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A Neuroergonomics Approach to Human Performance in Aviation

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Human performance issues in aviation

The technical progress of brain imaging over the last decade has dramatically revolutionized our understanding of the brain structures and functions underlying perceptual, motor, and cognitive processes. This corpus of knowledge is of great importance for any disciplines concerned with the evaluation of human performance. Since the early 2000's, neuroergonomics, the intersection of neuroscience, cognitive engineering and human factors, proposes to examine human-technology interaction and the underlying brain mechanisms in increasingly naturalistic settings representative of work and in everyday life situations. This discipline is defined by its founder, as the "scientific study of the brain mechanisms and psychological and physical functions of humans in relation to technology, work and environments" (Parasuraman, 2003). Aviation operations constitute an ideal domain to implement this approach. Because of the diversity of tasks involved when operating aircrafts or unmanned vehicles, diverse topics can be investigated ranging from motor control, attention, learning, alertness, fatigue, workload, decision-making, situational awareness, and anxiety. Neuroergonomics presents a relevant framework to understand the neural substrate underpinning pilot's performance as well as the neural mechanisms at the core of human error.

This is of importance as human error and poor human-system interactions are commonly cited as the main cause of accidents (Li, Baker, Grabowski, & Rebok, 2001). For instance loss-of-control (LOC) events form the most prominent category of accidents, of which there have been more than 50 in the last 5 years. A study revealed that 18 LOC were responsible for nearly 1493 deaths between 2002 and 2011 (Boeing, 2012) whereby the crews generally failed to react appropriately (Ancel & Shih, 2012; Bureau Enquêtes et Analyses, 2012, p. 447; Commercial Aviation Safety Team, 2008; Dehais et al., 2015; Spangler & Park, 2010). Beyond these psychomotor and perceptual issues, decision-making impairment is also known to be a contributing factor in the second prominent category of accidents "controlled flight into terrain" (CFIT) in which an airworthy aircraft is unintentionally flown into the ground (or the sea), often during the approach phase. Amazingly, 51% of accidents occur during approaches/landings whereas this phase represents only 4% of exposure time of a flight lasting 1.5 hours (National Transportation Safety Board, 2005). A paradigmatic accident is the one that killed the Polish President in 2010 near Smolensk where the crew persisted in a no visibility landing despite several auditory "Pull Up" alerts. According to the accident analysis, the crew may have feared a negative reaction from the President should they have to divert to an alternate airfield (Committee for Investigation of National Aviation Accidents, 2011).

These critical events and the inappropriate reactions of expert pilots present a challenge for human factor practitioners and aircraft manufacturers. On one hand, the understanding of performance and human error have been investigated through subjective and observable measures. Although this approach has paved the way to great progress, especially when observations led to descriptive modeling, an important part of pilot-cockpit interaction remains unknown. On the other hand, cognitive neuroscience has opened "the black box" and shed light on underlying neural mechanisms supporting human behavior. Despite decades of exciting progress, this discipline has mostly been limited to laboratory studies and the use of simplified paradigms to investigate cognition. Thus, neuroergonomics constitutes a paradigm shift away from the standard reductionist approach to neuroscience and from the typical lack of objective measures from field studies as conducted by human factors practitioners. In this chapter, we therefore propose to examine neuroergonomics and its benefit for flight safety. In the next sections, we present the neuroergonomics based methodology, then provide illustrations applied to the understanding of motor, attentional, and decision-making aspects of flying, followed by the proposal of neuroergonomic based solutions to enhance flight safety.

Neuroergonomics methodology

Neuroergonomics maintains that an understanding of neural processes underlying human behavior can best be understood by investigating the underlying interacting brain networks in the context of carrying out various real-world tasks under investigation, rather than under reduced isolated conditions that only occur in the laboratory. To that end, neuroergonomics promotes the use of various brain imaging techniques and psychophysiological sensors to investigate the neural mechanisms underlying phenomena that occur during complex real-life activities.

A challenge of importance for neuroergonomics is to succeed in reproducing ecological conditions in well-controlled laboratory protocols and to determine solutions for application of portable devices to measure human performance in realistic settings. In laboratory settings, expensive high-resolution devices such as functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG) can be employed. Functional magnetic resonance imaging indirectly measures brain activity by primarily looking at blood oxygenation level dependent changes between various experimental conditions (Ogawa, Lee, Kay, & Tank, 1990). Excellent spatial resolution of brain activity both cortical and subcortical is provided by fMRI. However, one of the limitations of fMRI is that it lacks good temporal resolution (on the order of several seconds, limited by the slow rise of the hemodynamic response). MEG directly measures magnetic fields generated by simultaneous local field potentials in large groups of similarly oriented neurons (Baillet, 2017). The temporal resolution for MEG is good (on the order of 1 msec), and the transparency of magnetic fields with respect to various tissues (skin, bone, cerebral spinal fluid) provides advantages over electroencephalography (EEG) with respect to source localization. Using individual specific anatomical MRI to model the brain spatial resolution lower than one cm can be achieved (Sato et al., 2004).

While fMRI and MEG both provide precious insights into the neural mechanisms underlying specific cognitive processes, these techniques have several drawbacks that constrain the design of ecological protocols to examine the brain "at work." The main drawbacks of fMRI and MEG techniques for ecological protocols are the lack of portability (fMRI and MEG both require specialized facilities with shielded rooms and cannot be moved), the large susceptibility to artifacts caused by very small head movement (participants must keep their head very still), and the considerable expense for these devices. Despite these apparent limitations, the use of these brain-imaging methods together with specialized fiber optic based equipment (e.g. joystick, pedals, throttle lever, steering wheel) and audio-visual display of realistic flight and driving simulation have been used to investigate neural activity underlying perceptual, motor, and cognitive processes involved with operating a vehicle (Callan et al., 2012; 2013; 2016; Adamson et al., 2014, Durantin et al., 2017).

Alternative functional neuroimaging techniques that could help overcome the aforementioned limitations associated with fMRI and/or MEG include measures derived from Electro-encephalography (EEG) and functional Near Infra-Red Spectroscopy (fNIRS). Portability of their instruments allows for non-invasive examination of brain function in real world settings. Less known than EEG, fNIRS is a non-invasive optical brain monitoring technique that provides a measure of cerebral hemodynamics within cortical regions. It has low temporal resolution but good spatial localization for the outer region of the cortex that has been verified with fMRI (Cui, Bray, Bryant, Glover, & Reiss, 2011). The use of these techniques recently has gained momentum, offering interesting prospects for human factors issues, as it is field-deployable (Ayaz et al., 2012; Gateau, Durantin, Lancelot, Scannella, & Dehais, 2015).

Therefore, one adequate solution to understand the neural mechanisms underpinning pilots' performance is to conduct a "progression" of experiments starting with well-controlled protocols with high resolution devices (e.g., fMRI, and MEG) but which are constrained to the use of low fidelity simulators, then proceeding to more ecological experiments in dynamic microworlds using motion based high fidelity flight simulators and brain recording devices that are portable but with lower resolution (e.g., fNIRS, EEG), to eventually conducting experiments in real flight conditions using these same portable brain recording devices (see Fig 6.1).

Figure 6.1 : Illustration of the Neuroergonomics methodology defined by Parasuraman and Rizzo (2007): from highly controlled but less ecological situations to highly ecological but less controlled situations. Cerebral and autonomous nervous system activations are compared across the different situations to ensure the validity of the measurements.

Perceptual and motor aspect of flying.

An understanding of the neural processes underlying perceptual and motor aspects of flying related to performance and learning will provide insight for neuroergonomic based application of enhanced training paradigms and facilitative technology. Experience shapes the way that the brain processes information. Brain processing and neuroanatomical differences between pilots' and non-pilots' have been investigated to explore effects of experience. In an fMRI experiment (Callan et al., 2013) looking at execution and observation of aircraft landing it was found that pilots showed greater activity than non-pilots in brain regions involved with motor simulation 'Mirror Neuron System' thought to be important for imitation based learning. It is interesting to point out that glider pilots compared to non-pilots show higher gray matter density in the ventral premotor cortex thought to be a part of the 'Mirror Neuron

System' (Ahamed, Kawanabe, Ishii, & Callan, 2014). Pilot's also showed greater activity when observing their own previous versus another person's aircraft landing performance in the cerebellum suggesting a role of motor simulation based error-feedback learning (Callan et al., 2013). Pilots utilize unsupervised imitation based learning in the cortex and error-feedback based learning carried out in the cerebellum (Callan et al., 2013). The results of these experiments given above are consistent with the hypothesis that experience (piloting in this case) shapes the way in which the brain processes perceptual motor tasks.

Brain activity from perceptual motor brain regions has been used in a brain-machine-interface based neuroadaptive automation application to improve performance (Callan et al., 2016a). In this case performance was defined as response speed to recover from an unexpected perturbation in flight attitude (Callan, Terzibas, Cassel, Sato, & Parasuraman 2016). The experiment was carried out recording brain activity with MEG during a flight simulation task. The goal of the experiment was to utilize only perceptual motor activity occurring normally during task performance to identify the perception of a perturbation and the intention to move. Machine learning over brain activity to detect the perturbation in flight attitude was used to train a classifier on data collected on a simple task. The trained classifier was then used on a complex task in which the pilots were to maneuver through the Grand Canyon while experiencing an unexpected perturbation in flight attitude. This neuroadaptive automation application (automated initiation of control stick deflection of flight surfaces - elevator) utilizing a brain-machine-interface was able to selectively detect motor intention to the perturbation from continuous motor control used to continuously maneuver the airplane improving response speed from a mean of 425.0 ms to 352.7 ms (mean time savings of 72 ms). One of the most important aspects of this research was that it was able to increase overall system performance (faster response speed) using brain activity naturally occurring during operation of the piloting task without any additional workload incurred on the pilot.

Attentional aspect of flying

An important component of flying is related to the monitoring of the flight deck and the external environment. There have been recent concerns raised by the National Transportation Safety Board and the International Civil Aviation Organization (Civilian Aviation Authority, 2013) about the crew's proficiency to supervise flight parameters. These institutions identified poor monitoring as a contributing factor involved in most of the major civilian accidents, such as the Colgan Air Flight 3407 (Spangler & Park, 2010), the Asiana Air Flight 214 (National Transportation Safety Board, 2015), the Turkish Airlines Flight 1951 (Dutch Safety Board, 2010), or more recently the UPS Airlines Flight 1354 (National Transportation Safety Board, 2013) crashes to name a few.

Whereas these visual attentional issues and causal factors are now well documented (Dehais, Behrend, Peysakhovich, Causse, & Wickens, 2017, Reynal, Colineau, Vernay, Dehais, 2016, Casner & Schooler, 2015, Parasuraman, & Riley, 97), insufficient attention has been given to its auditory attentional counterpart. Indeed, several accident analyses (Bliss, 2003; Mumaw et al., 2017) and research in the aviation domain (Dehais et al., 2012; Dehais et al., 2014; Dehais et al., 2016; Dehais, et al., 2017) have revealed that absence of response to auditory warnings could take place in the cockpit. The understanding of this phenomenon is complex and advocate for the use of a neuroergonomic approach. Indeed, contrary to visual attention, which can be measured by the recording of eye movements (Duchowski, 2007), the understanding of auditory attentional processing is more dependent on the use of brain imaging techniques.

Following a neuroergonomic methodology (see Fig. 6.1), we conducted a series of experiments using respectively fMRI, and EEG in simulated and real flight conditions. This approach led us to explore the « where » (i.e. brain areas), the « when » (i.e. temporal dynamic) and the « how » (i.e. underlying neural mechanisms) underpinning alarm misperception. We first carried out an fMRI study to investigate the activity of the brain regions during episodes of alarm misperception using a first-person view « red bull air race » flight simulator (Durantin, Dehais, Gonthier, Terzibas, & Callan, 2017). During the flight scenario, the pilots had to pass through several gates using a joystick while auditory alarms, periodically triggered at irregular intervals, were to be reported by the volunteers. In order to maintain a high level of engagement and force pilots to scan both the instruments and the world outside the plane, a light in the flight deck indicated the orientation (either horizontal or vertical) in which pilots were to fly through the gates. The results revealed that pilots missed about 35% of the alarms, but more interestingly, the fMRI analyses revealed that auditory misses relative to auditory hits yielded greater differential activation in several brain structures involved with an attentional bottleneck (Tombu et al., 2011). These latter regions were also particularly active when flying performance was low, suggesting that when the primary task demand was excessive, this attentional bottleneck attenuated the processing of non-primary tasks to favor execution of the visual piloting task. Deeper analyses lend support to this hypothesized mechanism via reduced functional neural connectivity from some of these attentional bottleneck regions to auditory processing regions for missed audio alarms relative to hits (Durantin et al., 2017). This latter result suggests that the auditory cortex can be literally switched off by top down mechanisms when the flying task becomes too demanding.

Although fMRI is a valuable tool for identifying the brain areas responsible for alarm misperception, its temporal resolution is too low to measure when this phenomenon may occur. For this, we conducted a second experiment (Scannella et al., 2016) to assess the dynamics of alarm misperception in the cockpit by using EEG and analyzing event related potentials (ERPs). Seven participants were placed in a motion flight simulator facing a critical landing situation with smoke in the cabin requiring an emergency night landing in adverse meteorological conditions. During the task, a low pitch tone was presented, either standard, which participants were told to ignore and a deviant high pitch tone (“the alarm”, probability = 0.20) that participants were asked to report. The pilots failed to respond to 56% of the auditory alarms. In addition, the analysis of neurophysiological signals showed that the missed over the hit alarms led to a drastic reduction of the amplitude of the auditory N100 (perceptual) and P300 (attentional) event related components. These results were consistent with previous findings (Giraudet et al., 2015; Scannella et al., 2013) and also suggested, together with the pre-cited fMRI study (Durantin, Dehais, Gonthier, Terzibas, & Callan, 2017), that alarm misperception phenomenon occurs even during early stages of auditory processing.

Lastly, a third experiment was conducted in actual flight conditions to improve our understanding of the neural mechanisms underlying alarm misperception (Callan et al., 2018). Whereas the previous study focused on the analysis of ERPs is informative, it does not provide insight into oscillatory and phasic properties thought to modulate perceptual cortices by inducing phase resetting (Yamagishi et al., 2008). Interestingly enough, Inter Trial Coherence (ITC) can measure these modulations over the EEG signal. In this experiment, we used a similar odd-ball paradigm in which the pilots were to ignore a frequent tone and to respond by button press when they heard a deviant chirp sound. The experiment was conducted using a DR400 4 seat airplane with thirteen pilots who were equipped with a 64 channel Cognionics dry-wireless EEG system to measure their brain activity. A flight instructor was present on all flights and in charge of initiating the various scenarios consisting of diverted flight plan, simulated engine failure, off field emergency landing procedures, and low altitude circuit patterns. The results of our in-flight EEG experiment demonstrated that the pilots missed 38% of auditory targets and that these misses, in comparison to hits, were associated with a reduction in phase resetting in alpha and theta band frequencies, as measured by ITC (Callan et al., 2018). These results suggested that the auditory cortex fails to be in phase with the external auditory environment to adequately process the alarms. This finding is consistent with our first fMRI study disclosing that the activation of the attentional bottleneck led to a de-synchronization of the auditory cortex preventing from an accurate processing of the alarms.

These three experiments represent typical illustrations of the neuroergonomics approach from basic experiments conducted with high definition measurement tools in the lab to the measurement of cognition in realistic settings. First, this approach allows one to confirm the consistency of the measurement collected through different devices and settings: Early gating mechanisms are taking place in the auditory cortex and impair the processing of auditory alarms. These findings provide new insight on auditory alarms misperception that is usually not attributed to attentional limitations, but rather due to decision biases according the human factors literature (see Dehais et al..2014). Secondly, this three-step methodology provided complementary findings on the temporal dynamics, the brain areas as well as the mechanisms underpinning the interactions between these cortical regions responsible for auditory alarm misperception.

Decision making aspect of flying

Decision-making has always been a fundamental aspect of flying and navigation. Once take-off has been accomplished, the aviator is sometimes confronted by the explore/exploit dilemma: that is should I go-on with my plan or should I divert. Unfortunately, several safety analyses and experiments conducted in the simulator have found evidence of situations in which pilots are unable to adapt to environmental changes and press on into deteriorating conditions (Dehais et al., 2003). An area of ongoing research is concerned with addressing pilots' tendency to try to reach the final destination at all costs despite evidence that this goal is not relevant anymore (Orasanu et al., 2001). A study conducted by Rhoda and Pawlak (1999) demonstrated that in 2000 cases of approaches under thunderstorm conditions, two aircrews out of three kept trying to land especially if their flight had been delayed, they were in sequence behind another airplane, or if it was a night flight. A first attempt to understand this phenomenon is to consider commitment escalation (Staw, 1981). This theory stipulates that the higher and longer is the level of commitment to achieve an important goal, the harder it is to drop this goal even if it is not relevant anymore. O'Hare and Smitheram (1995) have observed that the probability for a pilot to continue visual flight rules into dangerous weather grows as the pilot gets closer to the final destination.

A complementary explanation to commitment escalation resides in the large range of aversive consequences associated with the decision to abort a goal. This framework has been particularly applied to the aviation domain to understand why pilots persist in erroneous landing instead of going-around or diverting. O'Hare and Smitheram, (1995) hypothesized that the frame in which human operators make their decisions shifts from gains to losses as goal achievement gets closer, resulting in increased risk taking. Indeed, prospect theory (Kahneman & Tversky, 1979) postulates that people become less risk aversive (in other words, take more risk) when decisions are framed in terms of potential loss. For instance, a go-around has a cognitive cost as it may lead to great difficulties in reinserting the aircraft back in the traffic pattern. It also increases uncertainty as pilots rarely perform this maneuver during their operational career (Bureau Enquêtes et Analyses, 2013). All these emotional pressures could alter the rational reasoning by shifting decision-making constraints from safety rules to economic ones.

To investigate this issue, Causse et al. (2013) used a simplified, but plausible, landing task based on a standard cockpit instrument landing system, to estimate changes in brain activity related either to the type of incentive (neutral or financial) or the level of uncertainty (low or high as manipulated by the degree of flight path deviation). A payoff matrix was designed to reproduce the negative consequences linked with the decision to go-around in a manner efficient enough to provoke risky behavior. Combined with behavioral outcomes, the neuroimaging results revealed a shift from rational to erroneous decision making in response to uncertainty when financial incentive was present. Whereas a large network of prefrontal regions (responsible for rational decision-making) was observed in response to increased uncertainty, a different collection of brain regions, not including these frontal regions, was found when biased financial incentive was combined with uncertainty. Participants with poor decision-making performance who adopted more risky behavior demonstrated lower activity in the right dorsolateral prefrontal cortex. This interesting outcome demonstrated that reward and uncertainty can temporarily jeopardize rational decision-making supported by a specific cerebral network during complex and ecologically valid tasks. This approach provides neurocognitive correspondence on erroneous decision-making made by pilots.

Emerging Technological Solutions

Another important facet of neuroergonomics is to design technical solutions to improve human system interactions in complex real-life situations. Neuroadaptive automation that uses operator mental states and assessment of the situation of the vehicle can be utilized to enhance overall system performance by means of a real-time adaptable interface (Fig. 6.2 adapted from figure 4.3 in Vidulich, 2004). The goal of neuroadaptive automation is to enhance overall system performance by facilitating human actions and decisions through the use of artificial intelligence and adaptation algorithms that drive a real-time adaptable interface. Through the use of 'Big Data' artificial intelligence is able to utilize the dynamic actions of the pilot in relation to the state of the vehicle in the environment to assess the situation (Situation Assessor). Machine learning and artificial neural networks (Adaptive

Algorithms) are used to decode mental states in relation to the ongoing situation to predict operator action and activate appropriate response through automation (Real-Time Adaptable Interface and/or override control if necessary). The situational awareness of the pilot can be predicted by assessing the perceptual, attentional, and memory states of the pilot in relation to the situation assessor. Feed-forward prediction of the pilot can also be estimated by looking at the response to direct feedback and the real-time adaptable interface that can act as an error signal. The performance of the pilot is facilitated by optimally delivering only the most relevant information via the real-time adaptable interface based on the situational awareness and mental state of the pilot given the task at hand. System performance can also be enhanced by augmenting such things as response speed by initiating control of the vehicle based on the motor intention of the operator (see Callan et al. 2016a discussed above). Additionally, brain stimulation methods can be utilized to facilitate operator performance and training. Two major components of the proposed neuroadaptive automation system are brain computer interface (BCI) technology and brain stimulation methods that are discussed more extensively below.

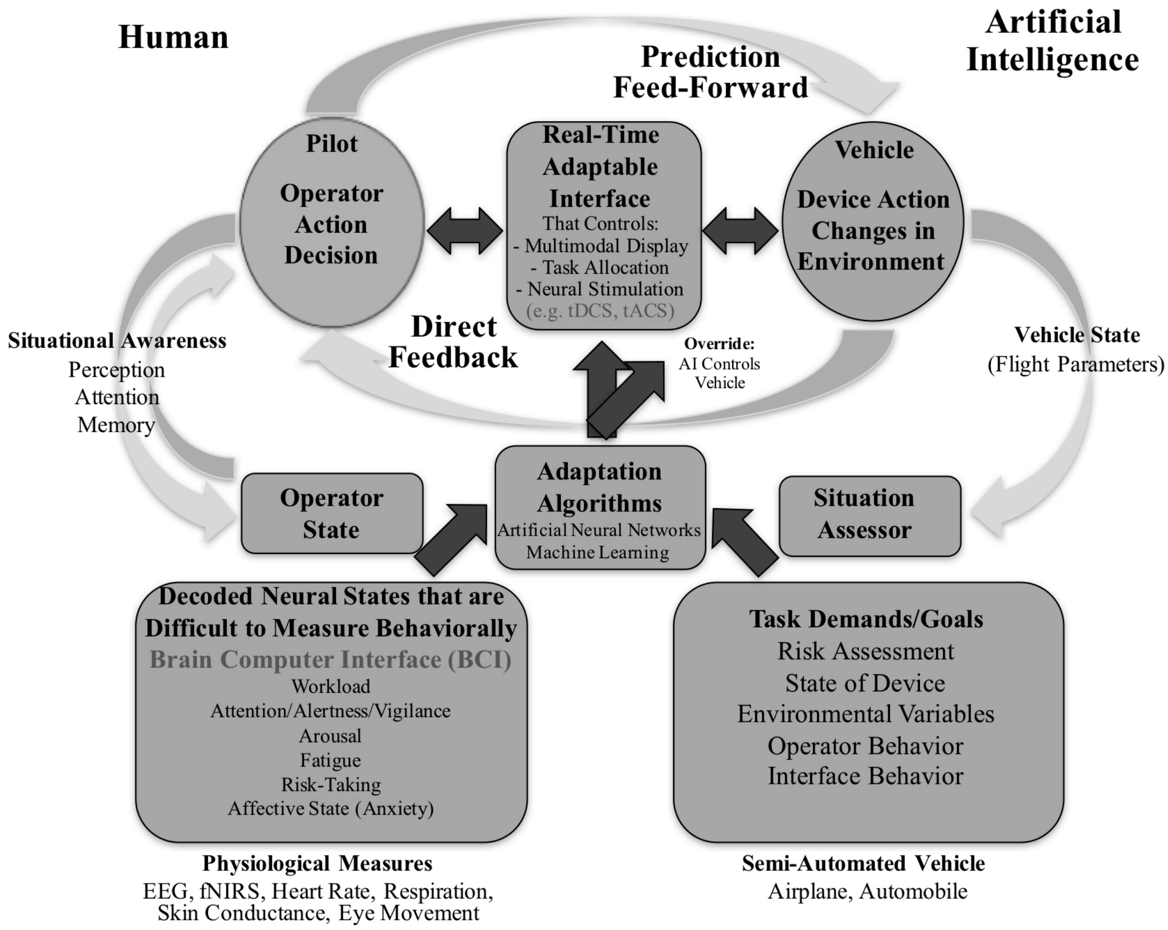

Figure 6.2: Neuroadaptive Automation Based on Integrating Decoded Operator Neural States in Relation to Situation Assessment.

BCI could be classified as active or passive and there are three major areas of research: (1) inferring neural correlates of mental workload, (2) target specific motor, perceptual, attentional or decisional processes to predict performance, and (3) developing effective trigger algorithms. An exciting field of research is related to the implementation of “active” and “passive” BCI based on the real-time processing of the neurophysiological and physiological signals. “Active” BCI allows a user to control artifacts with one’s brain wave without requiring any physical actions on the user interface. Despite initial spectacular promises, the use of such BCI is still limited to the control of a few actuators. This seriously limits its use for controlling aircrafts (Fricke, Paixão, Loureiro, Costa, & Holzapfel, 2015). Moreover, it requires a lengthy procedure to train the user to focus on controlling his brain waves. The attention required to control these brain waves leaving few cognitive resources to monitor or interact with other relevant systems (Lotte, Larrue, & Mühl, 2013). In contrast, "Passive" BCIs – or neuroadaptive technologies - are not meant to directly control a device (e.g. a mouse) via brain activity but to support "implicit interaction" (Zander, Kothe, Jatzev, & Gaertner, 2010). Research on "passive" BCIs provides interesting insight as its goal is to derive the human operator's cognitive state, such as low vigilance state, or high mental workload, and then adapt the nature of the interactions to overcome cognitive bottlenecks (Roy, Bonnet, Charbonnier, & Campagne, 2013, Roy, Bonnet Charbonnier, & Campagne, 2016).

The design of neuroadaptive user interfaces (see Fig. 6.2) represents a growing field of research for human-system interactions (Roy & Frey, 2016). One area of research has been to infer the neural correlates of mental workload with portable brain imaging techniques such as EEG and fNIRS. An extensive review in the field of workload in aviation has shown that an increase in mental workload is associated with an increase in EEG power in the theta band (4-8Hz) and a decrease in alpha-band power (8-15Hz) and that the transition from high mental workload to mental fatigue is characterized by increased EEG power in theta as well as delta (<4Hz) and alpha bands (Borghini, Astolfi, Vecchiato, Mattia, & Babiloni, 2014). Changes in oxygenated hemoglobin concentration in the prefrontal cortex is also known to be a relevant predictor of a pilot's mental workload variation (Ayaz et al., 2012; G. Durantin, Gagnon, Tremblay, & Dehais, 2014; Gautier Durantin, Scannella, Gateau, Delorme, & Dehais, 2015). Based on this latter assumption, a prefrontal fNIRS-based passive BCI was implemented in a motion flight simulator to detect two levels of mental workload. During the experiment, the pilots were tasked to read back air traffic control instructions of two levels of difficulty (eg. "Speed 150, Heading 150, Altitude 1500, Vertical Speed +1500" vs. "Speed 238, Heading 155, Altitude 2300, Vertica Speed +1800") while supervising the flight. A classifier was trained to perform on–line single trial working memory loads classification with 80% of accuracy (Gateau et al., 2015). Interestingly enough, when this protocol was adapted to be performed in real flight conditions with a light aircraft (Gateau, Ayaz, & Dehais, in Revision), classification accuracy up to 78% was obtained, thus demonstrating the feasibility of monitoring cognition in extreme and complex real-life situation with fNIRS.

In addition, the use of connectivity metrics – that is the analysis of the co-activation of long-range neural networks – appears to be particularly suited to assess the dynamics of cerebral activity. Such an approach was initially used in motion based flight simulators (Astolfi et al., 2012) and more recently connectivity metrics were successfully used to discriminate different level of engagement during automated and manual landing (Verdière, Roy & Dehais, 2018).

Another area of research is to measure and target specific motor, perceptual, attentional or decisional processes to predict performance. For instance, EEG has been used successfully to detect the onset of pilot-induced oscillations with 79% accuracy in actual flight conditions (Scholl et al., 2016). Utilizing artifact cleaning (Automatic Subspace Reconstruction; Mullen et al., 2013) and removal (Independent Component Analysis) techniques it was possible to train a classifier to detect the presence or absence of an audio stimulus with around 79.2% accuracy even in an open cockpit biplane in-flight with considerable vibration, wind, acoustic noise, and physiological artifacts (Callan, Durantin, & Terzibas, 2015). Such technical advances pave the way to implement passive BCI to detect auditory alarm misperception in the cockpit.

The identification of degraded cognitive states remains challenging but one other important step is to dynamically trigger adequate solutions to improve flight performance. One first category of solutions consists of designing new alerting systems for more efficient interaction (Causse, Phan, Ségonzac, & Dehais, 2012). For instance, it has been shown that switching off the displays for a very short period is an effective way to mitigate attentional tunneling (Dehais, Causse, & Tremblay, 2011; Dehais, Tessier, Christophe, & Reuzeau, 2010). A second type of solutions resides on reallocating tasks between the human and automated systems based on neurophysiological index. This concept known as "adaptive automation" aims at automatically share tasks between human and automation to maintain a constant, acceptable and stimulating task load to the pilot. The hyperscanning of two pilots – that is the simultaneous neurophysiological measures of the crew - could enable extension of this concept to the optimal distribution of workload (Astolfi et al., 2012).

Another form of neuro-based technology that can be used to enhance performance and facilitate training of real-world tasks are brain stimulation methods. Transcranial direct current stimulation (tDCS) involves the application of low intensity electric current through the scalp to underlying brain tissue. Several studies have shown that tDCS can improve performance and learning on perceptual, motor, and cognitive tasks (Brunoni & Vanderhasselt, 2014; Coffman, et al., 2014; Jacobson et al., 2012; Parasuraman & Galster, 2013). This improvement in performance and learning is thought to be mediated by enhancing cortical excitability leading to long-term-potentiation/depression (Coffman et al., 2014; Nitsche & Paulus, 2000). Enhancement of human abilities by tDCS has been demonstrated in neuroergonomic context (Parasuraman and Mckinley, 2014). Simultaneous fMRI and tDCS on an aviation related visual search task (Callan et al., 2016b) was used to further investigate the neural processes underlying task related modulation of resting state brain activity resulting from tDCS. It was found that the degree of functional connectivity from the site of stimulation in the precuneus to the substantia nigra predicts future enhancement in visual performance induced by tDCS (Callan, Falcone, Wada, Parasuraman, 2016). The substantia nigra is part of the dopaminergic system and is involved with value dependent learning. These individual differences in the improvement in performance as a result of training were only found for the active tDCS group and not for the sham tDCS group. These results show that there are individual differences in the extent to which tDCS enhances plasticity in task related neural networks leading to improved performance. This suggests that one could use the knowledge of relative connectivity strength in these networks to optimize individuals training time and future performance. The use of tDCS as well as other brain stimulation methods such as transcranial alternating current stimulation (tACS) and temporal interference noninvasive deep brain stimulation (Grossman et al., 2017), can be enhanced by utilizing high-density electrode configurations that are able to more focally stimulate specific cortical and subcortical regions in multiple areas of the brain simultaneously. These methods will allow for considerable advancement in neuroergonomic applications used to facilitate performance and training in real-world situations.

Conclusion

This chapter proposed a first overview of neuroergonomic research in aviation and its potential benefits for flight safety. Our motivation was to demonstrate the potential of measuring the neural mechanisms underpinning motor, perceptual/attentional and decisional aspects of flying. This review revealed the subtle dynamic of brain activity when facing complex real-life operational situations. Moreover, neuroergonomics studies demonstrate, that fNIRS and EEG can be effectively used in the noisy environment of a flight simulator and more importantly, even in the noisy environment of an airplane by using various signal processing techniques. Thus, bringing us closer to the realization of neuroergonomics based technology in the cockpit to promote performance, safety, efficiency, and wellbeing of the pilots, crew, and passengers. Indeed, using this information it may be possible to develop neuroadaptive cockpits (Fig. 6.2) to reduce workload and to facilitate the processing of critical information. We therefore strongly believe that this approach can be beneficial not only for basic neuroscientists concerned with the understanding of the brain functioning but also for Human Factors researchers and practitioner.

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