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Evaluating the Suitability for Eye Tracking In Simulated Rotary-wing Flight

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14. ABSTRACT

Eye tracking is gaining favor in operator state monitoring (OSM) in that it provides non-invasive access to arousal, autonomic tone, neurological condition, and potentially, cognitive workload by recording changes in pupil diameter and eye movement dynamics. However, the operational environment of rotary-wing aviation has unique challenges to effective eye tracking, such as uncontrolled luminance changes, exposure to vibration, and more physical movement by the aviator than is typical in fixed-wing and ground vehicle systems. Developments in eye tracking technology have enabled researchers to achieve better access to human subjects' behavior in a wider range of settings, potentially allowing the assessment of cognitive workload, fatigue, and changes in autonomic function in military operational settings. Many different eye tracking systems are currently available. These can be broadly categorized by configuration as remotely mounted multi-camera arrays, remotely mounted single cameras, and head-mounted camera arrays. These different configurations each have their own pros and cons. To date, no comparison between these different systems has been completed to determine which configuration is most suitable for a cockpit environment. Here, we present findings from studies of workload supporting the scientific validity of eye tracking variables for consideration in OSM as well as findings from an evaluation of different

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14. Abstract (continued)

configurations in a simulated cockpit.
Method:
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In our continued efforts to develop and expand USAARL's eye tracking capabilities and appraise the suitability for eye tracking in operational settings, we have recently conducted a direct comparison of the performance of three eye trackers in a flight simulator. Eye camera systems with three unique mounting configurations were evaluated sequentially by rated aviators (n = 5) while they performed a choreographed sequence of fixations around the cockpit, followed by an overland flight. These were completed in the Cockpit Academics Procedural Tool – Enhanced Visual Capable System (SGB-Enterprises, CA, USA) fixed-base UH-60M flight simulator. This simulator was constructed for USAARL by combining it with a 12-foot projection dome (Q4 Services, CA, USA) and X-IG image generation software (CATi Systems, AL, USA). The eye tracking systems evaluated included one with a single camera mounted remotely on the dashboard directly in front of the pilot, another with five cameras mounted remotely in locations spread throughout the cockpit, and the last with small cameras fixed to a frame worn on the head (like eyeglasses).
Results: All three systems were able to collect data with some success and support the inclusion of eye tracking in operationally viable operator state monitoring systems. In addition, a survey of experts in the fields of physiology, psychology, and human performance rated the extent to which various physiological measures may be useful in OSM, and more specifically, predicting cognitive workload. With respect to eye tracking, 76.1% of respondents to the relevant survey questions (total respondents = 21) rated these measures as "likely" or "very likely" able to detect changes in cognitive workload. 72.7% of these respondents also reported that changes in cognitive workload can be detected using pupillometry, or the measurement of changes in pupil size. These responses are supported with data collected by USAARL researchers demonstrating that increases in pupil diameter are associated with increasing cognitive challenge (Aura et al., 2021) on an n-back sequential memory task.
Discussion:
A direct comparison of the performance of multiple eye tracking systems found that modern eye tracking systems (configurations: multi-camera, head-mounted) can perform at an acceptable level within the unique mounting constraints of the UH-60M cockpit layout. As the simulator used in this activity was fixed, and did not have motion capability or simulated vibration, we cannot yet determine how these systems will tolerate those additional forces. Future efforts are underway to conduct a second phase of testing to address the impact of these forces in a full-motion simulator. This is supported by significant pupillometric effects found in prior USAARL research efforts looking at eye tracking metrics and direct manipulations of cognitive workload (Aura et al., 2021). In addition, most of the survey respondents support including eye tracking and pupillometry in future, multi-modal, physiological operator state monitoring suites. In summary, eye tracking remains an integral part of USAARL's research surrounding operator state monitoring. As we learn more on the feasibility of including eye tracking systems in efforts moving closer the operational environment, we will continue to provide U.S. Army decision-makers with recommendations for Future Vertical Lift projects.

Evaluating the Suitability for Eye Tracking in Simulated Rotary-wing Flight

Chris Aura[1], Xiaomin Yue[1,2], Kevin Andres[1,2], Michael Wilson[1], & Katie Feltman[1]

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Background

Advances in digital video sensor technology have allowed higher resolution infrared images of the eyes to be collected from increasingly smaller camera systems. Advances in computer vision and feature recognition algorithms allow modern infrared video-based eye trackers to make precise, detailed recordings of the eye's behavior in near real-time, and under an expanding variety of conditions outside of the strict constraints of the laboratory setting. Eye-related operator state monitoring metrics, including gaze patterns, eye movements, and pupillometry, are impossible to obtain without effective tracking of the pupil. Thus, the analyses specific to the proportion of time where pupil tracking data were lost or spurious over the course of a choreographed sequence of fixations about the cockpit followed by a short, low-level, flight through a simulated urban environment.

Methods

Figure 1: UH-60M Black Hawk Forward Cockpit Layout

- CAPT-E fixed-base UH-60M simulator (SGB Enterprises; CA,USA) running XiG software (CATi; AL, USA)
- 5 currently rated, UH-60M pilots evaluated each system within a single session.
- Flight scenarios were chosen to maximize head-motion but minimize effort.

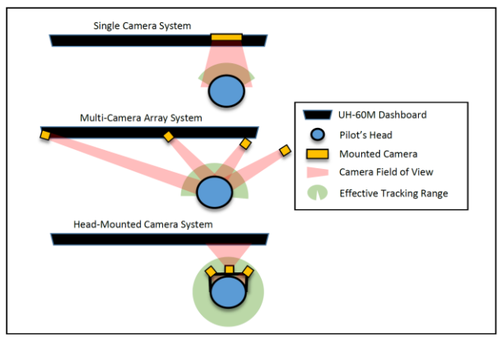

Figure 2: Diagram of the camera mounting positions in the UH-60M Cockpit

Methods

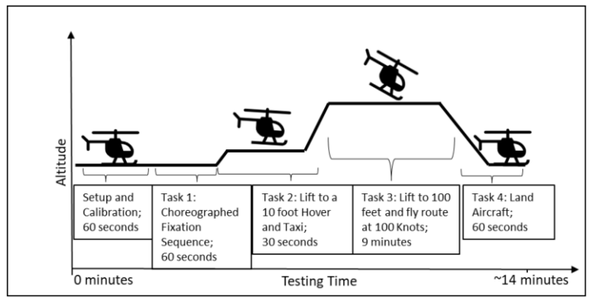

Figure 3: Timeline of the procedure

Results

	Single Camera System	Multi-Camera Array	Head-Mounted System
Cameras	1 camera facing the pilot from a single location	4 cameras facing the pilot from different angles	3 cameras mounted on a single frame; 1 on each eye, 1 looking forward to capture scene view
Advantages	Simple setup, simplified analysis, nothing on the head	Simplified analysis, nothing on the head, flexible mounting locations	Simple setup, mobile, direct view of both eyes
Disadvantages	Limited effective mounting locations, restricted view of the eyes	Complex setup, expensive	Mounted on head, may obstruct visual field
Performance	9%-34% data loss, poor but usable	2%-6% data loss, very good performance	0.2-1.6% data loss, excellent performance

Discussion

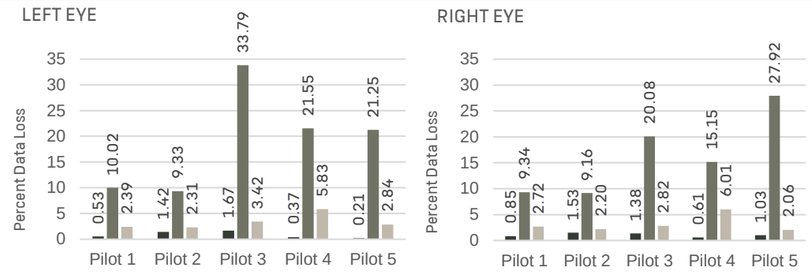

Figure 4: Tracking data loss in the left and right eyes for the single camera (Green), the multi-camera array (Black), and the head-mounted camera (Tan) systems.

- The single camera system favored the right eye, while the head-mounted and remote-array systems captured both eyes equally well.
- Single camera systems can collect usable data in a fixed-based UH-60M simulator.
- Head mounted systems and remote array systems both performed with minimal data loss and may be well suited for inclusion in future physiological monitoring systems.
- Eye tracking systems are emerging that can effectively tackle the operational environment, but the advantages and disadvantages of each mounting configuration should be leveraged against the study design.

Future Directions

- 6 simulator-based studies are currently underway at USAARL using eye tracking as a physiological measure.
- Future studies at USAARL are using data from this evaluation to select the eye tracking system best suited to those research conditions.

References

Aura, C. J., Yue, X., Andres, K., Feltman, K. (2023). *Direct comparison of eye tracking data loss between systems utilizing three common camera mounting configurations in a UH-60M Black Hawk simulator* (USAARL-TECH-TR--2023-22).

Aura, C. J., Temme, L. A., St. Onge, P., McAtee, A., Wilson, M., Bowers, B., Baugher, K., Hayes, A. (2021). Operator state monitoring via pupillometry: Measuring mental workload under varying luminance conditions. *SPIE* (11757).

Eckstein, M. K., Guerra-Carrillo, B., Miller Singley, A. T., & Bunge, S. A. (2017). Beyond eye gaze: What else can eye tracking reveal about cognition and cognitive development? *Developmental Cognitive Neuroscience, 25,* 69–91. doi: 10.1016/j.dcn.2016.11.001

Kahneman, D., & Beatty, J. (1966). Pupil diameter and load on memory. *Science, 154*(3756), 1583–1585. doi: 10.1126/science.154.3756.1583

Leslie, D. (2020). Understanding bias in facial recognition technologies: An explainer. The Alan Turing Institute. https://doi. org/10.5281/zenodo, 4050457.

Vogels, J., Demberg, V., & Kray, J. (2018). The index of cognitive activity as a measure of cognitive processing load in dual task settings. *Frontiers in Psychology, 9*, 2276. doi:10.3389/fpsyg.2018.02276

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