# Evaluation of Performance, Fatigue and Workload During Real-Time, Reactive Telerobotic Mission Control Operations


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## INTRODUCTION

- Telerobotic operations involve a user operating a robot from a different location from where the activity is taking place.
- It can be difficult for humans to maintain performance when faced with physiological stressors, such as fatigue or illness.
- Operations require vigilance for extended periods, raising safety concerns surrounding operator's **fatigue** and **workload**.
  - Every hour of wakefulness increases the drive to sleep, causing increased reaction time (RT), increased lapses in attention (RT > 500 ms), and decreased memory capability [27, 40, 66].
  - The NASA Task Load Index (NASA-TLX) was created to evaluate the multiple attributes surrounding workload (e.g., mental and physical demands)[44, 45].
- The upcoming **Volatiles Investigating Polar Exploration Rover (VIPER)** mission involves remotely controlling a lunar vehicle from an Earth-based mission control station.
  - Goal of VIPER is to excavate the moon for volatiles (water) deep in the surface near the south pole.
  - 100-day, continuous operation

## PURPOSE

- We aimed to evaluate fatigue and workload to gain a better understanding of the staffing requirements for the VIPER mission.
- We evaluated **fatigue** and **workload** of trained operators (i.e., former Resource Prospector mission, now under the name VIPER) using the computer-based simulated control center environment at NASA ARC
- We evaluated:
  - How many hours an individual could drive before experiencing elevated fatigue and workload
  - Whether there were differences in the length an individual could sustain performance during midday compared to after midnight
- **Hypotheses:**
  - Performance of the drives would worsen over time
  - Midnight drives would result in worse performance relative to the midday drives

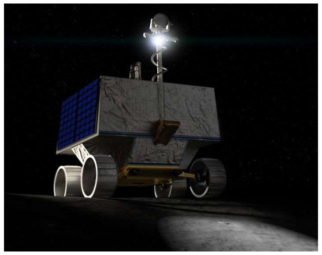

**Figure 1:** NASA's concept of the Volatiles Investigating Polar Exploration Rover (VIPER), taken from the NASA.gov website; credit to NASA Ames and Daniel Rutter for the image

## METHODS

### Participants

- Of the 16 trained operators, a total of seven (n = 7, 1 female) participated (5 drivers; 2 real-time scientists).
  - Due to the uneven distribution of drivers and real-time scientists (RTSci), two researchers from the Fatigue Countermeasures Lab at NASA ARC acted as RTSci.

### Driver activities

- Drivers operated a 3D projected word space of the moon (320m x 320m) while maintaining health of the rover.
  - Preventing crashing the rover (i.e., tilt over 15/25°)
  - Maintaining sun exposure on the solar panels
- Drivers issued commands to the rover, such as capturing hazards or photo-realistic images of the space around the vehicle.

### Real-time scientist activities

- Observed flow of data from the hydrogen sensors on the rover
- Provided input on specific locations to travel to within the traverse plan

### Measures

- Prescreen:
  - **Morningness-Eveningness Questionnaire** (MEQ)
  - **Pittsburgh Sleep Quality Index** (PSQI)
  - **Epworth Sleepiness Scale** (ESS)
- Sleep and Performance:
  - **Actigraphy** (Actiwatch Spectrum, Respironics Inc®).
  - **Karolinska Sleepiness Scale** (KSS)
  - **NASA Task Load Index** (NASA-TLX)
  - **NASA Psychomotor Vigilance Task** (NASA PVT; 5-min)

### Protocol

- Participants were randomized into two drives: **noon** (1200 – 1700; first drive for n = 4; second drive for n = 3) and **midnight** (0000 – 0500; first drive for n = 3; second drive for n = 4).
- Each drive lasted 5h total with performance testing every 25 min.

### Analysis

- **PVT:** mean RT, lapses (i.e., RT > 500 ms), optimum response timing, cognitive slowing, and two standard deviation limits (from mean)
- **TLX:** weighted workload and two-standard deviation limits (from mean)
- Paired t-tests used to evaluate the relationship between drives

## RESULTS

### KSS

- Statistically significant increase from the noon drive ($M = 3.12$, $SD = 1.44$), to the midnight drive ($M = 5.06$, $SD = 2.28$), $t(65) = -9.13$, $p < .0001$, 99% CI [-2.37, -1.30]

### NASA-TLX

- Statistically significant decrease from the noon drive ($M = 37.93$, $SD = 20.09$), to the midnight drive ($M = 32.09$, $SD = 21.74$), $t(65) = 2.81$, $p = 0.007$, 99% CI [0.32 , 10.98]

### NASA-PVT

- No difference between the noon drive ($M = 322.58$, $SD = 21.75$), to the midnight drive ($M = 323.49$, $SD = 31.78$), $t(65) = 0.15$, $p = .89$, 99% CI [-9.96, 10.00]

## RESULTS (cont.)

- Increased time on task leads to poorer performance
- PVT performance exceeded two standard deviations from baseline after approximately **three hours** of driving (during both drives)
- Performance was more variable between participants as time went on, especially during the midnight drives, suggesting that shorter durations of driving might be preferable.

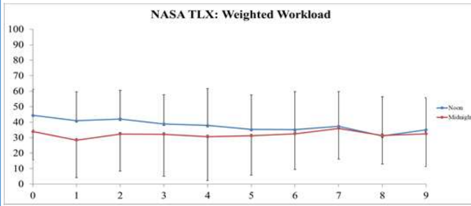


**Figure 2:** Comparison of the average weighted workload (x-axis) throughout the two drives ( from the NASA-TLX; error bars represent standard deviation

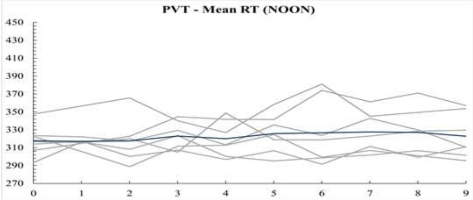


**Figure 3:** Average RT throughout the noon drive displaying individual variation (in grey) with the average RT (in blue)

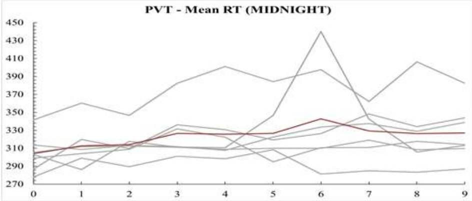


**Figure 4:** Average RT throughout the midnight drive displaying individual variation (in grey) with the average RT (in red)

## CONCLUSION

### Main Findings

- Contrary to our hypotheses, we found that overall weighted workload was slightly higher during the noon drives compared to the midnight drives.
  - Temporal and Mental Demand, followed by Effort, were the highest rated demands during the noon drives.
  - Mental Demand, followed by Own Performance and Effort, were the highest rated demands during the midnight drives.
  - Physical demands were rating slightly higher in the midnight drives ($M = 11.36$) compared to the noon drives ($M = 8.94$).

### Future Directions

- Further simulation testing with more participants, potentially assessing handoff procedures from one shift to another.

## CHALLENGES

1. **Scheduling**
2. **Timing**
3. **Technical Difficulties**

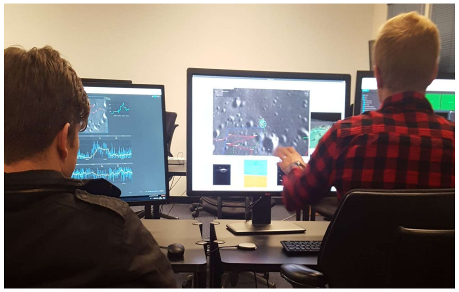

**Figure 5:** Personal photo taken during an evening of simulation testing: left monitor is for the RTSci operator viewing the two-count channel, and the two monitors on the right are for the driver. Middle monitor displays the 3D worldspace, and the rightmost monitor displays all the images captured.

## RECOMMENDATIONS FOR OPERATORS

- At least 10 full-time drivers will be needed to cover 24/7 operations (based on graph below)
- Length of shift should not exceed 8 hours, else sacrifice alertness and performance[7, 32]
- Duration of drive should not exceed 4 (day) or 3 hours (night)
- No personnel scheduled for more than 2 night shifts in a row[39, 63]
- Shifts should be fast, forward rotating (i.e., clockwise)[80]
- Personnel should have at least 10 hours of recovery (day shift)
- Personnel should have at least 12 hours of recovery (night shift)
- Accommodations to personnel (e.g., lodging or commuting)
- Fatigue Risk Management training to all staff prior to mission

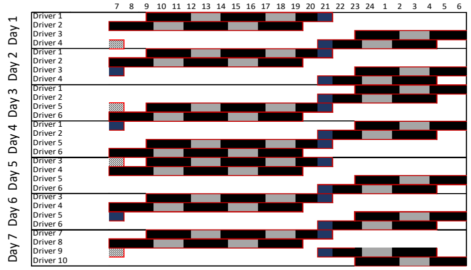


**Figure 6:** Example shift schedule for 12 hour operations. Each driver is scheduled for either an early morning shift (07:00), late morning (09:30), night (21:00), or late night (23:30). Day shifts last for 12 hours, nights for 8 hours. Each drive is shaded black, with "breaks" scheduled in between (in grey). Blue shaded regions represent handover to the next shift. Each drive lasts three hours, followed by a two hour break. Each handover lasts one hour.

## REFERENCES