Experimental design for fatigue detection in varied ambient lighting conditions

Katharine Woodruff
Avionics
Collins Aerospace
Cedar Rapids, IA, USA
katharine.woodruff@collins.com

Stephanie Dutra
Avionics
Collins Aerospace
Cedar Rapids, IA, USA
stephanie.dutra@collins.com

Adelaide Danna
Avionics
Collins Aerospace
Cedar Rapids, IA, USA
adelaide.danna@collins.com

Peggy Wu
Raytheon Technologies
Research Center
East Hartford, CT, USA
wup1@rtx.com

Tom Ferris
Industrial & Systems Engineering
Texas A&M University
College Station, TX, USA
tferris@tamu.edu

Cheyenne Matthews
Avionics
Collins Aerospace
Cedar Rapids, IA, USA
cheyenne.matthews@collins.com

***Abstract*—**Technological advances in the aircraft continue to improve aircraft performance and extend the duration of operational missions; however, the physiological demand on pilots increases as well. With the increasing length and complexity of missions, monitoring constructs such as fatigue, attention, and stress become safety critical. This paper specifically looks at measuring fatigue and the experimental design to yield various levels of fatigue. There were 3 lighting conditions during data collection to represent varied lighting that occurs in operations. The experimental tasks and design are described, as well as the behavioral coding used during data collection. Lastly, current progress and future works are discussed.

Keywords—*experimental design, fatigue, lighting conditions*

I. Introduction

In missions such as dynamic air refueling, operators must maintain attention and vigilance for extended periods of times, requiring performance endurance that approaches human physiological limitations. To minimize safety risks associated with these degraded performance events, biometric monitoring technologies such as eye-tracking systems can be used to monitor fatigue. When conducting a pupillometry-based experiment to detect fatigue, a constant light environment is not fully representative of the variance of lighting conditions encountered by an operator. For example, an operator may encounter clear sky operations at noon, dusk, and darkness in the same mission. To represent this range of operational environment lighting conditions and its potential impact on pupillometry results, varied ambient lighting conditions are used in this fatigue detection experimental design. Objective fatigue detection through eye tracking is validated through ground truths such as performance measures and subjective surveys. This abstract describes the experimental design used to simulate the various lighting conditions encountered in operations.

Work was supported by the Air Force Research Laboratory (AFRL).

II. Methods

A. Materials

Internal Review Board (IRB) approval from Texas A&M University was received prior to data collection. Participants wore an Oura ring [1] 18 hours before data collection. A large screen display was placed 3-4 feet from the seated participant. The TV displayed a pre-recorded monitoring task that was derived from the NASA Multi-Attribute Task Battery (MATB) [2]. During data collection, the participants were instrumented with the following physiological sensors: eye tracker, electrooculography (EOG), electrocardiography (ECG), respiration belt, pulse oxygenation, and electro-dermal monitoring. Video of the participants was recorded as well.

B. Participants

There were 43 males and 6 females for a total of 49 participants, 5 of which were pilots. The highest education level completed by the participants varied, with 6 having completed high school or their GED, 37 having completed some 4-year college, 2 having graduated from a 4-year college, and 3 having completed some graduate school. Of the participants, 38 had no visual correction while 10 had visual correction. Participants were recruited from Texas A&M University via email and flyers.

C. Design

Participants had two in-person meetings in this study. In the first visit, participants would be briefed on the study purpose and tasks and fill out the IRB approved consent form. Next, color and visual acuity tests would be conducted to confirm study qualification. Lastly, demographic surveys would be administered, and the participant would receive their Oura ring. Participants were asked to stay awake for 18 hours prior to their experimentation start time and refrain from caffeine, tobacco, and alcohol consumption for at least 24 hours before experimentation. The second visit was the experimentation session. Upon arrival, the participants were instrumented with physiological sensors for data collection. Participants would perform the MATB for 10 min. at a time on the large screen TV. In between MATB sessions, participants would perform the Psychomotor Vigilance Test (PVT) [3] and then the Karolinska Sleepiness Scale (KSS) [4] would be administered.

D. Multi-Attribute Task Battery (MATB) Task

The MATB task simulates instruments and sensors that a pilot monitors during flight. The task involves fluctuating gauges that require the participant to press the button on a keyboard when the levels of one of the gauges reaches a critical point. This task is performed for 10 min. increments.

E. Psychomotor Vigilance Test (PVT) [3]

The PVT task was administered every 10 min. to measure fatigue as a function of tactile response time. The task requires participants to press a tablet screen when visual stimuli spontaneously appear on the screen for a 3-min. period. This task was performed in 10-min. intervals following the MATB task.

F. Karolinksa Sleepiness Scale (KSS) [4].

The KSS is an in-situ 10-point subjective scale that measures the sleepiness of participants. The scale ranges from extremely alert (1) to extremely sleepy with an inability to stay awake. Participants were asked to self-report the level that best represented their fatigue in 10-min. intervals following the MATB task.

G. Lighting Conditions

1) Condition 1: consistent lighting with a static light source, approximately 10^-3 (.001) candela per square meter (cd/m^2), which is an illumination level similar to that experienced naturally during daytime flight. Condition 1 was administered until there were 5 microsleeps, 2 long sleeps, or 2 hours had passed.

2) Condition 2: sinosoidally-varied lighting between 10^-3 and 10^4 (10,000) cd/m^2, which represents the transition of nighttime flight lighting to daytime flight lighting. The light would fluctuate from one extremum to the other over 10 min. periods. The next 10 min. period would start at the last extrema and fluctuate to the other. For example, if the 10 min. period started with daylight and ended with darkness, the next 10 min. period would start with darkness and end with daylight. This was to simulate the transitions of light that can occur in operations. Condition 2 was administered until there were 5 microsleeps in 1 light cycle, 1 long sleep, or 2 hours had passed.

3) Condition 3: flash lighting between 10^-3 and 10^4 (10,000) cd/m^2, which represents extreme weather. The lighting would flash on and off in random intervals throughout the condition. This was to represent lightning. Condition 3 was administered for 1 PVT cycle.

H. Behavior Coding

Participant behaviors were manually coded by researchers monitoring the data collection, *Fig. 1*. These tags will inform the eye tracking algorithms. Researchers were trained on the following metrics: *Blink* is defined as any eye movement that results in a closure of at least 70% (covering pupil) followed by the eye re-opening. *Short blink* was defined as a blink less than 200 milliseconds (ms). *Long blink* was defined as a blink greater than 200 ms. *Long sleep* was defined as 2-4 min of eyes closed. *Microsleep* was defined as longer than a long blink but shorter than an eyes closed/asleep. *Head nodding* was defined as any dramatic/obvious swaying of the head. A researcher tags these behaviors in real-time along with the task completions.

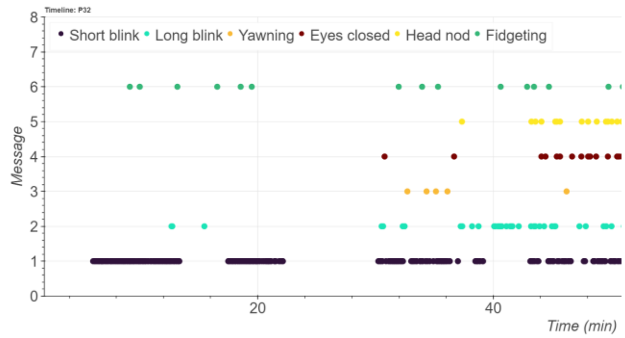

Fig. 1. Sample of behavior tags for one subject.

III. Discussion and Future Work

This paper describes an experimental design to elicit various fatigue levels through the manipulation of ambient lighting. There are 3 conditions of ambient lighting during experimentation to simulate varied lighting in operations. Performance measures from tasks and subjective surveys will be used as the ground-truth for fatigue levels. Currently, the data is in the preprocessing stage and will verify that participants are experiencing fatigue from this experiment by comparing the PVT and KSS scores of the beginning of each condition to the end of each condition. The manual behavior codebook will also need to be verified through inter-rater reliability. After the ground truths and experiment design are validated, the physiological measures will be analyzed to define objective, real-time fatigue level measures.

Acknowledgment

The work was supported by the Air Force Research Laboratory (AFRL).The views expressed herein are those of the authors and do not represent the official policy or position of the US Air Force.

References

[1] “Oura Ring.” [Online]. Available: https://ouraring.com/product/heritage-gold

[2] Chancey, Eric, “NASA Multi Attribute Task Battery (MATB).” NASA. [Online]. Available: https://matb.larc.nasa.gov/test-2/291-2/

[3] D. F. Dinges and J. W. Powell, “Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations,” *Behav. Res. Methods Instrum. Comput.*, vol. 17, no. 6, pp. 652–655, Nov. 1985, doi: 10.3758/BF03200977.

[4] A. Shahid, K. Wilkinson, S. Marcu, and C. M. Shapiro, “Karolinska Sleepiness Scale (KSS),” in *STOP, THAT and One Hundred Other Sleep Scales*, A. Shahid, K. Wilkinson, S. Marcu, and C. M. Shapiro, Eds., New York, NY: Springer New York, 2011, pp. 209–210. doi: 10.1007/978-1-4419-9893-4_47.