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Evaluation of Helicopter Performance Indicators for Use in Development of Digital Twin Based on Physiological Sensor Data From the Aviator

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ABSTRACT

Increasing the likelihood of mission success has always been an area of interest in military research. The recent developments in computing and biomedical technologies are providing the unique opportunity to potentially monitor aviator performance in real-time and use that information to increase or maintain performance. However, identification of a meaningful performance measure is key. The current paper discusses preliminary work evaluating a measure of helicopter performance and associated physiological changes. This effort may assist in the development of human digital twin systems that can be used to further increase aviator performance.

Keywords: Human digital twin, Aviation, Physiological monitoring

INTRODUCTION

Ongoing work within the military, as well as in the civilian sector, continues to pursue the goal of operator state monitoring (OSM) through physiological metrics. The overarching goal of this effort is to provide a near real-time objective assessment of an operator's state that is predictive of performance degradation. It is anticipated that such an endeavor would result in a human digital twin system (HDTS) (Miller & Spatz, 2022), whereby the physiological data collected from the human operator would be used to model and predict operator states under different flight conditions, subsequently used to predict future performance. Creation of such a system will require large quantities of data that will need to be accumulated from a variety of flight conditions (i.e., weather) and types of maneuvers (e.g., hover, takeoff). Although significant progress has been made to-date, a key component remains undefined. We have yet to define which aspects of performance are critical to be predicted within such a system. To maximize the utility of OSM within an operational setting, detecting when performance is likely to be degraded, or has begun to degrade, is essential for the system to make use of this information, ultimately engage some form of adaptive automation – through an HDTS. While a plethora of work has been completed to-date to determine the performance parameters necessary for implementing various cues to the aviator or, in some cases, automation (e.g., automatic ground collision avoidance system), much of this work has been done with a relatively narrow scope. Ongoing work, through literature review, is aimed at evaluating performance parameters to determine which aspects of aviator performance have been demonstrated to indicate adequate performance across different maneuvers.

As a starting point for initial study, the approach phase of flight was selected for examination because it is the phase of flight where the majority of accidents occur (Payan et al., 2017). By narrowing focus to this one segment of flight, we can begin determining whether we are able to establish a reliable relationship between physiological measures and performance outcomes.

METHODS

Study was approved by the U.S. Army Medical Research and Development Command Institutional Review Board. The data reported here is a subset of data from a larger study evaluating the effects of multisensory cueing on aviator performance; please refer to Feltman et al. (2024) for full study details.

Sixteen male rotary-wing aviators from the Fort Novosel, AL area participated in the study. Participants all reported good health and were current and qualified UH-60 pilots. Participants had a range of flight experience, with flight hours in the past year ranging from 20 to 400 hours ($M = 170.26$, $SD = 139.14$).

Materials and Equipment

The study utilized cues that are components of the Integrated Cueing Environment (ICE) which was developed by researchers at the Army's Aviation and Missile Command (see Godfroy-Cooper et al., 2019) for further description. ICE cues were developed mainly with the goal of aiding pilots during degraded visual environment flight. As such, many of the cues involve the use of visual symbology. For the purposes of this study, one aspect of the visual symbology was of greatest interest, which was the vertical speed indicator and the vertical speed "cup" (see Figures 1 and 2 below). These symbols were used to provide the aviator feedback about current vertical speed, which is a key aspect of performance to monitor during the approach-to-landing phase of flight. When flying the approach phase, the aviator must maintain the target vertical speed, depicted as the magenta oval in Figure 1. The amount of time the pilot maintained the desired vertical speed when in the approach phase of flight is recorded as a performance measure. In addition, the vertical speed "cup" in Figure 2 cues pilots to maintain a desired horizontal velocity; this too is recorded as a performance measure, the duration of time pilots maintained the desired range.

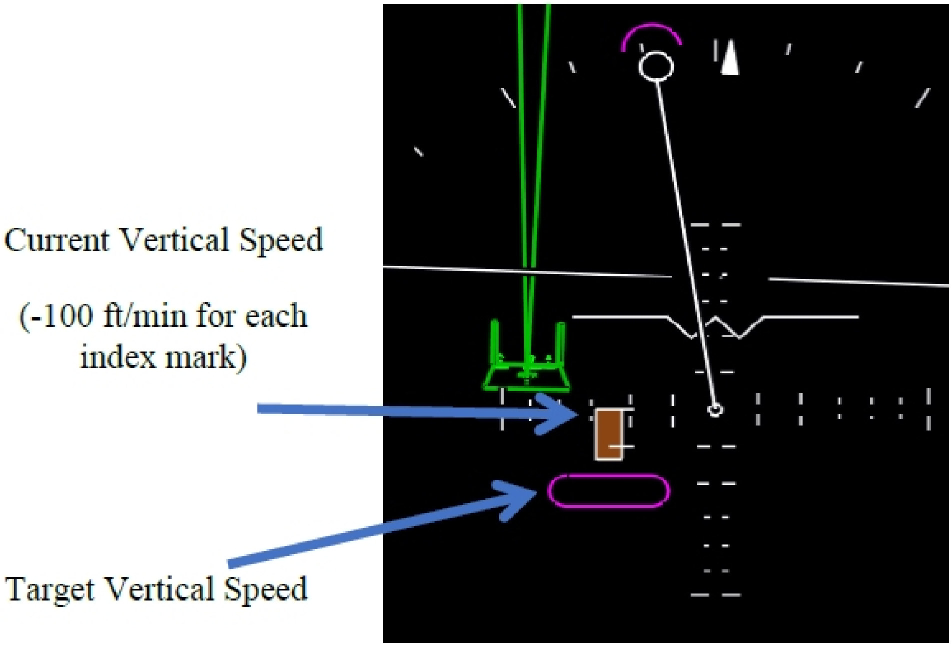

Figure 1: Vertical speed indicator.

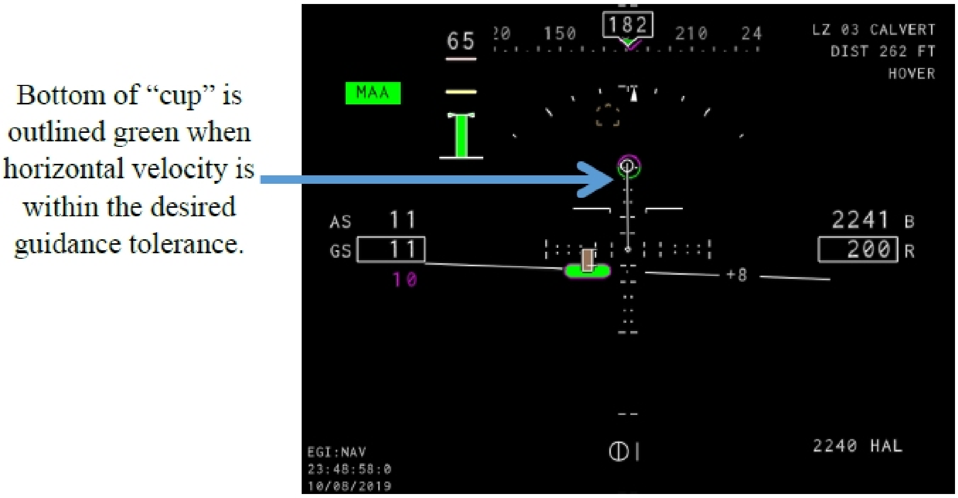

Figure 2: Vertical speed "cup".

All flights took place within the U.S. Army Aeromedical Research Laboratory's NUH-60 research flight simulator. This simulator consists of a simulator compartment that contains a cockpit, instructor/operator station, an observer station, and a six-degree-of-freedom motion system. However, for this study, the motion system was having a maintenance issue and was in the off mode. The simulator is equipped with an Rsi CV1-R dome and eight Barco FS40 projectors which simulate natural helicopter surroundings for day, dusk, or night. A Dell Precision laptop receives information concerning changes in the aircraft/simulator state parameters at a 60 Hertz (Hz) capture rate. The spatial resolution is 1/256 of a foot.

Three types of physiological data were collected in the study. These were: electroencephalograph (EEG), eye tracking/pupillometry, and electrocardiograph (ECG). The EEG data were collected using Advanced Brain Monitoring's B-Alert X24 wireless, wet electrode system with 20 channels corresponding to scalp locations according to the International 10–20 system. Data was aggregated from the following frontal channels to evaluate power spectral density (PSD) values: F7, F3, Fz, F4 and F8. The PSD frequency ranges that were evaluated included alpha (9-13 Hz), beta (14-30 Hz), and theta (4-8 Hz).

The eye tracking/pupillometry data were collected using a Pupil-Core binocular headset (Pupil Labs, Berlin, Germany). The Pupil-Core camera system uses small (0.5 centimeter [cm] x 1.5 cm) cameras mounted on a lensless frame similar to eyeglasses. The cameras were positioned to a location 2–4 cm off of each cheek, outside of the forward visual field so that they did not obstruct vision or interfere with task performance. The outcome measures evaluated included fixation counts and pupil diameter.

The ECG data were recorded using the BioPac MP150. Single-lead electrodes were placed on each of the participant's clavicles and one below the right pectoral area. Data were sampled at a rate of 1,000 Hz. Heart rate variability (HRV) was calculated by measuring the time difference between consecutive R-peaks. HRV indices, to include the mean and standard deviation, were computed using these time differences and used as outcome measures.

Procedure

Participants completed two visits for the study. The first visit included the consent process, completing measures not reported here, and training on the use of the cueing. The second visit is the focus of this paper. During the second visit, participants completed the evaluation flights. The evaluation flights consisted of two routes, each with three flight scenarios featuring different missions (air assault, resupply, medical evacuation [MEDEVAC]). The maneuvers performed during each flight scenario are summarized in the table below. While performing the flight scenarios, a research pilot was seated in the cockpit with the participant to act as a co-pilot and direct the scenarios. Participants were instructed to maintain airspeeds between 80 and 90 knots indicated air speed (KIAS) and to maintain an altitude at or below 300 feet above ground level (AGL). The flights all occurred within a San Francisco visual database that featured mountains and desert terrain. Workload was manipulated throughout the flight scenarios to mimic the stressors experienced in operational settings.

Table 1. Summary of flight mission tasks.

Mission Scenario	Maneuvers
Air Assault	Visual meteorological conditions (VMC) takeoff VMC approach Terrain flight Shipboard operations
Resupply	VMC takeoff VMC approach Terrain flight Landing
MEDEVAC	VMC takeoff VMC approach Rescue hoist operations Landing

RESULTS

Analyses were conducted using R version 4.2.1 (R Core Team, 2022; RStudio Team, 2022). The following packages were used for analyses: lmerTest (Kuznetsova et al., 2017), rstatix (Kassambra, 2023), and tidyverse (Wickham et al., 2019).

Regarding the flight performance outcomes, we found the amount of time spent within the target region of the visual speed indicator was sensitive to the introduced cueing manipulations, $F(3, 297) = 3.76, p = 0.011$. The physiological data were also evaluated to determine whether they supported this change in performance from a workload standpoint. The results of the EEG analyses were non-significant, whereas significant differences were found for the ECG and eye tracking measures. Mean heart rate (beats per minute) was statistically significant, $F(3,\ 118) = 8.02$, $p < 0.0001$. There was also an effect of condition on HRV means, $F(3,\ 118) = 9.39, p < 0.0001$. From the eye tracking data, a significant effect of condition was found for two of the three outcome variables. There was a significant effect of condition on fixation counts, $F(3, 172) = 3.30, p = 0.02$. There was also an effect of condition on pupil diameter, $F(3,\ 170) = 5.61, p = 0.001$.

CONCLUSION

This study provided an initial assessment of a flight performance measure for future aircraft that could be used in an HDTS. Should this type of cueing be utilized in future aircraft, an HDTS using aviators' physiological inputs could be developed where changes in those physiological inputs can aid in determining potential performance deviations. Such a system could aid in correcting a problem before it leads to a mishap, thus improving aviator safety. By identifying performance measures that can be used in conjunction with real-time physiological data measures, we may be able to develop HDTS to aid in increasing mission success by predicting the impact dynamically changing environments will have on performance. The measure used in this study, time spent within the target region of the speed indicator during approach performance, may provide a piece of the puzzle to reach this end goal.

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