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Operator Engagement During Prolonged Simulated UAV Operation

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Abstract: Unmanned aerial vehicle (UAV) operation is demanding in terms of attentional resources' engagement. As systems grow more automated, the operators are placed in long monitoring phases most of the time. Although UAV operators' fatigue state has been extensively assessed at the behavioral and oculomotor levels, to our knowledge there is a lack of literature regarding potential cardiac and cerebral markers. Therefore, this study was designed to investigate which markers of operators' engagement could be used for mental state estimation in the context of UAV operations. Five volunteers performed a UAV monitoring task for two hours without any break. The task included an alarm monitoring task and a target identification task using a joystick. Only ten alarms occured during the session, amongst which only seven required an identification from the operator. The investigated markers were of oculomotor (eye-tracking), cardiac (ECG) and cerebral (EEG) origin. In addidtion to a significant modulation of the alpha power, the blink rate and the number of fixations with time-on-task, the main results are a significant correlation of response times with both the cardiac Low Frequency / High Frequency ratio and the number of ocular fixations.

Keywords: UAV operators; Fatigue; Eye-tracking; ECG; EEG.

1. INTRODUCTION

Unmanned aerial vehicle (UAV) operating is a complex task performed in a dynamic and uncertain environment. During UAV operation, the human operator is often faced with difficult decisions that have to be made within a limited amount of time. However, and as the systems grow more automated (higher decision-making autonomy) the operators are requested to operate at irregular and very interspaced intervals (Cummings et al., 2013). Hence, they can be waiting in a very long and monotonous monitoring phase. Recently, the behavior and the attentional level of operators placed in such a task has been studied (Cummings et al., 2013; Mkrtchyan et al., 2012). These studies have shown that during prolonged missions, operators' performance decreases (e.g. increase in reaction time). These behavioral degradations are due to the occurence of mental states that seem relevant to estimate online in order to implement adaptive systems. Such biocybernetical systems could adapt themselves online to the operator's mental state in order to optimize its performance and increase operation safety in general.

1.1 Mental states and markers

Amongst the mental states that are of particular interest for monitoring monotonous tasks, mental fatigue and attentional resource engagement are crucial. They relate to increases in time-on-task (TOT), modulations of vigilance, and the occurrence of mind wandering. Attentional engagement fluctuates with time and decreases when mental fatigue increases. Mental fatigue is known to occur during and following long tasks that demand sustained attention like driving (Lal and Craig, 2002). It is characterized by a drop in performance. Hence, participants's reaction times increase almost linearly with growing time-on-task (Gale et al., 1977). The oculomotor activity is impacted by engagement and fatigue, with an increase in blink rate and blink duration (Morris and Miller, 1996). And the number of fixations are reported to decrease when the subjects disengage from the task at hand and perform mind wandering (Smilek et al., 2010).

As regards cardiac activity, this attentional disengagement is associated with an heart rate (HR) decrease and an heart rate variability (HRV) increase in the temporal domain. Moreover, the high frequency component of the frequential HRV increases and, depending on authors, the low frequency component decreases or increases (for a short review see Roy et al. (2013)). At the neurophysiological level, a decrease of engagement is characterized by an increase in power in electroencephalographical (EEG) low frequency bands such as the theta and alpha bands (Pope et al., 1995). Mind wandering is also known to elicit a higher power in very low frequency bands (i.e. delta and theta) and a lower power in higher frequency bands (i.e. alpha and beta) (Braboszcz and Delorme, 2011).

1.2 Towards neuro-adaptive systems

The main point in considering human operator's mental state is to perform an online interpretation of it that

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can be used to implicitely adapt the whole system. When concerned with cerebral markers, this biocybernetic loop (Fairclough, 2009) has recently been named passive brain-computer interface (BCI) by Zander and Kothe (2011). When these systems include additional measures such as cardiac and oculomotor measurements, the appropriate term is hybrid BCI (Pfurtscheller et al., 2010). In the context of UAV operations, the aim is to merge mental state measurements with the system state as well as the level of achievement of the mission, in order to, when a degraded state is measured, adapt the interface to relaunch the interaction (Talamadupula et al., 2014). In other words, a decisional framework, issued from the artificial intelligence literature, can for instance produce a plan (Talamadupula et al., 2014) or policy (Taha et al., 2011; Talamadupula et al., 2014) to handle such an adaptive interface's behavior, and in this sense, close the control loop as suggested by Pope et al. (1995).

As far as we know, research on operator-UAV interaction has mainly been conducted at the behavioral level (Cummings et al., 2013; Tessier and Dehais, 2012). Yet it has been proved possible to accurately estimate an operator's fatigue using multimodal information (i.e. cerebral, cardiac and oculomotor features) in a laboratory setting (Laurent et al., 2013). It remains to be evaluated whether these features are relevant in operational settings.

In this sense, the goal of this study was to evaluate the relevance of different mental fatigue markers extracted from different sensors in order to, in the future, perform an online evaluation of the engagement of operators that perform a UAV operation task during a prolonged period of time. The experimental protocol was carried on by five volunteers that performed an alarm monitoring task and a target identification task using a joystick during two hours without any break. This duration has been proved to be sufficient to reach the operators' maximal distraction state (Cummings et al., 2013). In order to put them in a monotonous setting, only ten alarms occured during the session, amongst which only seven required an identification. The investigated markers were of oculomotor (eye-tracking), cardiac (ECG) and cerebral (EEG) origin. With this experimental protocol, we expected to elicit performance degradations -in particular with increasing time-on-task- that would hopefully be correlated to several cardiac, oculomotor and cerebral markers.

2. METHODS

2.1 Participants

Five volunteers underwent the experiment (2 males; 24.6 years old - sd 2.6). All participants had a normal or corrected-to-normal vision. They were free of any medical treatment at the time of the experiment, and had no history of neurological or psychiatric disorder. Data acquisition was performed at the experimental facility of ISAE-SUPAERO (Toulouse, France).

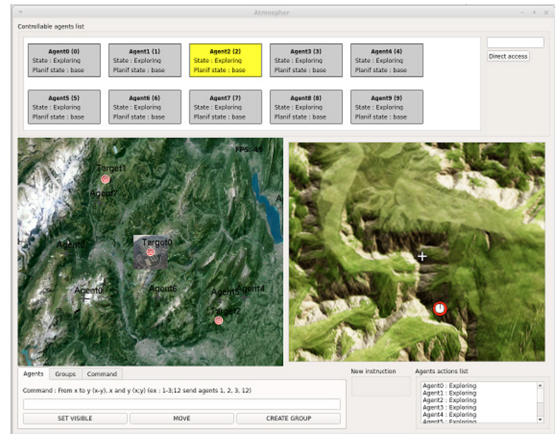

Fig. 1. Screen print of software Atmospher showing the yellow blink that announces the occurrence of a new target in the interface's right part.

2.2 Experimental protocol

The experimental protocol was implemented using Atmospher (Collart et al., 2015), a software simulating drone supervision. In this software, the participant has to monitor one UAV among ten. This UAV can end up in two situations that require an action from its supervisor:

- Identification task: The UAV is next to a target and must identify it. To that end, the participant must use a joystick to bring a reticle on the target's symbol. This situation is announced by the yellow blink of the UAV's button, which lasts for at most 30 seconds, and stops as soon as the participant moves the joystick (figure 1).
- Refuel task: The UAV's fuel level is starting to be low. The participant must then order the UAV to go back to base in order to refuel, or the UAV's default action (going on with the current mission) would risk totally emptying its fuel tank and bringing it to a crash. This situation is announced by the red blink of the UAV's button, which lasts for at most 30 seconds and stops as soon as the participant presses the Enter key on the numpad. At this moment, a decision pop-up appears and the participant must enter her decision using keys 1 (go back to base) or 2 (go on with the mission) of the numpad (figure 2). The participant is strongly encouraged to always choose 1.

During the whole experiment, the UAV's button can also blink in green for 5 seconds, but this signal does not require any response from the participant. The buttons standing for other UAVs may also blink in red or yellow for 30 seconds or in green for 5 seconds and do not require any response from the participant either.

2.3 Data acquisition

The experiment took place on mornings, from 9am to 12pm, in a room with low light. The participants sat on a chair in front of a computer screen, a joystick and a numpad. The screen showed only the window of the software Atmospher, with which they interacted through