Development of Neurometrics for Selective Attention Evaluation in ATM

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***Abstract*— The European Air Traffic Management (ATM) system is expected to face challenging situations, with the growth of air traffic, the increase of its complexity, the introduction of innovative concepts and increased automation. The roles and tasks of Air Traffic Controllers (ATCOs) will change in the future and it is vital to enhance the comprehension of human responses to their role changing, that is, from active control to monitoring of complex situations and managing unexpected system disruptions. ATCOs performance is recognised to be impacted by several aspects such as stress, emotions, available attentional resources, attention focus and so on. In the recent years, the concept of Human Performance Envelope (HPE) has been introduced as new paradigm in Human Factors. Rather than focusing on one individual factor (e.g. fatigue, situation awareness, etc.), the HPE considers their full range, mapping how they work alone or in combination leading to a decreased performance that could affect safety. At the EU level, the STRESS project is currently addressing the research goal of monitoring the operator's performance by including all the available behavioral and neurophysiological data in order to characterize the Human Factors involved when dealing with the considered task. In line with this, the proposed study will show the results coming from the experiments performed in controlled environment for the evaluation of the user's attentional level, and the definition of the neurophysiological indexes for the characterization and assessment of the selective attention along the execution of ATM activity.**

Keywords- Attention; ATM; Neurophysiological indexes; Multimodal Measurement; Human Performance Envelope; ATCO

I. Attention in Air Traffic Management

The latest SESAR Global demonstrations, such as the one regarding the System-Wide Information Management (SWIM), have shown that the development and evolution of the "next" generation of innovative and unconventional ideas, concepts and technologies that define the performance of the future European Air Traffic Management (ATM) system, and contribute to its successful evolution, are already in place [1]. This new era not only concerns the introduction of advanced technologies, but it will deal with a revised founding principles and building blocks of information sharing, service orientation, federation, open standards, and information and service lifecycle management. In compliance with the International Civil Aviation Organization (ICAO) and European Aviation Safety Agency (EASA) regulations and directives [2], [3], SESAR is delivering the performance necessary to meet the growing demand for air transport from a worldwide perspective in order to achieve performance ambition levels for 2035 through significant operational changes. These consist of improvements to technical systems, procedures, human factors and institutional changes supported by standardisation and regulation [4].

In the near future, we may see the introduction of a new generation of highly automated supporting technologies that are able to autonomously (or partially autonomously) manage tasks that are currently carried out by human operators and/or to provide inputs to human decisions that the operators will hardly be in a position to question. The introduction of higher levels of automation will bring about a new task allocation between the human and the machine [5]. Tasks previously carried out by the human, for example the provision of separation, are supposed to be partially delegated to the system. Highly automated systems are expected to take over operators' repetitive tasks, while human role is expected to be focused on strategic planning, intervening on exceptions and monitoring the system's behavior [6][7]. In general, rather than governing directly flight operations, pilots and Air Traffic Controllers (ATCOs) will likely supervise the automated systems. So, the ATCOs role would be shifted from *active* to *passive* (e.g. system monitoring) [8].

This implies the need for a radical revision of the competences required to perform the tasks [9] as well as a refinement of the Human Performance Envelope (HPE) and all its aspects such as stress, emotions, available attentional resources, attention focus and so on. Indeed, assuming that the equipment and the pilots all perform correctly, the controller's workload would be expected to decrease in nominal situations, since they are interacting with fewer aircraft and supported by improved automation systems. It also seems plausible that the controller's situational awareness of the airspace would decrease as well, since they would not be focusing as much attention as they previously did on many of the aircraft [10]. However, for an unknown period of time, certain aircraft in the system would be properly equipped to participate according to the new rules, allowing more autonomy, but others would not be, and the controller would be required to manage their flight path. Consequently, ATCOs have to process *selectively* the vast amount of information whom they have to face, prioritizing some aspects of information while ignoring others by focusing on a certain location or aspect of the visual scene [11]. Attention can be classified into three main components [12]:

I. *Selective attention*: The ability to process or focus on one message in the presence of distracting information.

II. *Divided attention*: The ability to process more than one information at the same time.

III. *Visual attention*: The mechanism determining what information is or is not extracted from our visual field.

One important concern for a notification system in ATM field is that seemingly prominent objects in the visual field can sometimes elude attention despite their relevance and importance to the primary task [13]. This lack of attention or distraction usually affects Human Performance (HP) by causing the omission of procedural steps, forgetfulness to complete tasks, and taking shortcuts that may not be for the better. A performance decrement can be noticed when attention, workload and task difficulty increase; the reaction time and number of errors increase as well, while accuracy and number of completed tasks decrease [14][15]. Reduction of the performance in monitoring, tracking, auditory discrimination, and reduction of visual field can be observed too[16].

One of the objectives of the STRESS project (*human performance neurometricS Toolbox foR highly automatEd SystemS design*) is to support the aforementioned transition to higher automation levels, by addressing, analysing and mitigating its impact on the HP [17]. In fact, the roles and tasks of ATCOs will change in the future and it is vital to enhance the comprehension of human response to changes in role, monitoring of complex situations, unexpected disruptions. It is also vital to develop tools to investigate such aspects and to monitor in real time controllers' fitness to the task, anticipating risks and problems.

II. Neurometrics for Selective Attention

Attention is the ability to select only the relevant part of an information ignoring the useless ones[18]. Attention is adopted for a wide range of everyday activities, like driving a car, watching a movie, or talking with friends, and it becomes very important and even necessary in most of the workplaces like a hospital, or an airport or an air traffic control room. Because of the significant role played by the attention in so many different fields, researchers from multiple disciplines like neuroscience, psychology end ergonomics focused their work on the study of the attentive processes. Lacks of attention during safety risk activities may lead to catastrophic outcomes. Attention in operational environment might be studied observing and analysing people while performing their job allowing to understand what are the aspects of the workplaces, i.e. interactions with colleagues or instrumentation, or work demands, i.e. time pressure or co-working, that may interfere with attention, and operate on the environment and technologies according with the findings. To get more replicable and general information about attention, the most appropriate method is the laboratory setting, by adopting tasks and protocols created *ad-hoc* for a proper evaluation of the attention with full control on the participants, experimental conditions, and surrounding environment.

According to the most solid theories, attention is a multifaceted concept. Firstly, it is defined as a set of cognitive processes that lead to discriminate useful information in a framework of distractors [18], but this is only one of the characterizing aspects. In line with [19], [20], attention is divided in two main domains: *intensity* and *selective aspects*. The *Intensity* aspect of attention embraces alertness and sustained attention (or vigilance [21]): task execution with an optimal level of performance is possible because for the entire duration of the task there is an appropriate level of arousal managing resources involved in orienting and selecting [22]. This capacity of controlling the focus represents the second main aspect of attention that involves the *Selective* and the divided attention. Each of these attentive components is elicited by opportune tasks and shows neurophysiological correlates. The role of the *Autonomic Nervous System* during attentional processes has been less investigated, with respect to the *Central Nervous System* (i.e. brain activity) without taking into account pure clinical research. In general, the widely demonstrated concept is that intensive cognitive processes, such as mental effort and attention, are accompanied by increased autonomic arousal [23]. In this regard, the objective of the proposed work was to assess the level of user's selective attention trough a multimodal approach, by considering several behavioural and neurophysiological signals, such as the *Electroencephalogram* (EEG), *Electrocardiogram* (ECG), *Electrocardiogram* (EOG), *Galvanic Skin Response* (GSR), *Reaction Time* (RT), and number of correct responses.

For the selective aspect of attention, scientific literature reports significant theta and beta EEG activity increasing, and alpha EEG decreasing in correspondence of a target revelation[24],[25],[26]. Furthermore, higher desynchronization (i.e. decrement) in the alpha EEG band over the left brain hemisphere than in the right one, and on the anterior brain cortex than on the posterior brain areas were found[27]. Evidences on the sustained aspect of attention showed that an attentional increase was reflected by an *Heart Rate* (HR) decreasing, because of the assumption that during HR deceleration the brain cortex would be activated, which in turn would facilitate processing of external stimuli [28]. Also, studies in selective attention found a decrement of low frequencies in *heart rate variability* (HRV) [24]. *Skin Conductance Level* (SCL) and *Response* (SCR) are considered the gold standard measures of the attention [29]: higher the user's attention level is, higher SCL and SCR are. Also, the magnitude of the SCR, i.e. its peaks amplitude, is affected by short term changes in the general level of attention of the participant and also by the amount of attention being directed to a particular stimulus[30]. These evidences are summarized in the following table.

TABLE I. LITERATURE EVIDENCES

Features	***Modulation for higher attention level***	***Ref.***
EEG	Increment of theta and beta band activity. Decrement of alpha activity more in left and frontal brain areas than in right and posterior brain	24÷27
HR	Decrement	28
HRV	Decrement of low frequencies	24
SCL	Increment	29
SCR	Increment in peaks amplitude	29-30

III. MATERIAL AND METHODS

A. *Participants*

The experiments were conducted following the principles outlined in the Declaration of Helsinki of 1975, as revised in 2000. It received the favorable opinion from the Ethical Committee of the Sapienza University of Rome. The study involved only healthy Students from the Sapienza University of Rome recruited on a voluntary basis. Informed consent was obtained from each participant on paper, after the explanation of the study. Thirteen healthy volunteers (27±3 years old) their informed consent for taking part at the experiment. In particular, 7 males and 6 females took part at the experiments. All the participants took part to a practice session before starting with the experiment in order to avoid results due to learning processes.

B. *Conjunction Visual Search Task (CNJ)*

The *Conjunction Visual Search Task* (CNJ) consists in presenting visual stimuli on a screen and finding out the *target* among *distractors*, and reacting as fast as possible by pressing the space bar on the keyboard [31]. Both target and distractors were rectangular bars (size: 0.5*1.6 *Visual Angle* - VA): in particular the target was a red vertical bar, while the distractors could be green or red and vertical or oblique bars depending on the conditions (see below for details). No action was required when the target was not presented. All the stimuli were presented on a black background on a 25 position's matrix filled with 8 elements: 7 distractors and 1 target (target events), or 8 distractors (no-target events). The matrix was presented at the participants for 2 seconds and between two trials a fixation cross was presented at the centre of the screen for a random interval between 0.25 ÷ 1 second.

C. *Experimental Protocol*

The experimental protocol consisted in accomplishing the *Conjunction Visual Search Task* (CNJ) under three conditions requiring different levels of attention (Figure 1). In particular, the *Easy* (E) condition was a pre-attentive level (*low attention*) based on one feature (colour); the *Hard* (H) condition was based on an orientation feature (*medium attention*), while the *Conjunction* (C) condition was based on two features (colour and orientation - *high attention*). In particular, in the E condition, the distractors were green vertical rectangular bars. In the H condition, the distractors were red rectangular bars rotated by 45°.

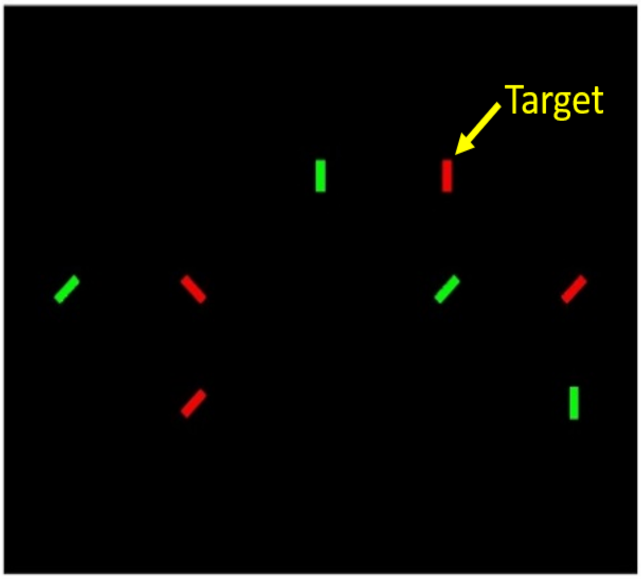

Figure 1. The CNJ task has been proposed under three different conditions. The *Easy* condition was a pre-attentive level (low attention) based on one feature (colour); the *Hard* (H) condition was based on an orientation feature (medium attention), while the *Conjunction* (C) condition was based on two features (colour and orientation - high attention).

Finally, in the C condition the target was defined by two different features, colour and orientation, while the distractors were vertical and 45° rotated green and red rectangular bars. The conditions within the CNJ task (*Easy*, *Hard* and *Conjunction*) were randomized in order to avoid any habituation and expectation effects. The task was divided into two blocks comprehending 180 trails each. In each block participants performed 60 trials of three different conditions which required different level of attention. The participants performed 10 practice trials per condition before starting with the experiments. Each experimental trial included 30 target events and 30 no-target events. The experimental protocol lasted about 45 minutes in total.

During the entire experiment, the EEG, ECG, and EOG (used to remove eye-related artefacts from the EEG signal) signal were recorded using a high-resolution 64-channel system, while the *Galvanic Skin Response* (GSR) was recorded using the Shimmer GSR+ devices. Participants seated at a distance of 60 cm from the monitor (Figure 2). This preparation was followed by the baseline period of data collection for all neurophysiological variables. During the baseline period, the participants were asked to sit calmly and rest for a minute with their eyes open, and then a minute with the eyes closed. Right after the baseline, the participants filled the *Visual Analogue Scale (VAS)* in order to collect their subjective baseline, and during the experiment, at the end of each condition (E, H and C), participants were asked to rate their perceived attentional level using the VAS scale. The VAS comprised four items: Alertness, Attentiveness, Interest and Motivation. Each of the items consisted in a 100 points scale between opposite states (i.e. Attentive/Dreamy, Interested/Bored). This modified version of the scale was taken from [32].

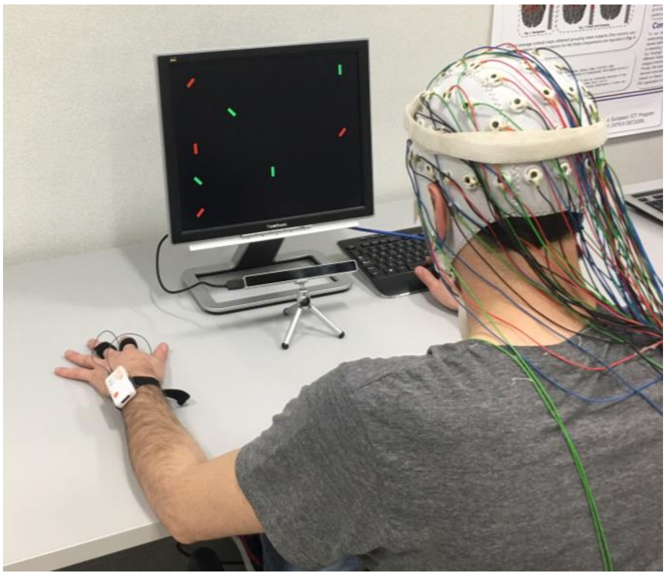

Figure 2. Experimental setup. The participant seated comfortably in front of the screen where the stimuli were presented on. During the entire experiment, the EEG, ECG, EOG signal were recorded using a high-resolution 64-channel system, while the Galvanic Skin Response (GSR) was recorded using the Shimmer GSR+ devices.

To assess both the accuracy and the speed of the user within one synthetic index, the combination between the Reaction Time (RT) of the corrected responses divided by the percentage of correct responses has been used (Equation 1).

$$\textit{Inverse Efficiency Score}\ (\text{IES}) = RT_{TRUE} / \%TRUE_{resp} \qquad (1)$$

In cognitive research, such an index is called the *Inverse Efficiency Score* (IES) [33], and it has been used to compare the performance across the three different levels of attention required during the CNJ task (*Easy*, *Hard* and *Conjunction*).

D. Statistical Analysis

Subjective Data - By the VAS questionnaire, the participants rated the perception of the attention demand across the different experimental phases (E, H, and C). Repeated measure ANOVA has been performed on such scores by considering as *within* factor the attention conditions (3 levels: E, H and C).

EEG Data - The *Power Spectral Density* (PSD) of the different EEG rhythms have been normalized with respect to the corresponding *References* conditions by means of two-tail paired t-tests. Then, repeated measures ANOVAs have been performed on the normalized PSDs values of each EEG channel and band by considering as *within* factor the different experimental conditions. When the results of the ANOVA was significant ($p<0.05$), the post-hoc analysis was performed as well. Then, the differences between couple of conditions (e.g. E vs H, E vs C, and H vs C) in correspondence of significant results ($p<0.05$) were saved, while no significant comparisons were set equal to zero. At the end, for each EEG channel, we obtained a structure were only the statistically significant comparisons, EEG channels and bands were kept. Finally, on such EEG channels, repeated measure ANOVAs have been performed with the aim to assess how the considered EEG rhythm changes across the different experimental conditions (*within* factor: experimental conditions) and to define the neurometrics for the evaluation of the investigated cognitive phenomena (e.g. selective attention).

ECG Data - The *Heart Rate* (HR) and *LF/HF* ratio of the *Heart Rate Variability* (HRV) [34] across the experimental conditions of the CNJ have been normalized by computing the *z-score* for each participant [35]. Then, repeated measures ANOVAs and Duncan's post-hoc tests have then been performed on the two ECG-based indicators with the aim to find out eventual differences across the experimental conditions.

GSR Data - The mean value of the SCL and the mean amplitude of the SCR peaks [30] during the experimental conditions of the Conjunction Visual Search (CNJ) have been normalized, by computing the z-score, for each participant in order to perform group analysis. In particular, the two GSR-based indicators have been compared by means of repeated measures ANOVA. Duncan's post-hoc test has been then performed to assess possible differences between the attention conditions.

IV. Results

A. Subjective Results

The result of the repeated measures ANOVAs on the VAS scores is reported in Figure 3. The perception of the attention across the experimental conditions did not report any statistically significant changes ($F(2, 22) = 0.36$; $p = 0.7$). However, the trend of the graph reveals that the Conjunction condition was perceived more attentional demanding than the previous ones (Easy and Hard).

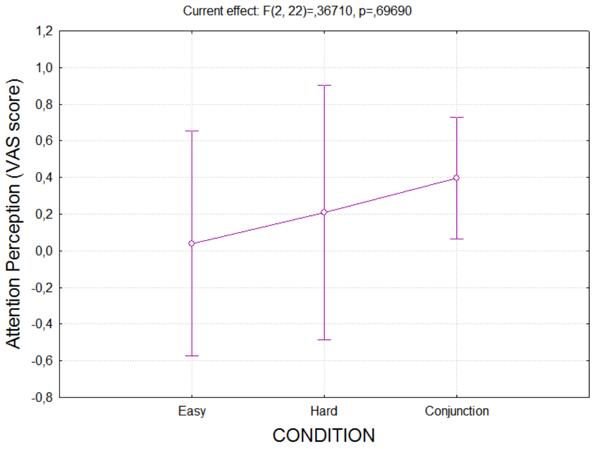

Figure 3. VAS score related to the subjective perception of the attention demands. The ANOVA did not report any changes across the experimental conditions in terms of attention demands perception (F(2, 22) = 0.36; p = 0.7).

B. *Behavioural Results*

Figure 4 reports the variation of IES index across the Easy, Hard, and Conjunction conditions. The ANOVA showed that the participants reacted significantly faster in the Easy condition than in the Hard and Conjunction ones (all $p < 10^{-4}$).

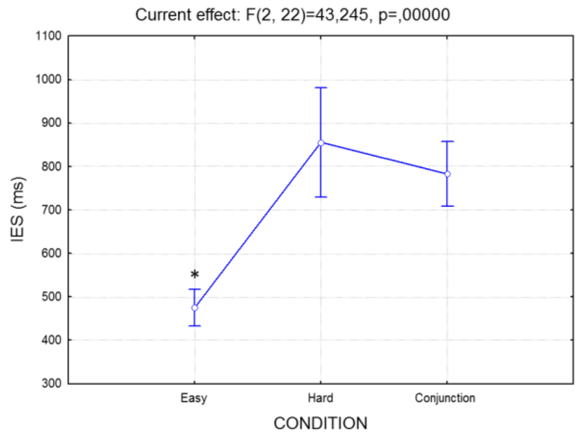

Figure 4. IES values throughout the Easy, Hard and Conjunction conditions. The ANOVA showed that the participants reacted faster in the Easy condition than in the Hard and Conjunction ones (all $p<10^{-4}$).

C. *Neurophysiological results*

EEG Data – In the following figures (Figure 5÷10), the results of the repeated measures ANOVAs have been reported for each EEG rhythms over the brain areas in which significant changes were found. In particular, the spectral maps report only significant changes (PSDs increment and reduction were plotted in red and blue shades, respectively; on the contrary, no significant differences were coloured in grey), and above them the statistical trends over the brain areas (frontal, central, parietal, and occipital). The asterisks highlight the experimental conditions resulted statistically different (p<0.05) from the others. When no asterisks are reported, the considered conditions were not statistical different. When the attention demand increased from *Easy* to *Hard,* and finally to the *Conjunction* condition, significant increments of the theta, beta and gamma EEG bands have been found over the whole brain.

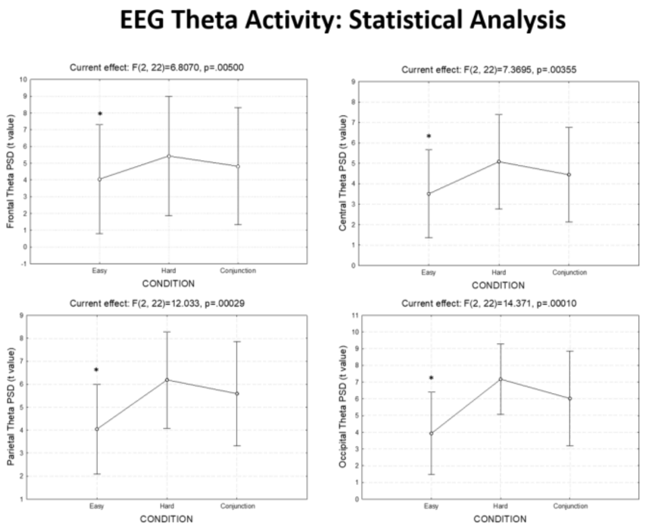

Figure 5. ANOVA results on the EEG theta activity performed over the different brain areas. The asterisks highlight the experimental conditions resulted statistically different (p<0.05) from the others.

In particular, theta (F(2, 22) = 13; $p < 10^{-3}$), and beta (F(2, 22) = 4; p < 0.03) reported the highest increments over the parietal and occipital brain areas (Figure 5÷8).

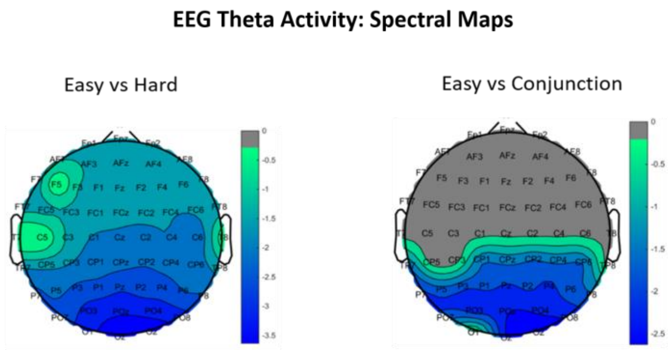

Figure 6. Cortical maps of the EEG theta activity over the different brain areas. PSDs increment and reduction were plotted in red and blue shades, respectively; on the contrary, no significant differences were coloured in grey.

On the contrary, the gamma band exhibited significant increment over the central (F(2, 22) = 8.15; p < 0.01) and parietal (F(2, 22) = 6.11; p < 0.007) brain areas (Figure 9 and 10).

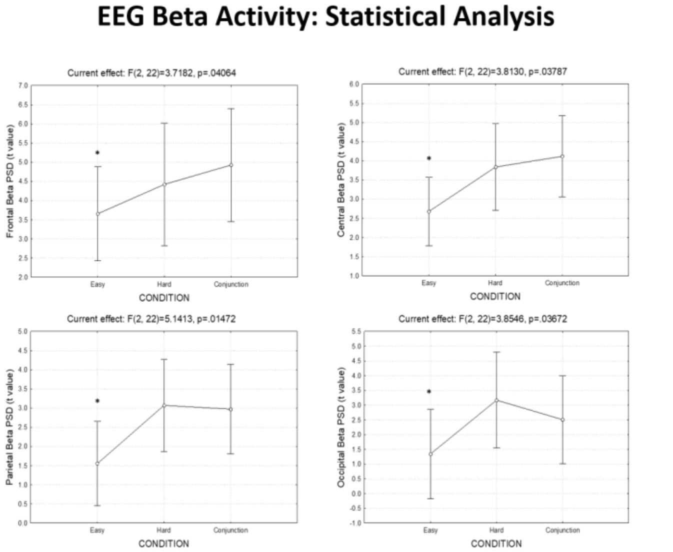

Figure 7. ANOVA results on the EEG beta activity performed over the different brain areas. The asterisks highlight the experimental conditions resulted statistically different (p<0.05) from the others.

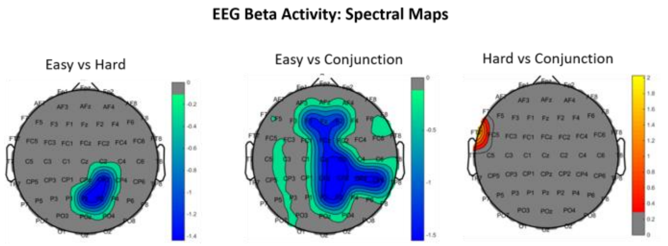

Figure 8. Cortical maps of the EEG beta activity over the different brain areas. PSDs increment and reduction were plotted in red and blue shades, respectively; on the contrary, no significant differences were coloured in grey.

Finally, between the *medium* and *high* attentional conditions, significant reduction of the frontal left gamma band has been reported ($F(2, 22) = 6.11$; $p < 0.007$).

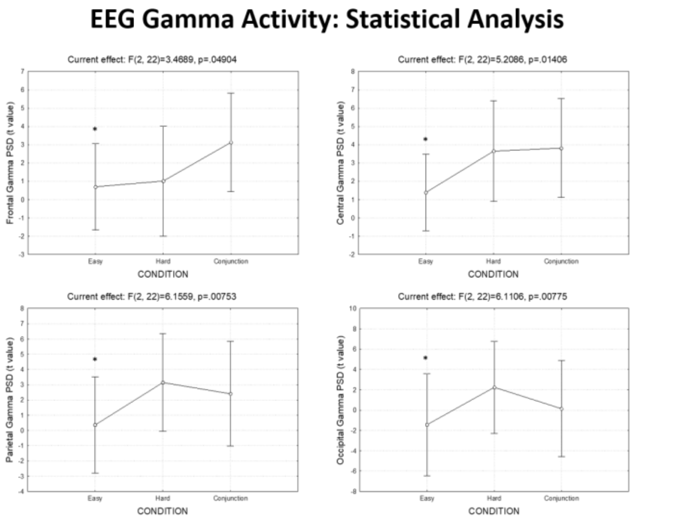

Figure 9. ANOVA results on the EEG gamma activity performed over the different brain areas. The asterisks highlight the experimental conditions resulted statistically different (p<0.05) from the others.

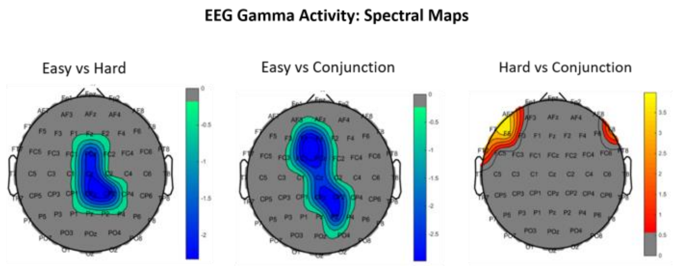

Figure 10. Cortical maps of the EEG gamma activity over the different brain areas. PSDs increment and reduction were plotted in red and blue shades, respectively; on the contrary, no significant differences were coloured in grey.

In addition, significant asymmetry within the beta and gamma bands over the posterior lobes was found, where the right hemisphere was more involved than the left one. Finally, between the medium (H) and high attentional (C) conditions, significant reduction of the frontal left gamma band has been reported ($p<0.007$).

No significant differences have been found within the alpha EEG band over the considered brain areas.

ECG Data - Neither the *Heart Rate* (HR) nor the *Heart Rate Variability* (HRV) showed significant differences among the different attention demand conditions. In other words, they did not change in response to variations of selective attention.

GSR Data- By one hand the SCL did not show significant variations among the different conditions of the Conjunction Task. On the contrary, by the other hand the peaks amplitude of the SCR increased significantly ($p = 0.035$) from the Easy to the Conjunction condition (Figure 11). In particular, the Duncan's post-hoc analysis highlighted that both the Hard and the Conjunction conditions induced SCR peaks significantly higher (respectively $p = 0.03$ and $p = 0.02$) than those ones induced by the Easy condition, whilst no significant difference was found between them (i.e. Hard and Conjunction).

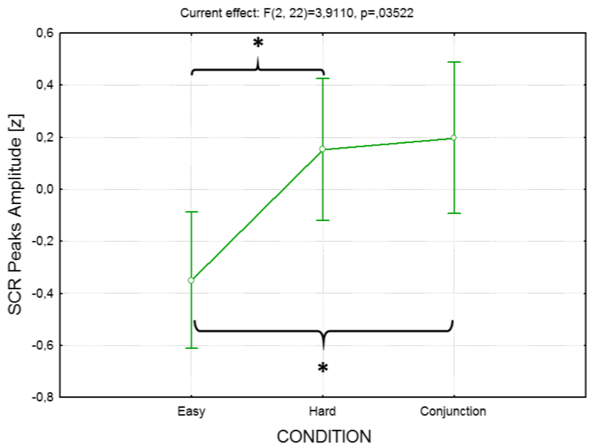

Figure 11. Variation of the SCR peaks among the different conditions of selective attention. The asterisks highlight the experimental conditions resulted statistically different (p<0.05) from the others

V. Discussions

The analysis of behavioural data (IES index) showed significant slower reaction time and higher percentage of correct responses in the *Easy* condition with respect to the others two. This can be explained by the pre-attentive nature of this condition. Instead, in the *Hard* and *Conjunction* conditions the IES increased significantly due to higher attentive resources required by the subjects to accomplish the task and discriminate two features in order to identify the target.

The self-reported measures during the CONJ task did not provide any significant differences in terms of attention perception.

When the attentional demand became high (*conjunction* condition) the theta band increased significantly over the posterior areas, while the beta and gamma bands increased significantly along the midline throughout the whole brain areas. Also, the beta band kept the asymmetry on the right hemisphere by showing an enhanced activity.

Concerning the activation of the *Autonomic Nervous System* in response to the different types of attention, the cardiac parameters, HR and HRV appeared to be insensitive to the variations of selective attention.

On the contrary, the SCR peaks amplitude seems to be very sensitive to the selective sphere of attention. Although the Hard and Conjunction conditions appeared no significantly discriminable, this effect probably depends on an intrinsic poor discriminability of the two conditions, since also neither the subjective (i.e. VAS questionnaire) nor the behavioural measures (i.e. IES index) were able to discriminate them.

Despite the small experimental sample, since the results were derived from controlled settings, they provided robust evidences for the assessment of the attention level while dealing with realistic tasks. In fact, the evidences suggest to select the theta, beta and gamma EEG bands and the SCR component of the GSR in order to define an index able to track the user's attention level.

VI. Conclusions

The results showed the possibility to assess different levels of the user's attention. In particular, they highlighted the current limitation in using single neurophysiological signal rather than a combination of them. In fact, by considering only the behavioural or GSR data, it was possible to discriminate only two levels of attention (Figure 4 and 11). On the contrary, if the EEG was integrated with them, the resolution of the neurometric would allow to measure three levels of attention (Figure 5÷10). In addition, the results suggest to define such a neurometric as a combination of the EEG estimated along the midline of the brain, and the SCR component of the GSR.

These evidences will be used for the next phase of the STRESS project: the *First Validation*. In the first validation, experiments will be performed at the University of Anadolu (Eskişehir, Turkey) by recruiting professional ATCOs and asking them to manage a realistic ATM scenario in which specific events will be designed with the aim to elicit different level of attention, stress and workload. In particular, such events will be designed with the support of Subject of Matter Expert (SME) and HF Experts, and by considering the experimental tasks used in the laboratory experiments. In fact, the CNJ task was selected by taking into account both the scientific validity and reliability of the task itself, and the similarity with the ATC activities, such as identify a specific aircraft among all the others, time and stressing pressure. The evidences will be then used in the first validation with the aims of 1) testing the proposed indexes for attention, stress, and workload evaluation in ecological settings, and 2) eventually combining them by considering the new evidences and conditions coming from realistic activities (e.g. more talking and movements).

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