Using Functional near Infrared Spectroscopy to Assess Cognitive Performance of UAV Sensor Operators during Route Scanning

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Keywords: Unmanned Aerial Vehicles, UAV, Sensor Operators, Cognitive Workload, Functional near Infrared Spectroscopy, fNIRS.

Abstract: The composition of UAV (Unmanned Aerial Vehicle) crew will sometimes define roles specific to tasks associated with the Ground Control Station (GCS). The sensor operator task is specific to both the type of platform and GCS they are operating, but in many instances the role of this operator is critical in determining mission success. In order to assess mission effectiveness we applied human performance measures that focussed on neurological brain imaging techniques and other physiological biomarkers in conjunction with behavioral data acquired from the sensor operator task. In the execution of the experiment, this included such tasks as route scanning, target detection and positive identification, and the tracking of identified targets. Within the scope of this paper, we reported the preliminary results for the route scanning task. Over the duration of three trials brain activity measures from the prefrontal cortex region were acquired via functional near infrared spectroscopy (fNIRS) in this research study. As the trials progressed, there was a significant difference between low and high performers on the route scanning task as determined by specific biomarkers, namely oxygenated haemoglobin. These findings support previous studies and indicates the benefits of applying neurophysiological measures in order to gain further objective insight into human cognitive performance. The use of fNIRS in this context is also discussed in terms of providing a key benefit in dynamically evaluating human performance in parallel with personalized training for UAV operators.

1 INTRODUCTION

A great deal of research is currently underway that focuses efforts on integrating routine flights of UAVs (Unmanned Aerial Vehicle) into the national airspace system (NAS). Of course this is not as straightforward as simply allowing such operations in current air traffic operations (utilising the same traffic management infrastructure), but requires a fuller understanding of not only the nature of UAV operations from this perspective but also the role of the human who is tasked to control such platforms. Thus, herein lies a unique problem. Apart from the obvious differences between operating a manned platform versus an unmanned platform, the composition and defined roles of a UAV flight crew is somewhat more dependent on the platform and nature of operations. In some instances several roles within the UAV crew may be shared across several crew members, alternate between them, or in some instances be carried out by the same individual (Wickens et al., 2005). This presents the operator as a focal point for ensuring not only the safe flying of the UAV, but also the operational effectiveness associated with the mission. By examining the way in which UAV missions are conducted within the defence realm, it is possible to use this as a means by which we can assess how the operator (in this instance the operator directing the sensor, as opposed to the pilot) may be assessed in terms of his/her effectiveness.

Previous evidence has suggested that nearly 70% of all UAV incidents may cite causal factors that would suggest the role of human factors as a contributing factor (Williams 2004). The sensor operator (SO) adopts a role that dictates a number of specific tasks. At some points these tasks may be to assist the pilot in command, perform other tasks not specific to the mission but pertinent to the safe operation of the flight (e.g. liaise with Air Traffic

Armstrong, J., Izzetoglu, K. and Richards, D.
Using Functional near Infrared Spectroscopy to Assess Cognitive Performance of UAV Sensor Operators during Route Scanning.
DOI: 10.5220/0006731502860293
In *Proceedings of the 11th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2018) - Volume 4: BIOSIGNALS*, pages 286-293
ISBN: 978-989-758-279-0

Control). However, we will focus on the SO tasks that are related to the mission context. Primarily this involves a great deal of sensor manipulation, either self-directed or instructed via a Mission Commander or third party. In many instances the sorts of tasks this would involve include scanning areas along the flight path both on the ground and in the air, searching and classifying tracks (and possible threats/targets); whilst also focussing on the operational requirements for the specific mission which may include other requirements of the SO, such as gathering intelligence in relation to building Pattern of Life (POL) and any behaviour that may stand-out from the norm within such POL (Kenner & Wolf, 2003).

Therefore the development of an efficient SO must therefore be entrenched within an effective training programme that allows the individual to develop appropriate cognitive styles (Kirton 2003) that best suit SO- specific tasks. In some instances these may present as a completely new skill set that must be effectively conveyed to trainees who may have prior knowledge/experience of SO tasks or even piloting manned aircraft. An appropriate training methodology must be therefore designed that will help to reinforce SO-specific cognitive styles that will best suit the SO tasks. This will not only provide a more effective means of conveying training to the individual, but also assist in effectiveness as related to the SO task; such as improving SO performance. This includes improved search behaviour and track classification and reducing incidents of false identification (Kowalski-Trakofler & Barrett, 2003).

Apart from taking into account the different cognitive styles of operators during training, it is important to consider the role of attention during the SO task. To some extent an individual's cognitive style (or aptitude for the task) will determine how they guide and control attentional resource and demand during the course of a task. However, it is beneficial to train attentional focus through the use of realistic scenarios that most accurately mimic those found in real-life (Wolfe et al., 2005). Prior studies have shown that repetitive visual search training does indeed help to transfer the search task from an overly active one to a task where it is nearly automatic. This can lead to improved target detection, and quicker response time in regards to identifying a track. (Treisman, Viera & Hayes, 1992). However, the ability to use training for facilitating preattentive processing (in terms of developing an instinctual pattern for attentional processing) remains elusive.

In order for the operator of the UAV to reach a particular level of operational competence, it is expected that the operator will present significant cognitive effort and activity associated with the region of the brain associated with performing those tasks. As with other muscle masses in the body, when effort is required then we can expect a great deal of metabolic activity, in order for the muscle to produce an output. This may be comparative to cortical activity when confronted with a task that has a level of cognitive demand on resources. In order to meet the metabolic demand associated with a task that requires cognitive effort we can observe increases in blood flow to the area of the brain that is asscoaited with the task. In essence this is the blood carrying the oxygen to the parts of the brain that require 'feeding' in order to address the task being considered. Traditionally these metabolic changes in brain states have been measured by MRI, fMRI, and EEG. While these established measures have allowed us to better understand the physiological mechanisms for cognitive activity they also have large degree of constraints that do not allow us to conduct real-time studies of participants in naturalistic settings (and at a reasonable cost).

However, the use of different brain-imaging techniques have allowed us to appreciate which areas of the brain are clossely associated with cognitive functioning. Of particular interest are the higher level cognitive functioninig that include such tasks as decision-making, problem-solving and attentional focus. Advances in optical brain imaging techniques, and in particular functional near infrared spectroscopy (fNIRS), allow us to monitor the hemodynamic changes of the participant as they progress through different tasks associated with SO role.

1.1 Functional near Infrared Spectroscopy

Functional near infrared spectroscopy is a neuroimaging modality that exploits the optical properties of biological tissues and hemoglobin chromophores. fNIRS deploys wavelength in the range between 700 to 900 nm. At this wavelength, the majority of biological tissues, including neural tissues, are transparent while the chromophores of oxygenated and de-oxygenated hemoglobin (HbO2 and HB, respectively) are found to be the main absorbers. By examining the manner in which light passes through cortical tissue (utilising the modified Beer Lambert Law), concentrations of oxygenated and deoxygenated hemoglobin can be calculated (Jobsis, 1977; Cope, 1988). The changes in oxygenated and deoxygenated hemoglobin are directly associated with changes in brain activity changes (Izzetoglu et al., 2004, Villringer et al., 1997).

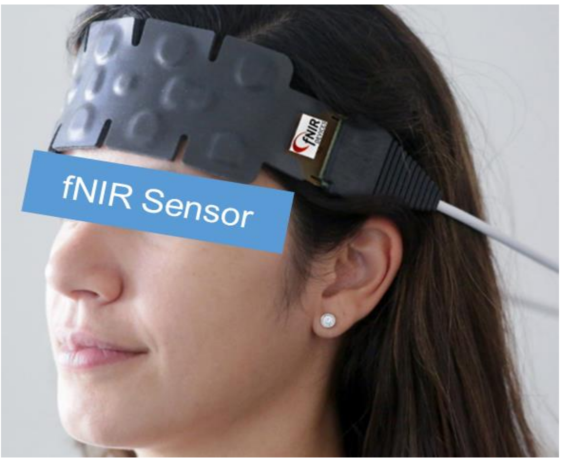

Figure 1: 16-Channel fNIRS System.

The current fNIRS system (as shown in Fig.1) used in this study is proven to be a safe, non-invasive optical method that can be utilized to monitor activity within the prefrontal cortex of the brain (Obrig et al., 1997, Villringer et al., 1997). Because of its portability and ability to capture continuous measures of the hemodynamic response while allowing measures in natural settings, fNIRS seems a suitable neuroimaging modality for assessment of pilot performance in high fidelity simulation as well as field study conditions.

1.2 UAV Training Simulator

In order to accurately translate the results of SO skill acquisition in the field, it would follow logically that the training apparatus must not only resemble the work environment of the SO, but also present a high fidelity representation of the task. (Cooke & Shope, 2004). To address this, we utilized Simlat's C-STAR simulator in this proof of concept study. The C-STAR system consists of Performance Analysis & Evaluation module (PANEL) that collects and processes simulation data, whilst producing comprehensive reports of trainees' performance in various tasks during a mission. The simulator has the capability to transfer views between sensor operator and pilot, as well as a realistic landscape, targets, and accurate representations of UAV operator controls. The software allows for two trainees and one instructor to operate the generic tactical unmanned vehicle (G-TAC UAV) simultaneously and in designated roles, as well as the capability of the instructor to manually or automatically preset 'emergency' situations that the pilot(s) might encounter such as cloud cover, precipitation, and equipment failure. This robust system is ideal for real world training of both the sensory operator and pilot roles of the UAV (Fig. 2).

Figure 2: UAV Simulator: C-STAR system.

2 METHOD

2.1 Participants

Fifteen participants between the ages of 19 to 40 ($\bar{x}$ = 23.8; SD =5.3) participated in the Institutional Review Board (IRB) approved study. Out of 15 participants, there was only one participant excluded due to an incomplete session. All participants (no prior UAV piloting experience) fulfilled inclusion and exclusion criteria of the IRB; they had either normal or corrected to normal vision, and were verified as right handed via use of the Edinburgh Handedness assessment.

2.2 Experiment Protocol

The experimental protocol incorporated scan and target search tasks. The generic tactical unmanned vehicle (G-TAC UAV) was utilized to automatically follow a pre-determined route. The trainee screen was separated into a GPS screen to the left and a sensor payload screen to the right (Fig. 3). The map screen was intended to show the location of the UAV and the route that the UAV has travelled along. The map screen was locked to the UAV position, so the SO could see the UAV move in conjunction with the map. However, the trainee was provided with the option to zoom in and out of the map. This was intentionally designed to rule out any confounding factors that may have occurred regarding the position of the vehicle on the map and consequent loss of situational awareness of the SO as they actively searched using the sensor screen to the right.

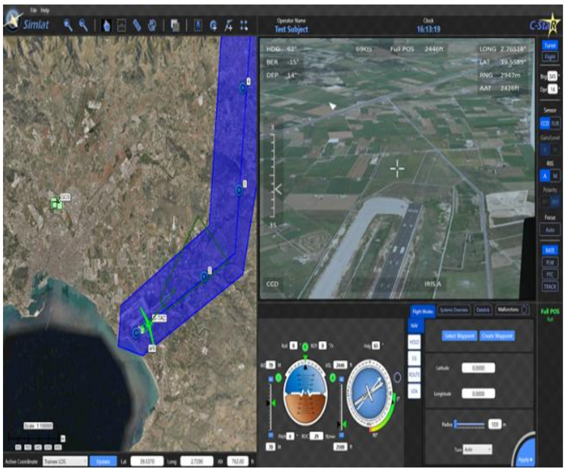

Figure 3: Experimental design view: Payload screen.

The sensor screen displayed the simulated model of the landscape of Mallorca, Spain. Within the sensor display a crosshair and zoom level gauge were utilised by the operator in order to complete their tasks. The simulated time and the duration of each session was provided to the operator and displayed above this display (Fig. 3). Other instruments were provided to the operator that displayed primary flight data, but were not able to be changed by the operator.

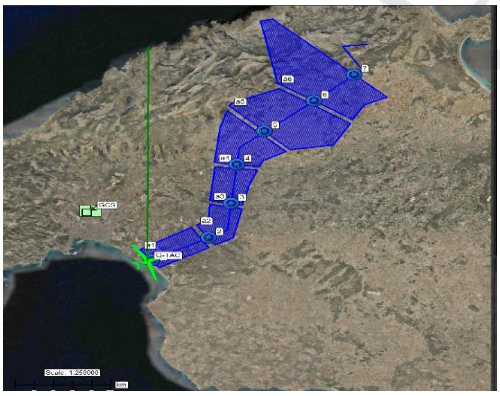

Figure 4: The route where the search task was performed.

At the start of each session the UAV was at 2500 feet with a 64 degree heading angle, and set to travel along a designated flight path at a fixed speed of 70 knots (80.55 miles per hour). Between each sub-area there was a length of 'dead space' at which time the instructor could reposition the camera angle to the widest zoom angle and positioned facing the nose of the UAV (Fig. 4).

As the vehicle proceeded along the waypoints, participants were instructed to scan the designated route. A successful scan was determined to be a scan at a zoom level lower than 15 degrees. Each sub-area consisted of one target that needed to be classified as a threat (in this instance a red civilian bus). To track and identify a target, the participant was instructed to zoom in as close as possible in the payload screen using the hat switch on the joystick. Once the target was located, the participant was instructed to lock onto the target when it was positioned in the camera's crosshairs. In order to ascertain successful identification, the participant was advised to track the target for three seconds before moving the sensor off the target and continuing to scan the surrounding area. Each trial lasted for approximately 17.5 minutes and was repeated 3 times, resulting in 52 minutes of total flight time in the session. The route and scanning area of the map were identical for all three trials, however location of the target component was changed each time. Clearly, this approach was implemented to prevent a participant from simply recalling the location of the target from the previous mission. The C-STAR simulator system recorded percentage of the area scanned, the duration of each session, and the time at which a target was identified.

2.3 Data Analysis

The following task protocol data was analysed within the scope of this paper:

The Scan Task: Participants were separated into low and high performers based on their behavioural performance data to conduct comparisons between fNIRS measurements amongst the trials. The simulator software provided behavioural data that determined the percentage of the designated area that was properly scanned, over scanned, or not scanned.

The percentage of properly scanned areas and the camera field of view was used as a direct metric for determining these performance levels (as shown in Fig. 5).

fNIRS Data Analysis: Continuous wave and 16-channel, covering left and right hemispheres, fNIRS system was used in this study. Sampling rate was 2Hz. For the fNIRS data analysis, a low pass filter with a finite impulse response and linear phase was applied to the raw light intensity data for each wavelength at each channel to tease out high frequency noise, respiration and cardiac cycle effects (Izzetoglu et al., 2005). Then, modified Beer-Lambert Law (MBLL) was used to calculate the oxygenated

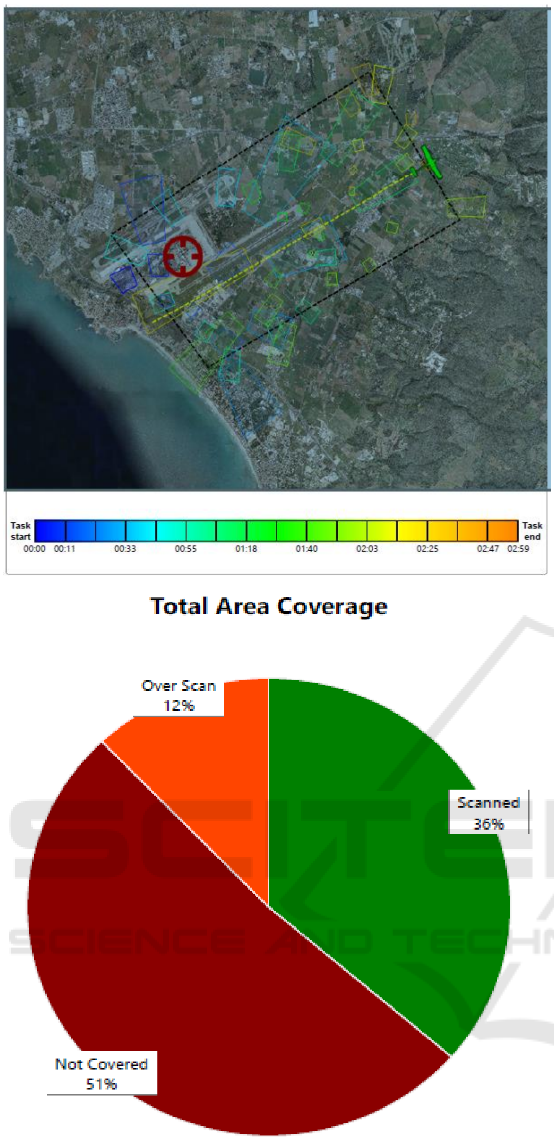

Figure 5: Example of performance analysis for scanning task.

and deoxygenated haemoglobin changes at each channel (Cope & Delpy, 1988; Villringer & Chance, 1988).

3 RESULTS

Based on the behavioural performance measures, the trainees were classified into two groups within the scope of the preliminary study reported here. Those who increased their scan percentage within certain field of view were placed in the high performers group (Fig. 6a). If a participant performed worse between initial trial and final trial, they were classified as the low performer (Fig. 6b).

A significant difference in scanning task was observed between initial and final trials, Trial 1 and Trial 3, respectively. These results were also confirmed by per participant analysis (Fig. 7). High

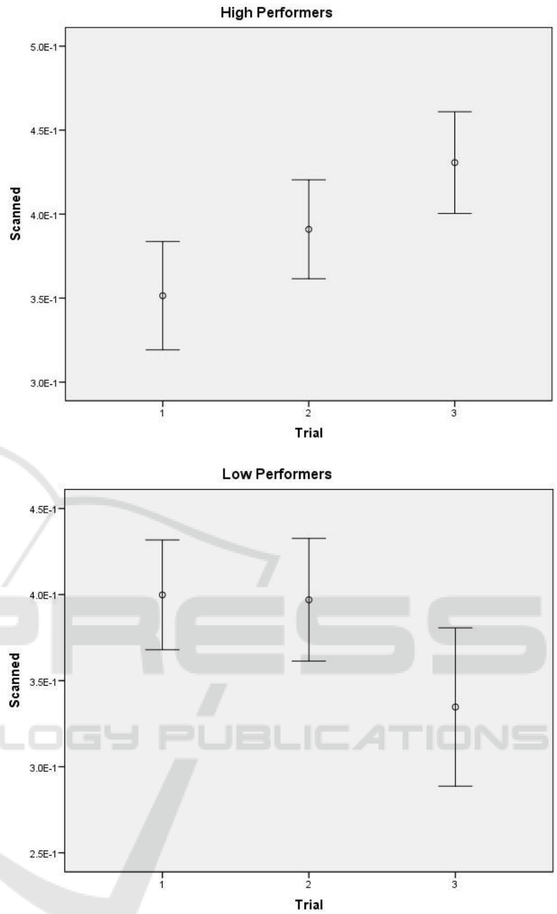

Figure 6: Scanned area measures (n=14 participants) versus trials for a. high performers (F (2, 107) = 7.419, p=.001), b. low performers, (F (2,143) =3.501; p= .033).

performers (n=6) revealed the expected task performance progress, whereas low performers' (n=8) task performance did not improve between initial and final trials.

The preliminary analysis for the fNIRS measures was to investigate the measures from the prefrontal cortex (PFC) region area associated with attention. We calculated oxygenation changes for low and high performers using MBLL. We hypothesized that the high performers would have higher oxygenation than low performers' levels. Figure 9 depicts oxygenation changes from Optode 11 located over the middle frontal gyrus of the right hemisphere

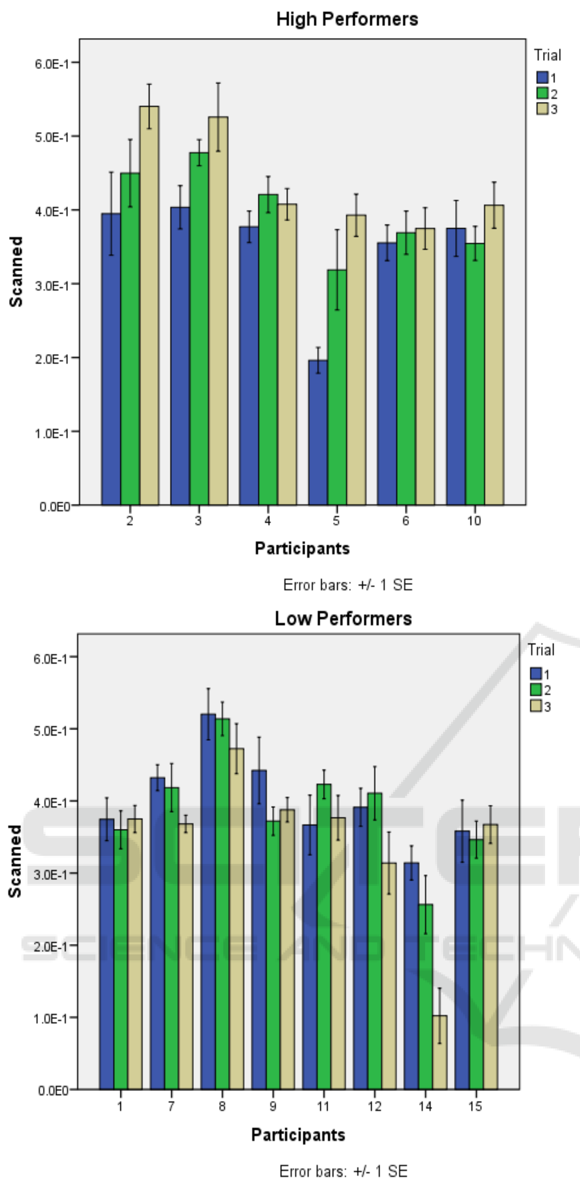

Figure 7: Performance measures by participant.

that was previously reported for the attention task studies (Izzetoglu M, 2007). The oxygenations changes were higher for the high performers as their scanning performance improved over 3 trials.

On the other hand, low performers oxygenation changes remained low, which would be expected when we observe their scanning task performance. However, a low oxygenation does not always mean a lack of cognitive effort. For example, we found that the high performers' oxygenation levels decreased as they became more proficient over time whilst performing the scanning task. A finding that has previously been reported using fNIRS when assessing

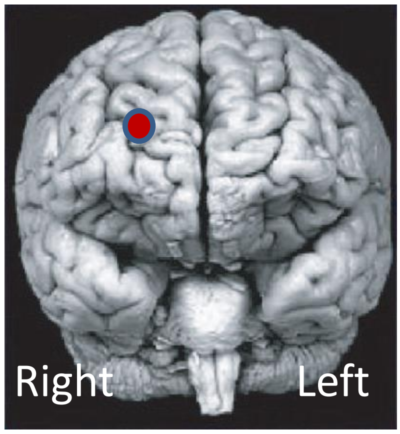

Figure 8: Approximate area of activation region related to the task reported here- fNIRS oxygenation changes.

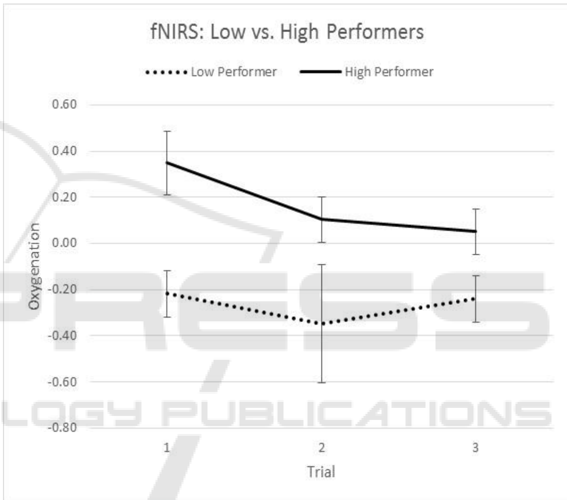

Figure 9: fNIRS results for the low and high performers. (F= 3.095, p=.083 for high performers between initial trial and final trial. For low performers, F<1).

unmanned and manned pilots while they were acquiring new skills (Ayaz et al., 2012; Hernandez, et al., 2015; Izzetoglu, et al 2014; Menda, et al., 2011). Thus a similar trend was observed here for the high performers. That is, while you become familiar with the task, the oxygenation levels at the PFC region decreased. This was not seen in the low performers during this study. There was no significant differences between final and initial trials for this group.

4 DISCUSSION

The ability of a UAV crew to conduct effective operations is based to a large extent on their training. The role of the SO is critical in determining the success of a mission and rapid decision making must often be made in a timely manner, and sometimes calls upon greater demand of attentional resources. This is particularly true of missions that require both rapid response to a changing environment, and also missions where vigilance may result in mental fatigue (and increased likelihood of human error). It is essential therefore that training regimes for operators takes these factors into account and in many cases this will often rely upon high fidelity simulation and scenario-based mission tasks. However, the evaluation techniques currently being used to assess such training tends to focus on behaviour markers related to task, rather than the cognitive ability of the operator. This study builds on the knowledge that we have already gathered by using other functional neurological imaging techniques (such as MRI, EEG) and harnessed the utilisation of fNIRS within a field-based study to demonstrate the benefits this form of measurement may have when assessing operator cognitive state. Further, there are vast amounts of research reported fNIRS studies in the aerospace domain. The training effect and expertise development for manned aircraft pilots was studied with the fNIRS and reported oxygenation decrease on PFC (Hernandez, et al., 2015). Cognitive workload of air traffic controllers was measured by using fNIRS and explored assessment of working memory from the PFC (Ayaz, et al., 2012). Further, we studied UAV pilots on landing and approach task while measuring the expertise development via fNIRS (Izzetoglu, et al., 2014; Ayaz, et al., 2012).

The current study identified that as participants acquired knowledge and gained new skills we are able to observe how they draw on oxygenation to increase their cognitive effort associated with different elements localised within the PFC. On closer inspection this localised oxygenation change is associated with parts of the PFC closely aligned with the middle frontal gyrus of the right hemisphere associated with attention.

The experimental protocol reported here was very complex task. Although these results, behavioural and neuro-physiological measures, are in line with previous reports, one should conduct further analysis for all the sub-tasks for the payload operators and investigate fNIRS measures acquired from all the PFC regions for each sub-task and overall task performance.

This study has demonstrated the benefit of utilising fNIRS as a biomarker for cognitive function of participants employed in conducting UAV sensor operator tasks. While it has highlighted the nature of cognitive function within the PFC, it also can be used as an evaluation of expertise during multiple training sessions.

ACKNOWLEDGEMENTS

The authors express their gratitude to Shahar Kosti for his valuable review and support for scenario design, UAV simulator setup and behavioral data. The authors also would like to thank Simlat, Inc for providing access to their UAV training simulator.

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