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Mirror neuron based alerts for Control Flight Into Terrain avoidance

Causse, M., Phan, J., Ségonzac, T., Dehais, F.

Institut supérieur de l’aéronautique et de l’espace (ISAE)
Toulouse, France
mickael.causse@isae.fr

ABSTRACT

Controlled flight into terrain (CFIT) accidents occur when an aircraft, under the control of the crew, is flown into terrain (or water) with no prior awareness from the part of the crew of the imminent catastrophe (Wiener, 1977). In commercial aviation, CFIT are among the deadliest accidents but the situation has continuously improved this last decade. In particular, a spectacular fall in the number of fatalities was made possible by the introduction of enhanced ground proximity warning systems (EGPWS). However, CFIT accidents remain the second leading cause of on-board fatalities and several crashes of this category involving airplanes equipped with EGPWS occurred since 2007. The human factor plays a major role in that type of disaster and studies show that visual and auditory alarms are not always taken into account. Yet, when a ‘PULL UP’ alert is triggered, the pilot has only a few seconds to react in order to avoid the impending CFIT. Most of the time, the procedure is quite simple: the pilot must pull full back on the stick and apply maximum thrust to gain altitude. In this study, we introduced a new type of visual alert specifically dedicated to activate the mirror neurons that appear to play a key role in both action understanding and imitation (Rizzolatti, 2004). Such motor neurons are known to fire either when a person acts or when a person observes the same action performed by another one. We hypothesized that an immediate understanding of a required behavior, displayed by a video that shows the appropriate actions to perform, will activate the mirror neurons and provoke an extremely rapid reaction from the pilots to prevent a potential collision. We designed short videos displayed in the primary flight displays in which virtual avatars explicitly performed the actions on the levers and on the stick. Three pilots completed 10 different flight scenarios during the approach phase with a full motion A320 flight simulator. In some of the scenarios, an alarm was triggered just before an imminent collision and the pilots had to immediately perform a go-around. The results showed that the videos with avatars allowed much shorter reaction times than the regular textual ‘PULL UP’ alerts. While the anti-collision maneuver was initiated in 7.60 s (SD = 1.83) with the regular alert, video mean reaction time was 1.27 s (SD = 0.31). This encouraging preliminary outcome opens new perspectives on mirror neuron based human machine interfaces.

Keywords: neuroergonomics, mirror neurons, HMI (human machine interface), CFIT (controlled flight into terrain) avoidance

1 INTRODUCTION

Controlled flight into terrain (CFIT) accidents occur when an aircraft, under the control of the crew, is flown into terrain (or water) with no prior awareness from the part of the crew of the imminent catastrophe (Wiener, 1977). In commercial aviation, CFIT are among the deadliest accidents but the situation has continuously improved this last decade: whereas 2152 people died in CFIT accidents during the 1992-2001 period, this number dropped to 1007 people during the 1999-2010 years (Boeing, 2002; Boeing, 2011). In particular, this spectacular fall in the number of fatalities was made possible by the introduction of ground proximity warning systems (GPWS) and enhanced ground proximity warning systems (EGPWS). These systems not only advice aurally the crew (e.g. repetitive ‘PULL UP’) but they also display a 2D representation of the terrain on a dedicated screen. However, CFIT accidents remain the second leading cause of on-board fatalities and several crashes of this category involving airplanes equipped with EGPWS occurred since 2007, including the Polish president's flight crash. The human factor plays a major role in that type of disaster as accidents analyses reveal that the aircrews do not initiate the go around maneuver because they fail to notice the visual and auditory EGPWS alerts. Yet, when a ‘PULL UP’ alarm is triggered, the pilot has only a few seconds to react in order to avoid the impending CFIT. Most of the time, the procedure is quite simple: the pilot must pull full back on the stick and apply maximum thrust to gain altitude. In the next two sections we examine the stress hypothesis and the more recent inattentional deafness hypothesis to explain such a visual and especially auditory neglect.

1.1 The stress hypothesis

It may appear surprising that visual and especially auditory alerts can be neglected as these types of alarms are known to present various advantages in emergency situations. They inform the pilots without requiring head/gaze movements (Edworthy, Loxley, & Dennis, 1991) and they provoke faster reaction times than visual stimuli (Wheale, 1981) which allow to be more efficient in emergency situations. However, their aggressive, distracting and disturbing nature (Edworthy, et al., 1991) can considerably increase pilot stress level during warning events, what may provoke a decline of flight performance and decision-making relevance. As a matter of fact, the immediate inclination for pilots can be to find a way to silence the noise, rather than analyzing the meaning of the alert (Peryer, 2005). In 1984, a well known accident (Avianca Flight 011, Boeing 747) demonstrated that an excessive number of auditory alerts may lead pilots to neglect GPWS alerts. From a psychophysiological point of view, a high level of stress is known to provoke a temporary disruption of high level cognitive processes (Porcelli, et al., 2008; Scholz, et al., 2009) and a growing neuroimaging literature demonstrates that this decline of intellectual ability under emotional factor is provoked by the deactivation of prefrontal cerebral structures activity (Qin et al., 2009). There is evidence that emotion may affect the attentional network in a way that attention orienting abilities are impaired (Pecher, Quaireau, Lemercier, & Cellier, 2010). Such impairment of selective attention under arousal seems related to a temporary decline of the activity of the locus coeruleus and a triangular circuit of selective attention (Tracy, Mohamed, Faro, Tiver, Pinus, & Bloomer, 2000). Such an impairment induced by arousal could partially explain the inability to detect visual (Dehais, Causse, Tremblay, 2011) and auditory alerts (Dehais, Tessier, Christophe, Reuzeau, 2009).

1.2 The inattentional deafness hypothesis

Tasks involving high perceptual load consume most of attentional capacity, leaving little or none remaining for processing any task-irrelevant information (Lavie, 1995). Indeed, reduced perceptual processing of task irrelevant information in high-load tasks leads to various forms of inattentional blindness (Mack & Rock, 1998). There is a growing body of evidence for a shared attentional capacity between the modalities of vision and hearing (Brand-D'Abrescia & Lavie, 2008; Santangelo, Olivetti Belardinelli, & Spence, 2007; Sinnett, Costa, & Soto-Faraco, 2006). Given the hypothesized shared attentional capacity between vision and hearing, an engagement in a visual task of high perceptual load is likely to produce a decline of the probability to process a concurrent auditory stimulus. This failure of an auditory stimulus to reache awareness has been recently named inattentional deafness (Koreimann, Strau, & Vitouch, 2009; Macdonald & Lavie). Macdonald & Lavie (2009) showed that up to 79% of participants engaged in a task under high visual load conditions failed to notice a task-irrelevant sound played through headphones. Whereas there are many situations in everyday life in which such phenomenon may be of low importance (eg. the failure to hear someone speaking while engaged in a computer task), inattentional deafness may have important implications with regards to safety, for instance in aviation. Indeed, inattentional deafness may be an additional potential contributive factor to the alarm neglect phenomenon. Numerous displays in modern cockpits are likely to produce this phenomenon and may provoke inattentional deafness, leading pilot to purely fail to notice yet critical alarms.

1.3 Exploiting mirror neuron property to cure alarm negligence

In this study, we introduced a new type of visual alert—which do not require semantic decoding of complex verbal information and do not introduce additional auditory alarm—specifically dedicated to activate the mirror neurons that appear to play a key role in both action understanding and imitation (Rizzolatti, 2004). Such motor neurons are known to fire either when a person acts or when a person observes the same action performed by another one. This type of alert can be a good candidate to inform the pilot of the action to perform, even if this latter is subjected to inattentional deafness or a high deleterious stress. Historically discovered in the rostral part of inferior area 6 (area F5) of the monkey (Rizzolatti, et al., 1990), there is growing evidence that these specialized neurons also exist in human (Rizzolatti, 2005). Functional imaging studies revealed activation in lower part of the precentral gyrus and of the pars opercularis of the inferior frontal during observation of actions made by another individual (Buccino, et al., 2001). The opercularis of the inferior frontal gyrus (basically corresponding to Broadman area 44) likely corresponds to the area F5 in monkey (Petrides & Pandya, 1994). The authors hypothesized that these regions support a mirror system dedicated to action observation/execution matching processes. More recently, a fMRI study of Chong et al. (2008) showed that the right inferior parietal lobe responds independently to specific actions regardless of whether they are observed or executed. Furthermore, magnetoencephalography (Hari et al. 1998) and EEG (Cochin et al. 1999) experiments revealed activation of motor cortex during observation of finger movement. More recently, an EEG experiment of Muthukumaraswamy (2004) showed suppression in the 8–13 Hz (mu) frequency band during the passive observation of object grip. Gastaut et al. (1954) showed that, at rest, sensorimotor neurons spontaneously fire in synchrony leading to large amplitude EEG oscillations in the mu frequency band. In addition, Gastaut et al. (1954) reported desynchronization of these rhythms—thereby decreasing the power of the mu-band EEG oscillations—not only when a subject performed an action, but also while the subjects observed an action executed by someone else. According to Muthukumaraswamy (2004), the mu reduction during the observation of an object grip movement indicates the existence of a brain structure that is functionally comparable to the monkey mirror neuron system. The activation of this hypothesized frontal mirror region in the human brain has also been observed using different modalities, for instance during the observation of static pictures (Johnson-Frey, et al., 2003) or robotic actions (Gazzola, Rizzolatti, Wicker, & Keysers, 2007; Oberman, McCleery, Ramachandran, & Pineda, 2007).

We hypothesized that an immediate understanding of a required behavior, displayed by a video that shows the appropriate actions to perform, will activate the mirror neurons and provoke an extremely rapid reaction from the pilots in order to prevent a potential collision. To test our hypothesis, we designed short videos displayed in the primary flight display (PFD) in which virtual avatars explicitly performed the actions on the levers and on the stick.

2 METHODS

2.1 Participants

Three low experienced male pilots rated for visual flight conditions were recruited from the local flying club. Mean flying experience was 53.33 hours (SD = 32.14). All participants were informed about the GPWS and the associated ‘PULL UP’ red textual message displayed in the PFD. Each participant provided written informed consent and received complete information on the study’s goal.

2.2 Flight scenario

All experiments were conducted in a 3 axis motion A320 flight simulator. The flight scenario was designed with flight instructors to reach a satisfying level of difficulty and realism. During the experiment, each pilot completed 10 identical landing scenarios during the approach/landing phases. Landing occurred in bad meteorological condition (strong crosswind, very low visibility and rain) to increase the stress level of the pilots. In addition, in order to increase the attentional load, the pilots had to count the number of occurrence of a red dot appearing on the screen in front of the pilot monitoring (see Figure 1).

Before the experiment, the pilots were informed that they were in charge of all the decisions and that a go-around procedure might be required in some of the scenarii. The flight scenario started at 2500 feet and the pilot were instructed that they had to maintain a 130 knots speed while piloting the aircraft in instrument flight rule condition with the instrument landing system.

Figure 1 View of the cockpit and the various EFIS. Alerts were displayed in the PFD. The red dot was displayed in peripheral vision on the pilot monitoring PFD screen. ND = Navigation Display; ECAM = Electronic Centralized Aircraft Monitor

2.3 Alerts

During landing 3 and 10, an alert was triggered (between 500 and 600 feets) to notify of an imminent collision. In response, the pilots had to perform immediately a go-around maneuver. All participants received one time the two types of alerts (see Figure 2), the classical TAWS (terrain awareness and warning system) 'PULL UP' and the mirror neuron based alert. The order of their occurrence during landing 3 and 10 was randomized across participants.

Classical TAWS 'PULL UP' alert: Similarly to current classical TAWS alert, the 'PULL UP' red text was displayed in the artificial horizon. In current aircrafts, if the barometric sink rate becomes too severe or if the aircraft is threatened by a terrain hazard, the GPWS voice annunciation "Whoop, Whoop, PULL UP" sounds; the master caution/warning lights illuminate, and the message 'PULL UP' is displayed in red on both PFDs. In our experiment, we exactly reproduced this sequence except that the voice annunciation was removed. This allowed us to focus on the visual effects of the alert and to artificially recreate the inattentional deafness phenomenon.

Mirror neuron based alert: the 212*170 pixels videos were displayed below the airspeed instrument to keep the t-basic visible (airspeed, altimeter, artificial horizon). In addition, as the airspeed in one of the most critical information during a go-around (a minimum speed must be maintained during this procedure), the proximity between the video and this instrument allows to reduce the distance of the ocular saccades.

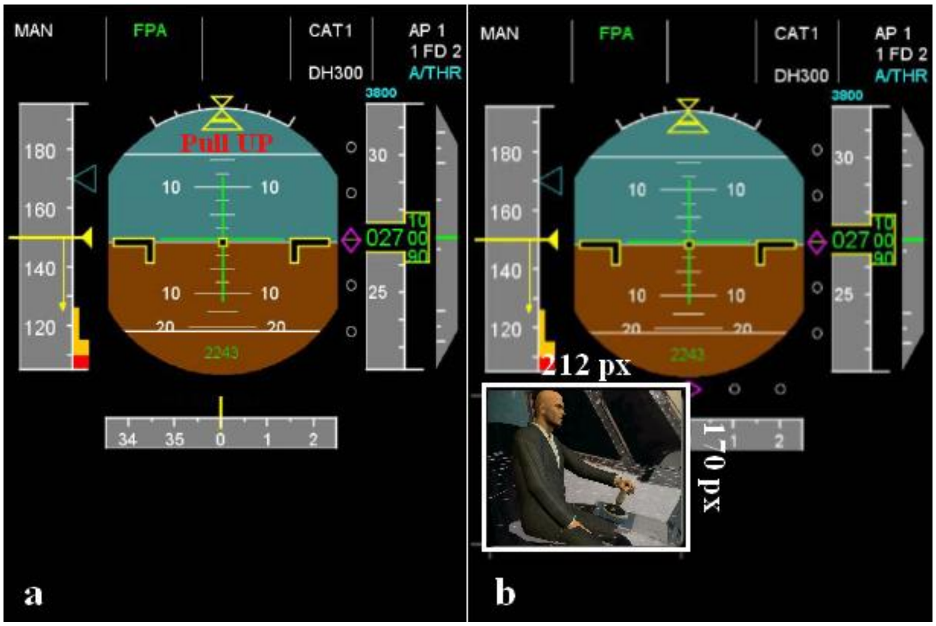

Figure 2 Illustration of the two types of alerts used during the experiment. a: the classical red TAWS 'PULL UP' message; b: the mirror neuron based alert

To assess the efficiency of both alerts, we compared the time taken by the pilots to initiate the go-around action for the regular 'PULL UP' textual message and for the videos. This reaction time corresponded to the time interval between the display of the alert and the time where the stick was set in back position by the pilot to gain altitude (See Figure 3).

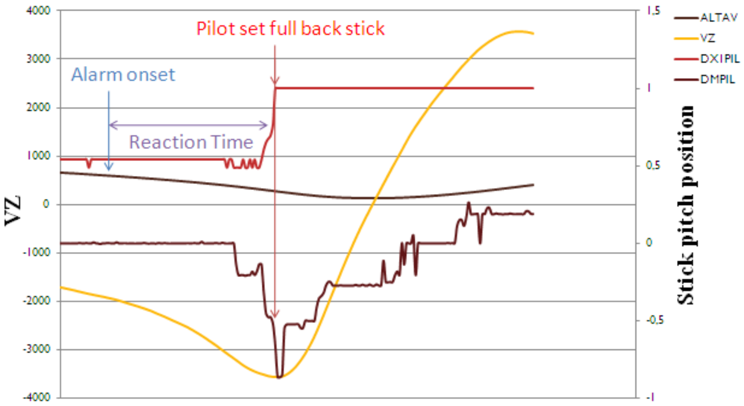

Figure 3 Typical pattern of values after the alarm occurrence. Altav = altitude; Vz = vertical speed; Dx1pil = throttle position; Dmpil = stick pitch position.

3 RESULTS

Given the small size of our sample, we solely present descriptive preliminary results and no statistical tests were performed. All participants reported that they perceived both alerts and that they perfectly understood their meaning and the action that had to be performed. The analysis of the reaction times showed that the avatar videos elicited much shorter reaction times than the regular textual 'PULL UP' TAWS alerts. While the anti-collision maneuver was initiated in 7.60 s (SD = 1.83) with the regular alert, video mean reaction time was 1.27 s (SD = 0.31), see Figure 4.

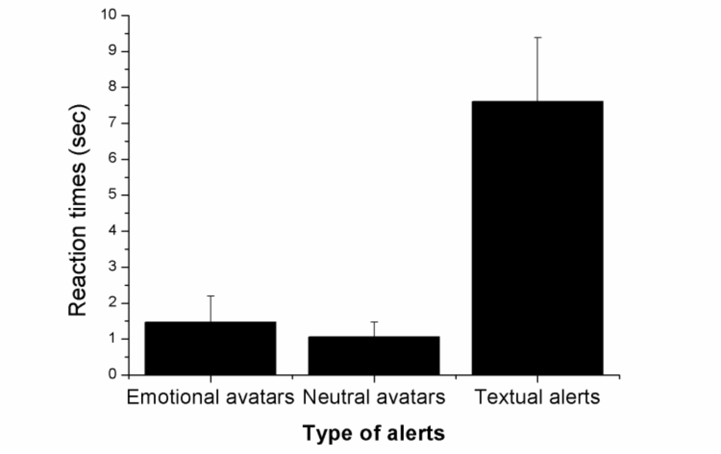

Figure 4 Mean reaction times across the 3 types of alerts. Emotional avatars and neutral avatars allowed faster reactions than classical 'PULL UP' TAWS alerts

4 DISCUSSION

In this experiment we assessed the efficiency of a new type of visual alert in eliciting a very fast reaction from the pilots, namely the pull up maneuver. To purely assess visual aspects and to artificially recreate inattentional deafness, the aural component of the alarm was removed. The results showed that the avatar videos allowed much shorter reaction times than the regular textual 'PULL UP' alerts. This encouraging preliminary outcome opens new perspectives on mirror neuron based human machine interfaces. A future experiment with a larger sample and professional pilots will be conducted to get more conclusive results on the superiority of this type of videos in comparison to the classical TAWS 'PULL UP' alert. In addition, a complementary EEG research will also be conducted and this study will allow to assess the efficiency of these alerts in stimulating mirror neurons. Indeed, the display of stimulus that generates an activation of the mirror neurons is known to provoke a decreased power of the mu-band EEG oscillations

(Muthukumaraswamy, et al., 2004; Oberman, et al., 2007). The observation of such an electrophysiological phenomenon would support that our avatars stimulate these neurons and it would provide evidence on their efficiency to trigger a rapid reaction by imitation in the pilot, even in much degraded situation (workload, stress…) where high level cognitive processes can be strongly altered.

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