Les Rendez-vous de l'AERO de l'INNOVATION

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ISAE SUPAERO Institut Supérieur de l'Aéronautique et de l'Espace

Neuroergonomics for flight safety

Preventing air crashes by adapting cockpit design and training to pilots' brains, is one of the goals of research in neuroergonomics, a new field that aims to detect the mechanisms of human error. By measuring brain activity, neurosciences and artificial intelligence combined with ergonomics and human factors can improve air safety.

From Human Factors to Neuroergonomics

It is well known that human factors are a contributing cause of accidents and disasters in many critical domains such as nuclear power, space exploration, medicine or aviation. In the case of air transportation, it is estimated that approximately 60 to 80 percent of aviation accidents involve human error. Since World War II, the study of human factors has flourished. In aviation, early research focused on the design of the cockpit (controls, displays…), and on the effects of altitude and environmental factors on pilots. Progressively, with the increasing complexity of computerized cockpits, research increasingly has focused on the operators' cognition (e.g. mental demand). Moreover, new developments single pilot operations and piloting from the ground constitute new challenges that call for extensive research. Thus, the approach to human Factors and Ergonomics has continuously evolved during the 20th century. Traditionally, the analysis of human-system interactions has primarily focused on subjective and observable behavior to study human work in the field. Although this approach has paved the way to great progress, especially when observations led to descriptive modeling, an important part of the pilot's brain functioning remains unknown. Since the early 2000's, Neuroergonomics, the intersection of Neuroscience, Cognitive Engineering and Human Factors, has offered an alternative approach to further extend our understanding of observable behavior by examining the brain mechanisms underlying the interaction between human and technology interaction. The main objective of Neuroergonomics, in the continuity of Human Factors, is therefore to enhance coupling human/technology coupling, by fitting system design to the human brain, and supporting activities by providing assistance, enhanced training, or improved operators' selection.

The Neuroergonomics group at ISAE-SUPAERO

The Neuroergonomics and Human Factors research group is part of the Department of Aerospace Vehicle Design and Control, at ISAE-SUPAERO, Toulouse, France. The group conducts studies on Human Factors applied to aviation safety, and is currently composed of 5 research and teaching faculty members and 15 (post)-doctoral students, with interdisciplinary expertise in Neuroscience, Signal Processing, Machine Learning, Computer Science, and Human Factors. This growing team has become a key player in Human Factors for flight safety. It has developed collaborations with major aeronautical firms and airlines, and provides expertise for flight civilian aviation authorities. It is also directly supported by two major research programs funded by the AXA Research Fund and Dassault Aviation. The group has developed a strong scientific network with first-ranked European, North American and Asian universities in the field. It enjoys a wide range of research facilities such as motion flight simulators, real aircraft, and combines cutting-edge brain imaging techniques and other psycho-physiological sensors.

The group's work goes beyond the analysis of subjective feelings and human behavior, by investigating the neural correlates supporting human performance. Researchers in the group have a unique methodology "from basic research to ecological experiments", ranging from controlled experiments performed in laboratory settings (e.g. with fMRI recordings) to studies conducted within simulators (i.e. flight and UAV monitoring simulators) and even in real flight conditions. Thanks to the diversity of platforms, they interrogate the neural bases of psychological phenomena at different levels of control or realism.

Fig. 1 *From controlled laboratory settings and simulations to real life experiments.*

The main goal of the research conducted in the Neuroergonomics and Human Factors group at ISAE-SUPAERO is to uncover the neural mechanisms that underpin human performance and to identify the risk factors of human errors. This makes it possible to design new solutions to improve training and more efficient warning systems and leads to implementation of real-time solutions to dynamically adapt the cockpit to the pilots' state.

Stress/emotion and mental workload

One particular topic of interest is the study of the effects of stress or emotion on brain performance. In our anxiogenic and stressful world, maintaining optimal cognitive performance is a constant challenge. This is particularly true in complex work environments (e.g. flight deck, air traffic control tower), where operators have to deal with highly dynamic and uncertain situations. It is believed that stress can reduce human cognitive efficiency, even in the absence of any observable impact on task performance. Yet, performance may be protected from stress effects thanks to compensatory efforts (e.g. coping), but only at the expense of a cognitive cost. Such psycho-physiological cost, invisible to the naked eye, may be indexed using neuroergonomic measures. A PhD student with Airbus Helicopter is currently investigating the impact of noise on pilots and passengers. We investigate brain activity and heart rate to objectively evaluate the level of stress, with the aim of identifying the type of noise that should be removed from the cockpit in order to maintain a high level of comfort.

It is also crucial to understand how the brain dynamically adapts to stressors and task demands to improve cockpit design and pilot training. For instance, stressful tasks that involve a high cognitive load consume most of the attentional resources, leaving little or no remaining resources to process any unexpected event and/or complex situations. Such mentally demanding situations and emotional pressure can promote risky behaviors that can jeopardize flight safety. A paradigmatic example is the pilot's inability to revise their flight plan or to abort the landing to perform a go-around. Such issues are at the core of our research and led us to design a simplified but plausible landing scenario to estimate changes in brain activity related to emotion and uncertainty with fMRI (functional Magnetic Resonance Imaging). Our results showed that risky decision makers, who were more likely to persist in erroneous landing decisions, exhibited a lower activation of some "rational" brain areas (see figure 2) than safe decision makers.

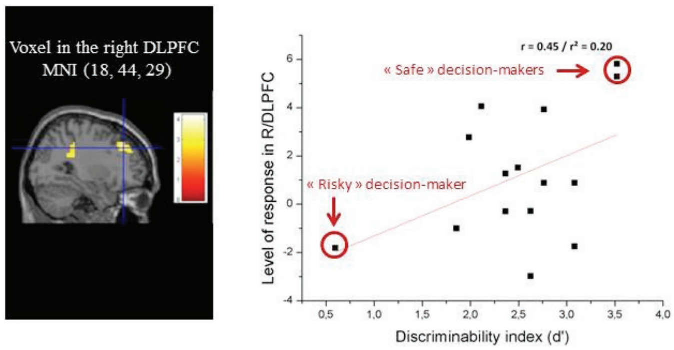

Fig. 2 *Reduced activation of the right prefrontal dorsolateral cortex in risky decision makers as compared to safe decision makers in a highly emotional aeronautical decision task (fMRI study).*

A high level of mental demands is also known to impair pilots' attentional abilities, leading them to miss critical warnings as reported in several accident analyses. Thus, the research group also focuses on understanding the mechanisms that underpin auditory alarm misperception. To investigate this phenomenon, the team has conducted a series of experiments in the context of air traffic control or flying, using different techniques such as fMRI, EEG (see figure 3) or eye tracking. Our results demonstrated that processing demanding visual situations (e.g. supervising multiple aircrafts on the radar screen or performing a difficult landing) can take over hearing to an extent that a high rate of auditory alarms can be missed. More interestingly, our findings allowed toidentify the neural networks and the temporal dynamics of this auditory attenuation that may have dramatis consequences in the cockpit. Moreover, our analyses revealed that the measure of the pupil size can offer a window to predict its occurrence.

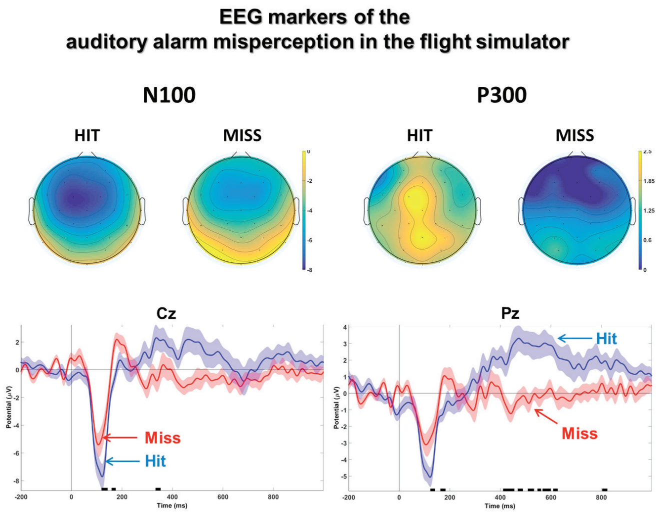

Fig. 3. *Neural signature of the inability to perceive auditory alarms in particularly stressful conditions (i.e. a difficult landing) across electrode sites.*

Designing new solutions

Our research has paved the way for the implementation of both upstream and downstream solutions that might help increasg flight safety and human performance. Upstream solutions encompass developing new training programs and enhanced cockpit designs (eg. new warning systems), while a direct downstream solution, that relates to cockpit and more generally interface design, is the implementation of an online physiological monitoring of the operator. This monitoring may help adapg the system to the user's cognitive and emotional states.

Training

A very first approach to improve flight safety relies on designing training programs to enhance pilots' cognitive abilities. For instance, an important aspect of training is to promote the capacity to inhibit previous knowledge in order to allow a good adaptation to new situations (e.g. new aircraft type). We investigate the neural networks of mental flexibility in order to quantify the real effects of various training programs on the maintenance of this flexibility. In addition, we assess the possibility of having brain-based precursor markers (e.g. resting state connectivity) of learning ability in order to predict the mental flexibility level before and after the training. Finally, we also evaluate flight crew behavior in controlled laboratory settings, motion simulators, virtual reality (VR) simulations, and real-life experiments. Eye-tracking studies examine questions about the efficiency of visual search, information retrieval, and visual strategies in skilled and novice operators. Using eye tracking during the training as a debriefing tool can also provide individual and objective feedback on the pilot's scanning pattern (a PhD in collaboration with Air France is currently focused on this topic). In this sense, we also develop advanced visualization techniques for examining visual scan paths in the cockpit (see figure 4). Finally, simulating complex environments (such as aircraft cockpit or air traffic control room) through a VR head-mounted device is a powerful tool for training. We explore the learning affordances of such simulations by comparing the data from VR sessions to motion flight simulators and real flight experiences.

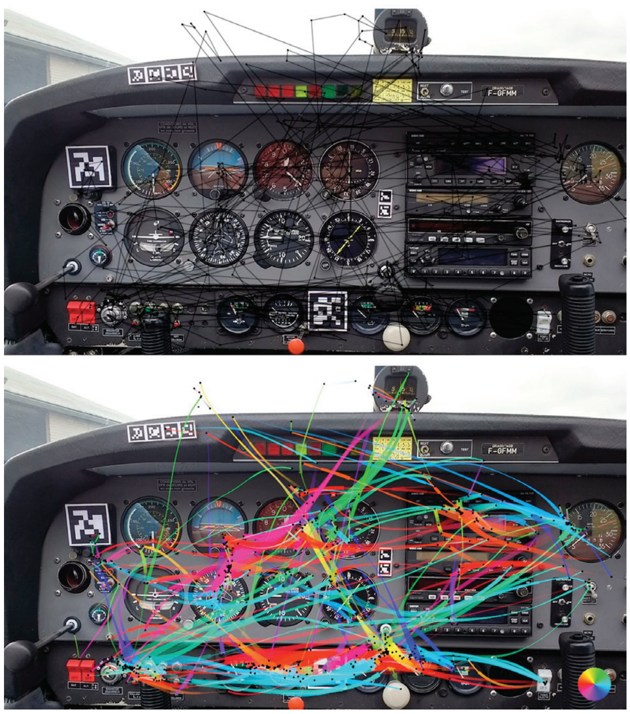

Fig. 4. *Visualization of a raw scanpath and its aggregated layout, where color codes the direction of eye movements*

Better warning systems

A complementary approach to enhance flight safety is to design more efficient warning systems to capture pilots' attention. For instance, one solution currently developed in the team is dedicated to improve pilots' reaction when facing an immediate threat (e.g. collision). For this, the proposed solution relies on the properties of neurons called mirror neurons discovered in 1990 by G. Rizzolati of the Faculty of Medicine of Parma. Mirror neurons are activated both when an individual performs an action and when he imagines himself performing it and even when he observes another person performing that action. However, the understanding of their operation opens a path towards the development of new alarm systems aboard the cockpit. For example, in controlled flight into terrain type accidents, sometimes the crew has only a few seconds to react in order to avoid the crash. Most of the time, the procedure is relatively simple: the pilot must pull the stick full-back and apply the maximum thrust to regain altitude. In case of emergency, the countermeasures are materialized by the display of the action to be taken, in this case a hand pulling the handle, in the form of an animation projected on a screen provided for this purpose. Thanks to the mirror effect the neurons that command to pull the handle would thus be "pre-activated". The first experiments show that this new type of alert divides the pilot's reaction time by three.

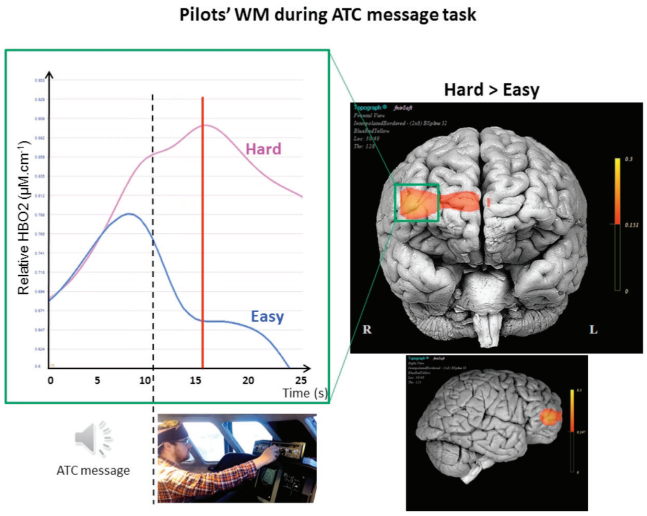

Fig. 5 *fNIRS-based Brain Computer Interface to monitor pilot's workload*

Physiological monitoring as an input for system adaptation

The abovementioned solutions provide an interesting framework to overcome pilots' cognitive limitations. Alternative solutions could also consist in dynamically reallocating tasks between the crew members and automation or artificial agents (i.e. adaptive automation). However, there are still many challenges involved in implementing these potential solution. In particular, a critical aspect of an adaptive support system is to provide help in a timely and accurate manner, specifically during periods of high vulnerability. Moreover, the characterization of mental states that would constitute incapacitations as well as the extraction of robust markers of such incapacitations still must be thoroughly investigated. For now, the team is focusing on degraded states (partial incapacitations) including high mental workload, cognitive fatigue, attentional impairment and error detection. Brain computer interfaces (also called biocybernetical loops) are one of the best tools to monitor pilots' cognitive state. In the Human Factors' perspective, these systems automatically extract information from recorded brain activity based on advanced signal processing and artificial intelligence technologies. We currently implement such neuro-adaptive systems in flight simulators (see figure 5) and real flight conditions to design a more adaptive cockpit.

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