Same Mission, Different Signals: Disentangling Workload and Fatigue in an Aviation-like Multitasking Environment

Jon Vogl[1], J. Andrew Atchley[1, 2], Sharon Bommer[1, 3], Charles McCurry[1, 3], Amanda Kelley[1]

[1]United States Army Aeromedical Research Laboratory, Fort Rucker, AL [2]Chickasaw Nation Industries, Norman OK [3]Oak Ridge Instite for Science and Education, Oak Ridge, TN

Background

- U.S. Army rotary-wing operations often combine high task demand with extended wakefulness, increasing safety risk when cognitive workload (CWL) and fatigue co-occur.
- Previous work considered the impact of sleep-loss fatigue and CWL for physiological monitoring; however, both are individually associated with changes in physiology and performance.
- This study assessed the impact of fatigue and CWL together to disentangle potentially overlapping influences at trial level.

Methods

Subjects

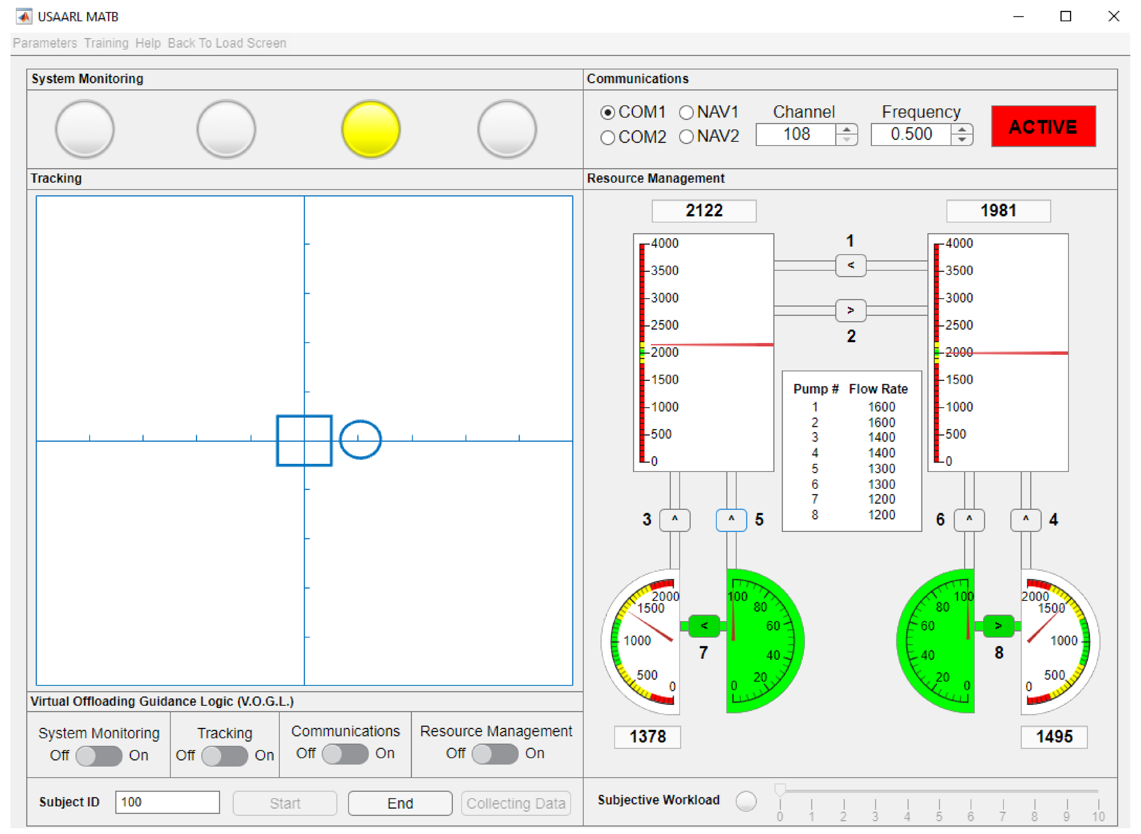
- 10 U.S. Army rotary-wing aviators experiencing sleep deprivation
- Subset of data from a sleep deprivation study (Kelley et al., 2025)

Apparatus

- **Task:** USAARL Multi-Attribute Task Battery (MATB; Vogl et al., 2024)
- **Physiology Sensors:**
  - Polar H10 electrocardiogram (ECG) chest strap (130 Hz)
  - Pupil Labs Core Binocular eye tracking headset (120 Hz)
  - B-Alert X24 electroencephalogram (EEG; 256 Hz)
- All data was synchronized and recorded using Lab Streaming Layer.

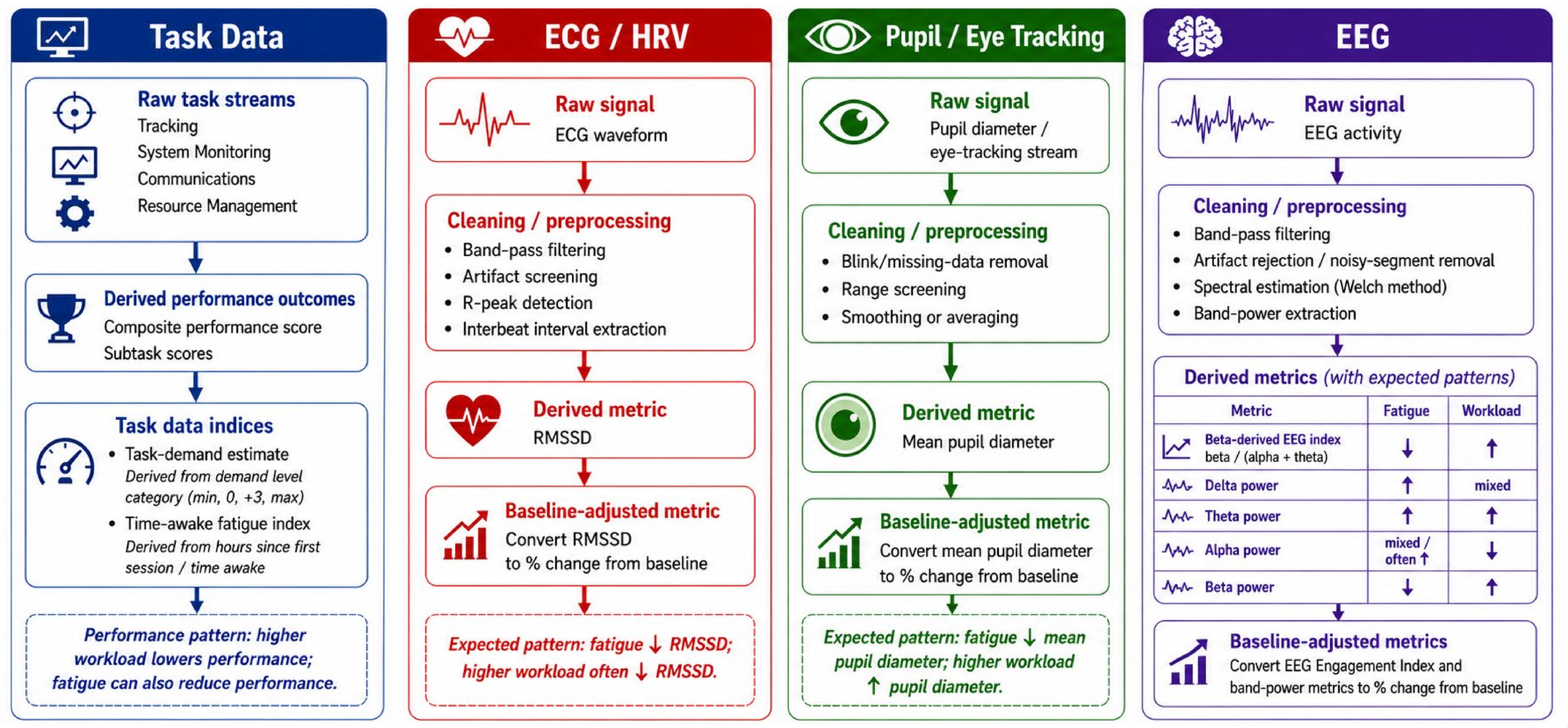
Procedure

- **Day 1 Training:** Task training to Comfortable Demand Level (DL/CDL)
  - **Training Target:** Identify DL that yielded 75% score consistently
- **34-Hour Sleep Deprivation Testing:** 4 sessions with 5 trials each
  - **Session Times:** 5, 12, 20, 27 hours from study start
  - **Baseline:** 5-minute PVT-style task for each session
  - **Trial Conditions:** Min DL, -3 CDL, CDL, +3 CDL, Max DL
- **Analysis:** Linear mixed-effect models: Workload x Fatigue

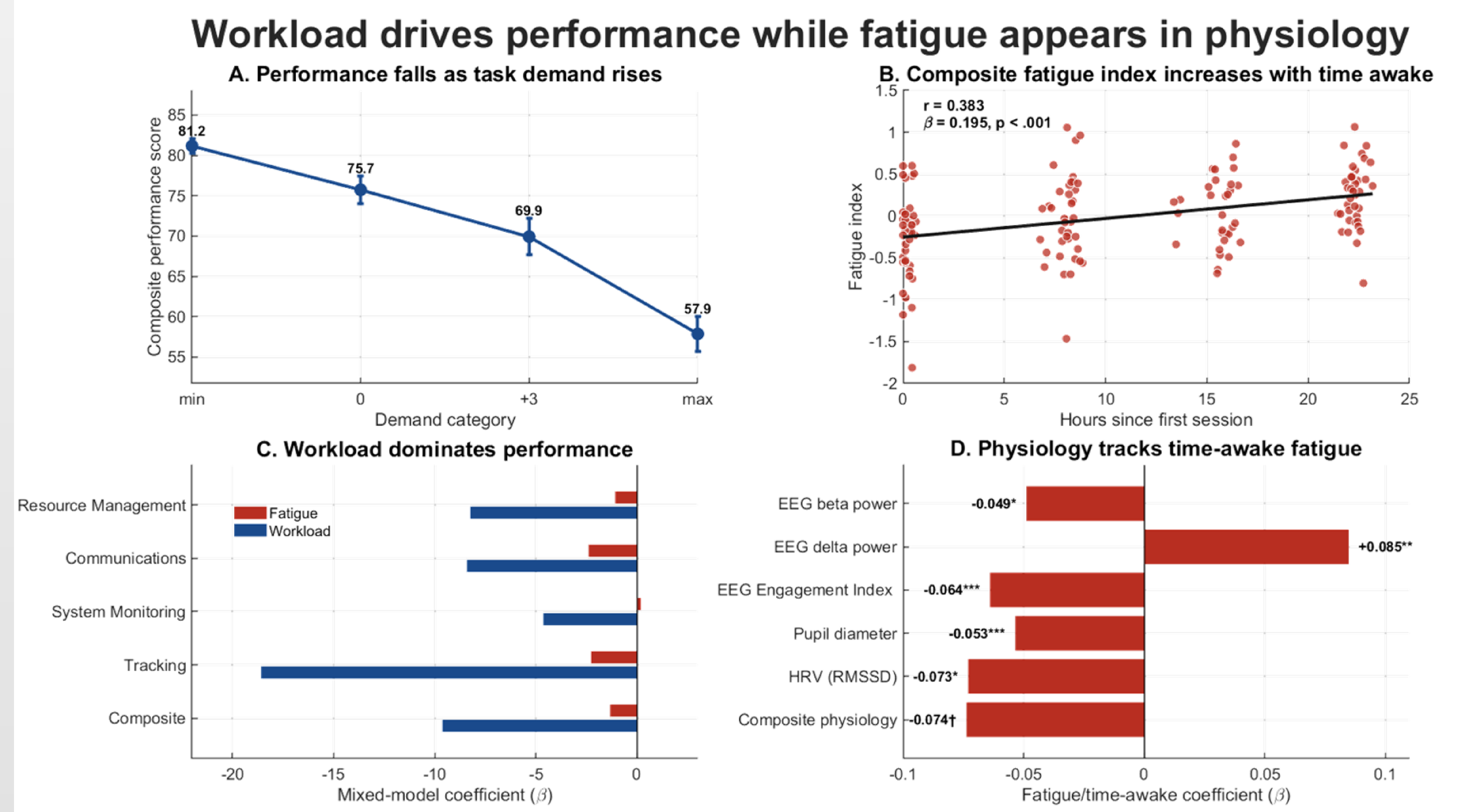


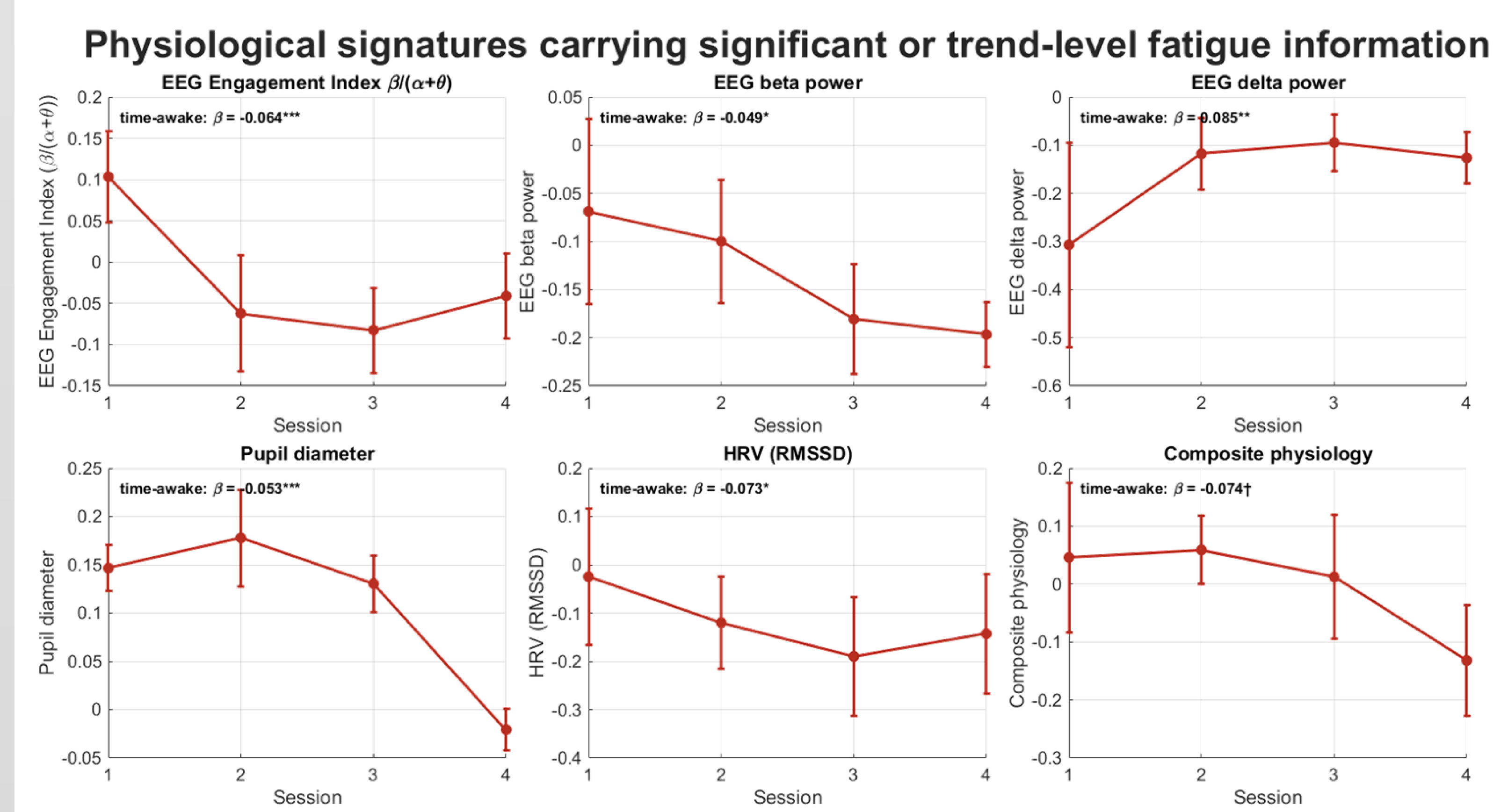
USAARL MATB (Vogl et al., 2024)

Data Processing



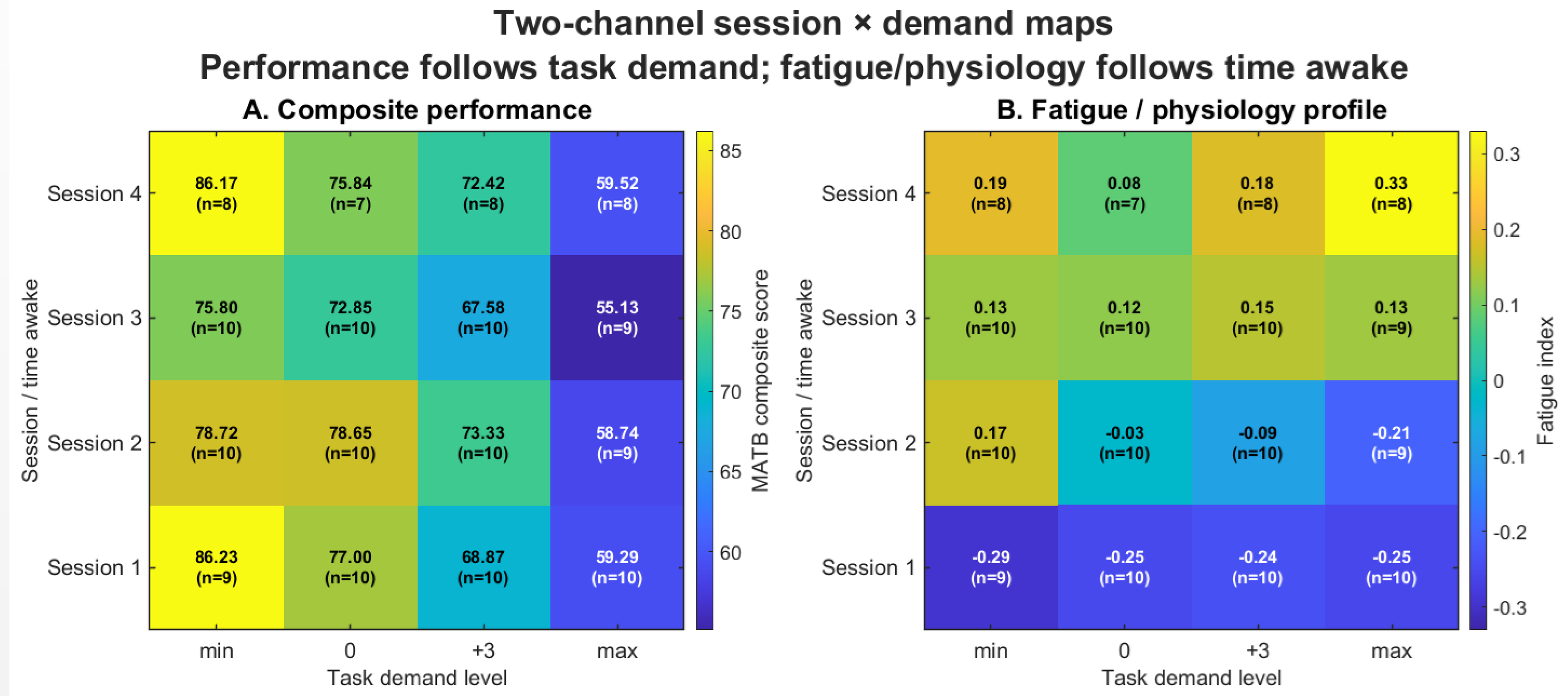
Results





Legend: * $p < .05$, ** $p < .01$, *** $p < .001$; † not significant

Results (continued)



Discussion

Workload and fatigue separated into different observable channels. MATB performance was primarily workload-limited, whereas several physiological measures were more sensitive to time-awake fatigue.

Performance remained the clearest near-term workload indicator. Increasing demand produced large decrements across all MATB performance scores, suggesting that performance-proximal measures are best suited for detecting immediate task-demand risk at trial level.

Physiology carried accumulating fatigue information that was not captured by performance alone. Pupil diameter, EEG engagement index β/(α+θ), HRV (RMSSD), EEG beta power, and EEG delta power shifted with time awake even when workload was controlled.

Composite workload × fatigue coupling was not robust at the trial level. The nonsignificant composite interaction suggests that fatigue did not simply amplify workload effects uniformly across overall performance; instead, workload and fatigue appeared as partially separable signal sources at the block analysis level.

Operational implication: use a two-channel monitoring strategy at the trial analysis level. Performance metrics can support workload management during high-demand task periods, while fatigue-sensitive physiology can support detection of accumulating time-awake risk and trigger mitigation before overt performance failure.

Sleep Study Details (Kelley et al., 2025)

This research was supported in part by an appointment to the Postgraduate Research Program at the U.S. Army Aeromedical Research Laboratory administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Army Medical Research and Development Command.

To learn more, visit:
https://usaarl.health.mil