EEG-engagement index and auditory alarm misperception: an inattentional deafness study in actual flight condition

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Abstract. The inability to detect auditory alarms is a critical issue in many domains such as aviation. An interesting prospect for flight safety is to understand the neural mechanisms underpinning auditory alarm misperception under actual flight condition. We conducted an experiment in which four pilots were to respond by button press when they heard an auditory alarm. The 64 channel Cognionics dry-wireless EEG system was used to measure brain activity in a 4 seat light aircraft. An instructor was present on all flights and in charge of initiating the various scenarios to induce two levels of task engagement (simple navigation task vs. complex maneuvering task). Our experiment revealed that inattentional deafness to single auditory alarms could take place as the pilots missed a mean number of 12.5 alarms occurring mostly during the complex maneuvering condition, when the EEG engagement index was high.

Keywords: Inattentional deafness, Auditory alarm misperception, EEG engagement index, Real flight conditions

1 Introduction

Neuroergonomics is an exciting field of research that has gained momentum over the last decade. It promotes multidisciplinarity and the implementation of brain imaging devices to understand cognitive functioning in complex real-life situations [1]. Neuroergonomics opens promising perspectives for applied disciplines such as Human Factors and Ergonomics. Generally, these latter emphasize behavioral and subjective approaches to address human performance issues. Whereas the scientific contribution of these disciplines is of great importance, they may appear limited to provide explanations for more complex phenomena that require the investigation of the cerebral activity. This is the case for auditory alarm misperception that has been shown to be involved in several aircraft accidents [2, 3]. Indeed, the dominant theory to account for this phenomenon is that pilots consciously choose to ignore these warnings due to cognitive biases [4] or poor design issues [5, 6]. Without denying the importance of these findings, recent Neuroscientific studies have postulated alternative perceptual and attentional explanations, known as the inattentional deafness hypothesis. There is a corpus of evidences that unexpected sounds may fail to reach awareness when highly engaged in visual tasks [7–9]. In these contexts, the visual modality may take over hearing via gating mechanisms at the visuo-auditory integrative [7, 10, 11] or higher levels [12].

Since flying is an activity that mainly solicits visual processing, inattentional deafness is more likely to take place in the cockpit, thus leading to auditory alarm neglect. Some experiments conducted in flight simulators have shown the existence of this phenomenon during the landing phase [3, 13, 14]. More recently, an electroencephalography (EEG) study involving a critical scenario in a flight simulator (i.e. approach with burning engine and smoke in the cabin) yielded a high rate of auditory alarm misperception. The EEG analyses revealed that misses were associated with lower N100 and P300 amplitude than hits [15], confirming the existence of an early and unconscious gating mechanisms. Interestingly enough, an EEG experiment conducted under real flight conditions disclosed that a reduction in phase resetting in alpha and theta band frequencies was a neural signature of inattentional deafness [16]. These studies demonstrate the importance of adopting a Neuroergonomics approach to underpin the neural mechanisms at the core of human performance and erroneous behavior.

There is still the need to understand the causal factors that promotes the occurrence of inattentional deafness. Excessive cognitive workload and limited resources theories are generally thought to be the main cause of such auditory attention impairment [4, 9]. However, cognitive workload should not be viewed as the resultant of an external demand applied on an individual passively adapting to it, but rather as an active process that depends on the human operator's level of engagement. Thus, the allocation of cognitive resources has to be considered as the product of the level of task demand by the level of task engagement. We state that level of engagement mainly depends on task utility/reward, associated risk and time on task (i.e. sunk cost effect - see [17, 18]). This explains why auditory misperception is more likely to occur during the landing (i.e. final destination) even during visual flight rules conditions [19, 20].

In the present study, we intend to investigate auditory misperception with EEG in more ecological settings than previous research [15, 19–21]. The main objective was to show that inattentional deafness could take place in the cockpit, especially during high level of engagement episodes. We manipulated the flying task to induce two levels of engagement. Additionally, we computed an EEG index defined by [22] to verify that our conditions were effectively leading to different levels of task engagement [22–24]. Eventually, an additional motivation was to show the feasibility of extracting this index with a dry electrodes system under ecological settings.

2 Material and Method

2.1 Participants

Four healthy male pilots (97.5 mean flight hours), participated in the study after they gave their informed written consent. All reported normal auditory acuity and normal or corrected-to-normal vision. The experimental protocol was approved by the European Aviation Safety Agency (EASA permit to fly approval number: 60049235).

2.2 Experimental scenario

The experiment was conducted at Lasbordes airfield (Toulouse, France) in which the pilots were to respond by button press when they heard an auditory alarm (chirp sound). Two hundred and thirty stimuli were presented every 10 to 15 seconds. The experiment lasted approximately 1 hour (i.e. from take-off to final taxiing). During the experiment, an instructor manipulated two levels of task engagement. The low task engagement condition involved simple navigation above 1700 feet and the high task engagement condition involved several complex maneuvering exercises such as simulated engine failure, off field emergency landing procedures, and low altitude circuit patterns. There were an equal number of auditory alarms between the two conditions.

2.3 Aircraft

The ISAE-SUPAERO DR400 light aircraft was used for the purpose of the experiment (Fig. 1). It was powered by a 180HP Lycoming engine and was equipped with classical gauges, radio and radio navigation equipment, and actuators such as rudder, stick, thrust and switches to control the flight. The participant was placed on the left seat and was equipped with the EEG dry electrode system. A switch button was attached to the stick to collect pilots' response. The participants wore a Clarity Aloft headset that was used to trigger auditory stimuli from a PC via an audio cable. The participant could still communicate with the other crew members, air traffic controllers when he received auditory alarm. The safety pilot was an ISAE-SUPAERO flight instructor. He was right seated and had the authority to stopping the experiment and taking over the control of the aircraft for any safety reason. The backseater was the experimenter: his role was to set the sensor, to trigger the experimental scenario and to supervise data collection.

Fig. 1: Left: a participant equipped with the 64-chanel Cognionics dry electrodes system. The aircraft was a Robin DR400. Right: the response button attached to the stick.

2.4 Neurophysiological measurements and analyses

The 64 channel Cognionics dry-wireless EEG system was used to measure brain activity. EEGLAB was used for analysis of the EEG data for each pilot. The continuous EEG data was filtered between 1-30Hz, underwent automatic channel rejection, and was cleaned using automatic subspace reconstruction. For each condition, we computed the following EEG engagement index [22, 25]: average power in beta [13 30 Hz] / (average power in alpha [8 12 Hz] + average power in theta [4 8 Hz]) .

3 Results

3.1 Behavioral results

Our experiment revealed that inattentional deafness to auditory alarm could take place as the pilots missed a mean number of 12.5 alarms (SD=5.6) with 71,2% of them (SD=11%) occurring during the high engagement flying condition.

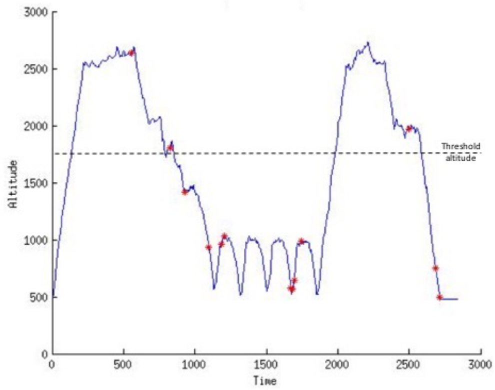

Fig. 2: Altitude in function of time. Red stars indicate misses. The threshold altitude was set at 1700 feet (dashed black line). Note that this latter participant missed 9 alarms out of 12 below this threshold (i.e. in the high task engagement condition)

3.2 EEG results

As illustrated by Fig. 3 for two participants, the computed EEG engagement index appeared to be related to this phenomenon, as its mean was higher during the high engagement condition (Fronto-central area: 0.48, SD=0.07; Parietal area: 0,46, SD=) than during the low engagement condition (Fronto-central area: 0.44, SD=0.03; Parietal area: 0.51, SD=0.12). Please report to Tab.1 for more details.

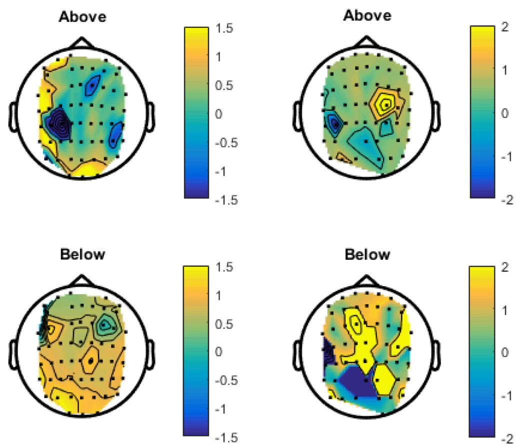

Fig. 3: Fontro-central region of interest: engagement ratio power spectral results for 2 participants above (i.e. low engagement condition) and below (i.e. high engagement condition) the altitude threshold.

Fronto-central		Parietal	
above	below	above	below
0,44	0,58	0,50	0,64
0,42	0,47	0,51	0,58
0,48	0,50	0,42	0,43
0,42	0,39	0,41	0,38

Tab. 1: EEG engagement index for all the participants in the fronto-central and parietal regions of interest above and below the altitude threshold.

4 Discussion

The objective of this study was two-fold: first, we wanted to show that auditory alarm misperception could occur under engaging flying conditions. Second, we aimed at measuring the neural correlates of this phenomenon. This was challenging as we collected data in highly ecological conditions with a dry electrodes device. To meet this goal, we designed a scenario involving two levels of task engagement (simple navigation task vs. complex maneuvering task) with four participants in an actual light aircraft.

Consistent with previous findings [16], our experiment showed that inattentional deafness to auditory alarms could take place in an actual cockpit. This is an important step as most of the studies that demonstrated the occurrence of this phenomenon were conducted in simulated conditions [19–21]. The four participants missed a mean number of 12.5 alarms which is important considering that any absence of response to such stimuli could jeopardize flight safety as revealed by aviation accidents [2, 26]. As expected, our behavioral results disclosed that the occurrence of auditory misses was higher in the high task engagement conditions when pilots faced complex and unexpected situations such as engine-off emergency landings. These complex engaging situations are known to increase pilots' visual load as they have to carefully scan several flight parameters, perform quick actions while controlling the trajectory, and finding a grass airfield or safe fields in the country side to land. On the other hand, the simple navigation task consisted of following predefined routes at higher altitude with no time pressure. These results confirmed basic studies revealing that auditory sounds could go unnoticed when visual load is high [7–9].

Our EEG analyses support the hypothesis that inattentional deafness occurs more often during high piloting task engagement. We computed an index using the average power in the beta (13–30 Hz), alpha (8–12 Hz) and theta (4–8 Hz) bandwidths that has been shown to be related to task engagement [22–25]. This index increased in the difficult flying condition that led to higher miss rate. This suggests that the pilots were particularly mentally engaged when performing the most critical landing maneuvers. Indeed, the utility/reward of these goals were high for the pilots that were particularly committed to achieve them. The miss rate and the few number or participants did not allow us to perform event related potential or inter-trial coherency analyses as respectively achieved by [21] and [16]. However, our findings do bring complementary explanations and provide additional metrics to understand the phenomenon of inattentional deafness to auditory alarms. This study shows together with others [16, 27] that dry EEG electrode systems can be implemented in actual cockpits. It paves the way to the on-line monitoring of pilot's attentional state and cockpit adaptation for safer operation. This is of key importance as transportation aircraft manufacturers are currently developing the concept of single pilot operation. As the pilot would be alone in the cockpit, task demand and level of task engagement would be higher and he/she could not rely on a second pilot to assist him/her to detect alarms. Additional perspectives would be to test different designs in real flight conditions such as spatialized warnings that have been shown to be more efficient to capture attention [28], and further to implement an online estimation of the cerebral features associated with their processing with robust methods such as detailed in [29].

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References

1. Parasuraman, R., Rizzo, M.: Neuroergonomics: The brain at work. Oxford University Press, USA (2007).
2. Bliss, J.P.: Investigation of alarm-related accidents and incidents in aviation. Int. J. Aviat. Psychol. 13, 249–268 (2003).
3. Dehais, F., Tessier, C., Christophe, L., Reuzeau, F.: The perseveration syndrome in the pilotís activity: guidelines and cognitive countermeasures. Hum. Error Saf. Syst. Dev. 68–80 (2010).
4. Bliss, J.P., Dunn, M.C.: Behavioural implications of alarm mistrust as a function of task workload. Ergonomics. 43, 1283–1300 (2000).
5. Peryer, G., Noyes, J., Pleydell-Pearce, K., Lieven, N.: Auditory alert characteristics: a survey of pilot views. Int. J. Aviat. Psychol. 15, 233–250 (2005).
6. Hasanain, B., Boyd, A.D., Edworthy, J., Bolton, M.L.: A formal approach to discovering simultaneous additive masking between auditory medical alarms. Appl. Ergon. 58, 500–514 (2017).
7. Molloy, K., Griffiths, T.D., Chait, M., Lavie, N.: Inattentional deafness: visual load leads to time-specific suppression of auditory evoked responses. J. Neurosci. 35, 16046–16054 (2015).
8. Macdonald, J.S., Lavie, N.: Visual perceptual load induces inattentional deafness. Atten. Percept. Psychophys. 73, 1780–1789 (2011).
9. Raveh, D., Lavie, N.: Load-induced inattentional deafness. Atten. Percept. Psychophys. 77, 483–492 (2015).
10. Lebib, R., Papo, D., de Bode, S., Baudonnière, P.-M.: Evidence of a visual-to-auditory cross-modal sensory gating phenomenon as reflected by the human P50 event-related brain potential modulation. Neurosci. Lett. 341, 185–188 (2003).
11. Scannella, S., Causse, M., Chauveau, N., Pastor, J., Dehais, F.: Effects of the audiovisual conflict on auditory early processes. Int. J. Psychophysiol. 89, 115–122 (2013).

12. Callan, D.E., Dehais, F., Gonthier, N., Durantin, G.: Inattentional Deafness is Signified by Activity in Brain Regions Involved with Attentional Bottleneck. Presented at the SFN'16 , San Diego (2016).
13. Dehais, F., Causse, M., Vachon, F., Régis, N., Menant, E., Tremblay, S.: Failure to Detect Critical Auditory Alerts in the Cockpit Evidence for Inattentional Deafness. Hum. Factors J. Hum. Factors Ergon. Soc. 56, 631–644 (2014).
14. Dehais, F., Causse, M., Vachon, F., Regis, N., Menant, E., Tremblay, S.: Inattentional Deafness to auditory alarms in aviation: A safety issue. Hum. Factors J. Hum. Factors Ergon. Soc. (Submitted).
15. Scannella, S., Roy, R.N., Laouar, A., Dehais, F.: Auditory neglect in the cockpit: using ERPS to disentangle early from late processes in the inattentional deafness phenomenon. Presented at the Neuroergonomics'16 , Paris (2016).
16. Callan, D.E., Gateau, T., Gonthier, N., Dehais, F.: Neural signatures of inattentional deafness in airplane pilots recorded in real flight with dry-wireless EEG. Presented at the Neuroergonomics'16 , Paris (2016).
17. Causse, M., Péran, P., Dehais, F., Caravasso, C., Zeffiro, T., Sabatini, U., Pastor, J.: Affective decision making under uncertainty during a plausible aviation task: an fMRI study. NeuroImage. (2013).
18. Causse, M., Dehais, F., Péran, P., Sabatini, U., Pastor, J.: The effects of emotion on pilot decision-making: A neuroergonomic approach to aviation safety. Transp. Res. Part C Emerg. Technol. (2012).
19. Dehais, F., Causse, M., Régis, N., Menant, E., Labedan, P., Vachon, F., Tremblay, S.: Missing Critical Auditory Alarms in Aeronautics: Evidence for Inattentional Deafness? Presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting (2012).
20. Dehais, F., Causse, M., Vachon, F., Régis, N., Menant, E., Tremblay, S.: Failure to Detect Critical Auditory Alerts in the Cockpit Evidence for Inattentional Deafness. Hum. Factors J. Hum. Factors Ergon. Soc. (2013).
21. Dehais, F., Roy, R.N., Gateau, T., Scannella, S.: Auditory Alarm Misperception in the Cockpit: An EEG Study of Inattentional Deafness. In: International Conference on Augmented Cognition. pp. 177–187. Springer (2016).
22. Prinzel, L.J., Freeman, F.G., Scerbo, M.W., Mikulka, P.J., Pope, A.T.: A closed-loop system for examining psychophysiological measures for adaptive task allocation. Int. J. Aviat. Psychol. 10, 393–410 (2000).
23. Chaouachi, M., Chalfoun, P., Jraidi, I., Frasson, C.: Affect and mental engagement: towards adaptability for intelligent systems. In: Proceedings of the 23rd International FLAIRS Conference. AAAI Press (2010).
24. Freeman, F.G., Mikulka, P.J., Prinzel, L.J., Scerbo, M.W.: Evaluation of an adaptive automation system using three EEG indices with a visual tracking task. Biol. Psychol. 50, 61–76 (1999).
25. Poussot, C., Roy, R.N., Bovo, A., Gateau, T., Dehais, F., Carvalho, C.: A Loewner-based Approach for the Approximation of Engagement-related Neurophysiological Features. Presented at the Submitted to IFAC , Toulouse (2017).
26. Dehais, F., Tessier, C., Chaudron, L.: GHOST: experimenting conflicts countermeasures in the pilot's activity. Proc. Int. Jt. Conf. Artif. Intell. IJCAI. 18, 163–168 (2003).
27. Callan, D., Durantin, G., Terzibas, C.: Classification of Single-Trial Auditory Events Using Dry-Wireless EEG During Real and Motion Simulated Flight. Front. Syst. Neurosci. 9, 11 (2015).
28. Andéol, G., Suied, C., Scannella, S., Dehais, F.: The Spatial Release of Cognitive Load in Cocktail Party Is Determined by the Relative Levels of the Talkers. J. Assoc. Res. Otolaryngol. 1–8 (2017).
29. Roy, R.N., Charbonnier, S., Campagne, A., Bonnet, S.: Efficient mental workload estimation using task-independent EEG features. J. Neural Eng. 13, 026019 (2016).