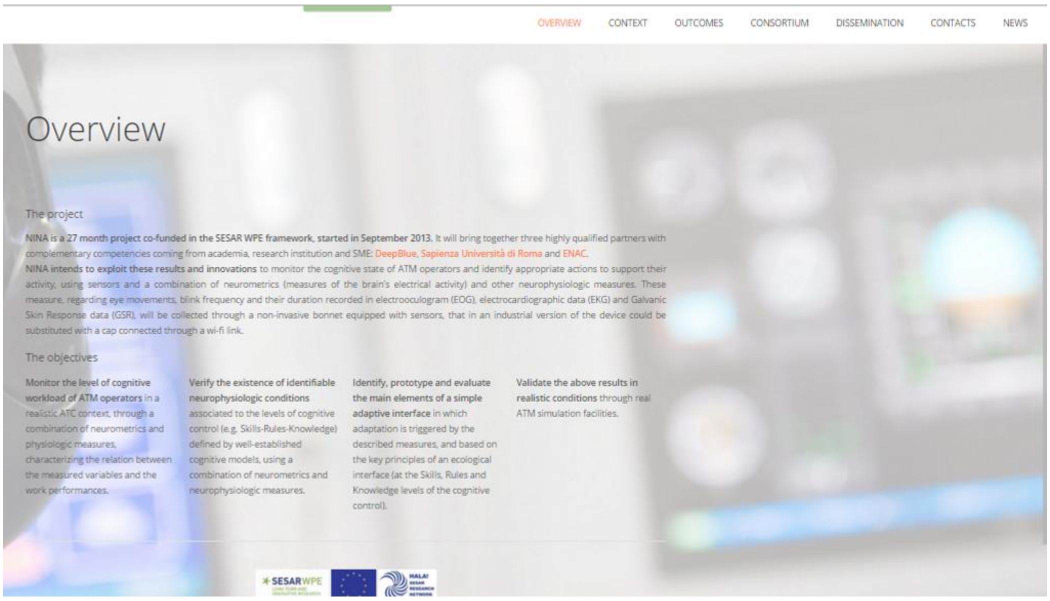

Figure 11: NINA web site: Overview section.

Information about NINA project are also available at http://hala-sesar.net/projects/blog/nina

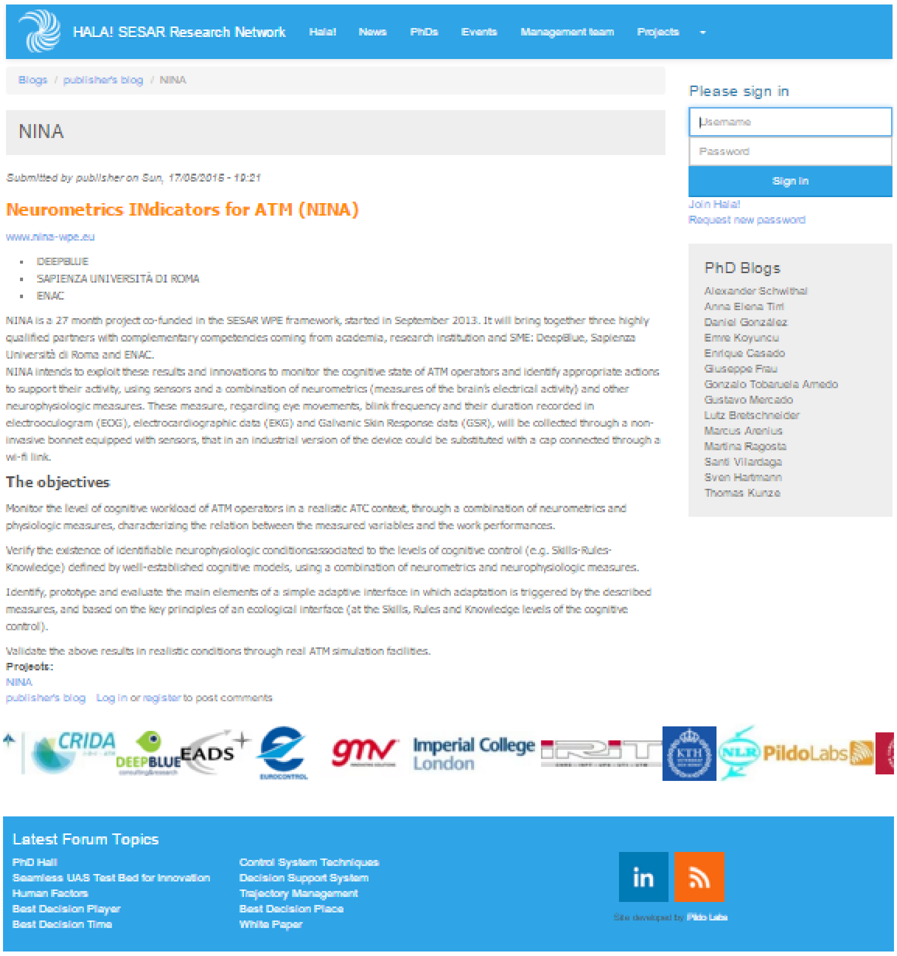

Figure 12: NINA description on HALA web site.

3.4 Press release

News on the NINA project has been released by ANSA (Agenzia Nazionale Stampa Associata) the leading news agency in Italy. The article describes the work done during the project, the main results achieved and the potential interests of NINA findings in future ATM scenarios.

http://www.ansa.it/scienza/notizie/rubriche/tecnologie/2015/11/18/intelligenza-artificiale-amica-dei-controllori-di-volo_1012ef53-7fdf-476a-a535-b24efe59e5aa.html

The news also received coverage by:

- La Repubblica (IT): http://www.repubblica.it/scienze/2015/11/18/news/intelligenza_artificiale_amica_dei_controllori_di_volo-127650569/
- Daily News 24 (IT): http://www.dailynews24.it/come-aiutare-i-controllori-di-volo-nina-neurometrics-indicators-for-atm/
- I Tech Feel (EN): http://itechfeel.com/computer-could-analyze-stress-levels-in-the-air-traffic-controllers/
- La Nacìon (ES): http://www.lanacion.com.ar/1848393-una-computadora-analizara-el-nivel-de-estres-de-los-controladores-de-transito-aereo
- Doble Llave (ES): http://www.doblellave.com/nina-al-rescate-de-los-controladores-de-vuelo/
- El Comercio (ES): http://www.doblellave.com/nina-al-rescate-de-los-controladores-de-vuelo/

3.5 Demonstrations

3.5.1 The 4th SESAR Innovation Days (2014)

During the fourth SESAR Innovation Days (SID) conference, hosted by Universidad Politécnica de Madrid, Spain in 2014, a practical demonstration has been performed and showed to the ATM European community, demonstrating the possibility to use the mental states of the user to realize a Brain-Computer Interface. In particular, the user wore the EEG cap with 8 electrodes. The task to perform was to use a communication system based on the user's brain activity to write on the screen a word by using only his/her brain activity: the P300 Speller. It consists in a matrix containing alphanumeric characters, where stimuli are provided by the intensification of rows and columns in the matrix. In particular, the intensification of the row and the column containing the character the subject wants to select, elicits a brain potential that can be recognized by the system and used to select to character.

3.5.1.1 Feedback

The demonstration was of high interest, because the attendees realized the potentiality to use the mental states of the user in operative environments, especially in the ATM field.

3.6 Exploitation plans

3.6.1 Università La Sapienza

The results obtained within this project confirmed the hypothesis about the possibility of monitoring specific mental states, i.e. mental workload, of the humans, in this case Air Traffic Controllers, by using neurophysiological signals recorded in ecological settings (not only in laboratory settings). Assuming that the human brain works similarly in different contexts, these results could be used in similar studies, i.e. the operator mental workload monitoring, also in other domains different from the aviation one.

At the same time, the efficacy of the techniques developed and used, such as the state classifier, and the methodologies adopted, could allow to carry out similar studies on different human mental states (e.g. attention, mental effort). In fact, in particular working environments, the monitoring of the operator's stress level, his/her attention intensity, the beginning of mental fatigue or drowsiness, could improve the working conditions, in terms of operator wellness, and enhance safety standards.

Last but not least, the adaptive interface successfully tested in the last validation session is an example of a functioning passive Brain Computer Interface (passive BCI) application. Thus, by one side it is a remarkable result in this scientific area. By the other side, such application could be used by all the consortium to develop advanced and reliable devices that would be very appreciated in this and the other domains where to improve the safety standards is a need and a must. It could be also a new and considerable business for this partner.

3.6.2 ENAC

The ENAC learnt from the NINA project how EEG measurement could be accepted by air traffic controllers during experiment, the constraints it induced and the benefits it could bring. The acceptance of EEG measurement was very high, but it was in an experimental context. If the different constraints to use EEG (installation, calibration, eeg expert) cannot be reduced, we cannot expect such acceptance using it every day on a working position. Some controllers were afraid that such a tool could be used against their interest; ENAC heard this and will take into account this remark.

The experimentations showed the possibility to measure workload, learning and SRK.

The workshop organized during Nina project with ATCOs and ATC expert outlined the forthcoming applications of such measurements. Those applications were thought for real work (for the controller himself and a supervisor), or learning (for ATCO student and the instructor).

3.6.3 Deep Blue

Deep Blue gained the following results from the NINA project

- A working method for the development of metrics for human factors concept in the ATM domain, this will be applied to other human factors concepts (i.e. in the STRESS and MOTO WPE projects) and further validated.

- A deeper understanding of the cognitive functions and related brain activity related to human factors concepts used in ATM, which will facilitate the collaboration with neurometrics field.

- A new Human Factors tool for measuring Work Load, training level, SRK level of cognitive control during human in the loop simulations (to be used together with other subjective tools such as NASA-TLX). This will be used, when needed, in future projects.

- A better understanding about the adaptive automation theme (pros, cons, expected acceptance by ATCOs, ideas for possible future solutions) that strengths the company contribution to the theme, especially in SESAR related projects.

4 Total Eligible Costs

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
26/06/2014	D0.0, D0.1, D4.1, D1.1A, D0.2	€ 67.218,74	10.120,12 (9.395,56 travelling costs and 724,56 other minor costs)	Paid
29/12/2014	D0.3, D0.4, D1.1B, D3.1, D4.2	€ 103.430,08	4.543,78 (3.652,28 travelling costs and 891,51 other minor costs)	Paid
08/07/2015	D1.2, D0.5, D1.3, D0.6, D3.2	€ 156.056,18	19.791,46 (19.255,12 travelling costs and 536,33 other minor costs)	Paid
26/11/2015	D0.7, D2.1, D0.8, D4.3	€ 114.247,52	4.410,97	Paid
to be issued	D3.3, D2.2, D0,9, D.10	**€ 119.535,40 (planned value)**	No travelling costs foreseen	N.A
GRAND TOTAL		**€ 560.487,92**	**38.866,33**	**€ 599.354,25**

Table 2 Overview of Billing

Company	Planned man-days	*Actual man-days	*Total Cost (*this values will be confirmed when the final invoice will be issued)	Total Contribution	Reason for Deviation
Deep Blue coordinator	*599*	*Ca. 700*	***€ 280.201,86***	***€ 210.151,40***	The deviation in person-days was due to the second validation exercise, where the subject sample was enlarged to increase the statistical validity of results for both the EEG based state classifier (for Workload, training and level of cognitive control assessment), and for the Adaptive automations (WP3). The original workplan was instead targeting only on the adaptive automation. The rationale for this choice was to enhance the scientific validity of project results. The impact was an increase of effort for the organization, planning and conduction of the simulations. The effort increase was cost neutral. This also reflected on other WPs (WP2 for the generation of the automations to be tested, WP1 for the refinement of literature review in order to have WL assessment and SRK assessment at the same time, WP4 for the dissemination of results).
ENAC	*329*	*Ca. 335*	***€ 166.712,31***	*€ 166.712,31*	
UniSap	*470*	*Ca. 570*	***€ 183.624,21***	*€ 183.624,21*	The schedule and experimental protocol of the second validation required longer person-days than planned previously. In fact, in order to validate statistically the examined cognitive phenomena (cognitive control behavior, impact of adaptive automation, online mental workload evaluation) the number of subjects involved in the EEG recordings was big (37 ATCOs), but the available time was quite limited. The impact was an increase of effort for the organization, planning and conduction of the simulations. The effort increase was cost neutral.
GRAND TOTAL	**1398**	**1580**	**Actual: € 492.088,42 (plus €138.449,96 estimated for final invoice) Total: € 630.538,38**	**€ 560.487,92**	See reasons provided before

Table 3 Overview of Effort and Costs per project participant

5 Project Lessons Learnt

What worked well?
The use of the neurophysiological signals, in particular the brain activity, to evaluate the operator mental workload, also in real-time. The state classifier allowed also to evaluate the training improvements of students and the three degrees of cognitive controls Skill, Rule and Knowledge.
The use of the triangulation method: the performance and subjective scores have shown correlation with the EEG-based workload, validating it with no doubt.
The simulation of ecological working conditions, allowed to test the proposed methodology in realistic operative environments (i.e. ATM settings).
The adaptive interface has been successfully triggered by the state classifier, allowing to readapt the ATM interface basing on the actual operator's workload.
The method used for developing the neurophysiological measures, bringing together the knowledge coming from the Human Factors field, the latest techniques and methods in neurometrics and a deep understanding of ATM working methods and needs.
What should be improved?
The analysis of the Skill, Rule, Knowledge-based events, in particular with the ATCO trainees, that were not able to recognize the Knowledge events. The definition of the events and the model to adopt have to be further improved (the experimental setup should be improved in order to simulate knowledge events, such as an unanticipated emergency).
The use of the Electrocardiographic signal in ecological settings, since the ATCO's movements were a great source of artefacts. A solution could be to find another body site to record it in a reliable way. Also the use of other neurophysiological signals, such as the Heart Rate (recorded by a pulse oximetry sensor), or the Galvanic Skin Response signal, could be investigated, with the aim to extend the features domain and improve the state classifier performances.
The intrusiveness of the recording system. Despite of the improvements done during the project (e.g. a lower number of EEG electrodes used, the removal of the EOG channel), the system is still intrusive for the operator. Technological improvements are already ongoing.
Some brain features are in common both for the workload and SRK levels evaluation. In other words, the state classifier could not be able to assess at the same time the workload and the SRK levels. This issue has been partly addressed, by considering different features to assess the two phenomenon, but further experiments are needed to be sure that the new set of features makes the two phenomenon (i.e. workload, SRK) independent.
The state classifier requires subjective calibration data quite similar to the operative task that the operator is going to perform. It means that, before starting to use the system "online", the operator has to perform a chunk of the operative task at specific difficult levels for few minutes to calibrate the system, and this could represent a limitation. In this regard, further studies are required to investigate the possibility to calibrate the state classifier by using a simple and standard task (different from the operative one), and to use subsequently to evaluate the workload during the operative task.

Table 4 - Project Lessons Learnt

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