Using Physiological Sensors to Understand, Measure and Adapt to Stressors in the C2 Environment

Leigh Baumgart
Kevin Cropper
William Fitzpatrick
Nathan Koterba
Jennifer McKneely
Jennifer Ockerman

APL
The Johns Hopkins University
APPLIED PHYSICS LABORATORY

Command and Control Environment

- Typically long duration activities with not much rest
- Increasing amounts of information to perceive, understand, and respond to with fewer operators
- Intensive and risk adverse operations where warfighter decision making is critical

Understanding Impact of Stressors to Cognition – Impact of Stress and Fatigue

		Executive Function	Attention	Working Memory	Sensory Input	Integrated Evaluation
Task Related Stress						
	Cognitive load	HIGH	MED	MED	MED	HIGH
	Physical load	LOW	HIGH	LOW	MED	LOW
	Situational Awareness	MED	HIGH	HIGH	HIGH	HIGH
Physiological Stress						
	Circadian	LOW	MED	LOW	LOW	MED
	Hydration	LOW	HIGH	LOW	MED	LOW
	Illness	LOW	MED	LOW	MED	LOW
	Mental fatigue	HIGH	MED	MED	MED	MED
	Sleep loss	LOW	HIGH	LOW	HIGH	MED
Environmental Stress						
	Hyperbaric	LOW	LOW	LOW	LOW	HIGH
	Hypoxia	LOW	MED	LOW	LOW	HIGH
	Noise	LOW	MED	LOW	HIGH	HIGH
	Vibration	LOW	LOW	LOW	HIGH	MED
	Sustained Accleration	LOW	LOW	LOW	LOW	HIGH
	Thermal	LOW	HIGH	HIGH	HIGH	MED

All Cognitive Functions are Critical for Effective C2 Warfighter Decision Making – and all are affected by Stress & Fatigue

Table from Boeing presentation at 1st Annual Augmented Cognition Conference

Motivation

- Need mechanisms to identify and manage stress, workload, and fatigue in C2
- In complex environments, there is a lack of structured, objective human performance assessment and measurement methods or techniques for accuracy, timeliness, situation awareness, workload
- Recent technological advances have afforded the ability to develop objective, non-interruptive measures of warfighter cognitive state – these need validation.

Provide an effective method (inclusive of human performance) to evaluate and improve new and existing C2 systems

Augmented Cognition

- Mitigate limitations and extend capabilities of human mind to increase operator's ability to perceive, comprehend, and understand information

  - Methods to objectively measure cognitive state
    - Bio-metric sensor technologies - including EEG, fMRI, fNIR, ECG, GSR, and eye tracking

  - Methods to alter operators' environment to account for cognitive state
    - Information content on displays
    - Slow rate of information presented
    - Provide decision aids

Correlate Physiological Measures with Operator Performance to Provide Better Insight Into Warfighter State and System Performance

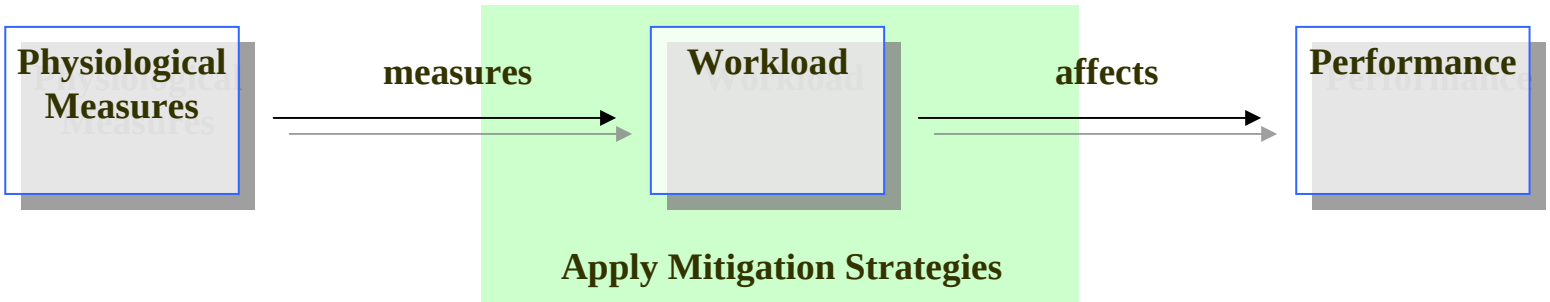
Augmented Cognition Background - Workload

- Lockheed Martin Advanced Technology Laboratory (LM-ATL) research with the Tactical Tomahawk Weapons Control System (TTWCS) (Poythress et al, 2006 and Tremoulet et al, 2006)
- During a TTWCS Human-Computer Interface evaluation, navy operators completed a three hour simulated Tomahawk test mission
- EEG, ECG, and GSR data were collected to investigate the weapon system operator's cognitive state in terms of mental workload
- Physiological data was fused into Lockheed Martin's Sensor-based Mental Assessment in Real Time (SMART) to produce an overall measure of operator workload

Augmented Cognition Background - Workload

- Results from SMART correlated with traditional workload measures gathered from the Multimodal Information Design Support (MIDS) system also collected during the test mission

- This research has led to further investigations of mitigation strategies (i.e., a prioritized task list) based on SMART measures and pre-determined thresholds of cognitive workload



Augmented Cognition Background - Fatigue

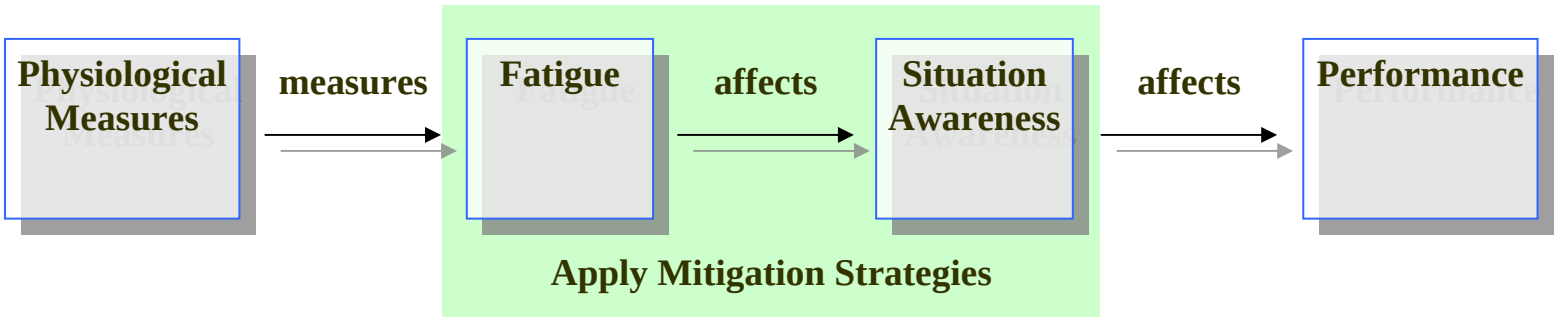
- **Johns Hopkins University Applied Physics Laboratory (JHU/APL) research in an Undersea Warfare domain to investigate the relationships between fatigue and situation awareness (SA)**
  (McKneely et al, 2006 and Moundalexis et al, 2007)

- **4 sonar operators experienced 36 hours of continued wakefulness to simulate chronic fatigue; ECG and eye tracking data collected in addition to objective SA measures**

- **Trends between levels of fatigue and SA were analyzed investigating the relationships between SA, physiological data, task performance, fatigue, and system configuration**

Augmented Cognition Background - Fatigue

- Results indicated that as the person became more tired, eye movements increased and the amount of effort and level of frustration were perceived by the participants
- Mean heart rate was significantly negatively correlated to hours awake and self reported sleepiness
- Although somewhat limited, results suggest the feasibility of assessing fatigue with physiological measures, and understanding the impact that fatigue has on operator SA and performance



Primary Research Objectives

- **Investigate relationships between physiological measures and operator performance under various conditions of stress and fatigue in a simulated emergency response environment to provide validation of physiological measures**

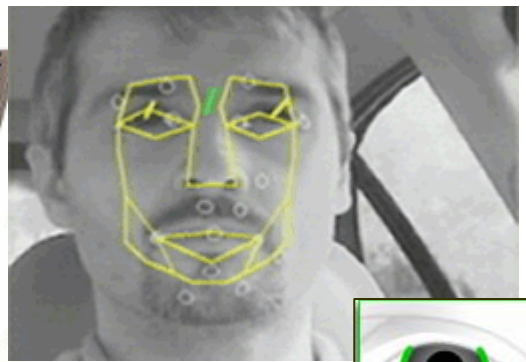
- **Develop a framework and scientifically sound evaluation methodology for C2 design, development, and assessment inclusive of objective, non-intrusive human performance considerations**

- **Integrate these performance relationships into process analysis systems, like JHU/APL's CAOC (Combined Air and Space Operations Center) Performance Assessment System (CPAS)**

Augmented Cognition Suite

Physiological Sensors
Thought Technology

EEG
Advanced Brain Monitoring



Eye tracking
Seeing Machines

Augmented Cognition Investigation - FY07*

- 14 Participants aged 18-25
- Tasked to monitor and interact with four instant messaging windows and a geospatial display during two fictitious emergency situations
- Five types of data will be collected (all within subjects comparison):
  - Wrist activity monitors to document sleep prior to testing
  - Objective data on the accuracy and timeliness of performance
  - Subjective data of perceived workload and fatigue
  - Physiological data (EEG, ECG, GSR, BVP, temp, and respiration)
  - Eye tracking data
- Two independent variables: scenario complexity and duration

* Currently under IRB Review

Procedure

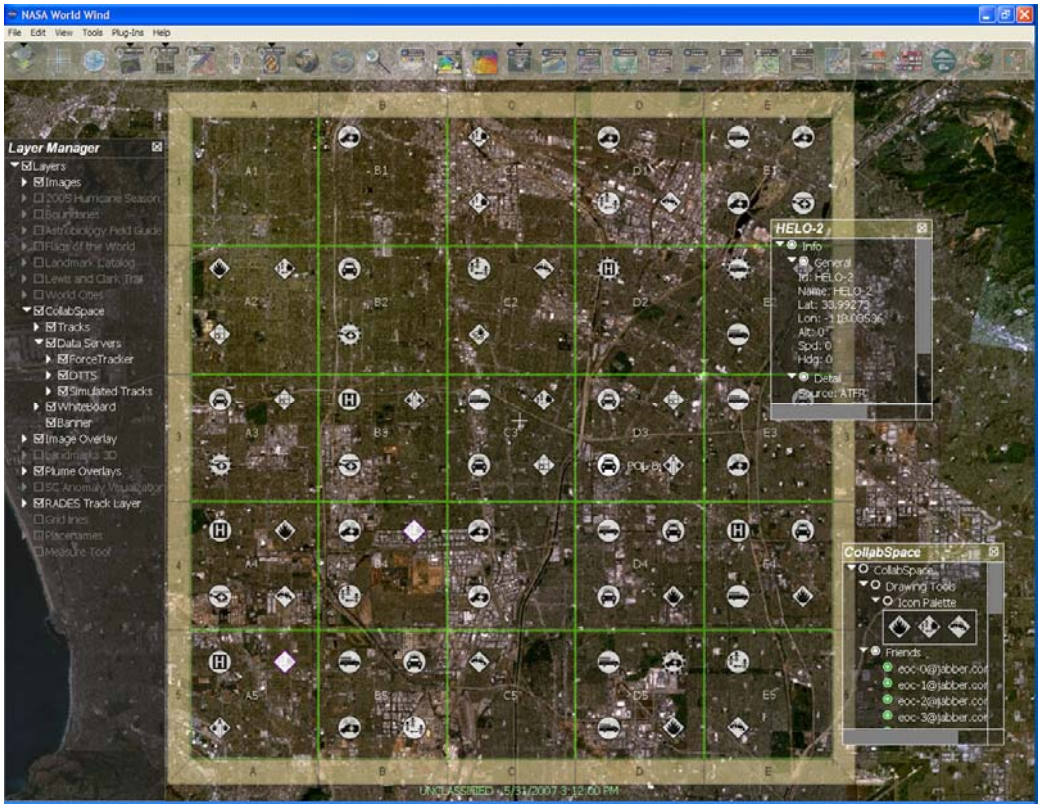
- Training, sensor calibrations, practice scenarios
- Monitor activity/sleep for 48 hours prior to test sessions
- All participants will complete 2 three hour scenarios: A and B (random order, 1 week apart)

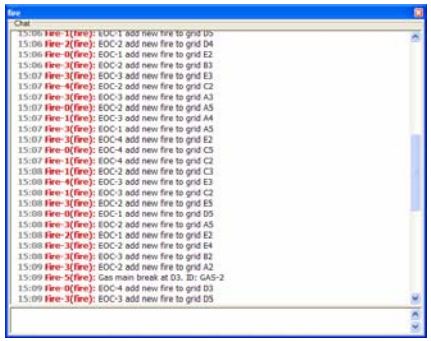
		Duration	
		Short (30-60 min)	Long (150-180 min)
Complexity	Low (more info)	Scenario A	
	High (less info)	Scenario B	

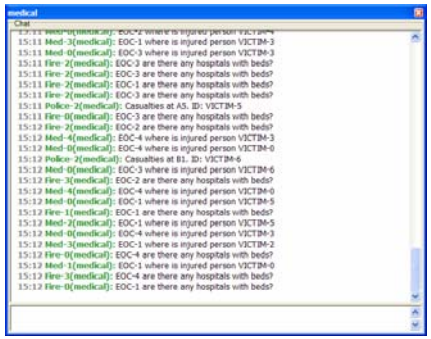
Emergency Response Scenarios

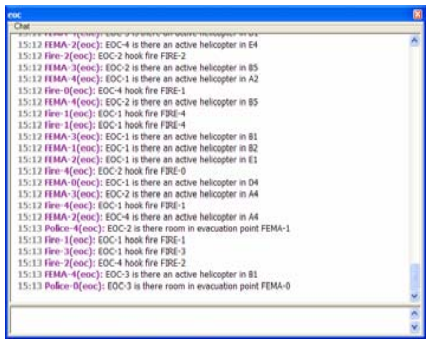
- Participants are told that they are an emergency operations manager at an incident command center in Los Angeles that was established due to earthquake activity
- Responsible for monitoring and interacting with four chat rooms and a geospatial display
- Three major tasks to keep up with during the scenario:
  - Responding to information requests through chat
  - Sending and retrieving surveillance helicopters
  - Managing victims

System to Deliver Scenarios -
NASA World Wind + JHU/APL CollabSpace









Measures

- **Objective Performance – timing and accuracy for three tasks (chat, helo surveillance, victim management)**
- **Subjective Measures – NASA TLX, Fatigue Assessment Survey, Stanford Sleepiness Scale, Situational Awareness Rating Technique (SART)**
- **Physiological Measures**
  - EEG - Brain activity and location
  - ECG - Heart rate (beats/min); Heart rate variability (ms)
  - GSR - Skin conductance (µS)
  - Respiratory - Rate of breaths (beats/min); Depth of breaths
  - Blood Volume Pulse - Blood volume in finger
  - Temperature - Peripheral temp (ºF / ºC)
  - Eye Tracker – Blinks; Pupil Diameter; PERCLOS; Saccades; Gaze Direction
- **Workload Index (LM-ATL SMART)**

Expectations

- Running Experiment July-Aug
- Expect correlations between physiological measures, output of SMART, objective performance measures, and subjective assessments such that validation of objective measures of human performance in complex tasking environment can be made

Value to Command and Control Domain

- Provides objective measures of cognitive states which can be used to evaluate and improve existing C2 systems and to design new C2 systems
- Potential for real-time operator monitoring of fatigue and stress in high stress environments
- Enhance training systems by objectively assessing both operator performance and cognitive state

Deliver increased capabilities to evaluate and improve new and existing C2 Systems

Questions?

The Johns Hopkins University Applied Physics Laboratory

Leigh Baumgart
leigh.baumgart@jhuapl.edu

Jennifer McKneely
Jennifer.mckneely@jhuapl.edu

References

- Case, F. T., Koterba, N., Conrad, G., Ockerman, J., & Vanderberry, R. (2006, June 20-22, 2006). *An instrumentation capability for dynamic targeting.* Paper presented at the 2006 Command and control Research and Technology Symposium, San Diego, CA.

- Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors, 37*(1), 65-84.

- McKneely, J. A., Bevan, M., Cropper, K., Iny, M., & Vaughan, F. (2006, June 20-22, 2006). *Initial investigation on fatigue in command and control situation awareness: Physiology and cognitive performance.* Paper presented at the 2006 Command and Control Research and Technology Symposium, San Diego, CA.

- Moundalexis, M., McKneely, J. A., & Cropper, K. (2007, March 19-21, 2007). *Undersea warfare situation awareness and fatigue.* Paper presented at the ASNE Human Systems Integration Symposium, Annapolis, MD.

References

- Poythress, M., Russel, C., Siegel, S., Tremoulet, P. D., Craven, P., Berka, C., et al. (2006, October 16-20, 2006). *Correlation between expected workload and EEG indices of cognitive workload and task engagement.* Paper presented at the 2nd International Conference on Augmented Cognition, San Francisco, CA.

- St. John, M., Risser, M. R., & Kobus, D. A. (2006, October 16-20, 2006). *Toward a usable closed-loop attention management system: Predicting vigilance from minimal contact head, eye, and EEG measures.* Paper presented at the 2nd International Conference on Augmented Cognition, San Francisco, CA.

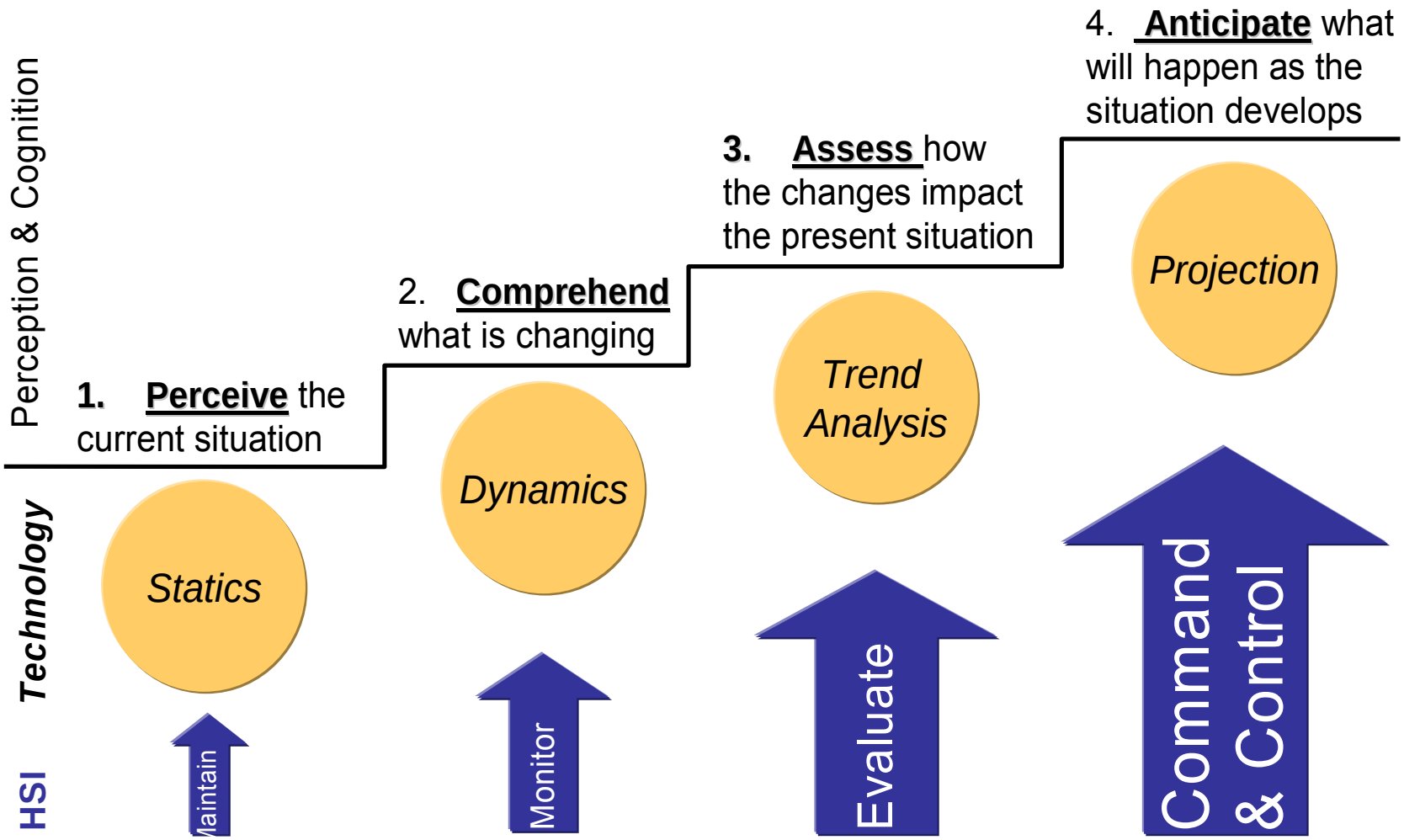
- Tremoulet, P., Barton, J., Craven, P., Gifford, A., Morizio, N., Belov, N., et al. (2006, October 16-20, 2006). *Augmented cognition for Tactical Tomahawk Weapons Control System operators.* Paper presented at the 2nd International Conference on Augmented Cognition, San Francisco, CA.

Back-up Slides

Future Work

- Complete initial augmented cognition investigation (this summer) to understand correlations between an operator's cognitive state and their performance
- Integrate with CPAS to provide more comprehensive assessment capabilities for both training and real-time operations
- Run experiments in C2 test bed at JHU/APL
- Evaluate alternate human-system integration solutions for mission performance and operator workload

JHU/APL Definition of Situation Awareness



Based on Endsely (2000)

NASA TLX Probes and Scales

- Temporal Demand
  - *Time Pressure*: How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?
    - None 1 2 3 4 5 6 7 Extreme
  - *Pace*: Was the pace slow and leisurely or rapid and frantic?
    - Slow 1 2 3 4 5 6 7 Frantic
- Effort
  - *Effort*: How hard did you have to work (mentally and physically) to accomplish your level of performance?
    - Little 1 2 3 4 5 6 7 Significant
- Performance
  - *Success*: How successful do you think you were in accomplishing the goals of the task set by the experimenter?
    - Completely Successful 1 2 3 4 5 6 7 Not Successful
  - *Satisfaction*: How satisfied were you with your performance in accomplishing these goals?
    - Completely Satisfied 1 2 3 4 5 6 7 Not Satisfied
- Frustration Level
  - *Frustration*: How secure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?
    - Relaxed 1 2 3 4 5 6 7 Stressed

Stanford Sleepiness Scale

- Administered at beginning and end of testing session.
- Scale values:
  - 1: Feeling Active, vital, alert, or wide awake
  - 2: Functioning at high levels, but not at peak; able to concentrate
  - 3: Awake, but relaxed; responsive but not fully alert
  - 4: Somewhat foggy, let down
  - 5: Foggy; losing interest in remaining awake; slowed down
  - 6: Sleepy, woozy, fighting sleep; prefer to lie down
  - 7: No longer fighting sleep, sleep onset soon; having dream-like thoughts
  - X: Asleep

Situation Awareness Rating Technique

- Demand on Attentional Resources
  - *Instability*: Likelihood of situation changing suddenly
    - Low -2 -1 0 1 2 High
  - *Complexity*: Degree of complication of situation
    - Low -2 -1 0 1 2 High
  - *Variability*: Number of variables changing in situation
    - Low -2 -1 0 1 2 High
- Supply of Attentional Resources
  - *Arousal*: Degree of readiness for activity
    - Low -2 -1 0 1 2 High
  - *Concentration*: Degree of focus required
    - Low -2 -1 0 1 2 High
  - *Division*: Amount of attention required in situation
    - Low -2 -1 0 1 2 High
  - *Spare Capacity*: Ability to pay attention to other tasks or things
    - Low -2 -1 0 1 2 High
- Understanding of the Situation
  - *Information Quantity*: Amount of information received and understood
    - Low -2 -1 0 1 2 High
  - *Information Quality*: Degree of usefulness of information
    - Low -2 -1 0 1 2 High