Physiological Monitoring Under Varied Conditions of Workload and Fatigue

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Learning Objectives

1. Understand the complex relationships between operational stressors in aviation.

2. Characterize the relationships between physiological signals and performance under varied conditions.

3. Decide whether research on operator state monitoring in the cockpit lends towards field testing.

Maintaining Performance in the Cockpit

- The next generation of Army aircraft are projected to:
  - Place higher cognitive demands on pilots
  - Require pilots to sustain performance for longer durations
- Operator state monitoring and adaptive automation provide the possibility to maintain optimal levels of engagement and performance in the cockpit through real-time monitoring and dynamic workflow

Operator State Monitoring Concept Areas

Concept	Research Questions	Description
Measurement	What observable variables are relevant? Does technology support measurement feasibility in the cockpit? What aspects of individual variability need to be measured? What method is used to process measurements?	Physiological variables, estimates of sleep quality and quantity, demographics, health status
Prediction	Is the system detecting a state (e.g., fatigue)? Is the system predicting performance?	State detection may estimate the probability of an adverse state whereas performance prediction may estimate the probability of degradation
Interpretation	How are measurements interpreted? Individually? In combination using a predictive algorithm? How are natural variations within an individual and between individuals controlled for?	Criteria thresholds for measurements or algorithmic output to indicate when automation is to be employed

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Study Objective

- To evaluate changes in physiological measurements and human performance under varied conditions of ***workload*** and ***fatigue***

- To evaluate the consistency of observed changes in physiological measurements across tasks
  - Considering that an OSM system will likely not be tailored to specific functional outcomes or even the same operational conditions, determining which parameters are most sensitive to detecting the effects of stressors will inform their utility in such a system

Methods

- Repeated-measures, within-subjects
- Sustained wakefulness period of 34 hours
- Participants
  - 11 rated aviators
    - All experienced in UH-60 aircraft
    - UH-60 flight hours (*M* = 1471.11, *SD* = 1433.83)
  - 10 male, 1 female
  - Ages between 27 and 46 years (*M* = 34.60 years, *SD* = 6.90)
- Initial visit
  - Consent
  - Medical screening
  - Familiarization with tasks
- Extended visit
  - 34 hours sustained wakefulness
  - Repeated testing

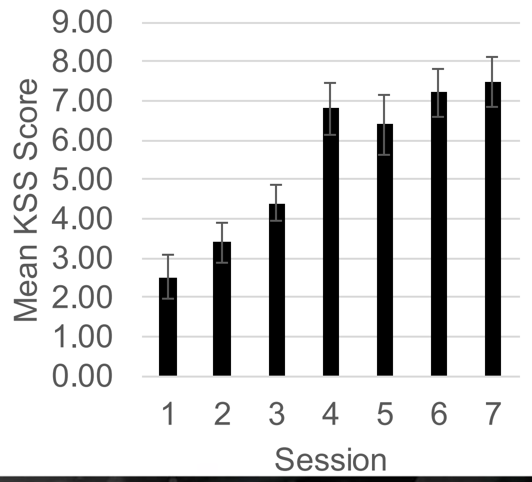
Schedule, Physiological Measurements, and Tasks

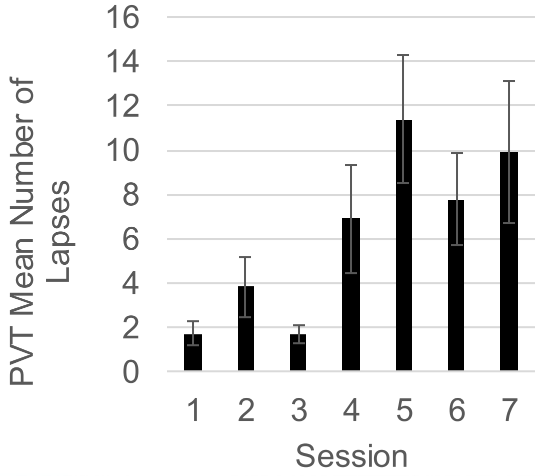
- Physiological measurements
  - Electrocardiography (ECG)
    - Heart rate variability, heart rate
  - Electroencephalography (EEG)
    - Global, parietal, and frontal alpha, beta, and theta activity
  - Pupillometry and eye tracking
    - Pupil diameter, blink rate
- Most tasks/tests repeated 4 times across 34 hours
- Tasks included:
  - Simulated flight scenarios (high/low workload)
  - USAARL MAT-B
  - Cognitive tasks
  - Subjective workload assessments
  - Subjective sleepiness and mood assessments
  - Psychomotor vigilance task

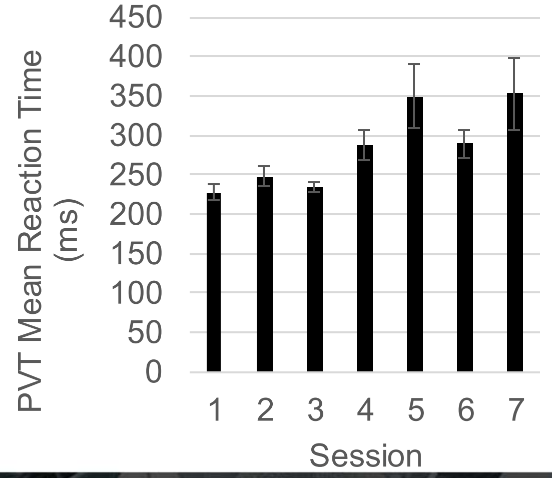
Fatigue Manipulation Check

- Fatigue manipulation confirmed with subjective (e.g., Karolinska Sleepiness Scale (KSS)) and objective (e.g., Psychomotor Vigilance Task (PVT)) data

Task/Questionnaire & Outcome Measures	Fatigue (Session) *p* Values (Effect Size [Partial Eta Squared])
KSS	
Score	< 0.001 (0.68)
PVT	
Mean reaction time	< 0.001 (0.48)
Number of lapses	< 0.001 (0.46)







Consistency of Effects Across Tasks

Physiological Measure	Workload Effects (tasks)	Fatigue Effects (tasks)	Workload*Fatigue Effects (tasks)
		ECG	
Heart Rate	_	USAARL MATB Cognitive tasks Simulated flight	_
Heart Rate Variability	USAARL MATB	USAARL MATB Cognitive tasks Simulated flight	_
		EEG	
Global Alpha Activity	Cognitive tasks	RVIP USAARL MATB Cognitive tasks	_
Global Beta Activity	_	Cognitive tasks	_
Global Delta Activity	_	Cognitive tasks	_
Global Theta Activity	_	USAARL MATB	_
Parietal Alpha	Cognitive tasks USAARL MATB	Cognitive tasks USAARL MATB	_

Consistency of Effects Across Tasks, cont.

Physiological Measure	Workload Effects (tasks)	Fatigue Effects (tasks)	Workload*Fatigue Effects (tasks)
EEG, cont.			
Frontal Theta: Alpha	_	Cognitive tasks Simulated flight	Simulated flight
Frontal Beta: Alpha	_	USAARL MATB Cognitive tasks	_
Eye Tracking			
Blink Count	Cognitive tasks	Cognitive tasks	_
Pupil Diameter	_	Cognitive tasks MATB Simulated flight	_

Discussion

- Fatigue effects were seen with a variety of physiological measures across all tasks
  - Pupil diameter showed sensitivity to fatigue in all tasks whereas at least one measure in each task category (e.g., cognitive tasks) showed sensitivity to fatigue in the majority of tasks
  - Sensitivity to fatigue is well established for many physiological measures whereas specificity has yet to be fully examined for any of these measures, thus a multi-sensor suite will ultimately be needed to circumvent ambiguity based on one physiological measure
- Workload effects were seen with at least one measure in each physiological measures category but only on two tasks
  - While workload was perceived as different between high and low flights, the high workload ratings were low compared to other studies
- Interaction effects were largely non-existent with all physiological measures across all tasks
  - While not specific to the overarching objectives of this study, these interactions on performance highlight the complex nature of realistic environments where multiple stressors are present

Conclusions

- Overall, the findings of this study demonstrate consistency of effects, in a laboratory setting with limited experimental control (e.g., nutrition and light exposure were unregulated), on functional performance outcomes
- Effective physiological monitoring can be achieved using a variety of physiological signals, as several, including pupil diameter, are demonstrated here to be particularly sensitive to fatigue
- A robust OSM system using multiple synchronized, physiological signals can be effectively implemented with commercial grade wearable sensors
- Results support OSM research advancing to testing in more realistic and field environments.

QUESTIONS?

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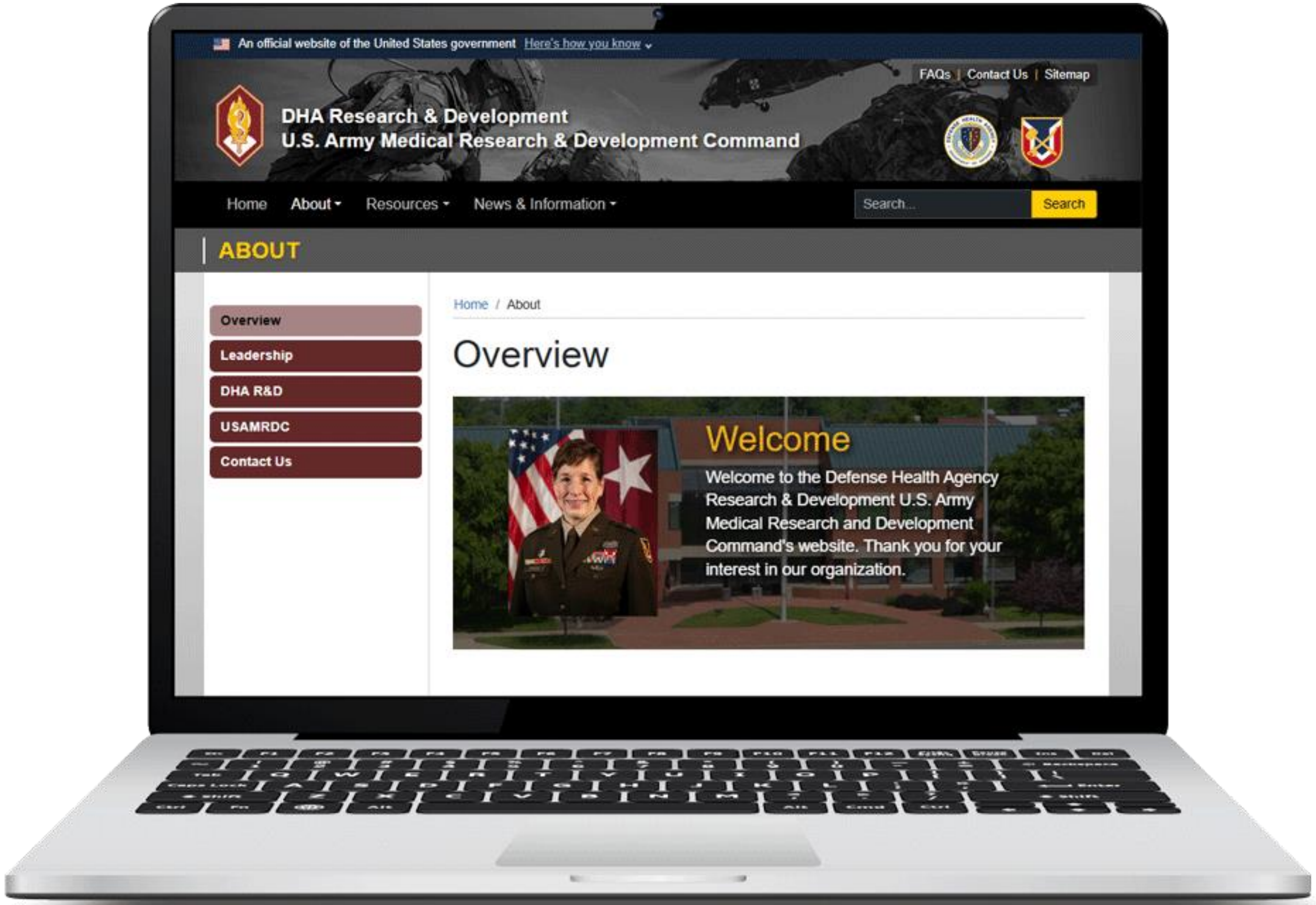

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