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 decreased 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** using the computer-based simulated control center environment at NASA ARC.
- Participants included trained VIPER operators
- 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

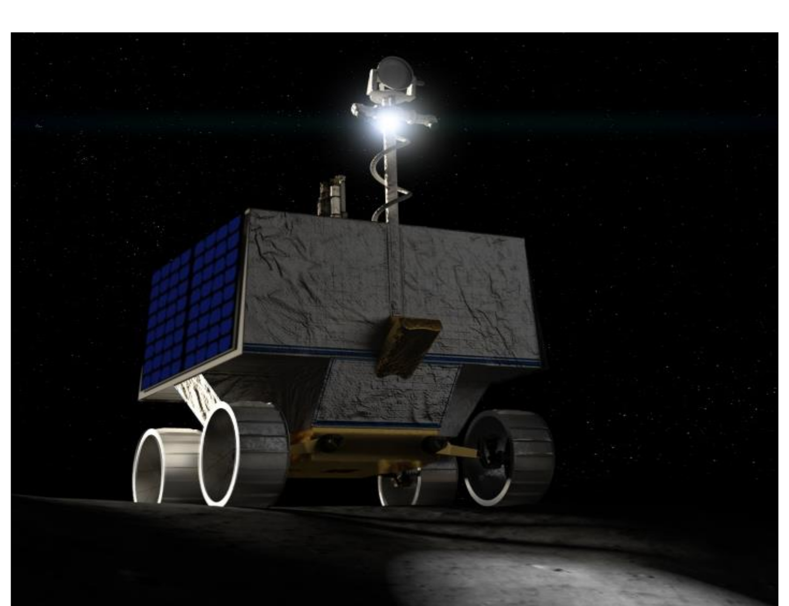

Figure 1: NASA's concept of the Volatiles Investigating Polar Exploration Rover (VIPER), taken from the NASA.gov website; credit to NASA Ames and Daniel Rutter for the image

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 both during the day and at night.
- At night, performance was more variable between participants, suggesting that shorter durations of driving might be preferable.

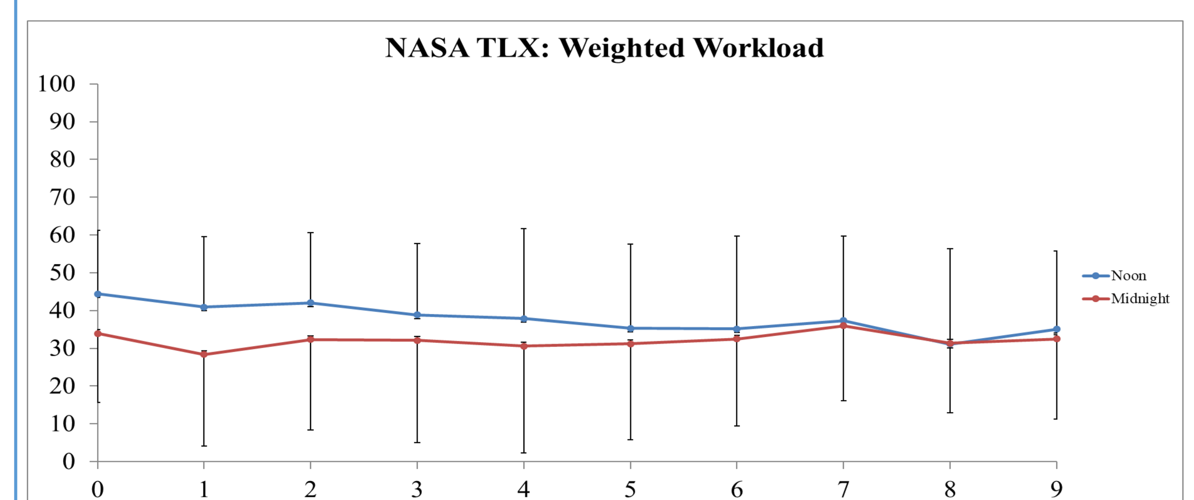

Figure 2: Comparison of the average weighted workload (x-axis) throughout the two drives (from the NASA-TLX; error bars represent standard deviation

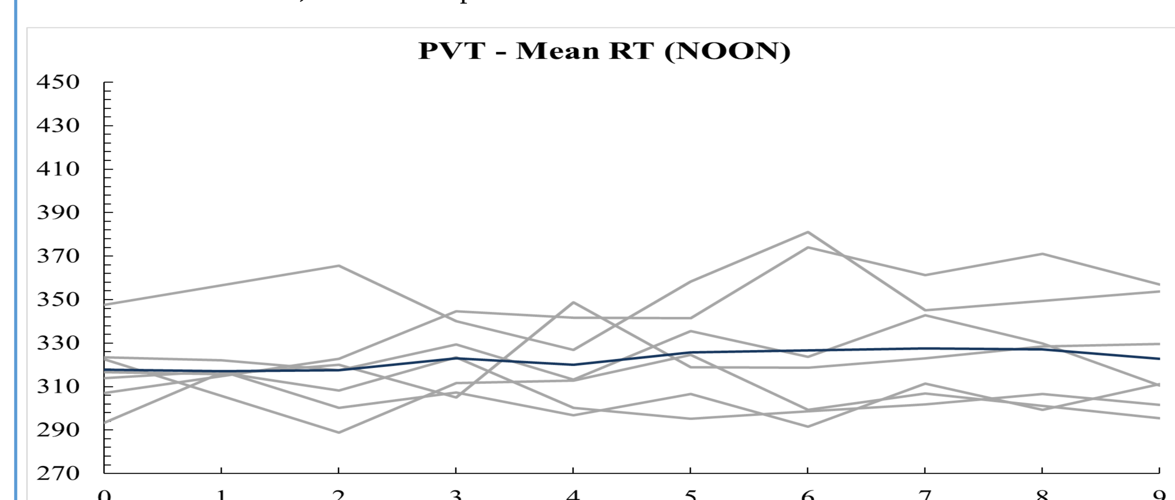

Figure 3: Average RT throughout the noon drive displaying individual variation (in grey) with the average RT (in blue)

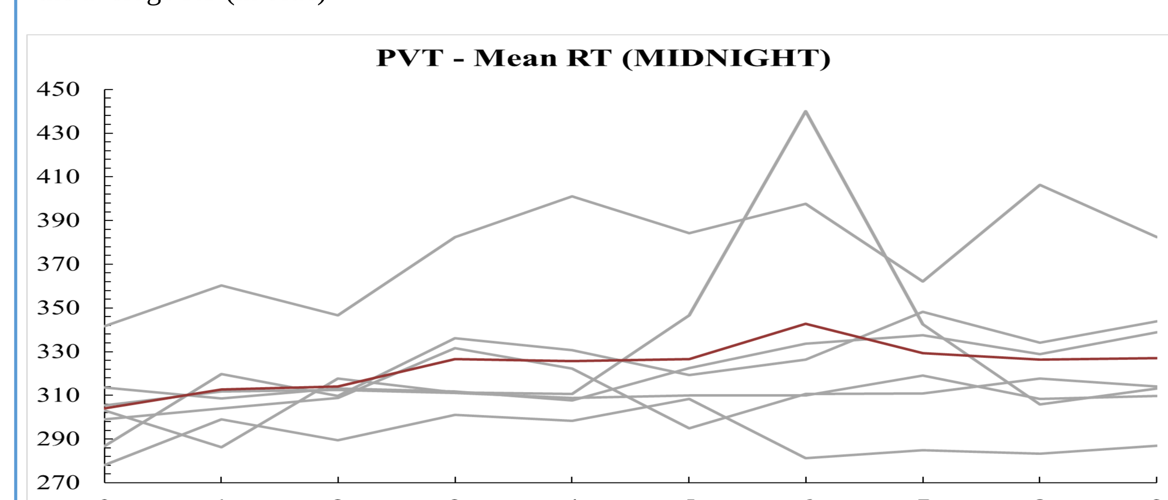

Figure 4: Average RT throughout the midnight drive displaying individual variation (in grey) with the average RT (in red)

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**

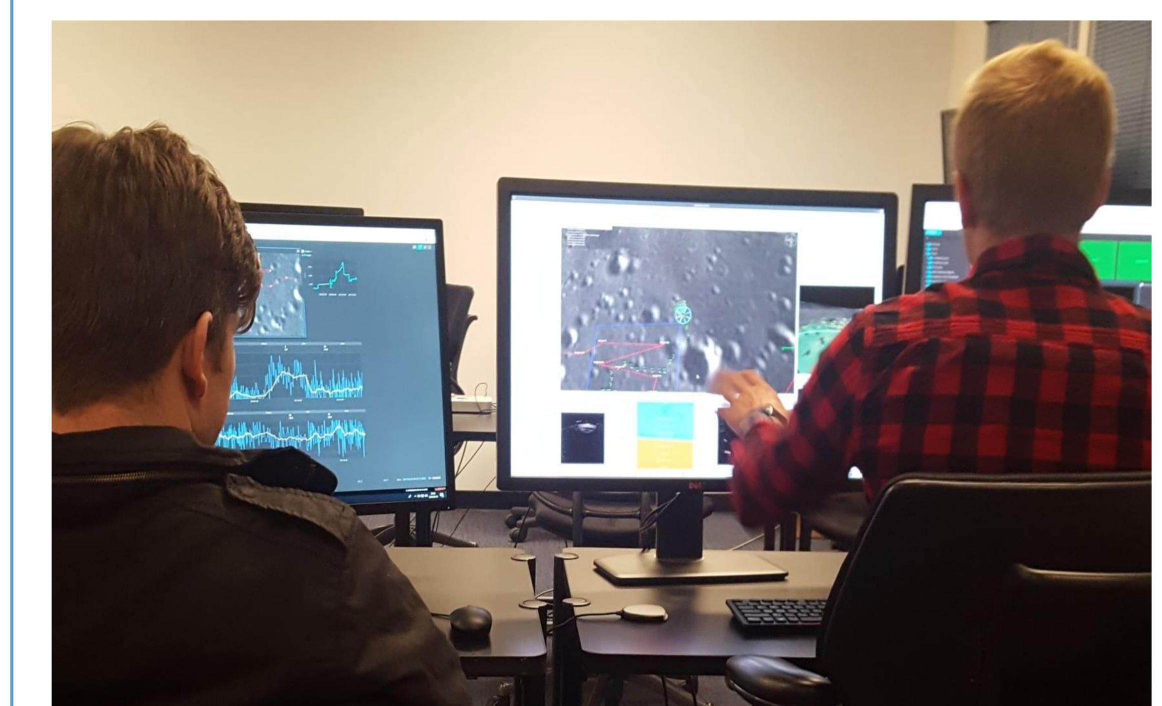

Figure 5: Personal photo taken during an evening of simulation testing: left monitor is for the RTSci operator viewing the two-count channel, and the two monitors on the right are for the driver. Middle monitor displays the 3D worldspace, and the rightmost monitor displays all the images captured.

RECOMMENDATIONS FOR OPERATORS

- At least 10 full-time drivers will be needed to cover 24/7 operations
- Length of shift should not exceed 8 hours, else sacrifice alertness and performance
- Duration of drive should not exceed 4 (day) or 3 hours (night)
- No personnel scheduled for more than 2 night shifts in a row
- Shifts should be fast, forward rotating (i.e., clockwise)
- 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

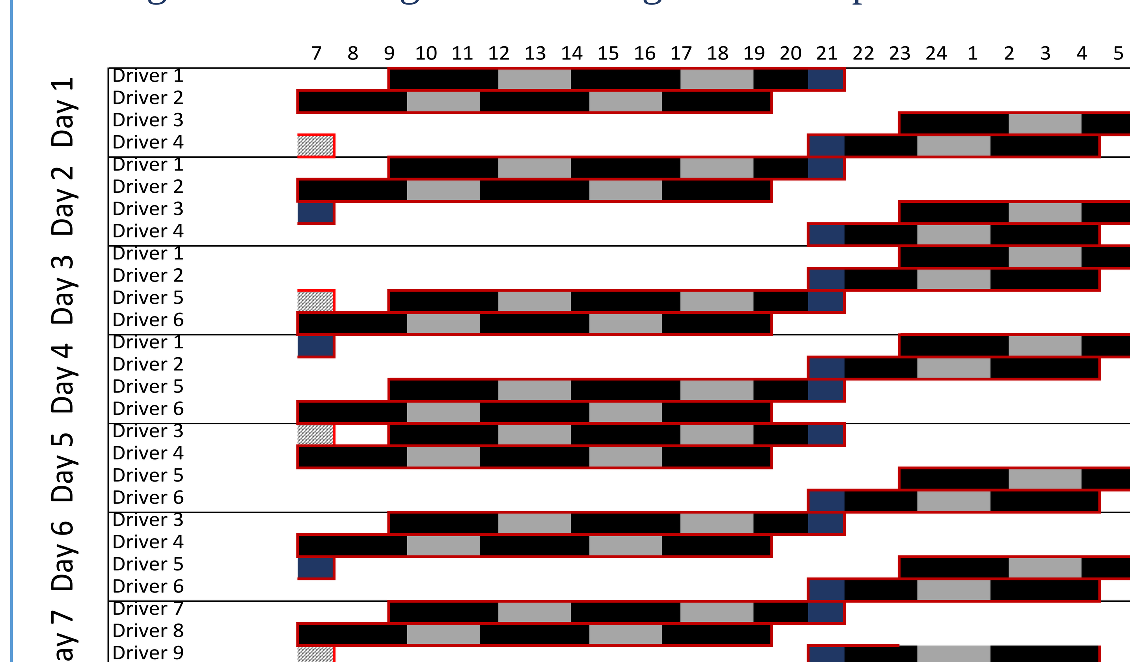

Figure 6: Example shift schedule for 12 hour operations. Each driver is scheduled for either an early morning shift (07:00), late morning (09:30), night (21:00), or late night (23:30). Day shifts last for 12 hours, nights for 8 hours. Each drive is shaded black, with "breaks" scheduled in between (in 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