Physiological Monitoring in Extreme Environments: The View from NASA

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Outline

- NASA Exploration Requirements
- NASA Ames Capabilities and Technologies
- Ames Laboratory Simulation Research
- Conclusions

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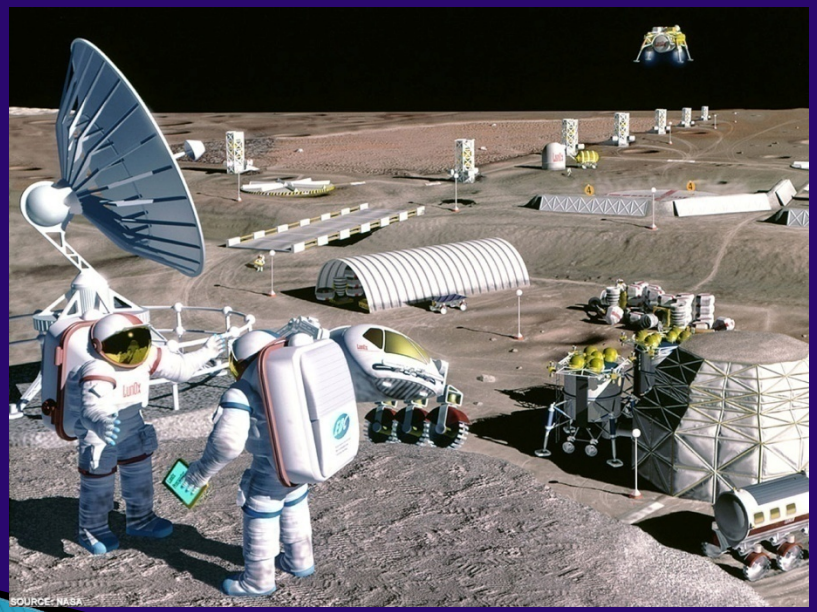
Exploration Missions: Unforgiving Isolated and Confined Environments

NASA REQUIREMENTS

- **Physiological / medical sensing**
- **Cognitive function monitoring**



NASA REQUIREMENTS

- **Non-intrusive technologies**
- **Real-time data**
- **Self-test tools**

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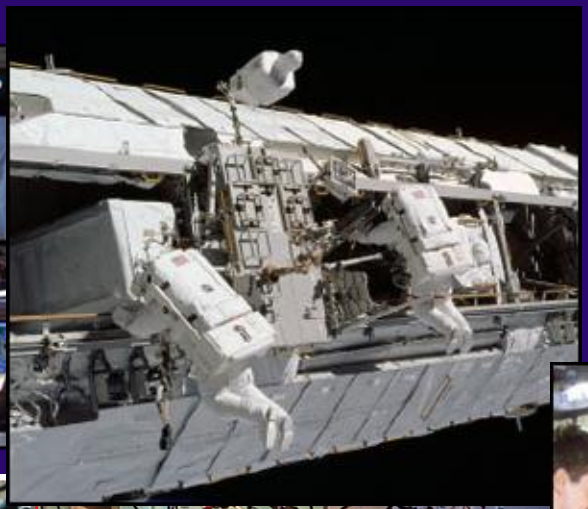
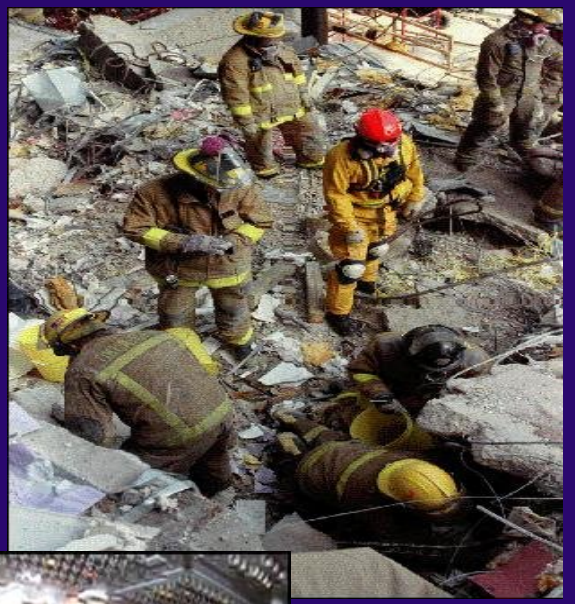
Research Domains





NASA Ames' Capabilities

- Location determination and communication
- Environmental sensing
- Portable medical / psychophysiological monitoring
- Human factors research
  - Cognitive and physiological monitoring
  - Countermeasures

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Location and Environmental Sensing

- Location determination and multipath suppression in enclosed structures
- Coding of transmissions to identify individual responders
- Data communication in extreme environments (fires, hazmat releases, etc.)

- Sensing:
  - Environmental
  - Gas concentration (down to ~ 100 ppb)
  - Chemical composition
  - O2, CO2, CO and NO, Biomolecule, Hydrocarbon

- Real time sensing:
  - gas pressure and temperature
  - sound intensity
  - radiation intensity sensing in real time
  - bioelectric potential sensing
  - sub-vocal speech

For further information: NASA Ames CODE DL
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Medical Monitoring

- Prototypes to measure, monitor and analyze
  - ***Microprocessor-controlled 3-channel Electrocardiograph***
  - ***Computerized Electrocardiograph with automatic interpretation based on over 80 criteria and over 150 ECG parameters automatically measured from the standard12 ECG leads***
  - ***Portable one-channel electrocardiograph***
  - ***Computerized spirometer***
  - ***Pulse oximeter***
  - ***Defibrillator***

For further information: NASA Ames CODE TI
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Human Performance Research

Technologies to monitor and support individual and crew performance

- Psychophysiological Research Lab
- Distributed Team Performance Lab
- Fatigue Countermeasures Lab
  - Examine relationships between behavior and physiology
  - Study impact of environment on health, performance, and safety
  - Develop and test countermeasures

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Fitness to Perform Studies – General Approach

- Determine predictive validity of RTP instruments in a distributed TEAM SIMULATION environment under SLEEP DEPRIVATION and TASK STRESS

  - PASSIVE: Incidental indicators, no active response required
    - Physiological responses (Kraft, et al, 2002)
    - Oculomotor (Index of Cognitive Activity) (Marshall, 2007)

  - ACTIVE: Objective, require deliberate effort by participants
    - WinSCAT (Sipes et al., 2005)
    - Psychomotor Vigilance Test (PVT) (Dorrian, Rogers & Dinges, 2005)
    - Automated Operator Span (AOSPAN) (Unsworth, et al., 2005)

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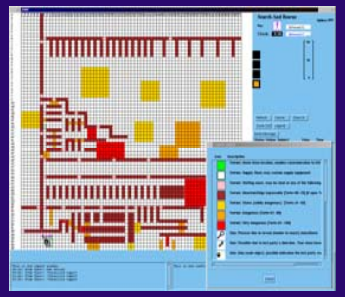
Team Simulation Overview

- Distributed Dynamic Lunar Search Simulation
  - Cognitive Team Processes
    - Plan and coordinate search
    - Share information
    - Manage limited resources
    - Cope with time stress
  - 4 searchers, 1 base camp coordinator
    - Communicate via e-mail, voice
  - 6 75-min. computer-based scenarios
    - Administered during 37 hr. awake period



Developed by Aptima, Inc.

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Physiological Monitoring

- FlexComp Infinity*
  - High quality of data and 2000Hz sampling rates
  - Ten physiological channels
  - Data transmitted by Bluetooth
  - Use prior to critical mission tasks
- Limitations
  - Sensitive to physical disturbances and wireless interference
  - Obtrusive and uncomfortable
  - Data can be only processed offline

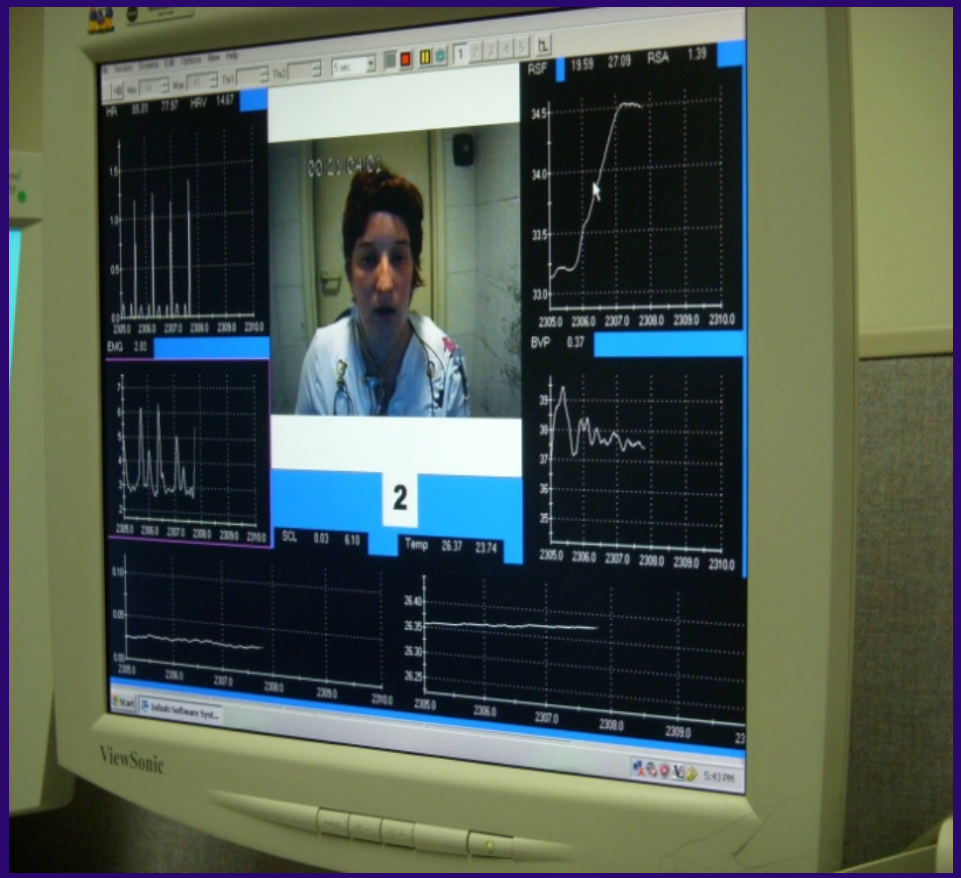
* http://www.thoughttechnology.com/
Thought Technology Limited.

FlexComp Infinity Measures

Electrocardiography (ECG)

Electromyography (EMG)

Skin Conductance Level (SCL)



Respiration Rate (RR)

Finger Pulse Volume (FPV)

Skin Temperature (ST)

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Physiological Monitoring

- Zephyr BioHarness*
  - Used in 2 NASA fatigue studies
  - Data logged for up to 16 hours
  - Lightweight and comfortable

- Limitations
  - Chest belt must be kept wet
  - Real-time analyses of ECG curves not available

* http://www.zephyrtech.co.nz/ Zephyr Technology Limited.

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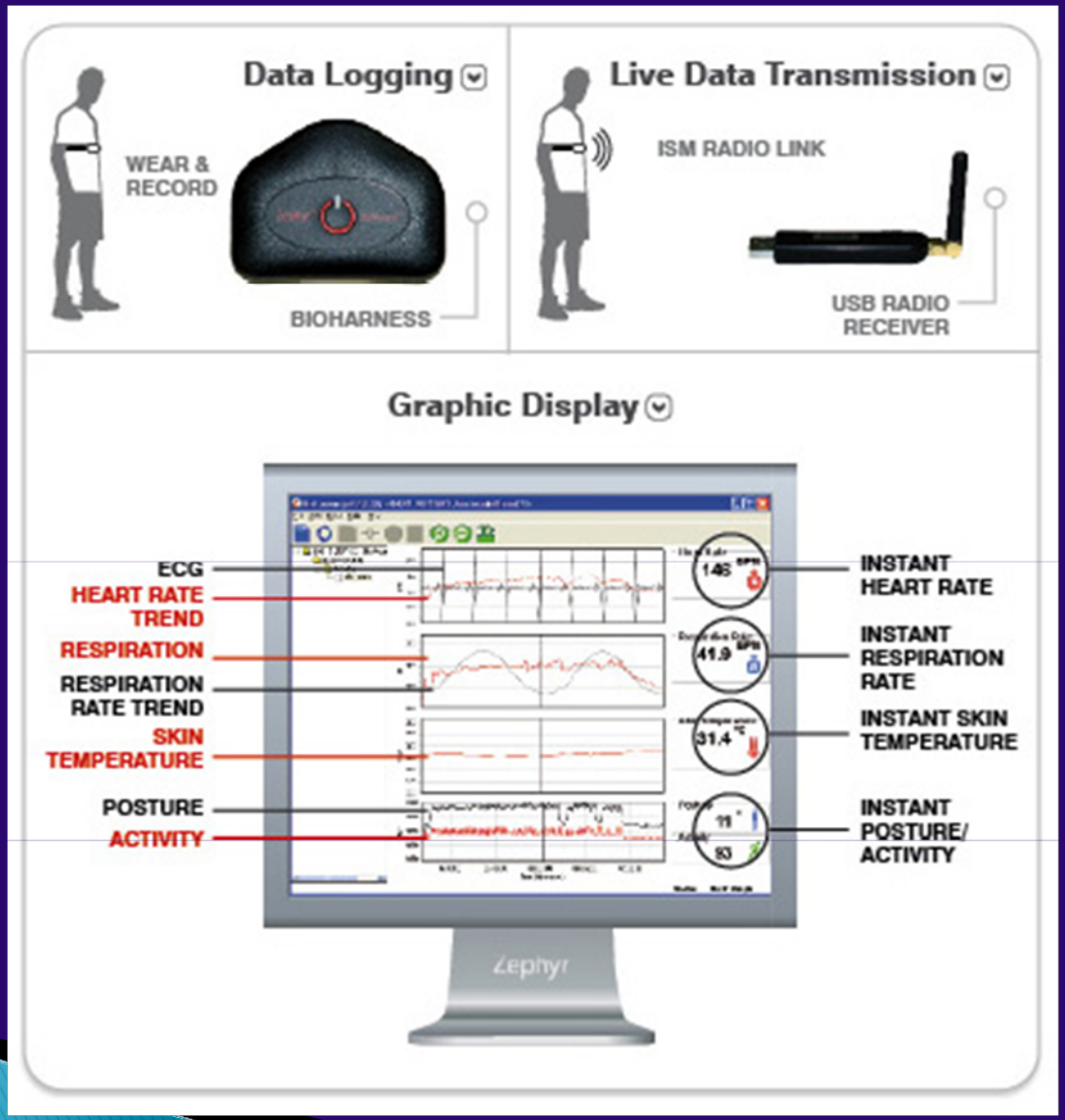
Zephyr BioHarness – Measures



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Oculomotor Monitoring

- Continuous Eye Monitoring*
  - Real-time measures of fatigue, stress and effort
  - **ICA (Index of Cognitive Activity)**
    - **The number of changes in pupil size per second (separately for the right eye and the left eye) yields a metric of cognitive effort**
  - **Validation tasks**
    - **Military tactical decision making, driving, arithmetic reasoning, distributed team search**
- Limitations
  - Current eye tracking cameras are bulky
  - Individual calibration required

* Marshall, S. P. (2007). Identifying cognitive state from eye metrics. *Aviation Space & Environmental Medicine, 78*(5), II, B165-175.

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Eye Tracking System

Cognitive Workload Assessment Dashboard (CWAD) is a proprietary EyeTracking system that displays the computed estimate of cognitive workload as it occurs during the task.

The workload history is plotted for each eye, allowing comparison of left and right eye responses to task difficulty and fatigue over the entire length of the task run.

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Current NASA Tool: WinSCAT

- WinSCAT*
  - Self-referenced test
  - Baseline established pre-flight on ground
  - Used prior to critical mission tasks

- Limitations
  - Disruptive, voluntary
  - Sensitive to motivation and practice effects
  - Designed to assess cognitive trauma, not fatigue, stress, workload

* Kane, R. L., Short, P., Sipes, W., & Flynn, C. F. (2005). Development and validation of the Spaceflight Cognitive Assessment Tool for Windows (WinSCAT). *Aviation Space & Environmental Medicine, 76*(6), B183-191.

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Future NASA Tool: PVT

- PVT*
  - 10-minute Self-test tool
  - Sensitive to sleep deprivation
  - Not sensitive to aptitude and practice effects
  - Use prior to critical mission tasks
- Limitations
  - Disruptive, voluntary
  - Designed to assess only vigilant attention and psychomotor speed
  - 3-minute tool being validated for Astronauts

* Dinges, D. F., Pack, F., Williams, K., Gillen, K. A., Powell, J. W., Ott, G. E., et al. (1997). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep, 20*(4), 267-277.

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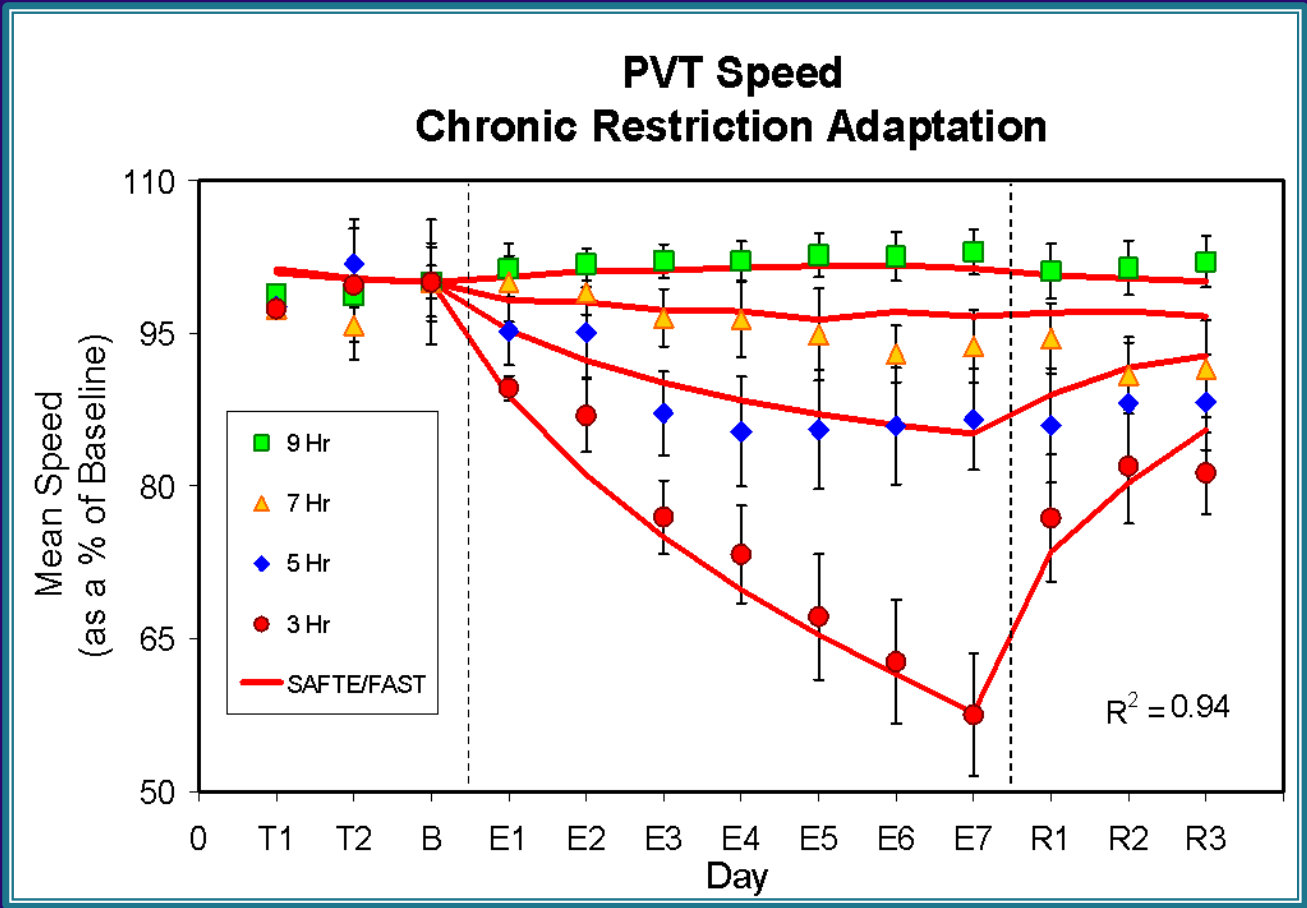
PVT and Sleep Restrictions



Patterns of changing reaction times on the PVT associated with varying levels of sleep restriction over a week and subsequent recovery sleep (Dinges, D. F., 1997).

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Research Tool

- AOSPAN*
  - 20 minute test of working memory
  - Better predictor of complex performance than simpler alertness measures
  - Good internal consistency (alpha=.78) and test-retest reliability (.83)

- Limitations
  - Disruptive, voluntary
  - Designed to assess working memory and RT, not fatigue and stress

* Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, 37(3), 498-505.

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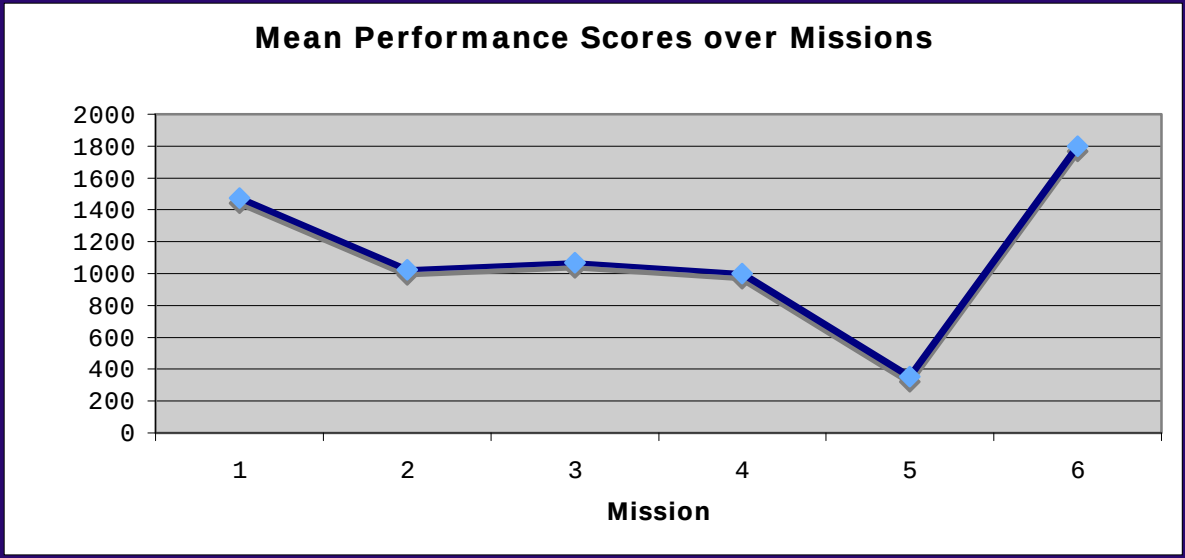
RESULTS: Mission Performance by Time, Task Difficulty



- Better performance on moderate than difficult missions (Mod = 1, 4, 6, Diff = 2, 3, 5)
- Mission performance reflected time of day and cumulative fatigue
  - E.g., Difficult mission (M-5) after awake for 27 hours
  - Some variability between individuals, but common fatigue & difficulty effects

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RESULTS: Physiological Monitoring

- PRIOR STUDY: Physiological measures reflected Task Difficulty
  - Heart Rate and RRI
    - HR higher on difficult missions
- No interpretable differences across Ss
  - Physio arousal did not differentiate more/less successful participants
- Teams with calmer Base Coordinators performed better
  - Lower variability in HR => higher team performance

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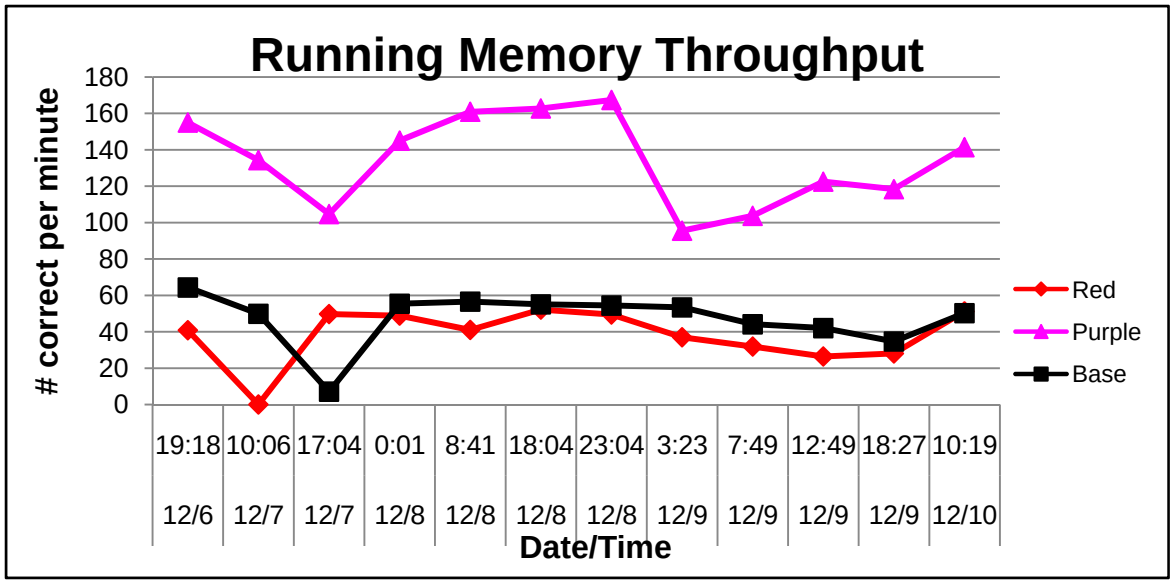
RESULTS: WinSCAT

WinSCAT reflects different temporal patterns and vulnerability across Ss.



Test batteries reflect differential impact of fatigue on distinct cognitive functions:
attention, memory, and reasoning.

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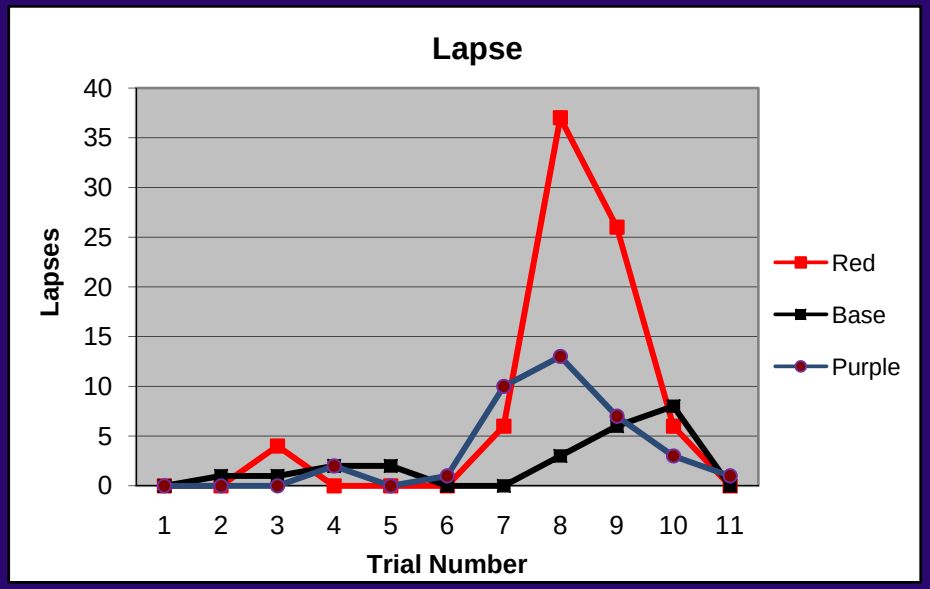
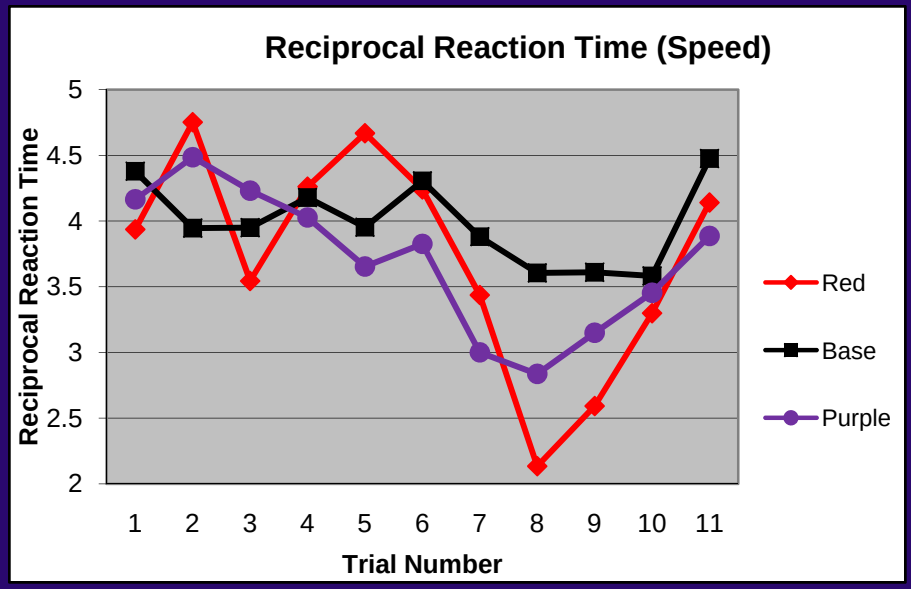
RESULTS: PVT

PVT illustrates different temporal patterns and vulnerability across Ss.





Psychomotor Vigilance Task (PVT)
Measures the ability to recognize and respond to rapidly presented variable interval stimulus over 10 minutes (Lapses = RT > 500ms).

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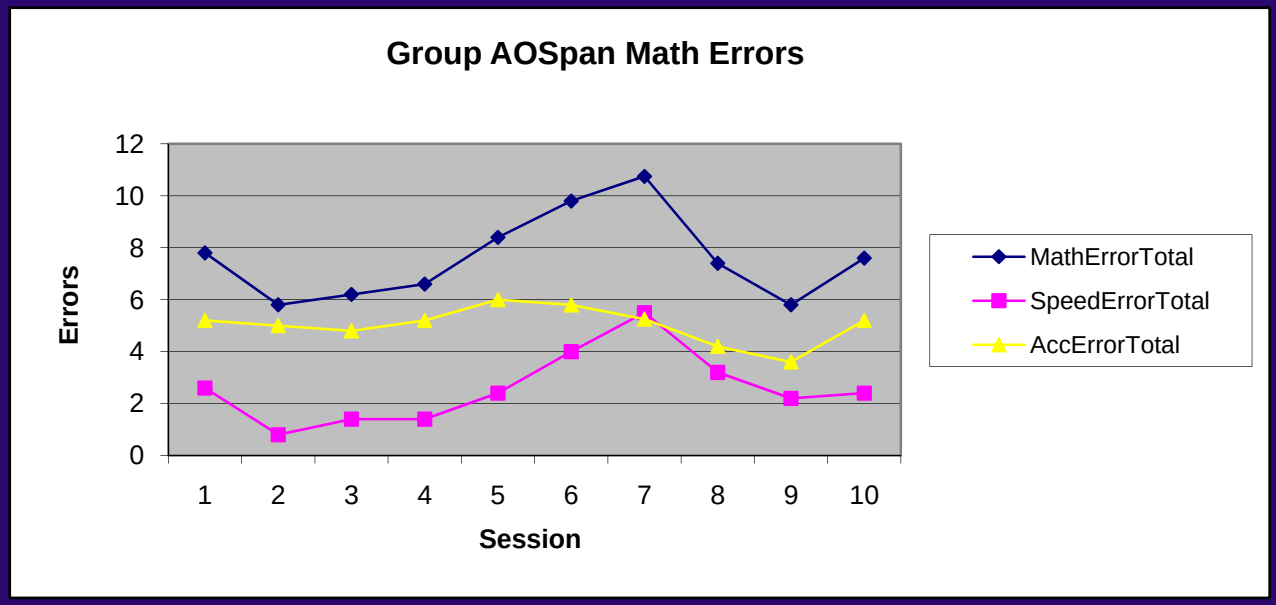
RESULTS: AOSPAN

Total Math Error scores reflected reduction in SPEED component



Mathematical and Speed (Lapses) Error rate increased during sleep deprivation.
Accuracy (working memory) Error rate did not increase during sleep deprivation.

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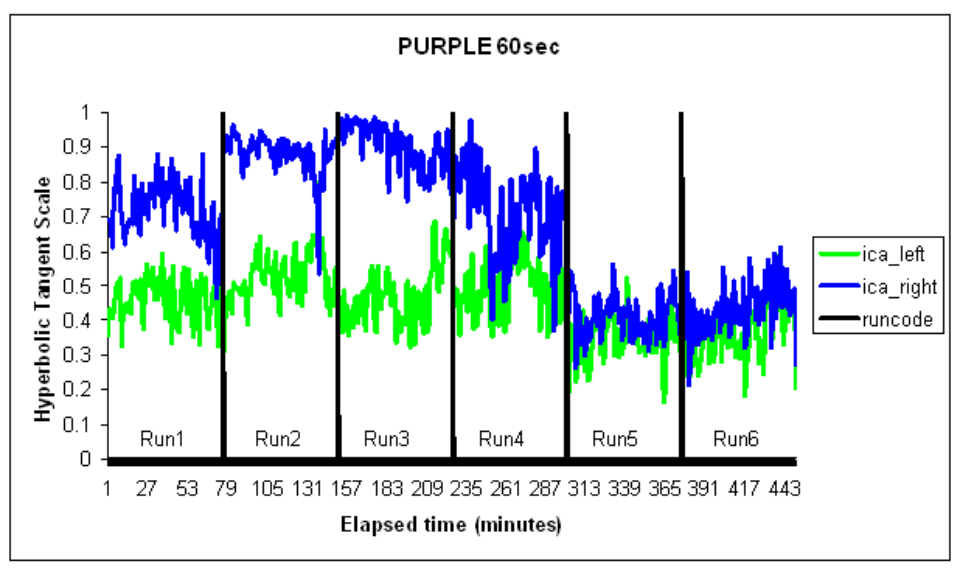
RESULTS: ICA

- **Oculomotor measures differentiated HIGH and LOW workload missions regardless of fatigue state**

- **Oculomotor responses differentiated FATIGUE levels, holding task difficulty constant**



Left and Right changes in pupil activity values across all 6 runs (1-min intervals).

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SUMMARY

PASSIVE: Incidental performance indicators that require no deliberate effort by participant

- Examples: Physiological measures, oculomotor measures, voice communication

- ADVANTAGES
  - –Continuous rather than point assessment
  - –Do not disrupt ongoing tasks
  - –Sensitive to both depressive and active stress states
- DISADVANTAGES
  - –Equipment may be cumbersome
  - –Limited automated analysis tools

ACTIVE: Self-contained tests that require deliberate effort by participants

- Examples: WinSCAT, PVT, Aospan

- ADVANTAGES
  - –Proven reliability; validated in numerous environments
  - –WinSCAT currently in use in ISS + prior missions
- DISADVANTAGES
  - –Disrupt ongoing work
  - –Susceptible to test-taking strategies, effort, ceiling effects
  - –Uncertain sensitivity to non-clinical stressors (e.g., fatigue)

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Conclusion

- NASA Ames has the capability --
  - To conduct research on individual and crew vulnerability in extreme environments
  - To develop, test and prototype monitoring technologies
    - Medical
    - Physiological
    - Environmental
    - Cognitive
    - Position data
  - To develop and evaluate COUNTERMEASURE technologies

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THANK YOU!

FOR FURTHER INFORMATION --

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