UAV Operator mental workload: A neurophysiological comparison of mental workload and vigilance

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UAV Operator mental workload - A neurophysiological comparison of mental workload and vigilance

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Human Factors can offer insights into the nature of human performance across many different domains. The steady increase of unmanned systems presents not only a unique challenge in terms of defining the nature of human-system interaction, but also the demand for providing decision support systems to assist the human operate multiple of these systems, or indeed operate beyond line of visual sight. The nature of cognitive performance can involve a high degree of complexity and in many instances result in disagreement over what it is that is actually being measured. The main cognitive processes that tend to be discussed in terms of operating UAVs tends to focus on mental workload and situation awareness. However, other constructs, such as vigilance, may be considered as important when we examine the task of commanding a UAV – more so when a single operator is supervising multiple UAVs. This paper presents the findings of a study whereby participants were asked to perform tasks involving the control of a UAV. Neurophysiological assessment was carried out by application of functional near infra-red spectroscopy, and results are discussed in relation to how this technique can provide insight into higher cognitive functions related to UAV operator state.

I. Introduction

How we interact with technology is of vital importance for us to harness the efficiencies it may offer and harness the benefits that may be promised. We have seen this many times across different domains and more so within domains that embrace technology as providing a 'game changer' in terms of facilitating such benefits. For example, the field of robotics is one such domain that holds technological development as the harbinger of not only market forces, but the increase of efficiency and safety (Richards, 2017). With the promise of increased efficiency and an associated increase in safety, aviation offers a good example of how technology has become ubiquitous across all aspects of operation; ranging from the flight deck all the way to aspects of Air Traffic Management (ATM). By adopting a Human-Systems Integration view we are able to assess the pros- and cons- of advanced technologies from a human perspective, and begin to better understand the complex interaction the human has with advanced technologies. The field of Human Factors (HF) shares a symbiotic relationship with aviation, by understanding humans in this context this discipline provides us with a means with which to better understand the human element. There have been a number of significant theories that attempt to explain the complex cognitive constructs that shape

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human decision-making and behavior that can be applied within the aviation context. This is an essential component within aviation as we try to not only improve the interaction between the human and the machine, but also to address the contributory role that the human plays within aviation accidents. However, it is important to note the vast majority of such past research has been within manned aviation. If we examine the HF literature in this area then we are quickly confronted with several main factors that are pertinent in forming our understanding of human cognition.

There are many means by which we can measure how humans interact with technology; ranging from objective (behavioural/task related) to subjective metrics. There has been a great deal of discussion pertaining to the validity and robustness of many scales related to human performance, but in this paper we are specifically interested in the application of objective metrics, and in particular how an individual's physiological state may be used to assess cognitive performance. In the past physiological measures have been applied to ascertain human performance in the cockpit, and in relation to adaptive automation on the flight deck (e.g. Byrne & Parasuraman, 1996). These measures traditionally tend to be used in flight simulators and, due to limitations in terms of space within the test environment, focus has been on sensors that are easier to apply to human subjects (such as the monitoring of heart rate, ambulatory blood pressure, electrodermal activity, respiration, etc.). The dynamics of the physiological states that are regulated by the autonomous nervous system (ANS) provide an opportunity to observe unconscious processing of stimuli as encountered by the subject, however we must be mindful that these parameters are also subject to change in response to maintaining homeostasis and as such should be used in combination with other physiological and subjective techniques in order to obtain the truest representation of altered mental state. Brain function monitoring techniques however may offer a more direct insight as to the associative cognitive processing experienced by the subject. In the past such neuroimaging methods have presented significant problems in application; both in terms of the portability of the system and the nature of data that is produced (and analysed). Advances in the use of functional near infra-red spectroscopy (fNIRS) provide an exciting opportunity to provide insight as to the physiological processing of information within an aviation context. This allows us to better understand the affect that complex systems have on human cognitive behaviour.

When we compare manned and unmanned aviation there are several distinct differences between the operator's (or pilot's) interaction with his or her system. Being removed from the actual vehicle instantly suggests that the operator will have less perceptual cues that would normally be associated with flying an aircraft (i.e. the physical vibration, orientation, attitude, etc.). These additional cues are normally taken for granted in operating an aircraft, but Williams (2008) suggests that after reviewing unmanned versus manned systems, there was indeed a 'severe' lack of information available to the operator. If we examine this closer then the lack of sensory information has been associated with specific UAV accidents (Tvaryanas, Thompson & Constable, 2005). To some extent we are left with a paradox whereby a user of an unmanned system requires more information due to the lack of perceptual cues and sensory information.

This would suggest that there are several important cognitive aspects that can affect how an individual interacts with a UAV. Unsurprisingly the Aviation Psychology literature is vast when we examine critical cognitive constructs that we believe are important in aspects of controlling an aircraft. As with any complex system a human only has a limited capacity of cognitive resource to perceive, process and act on the information. Due to the complex nature of UAV operation, it is of no surprise that there is an increasing reliance on more advanced automation (especially as we get closer to beyond line of sight operations). Of particular relevance are the attributes of mental workload and vigilance, and how these effect human performance. We will explore different methods for capturing human cognitive performance in UAV operations and discuss a recently completed study utilising objective neurophysiological assessment techniques.

II. UAV Operations and Human Performance

In a *typical* UAV mission, the operator (most likely remote from not only the aircraft but potentially also the flight operation zone) takes control of a system that has been readied for today's sortie. There will naturally be similarities in manned aviation sorties, in that a high degree of activity would be expected at the front and end of the flight with a reasonable degree of inactivity in the ingress/egress phases. This would suggest that the operator would undertake a substantial degree of monitoring to ensure the system is operating in the manner it ought to; whilst also being ready to deal with system or mission anomalies. If the flight involves a specific task, other than flying safely between waypoints, then the operator will expect to become busy as the area of operation gets closer. This would normally have a specific number of tasks associated with it in order to achieve the mission goal – which will most likely involve a degree of decision-making (normally associated with the payload/sensor carried by the UAV). We can envisage from such a mission that there are indeed lengthy periods of time where the human is tasked to predominantly monitor and supervise the system. If all goes well and no faults or incidents occur then the operator can expect a lengthy period of time simply monitoring a number of displays that are made available to them in order to build a picture of what is happening during the flight. The situation awareness of the operator is therefore dependent on not only the information being relayed by a remote system but the means by which it is conveyed to them on the ground control station (GCS).

If the duration of the flight is long, or the operator is switching between multiple UAVs, it is fair to assume that the individual may exhibit signs of mental fatigue in the form of boredom or distraction. However, this does not mean that there is a decline of cognitive effort. Warm, Parasuraman, & Matthews (2008) propose that vigilance tasks are far from *un-stimulating* and mentally undemanding, suggesting that the mental effort is observed in both psychological and physiological metrics. The operator will most likely be highly trained in the system and more often or not have experience across other platforms (manned and unmanned). One of the key impacts of increased workload relate to the decrease in cognitive resources and the likelihood of making errors due to a degradation in situation awareness or an increase in error rate. We have all at some point experienced what it is to be bored, however it is a cognitive construct that is difficult to explain in terms of the mechanics that drive the associated feelings and reduced performance. It has been noted that the lack of vigilance has often been linked to a number of accidents that have ranged in severity (Warm, Parasuraman, & Matthews, 2008). There are two main determinants of boredom; that which is related to the individuals' personality (whether they show a higher propensity for being bored) and that of external stimuli from within the environment. Thus it is perhaps advisable not to select an individual who displays a tendency to achieve a state of boredom and engage them with tasks that involve little interaction or stimulation. Boredom in itself is not so much the issue, but the transient feelings that are attached to such a state: such as frustration, anger, distraction, and stress (Hill & Perkins, 1985; Fisher, 1993). Of course it also stands that if an operator is engaged in a lengthy laborious task then elements of mental fatigue will also play a part. Indeed, it is not uncommon to hear operators of UAVs report high levels of boredom over long periods of being on duty (Button, 2009).

There is, however, a tendency to discuss deficiencies in human performance when assessing the effectiveness of UAV operation, with familiar metrics being utilised to ascertain the level of performance being displayed (or perceived) by the operator. Traditionally there have been extensive studies to evaluate human performance on the flight deck (Harris, 2011) with a growing arsenal of metrics for assessing cognitive performance of the crew (predominantly those processes related to situation awareness and mental workload). Primary (and sometimes a non-intrusive secondary task) investigation are normally used to assess mental workload of the operator, with often more emphasis on subjective assessment and physiological metrics (Wittman, Kiss, Gugg, Steffen, Fink, Poppel, & Kamiya, 2006). The impact of increased mental workload on the human is of particular interest due to the consequent effects it can have over the success of a mission or flight (especially in terms of safety rather than effectiveness). This consequent increase in workload may also be related to a decrease in cognitive resources and the likelihood of making errors due to a degradation in situation awareness.

Early attempts at a unified theory of vigilance adopted different theoretical constructs, such as Inhibition and Expectancy theories (Hull, 1943 and Baker, 1959). However, adopting a behavioural model of vigilance has significant limitations and falls short of developing a comprehensive theory that can explain extraneous factors that can influence human behavior. Later approaches have drawn on arousal theory, stipulating that vigilance is closely associated with the individual's level of arousal, but this theory fails to address why physiological indices tend to record higher levels of catecholamine (Frankenhauser, Nordheden, Myrsten, & Post 1971) or electro-cortical activity (Davies & Parasuraman, 1982) which tend to be associated with higher levels of mental workload. An alternative to this approach, which may also go some way in explaining some of the discrepancies, can be adopted from Resource theory (Moray, 1967; Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975), whereby an individual's vigilance was a direct indication of their mental capacity that could be allocated to the task at hand. Thus, over time and exposure to a task, the individual slowly uses the cognitive resource they hold and arrives at a decrement in performance (with the re-supply of cognitive resource not meeting the demand of the task).

In order to design a system that takes into account the intricacies of a system that demands the human 'takes a back seat', it is imperative for the designer of such a system to understand the nature of human vigilance. By understanding the nature of information presentation and how the system interacts with the human it is possible to increase the likelihood of human-system partnership and minimize the occurrences of human error; especially those errors usually associated with boredom and lapses in concentration. Cognitive theories of vigilance have shown us the importance by which information is presented to the human (in terms of which modality and the rate/saliency the information is afforded).

It is not uncommon to hear operators of unmanned aerial systems report high levels of boredom over long periods of being on duty (Button, 2009) or the crew of highly automated missile batteries (Hawley, 2006), and perhaps we have all heard stories of how little pilots have to do in terms of flying today's passenger aircraft – although the modern automated flight deck is noted as being an issue for vigilance (Rudisill, 1991). It is fair to say that any human operator who is sat in front of a series of visual displays and asked to monitor for anomalies will encounter some degree of boredom. Boredom in this sense, as a result of performing a dull and monotonous task with very little stimuli to excite perceptual responses may certainly be viewed as a form of mental fatigue. In this instance we are now examining an operator who not only may have periods of time where they are trying to engage with a highly complex and autonomous system but also asking them to monitor for anything out of the ordinary or something that triggers a response to act upon (i.e. a situation that is indigenous to the mission such as identifying a particular target, or an incongruent event that is not anticipated or expected such as a system failure).

By introducing more levels of technological support to the user there is almost a perceived effort to 'design out' the human by identifying tasks that the machine may be either better suited to perform or could address tasks that are identified as being safety critical. The state of mental overload and underload has been shown to have an effect on human performance (Lysaght et al, 1989; Hancock & Caird, 1993). While a great deal is known about the assessment and evaluation of mental overload, and some discussions as to countermeasure techniques to assist the user (May & Baldwin, 2009), not much is known as to how to assess states where underload is present (especially at a level that can impact performance).

III. Physiological Assessment of Operator Cognitive States

It has been well documented that brain imaging techniques can provide insight not only in terms of blood flow, but the nature of neuronal activity (Heeger & Ress, 2002; Izzetoglu, et al., 2005, 2007). The use of fNIRS allows us the ability to examine the dynamics of blood oxygenation at surface level of the cerebral cortex. Neurons consume energy in order to function, and fluctuation in neuronal firing can be measured by glucose metabolism. In order for this to be achieved oxygen is required, and as metabolisation increases in parallel with glucose uptake, there is an associated increase in oxygen movement (via oxy-haemoglobin) to the neural tissue. This is achieved by the exchange of oxygen in the capillaries within the neural tissue.
The resultant release of oxygen into the neural tissue creates a transformation of the carrier (i.e. oxy-haemoglobin) into deoxyhaemoglobin. This fluctuating state of oxyheamoglobin and deoxyhaemoglobin may be viewed as correlates of changing brain state, that are translated to neural activity. The application of fNIRS activates a number of small light emitting diodes to pass light energy (photons) towards the forehead (as in Figure 1).
Skin, tissue, and bone are almost transparent to near infrared frequencies (700-900nm) whereas oxyhaemoglobin and deoxyhaemoglobin exhibit greater absorption. A multiple series of source/detector sensors are placed on the participant's forehead, which thus allows the use of multiple wavelengths and comparison of the subsequent absorption spectra. This is achieved by applying a modified version of the Beer Lambert law, in that the relative concentrations of each carrier state may thus be be calculated (Izzetoglu, 2004; Meiri et al. 2012).

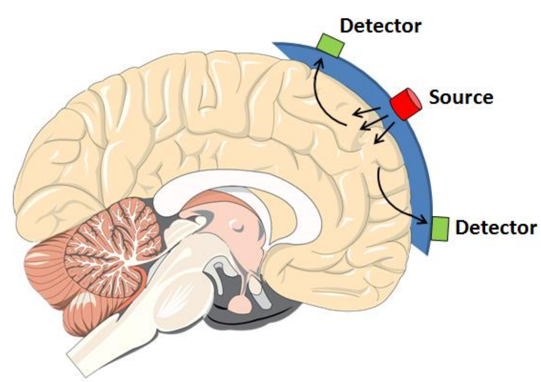

Figure 1. Schematic representation of LED and detector placement of fNIRS

IV. STUDY

During the study, the participants were presented with a number of flight scenarios varying in difficulty and asked to control a simulated model of a generic UAV, as in Figure 2.

Figure 2. View of UAV training simulator (C-STAR© Simlat Inc.)

In this preliminary study, participants were recruited who had no prior experience with UAVs, and thus did not possess the required skills of situational awareness and spatial orientation usually associated with this task. All participants were handed control of the UAV after take-off and when the aircraft had reached a designated cruise altitude. During the flight participants were asked to perform the primary task (normally associated with the Sensor Operator), utilising full motion video (FMV) feed to navigate and scan the designated airspace in a safe and controlled manner. Participants were also given the task of searching for pre-defined targets on the ground.

Human performance was measured using both physiological testing - using the fNIRS system, and behavioural measures associated to the task - as defined via the training simulator (as in Fig 3). Initial results have indicated an increased proficiency in task execution and reduced brain activity in the prefrontal cortex as the subjects practiced. These initial findings are in agreement with previously reported studies (Ayaz at al. 2012; Izzetoglu et al. 2014). This would therefore suggest that the effects of training, and in particular the psycho-motor skills necessary to control a UAV can be assessed by using brain function monitoring methods.

V. Conclusion

This paper outlines the importance of key cognitive aspects that play a role in human-UAV interaction. The results of the study discussed in this paper are discussed in relation to the changing human performance characteristics as factors associated with increasing mental workload are manipulated - such as complexity of route, area of operation, and target saturation. The reported study outlines initial findings that point to key cognitive markers of human performance and how neurophysiological techniques can be applied to human performance assessment of UAV Operators. Further testing continues to begin to associate fNIRS data with cognitive attributes that can assist in our understading of human performance. Of particular interest are the higher cognitive functions such as decision-making, vigilance and trust. All of these elements are vital components of future UAV operations, more so with the increase in demand for UAV operations that require beyond line of sight (BLOS) operations. In order to achieve this then it is likely that high levels of automation (and even autonomy) will be integrated into the UAV, and ultimately pose a significant human factor that will need to be designed correctly in terms of human-system interaction and to limit the likelihood of human error.

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