Connecting Brain and Learning Sciences: An Optical Brain Imaging Approach to Monitoring Development of Expertise in UAV Piloting

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Abstract: In this paper we present our ongoing research project on UAV operator training and cognitive workload assessment for safe piloting to exemplify the potential for conducting interdisciplinary research that incorporates insights from learning sciences and cognitive neuroscience. The goal of the project is to devise cognitive neuromarkers to assess the cognitive workload experienced by UAV operators and to monitor their development of expertise through analysis of optical brain imaging data and flight-training videos.

The past decade has seen an increasing interest towards connecting research on learning sciences and cognitive neuroscience around various topics of common interest such as language learning, creative problem solving, learning disabilities and development of expertise (de Jong et al., 2009). Although the mind, brain and education movement has recently gained considerable momentum, initial findings of neuroscience on learning were received with reservations by educational researchers and practitioners (Bruer, 1997; Varma, Schwartz & McCandliss, 2006). This was largely due to lack of practical applications of neuroscientific findings to the design of real-life learning activities and environments. Earlier neuroscientific research in learning was confined to highly controlled laboratory settings and relied on protocols limited in scope due to the constraints imposed by the instruments used for monitoring brain activity. However, this body of research has brought important findings with regard to the correlations between brain activation patterns and basic cognitive processes such as attention, memory and visual/auditory perception that are fundamental to understanding the biological basis of higher order cognitive processes like learning. Different neuroimaging modalities such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and electroencephalography (EEG) studies have consistently found correlations between specific brain activation patterns and underlying cognitive processes. Moreover, recent advances in brain imaging technology have led to the design of more portable instruments that afford new ways to study learning in real life settings. Therefore, recent developments have opened up new and exciting possibilities for collaboration across learning sciences and cognitive neuroscience, which may shed further light on our collective quest for better understanding the nature of learning.

This paper introduces an ongoing research study where we aim to identify cognitive indices related to Unmanned Aerial Vehicles (UAV) operations by using an emerging optical brain imaging technique called functional near-infrared (fNIR) spectroscopy. We brought together an interdisciplinary team of researchers with backgrounds in cognitive neuroscience, biomedical engineering, signal processing, and learning sciences to study the correlation between increasingly competent performance demonstrated by novice pilots during simulated missions and brain activation data obtained from subjects' prefrontal cortices that correspond to an area known to be associated with executive functions (e.g. judgment, decision making, planning).

fNIR is a neuroimaging modality that enables continuous, noninvasive, and portable monitoring of changes in blood oxygenation and blood volume related to human brain function. fNIR technology uses specific wavelengths of light, introduced at the scalp, to enable the noninvasive measurement of changes in the relative ratios of deoxygenated hemoglobin (deoxy-Hb) and oxygenated hemoglobin (oxy-Hb) in the capillary beds during brain activity. Over the last decade, studies in the laboratory have established that fNIR spectroscopy provides a veridical measure of oxygenation in the brain. Our recent findings indicate that fNIR can effectively monitor cognitive tasks such as attention, working memory, target categorization, and problem solving (Izzetoglu et al., 2007). These experimental outcomes compare favorably with fMRI studies, and in particular, with the blood oxygenation level dependent signal. Since fNIR can be implemented in the form of a wearable and minimally intrusive device, it has the capacity to monitor brain activity under real life conditions and in everyday environments. Moreover, the fNIR system is amenable to integration with other established physiological and neurobehavioral measures, including EEG, eye tracking, pupil reflex, heart rate variability, respiration, and electrodermal activity.

Research on human factors of UAV flight has identified several reasons underlying mishaps in UAV operations (Cooke et al., 2006). Firstly, UAV operators have limited situational awareness due to the disembodied nature of UAV flight where operators need to fly UAVs by relying on limited camera angles. Since commands are transmitted over satellite links, UAVs are less responsive to operator input as compared to manned aircraft. In addition to this, typical UAV missions take long durations of time that require transitions from long periods of dull flight mode to critical moments where operators need to stay alert to engage with a target or to attend to a contingency. In short, physically and cognitively taxing aspects of UAV flight have resulted in a large number of mishaps during military and civilian use. Therefore, devising reliable indices for assessing cognitive load and level of expertise are of critical importance for evaluating training regiments and interface designs, and ultimately for improving the safety and success of UAV operations.

We are currently in the data collection phase of our research project. Our initial pilot study includes 10 adults who have no prior experience with UAV flight. The simulation platform is based on Microsoft's Flight Simulator X with the Predator UAV add-on by Firstclass Simulations. Using a complete joystick, throttle, and rudder pedal controller set, this simulation environment approximates an actual MQ-1 Predator user interface (Figure 1). After completing a demo session, each subject completed a total of 8 two-hour long training missions within three weeks. During each session subjects fly variants of the same mission, where they are asked to successfully take off, locate a submarine in a specified geographical area, pass over it to allow identification photographs to be taken, navigate back to an airfield with given coordinates, fly within 500ft of the ground en route to the airfield over mountainous terrain, and successfully land after following a contingency maneuver revealed towards the end of the mission. These aspects, as well as other factors such as crosswinds, are added to the simulation to create realistic cognitive and physical demands, similar to those experienced by a real UAV pilot. The simulation environment allows us to replay each session. In addition to the flight video, we collect brain activation data, as well as additional parameters such as pitch, roll, yaw, altitude, longitude, latitude and air speed from within the simulation to aid in the assessment of performance.

We employ both quantitative and qualitative methods to monitor the progress of each subject. Critical aspects of the mission that are likely to increase or decrease cognitive load (e.g. actively searching for a target, navigating towards a set of coordinates, etc.), are identified through video analysis and the flight data. Once critical moments are identified and sampled, fNIR data collected at those moments will be correlated with operator performance to identify cognitive markers indicating expertise development and cognitive workload.

Our preliminary analysis has focused on the moment when two pilots reported that they have detected the submarine by pressing a button during 16 missions. In an effort to measure the effect of sub sighting on the change in oxygenation levels in the prefrontal cortex, we have compared 100-second blocks before and after the subjects located the submarine. For preprocessing the signals, a linear phase, finite impulse response (FIR) low pass filter with cut-off frequency of 0.1Hz is applied to the raw fNIR data to eliminate high frequency noise. Next, for oxygenation calculations, modified Beer Lambert Law is applied to the filtered data to calculate oxy-hemoglobin and deoxy-hemoglobin concentration changes for 16 measurement locations (voxels). The averages of total hemoglobin concentration changes were calculated for pre- and post- blocks, and then normalized by calculating z-scores for each pair independently. Repeated measures analyses of variance, with the Geiser-Greenhouse correction, indicated that the decrease in oxygenation only at voxel 2 is significant in both subjects $F(1,28)=794.73$, $p<0.023$. This result is in-line with our previous findings (Izzetoglu et al., 2007) and can be interpreted as a sign of relief where cognitive resources corresponding to voxel 2 become less active once the search task is complete. Therefore, voxel 2 seems to be highly associated with the search process.

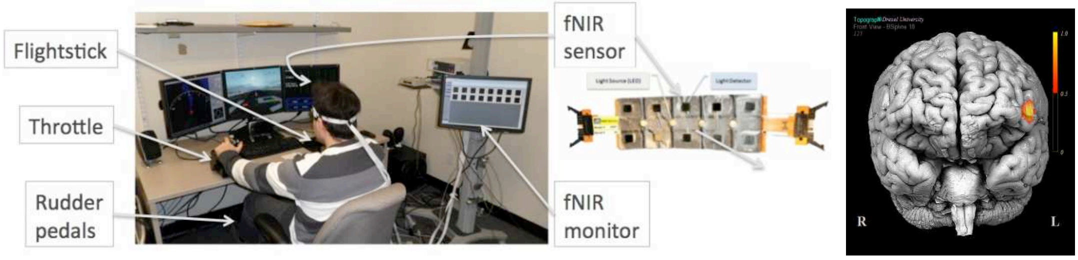

Figure 1: The Experimental Setup for the UAV study and the location of voxel 2

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