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Review

Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness

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ABSTRACT

This paper reviews published papers related to neurophysiological measurements (electroencephalography: EEG, electrooculography EOG; heart rate: HR) in pilots/drivers during their driving tasks. The aim is to summarise the main neurophysiological findings related to the measurements of pilot/driver's brain activity during drive performance and how particular aspects of this brain activity could be connected with the important concepts of "mental workload", "mental fatigue" or "situational awareness". Review of the literature suggests that exists a coherent sequence of changes for EEG, EOG and HR variables during the transition from normal drive, high mental workload and eventually mental fatigue and drowsiness. In particular, increased EEG power in theta band and a decrease in alpha band occurred in high mental workload. Successively, increased EEG power in theta as well as delta and alpha bands characterise the transition between mental workload and mental fatigue. Drowsiness is also characterised by increased blink rate and decreased HR values. The detection of such mental states is actually performed "offline" with accuracy around 90% but not online. A discussion on the possible future applications of findings provided by these neurophysiological measurements in order to improve the safety of the vehicles will be also presented.

Contents

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1. Introduction

It is well-known that driving a car (and to a major extent, an aircraft) requires substantial cognitive effort and attention from the operator's brain. According to the World Health Organisation (WHO) the primary cause of death in adults from 18 to 29 years old, and the ninth cause of human death globally, is represented by car accidents (Preventing Road Traffic Injury: A Public Health Perspective For Europe, 2009). These facts might indicate that the brain's capacities of attention, memory and awareness are often overestimated when we choose to drive a car. In fact, all individuals make mistakes, even when performing common everyday tasks. It is easy to quickly adapt strategies to avoid repeating errors, and this is called a learning process. When it comes to interactions with complex environments like those constituted, for instance, by thousands of vehicles moving in a chaotic traffic day, in a great city like Beijing or Paris, it is much harder to isolate and understand the problem quickly. In these situations, a driver could be involved in a crash, even without being responsible for the error. Depending on the different conditions in which the subject acts, errors can have a significant impact on the success of the performance or even on the safety of the human subject.

Hence, variables, such as situation awareness (SA), mental workload and fatigue, are important in the assessment of safety conditions.

Aircraft pilots have to operate more complex vehicles, and therefore go through a strict training programme before getting their flying license. Modern glass cockpits look tidy from the outside and are designed to be as intuitive as possible, but a complex system is functioning behind the scenes. As a result, it becomes increasingly challenging for pilots to fully and continuously manage the display systems of the new models of modern aircrafts, such in the evolution occurred from the MD-80 to the Airbus 330 cockpit. A proper understanding of the relevant information among the many presented on the cockpit is crucial for the pilot in emergency situations in which the time available for understanding the problem could be very short. Fortunately, both situations are rarely encountered in actual flights due to the excellent reliability of aircraft and on board systems. However, when they do occur, the pilot's mental state – a construct including SA, mental workload and fatigue – plays a crucial role in solving the problems.

Unfortunately, safety statistics show that inadequate SA has contributed to a significant number of accidents. Worldwide data shows that, in the period 1993–2007, 46% of the contributing factors that led to fatal accidents were cockpit crew related (CAANL, 2008). Also, the latest data published by Boeing (2011) shows that the in-flight loss of control and controlled flight towards the terrain caused the majority of fatalities in worldwide commercial jet accidents in the period 2001–2010. Pilots are normally trained to deal with system failures and emergency cases that were foreseen in the aircraft development phase. Also, modern aircrafts provide electronic guidance for the completion of mitigating procedures. Nevertheless, situations exist that require alertness from the pilot for noticing issues as well as clear judgement for tackling them. An example is provided by the crash of the Turkish Airlines Flight TK1951 during its landing in Amsterdam Schiphol Airport, The Netherlands, on 25 February 2009 (Dutch Safety Board, 2010). In this accident, nine people in the aircraft died, including the three pilots. The aircraft, a Boeing 737-800 with a glass cockpit, was damaged beyond repair. In the investigation that followed the accident, it was found that the crash was caused primarily by an automatic reaction of the aircraft in response to a faulty radio altimeter. In a situation with a higher workload than normal, the crew did not realise that the fault caused the auto throttle to reduce to idle power during the approach. Eventually, they were unable to successfully recover the aircraft from the resultant stall.

As is evident from the quoted accident statistics and illustrated by the above case, the flight crew is still the most commonly contributing factor in fatal accidents worldwide. Also, an ineffective pilot mental state (e.g., peak workload, lack of SA, fatigue) plays a role in the sequence of events leading to many of these accidents. Therefore, the need for a continuously improved understanding of pilot behaviour and how to optimise crew performance is particularly important.

While the concept of mental workload could be investigated with a large amount of different experimental setups, the characterisation of cerebral activity directly during the driving of vehicles or aircrafts in humans is of high interest for the potential translational characteristic of the results. In fact, understanding the cognitive workload of humans during driving tasks could be extremely useful for realising a class of devices in the future that could alert the driver or the pilot about the low level of his/her internal cognitive resources during travel.

These driving tasks could have similar characteristics in terms of the visuomotor and cognitive activities required in the driver/pilot.

It may be argued if the drivers and pilots perform the same tasks in terms of attention and cognitive demands. Of course there are significant differences for all concerns the internal environment (e.g., the cockpit versus the internal seat of the car) and for all concerns the external environment. For all concerns the internal environment, the pilots are requested to have a higher attentional demands due to the complexity of the instrumentation to be mastered along the cruise. Such kind of visual attention requirement is certainly higher than in normal drivers. In fact, the level of instrumentation inside the car is moderate and easy to understand when compared with the sequence of instruments available within the cockpit. In addition, the pilots have surely a higher level of attention request also from the acoustic point of view, due to the frequent radio interaction they have with the air traffic management system on the ground during the entire travel. Except the landing and take-off phase, the visual attention for the external environment is surely reduced in pilots when compared to the normal drivers, since pilots are trained to be more confident on the instruments instructions than on their senses (even visual). From this point of view, normal drivers put more attention to the environment outside the vehicle than the pilots. However, the external environment poses additional request for the mental workload for pilots when compared to the normal drivers, since the influence of weather on