COMMUNICATION DELAYS IN CISLUNAR SPACE: AIMS AND METHODS OF A LABORATORY STUDY EXAMINING EIHSO AND TEAM RISKS

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Background

- Space missions have inherent challenges with communication delays as distance from Earth increases
- Adverse effects of 50+ second delays on individual well-being, team cohesion, and overall task performance (Kintz et al., 2016; Larson et al., 2019; Parisi et al., 2024)
- Unlike Apollo:
  - Apollo moon missions = 1.5 sec one-way comm delay
  - **Artemis moon missions = 5 sec to 12 sec one-way comm delay !!**
- The Operations community currently sees this as a low-priority issue, feeling that people will adapt, however…
  - Lack of data on behavioral health, teamwork, and performance impacts in lunar delay range
  - Most research focused on Mars comm delay (Landon, Karasinski, et al., 2025, NASA/TM-20250003885)

Expected Comm Delay between Lunar Surface and MCC

5-12 second one-way communication delay between Earth & Moon

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Selected Comm Delay Studies to Date

HRP Research – Selected Communication Delayed Studies	0s	~10s	30s	~1m	3m	5m	20m
Individual Well-being							
Stress, frustration increased (Kintz, Palinkas et al., 2016, **ISS**; Bell et al., 2022, **harmon.**); adverse behavioral symptoms increased (adverse mood, confusion) (Basner et al., 2014, **Mars 500**; Roma, n.d., **HI-SEAS**)	x		x	x	x	x	x
Individual Performance							
Cognitive load increased (Fischer, Mosier, 2017, **lab**, **astros**); coping behaviors decreased, Van Wijk, 2018, **subs**				x		x	x
HSIA overlap; errors, time to complete task increased; hi-fi task performance decreased (Stankovic, Duda, et al., 2022, **HERA**, Draper sim)	x		x	x	x	x	
Team Performance							
HSIA overlap; errors, time to complete task increased (Fischer & Mosier, 2017, **lab**); fewer objectives met on EVA sim, hi-fi tasks (Larson et al., 2019, **HERA**; Bell et al., 2021, **HERA**; Dias 2021, space med emergency **sim**)	x		x	x	x	x	
Multi-team comm quality declined - interruptions, out of sequence (Fischer & Mosier, 2017, **lab**, **astros**; Kintz, Palinkas et al., 2016, **ISS**); comm reduced (Supolkina et al., 2020; 2021, **SIRIUS**, **Mars500**)				x		x	x
Multi-team shared mental models declined (DeChurch, 2021; Fischer & Mosier, 2020 **SIRIUS**), misunderstandings increased (Kintz, **ISS**)				x		x	
Team processes (coordination, team problem-solving, info sharing, shared leadership) declined (DeChurch, 2021, **SIRIUS**; Bell et al., 2022, **harmon.**; Dias 2021, space med emergency **sim**)	x		x	x	x	x	x
Team Functioning/Cohesion							
Social support declined (Goemaere et al., 2019, **HI-SEAS**; Fischer & Mosier, 2021, **NEK**; Nicolas et al., 2021, **Antarctica**; Bell et al., 2022, **harmon.**); conflict increased (Bell et al. 2019, **analogs**; Marcinkowski...2020, **HERA**)	x		x	x	x	x	x
Decline in multi-team system cohesion (Fischer & Mosier, 2020, **SIRIUS**) and psychological closing/ reduced communications (Bell et al., 2019, ICE **analog review**; **older Russian studies**)	x					x	
Family Connectedness							
Connectedness, satisfaction with relationships declined (Goemaere et al., 2019, **HI-SEAS**; Wu **VR**, **HI-SEAS**)							x

*0s includes ICE analogs & long-duration missions; *Bell 2022, harmonization, HERA C4/5, SIRIUS-19, ISS; *HERA: 0s,30s,1m,3m,5m; SIRIUS/NEK: 5m, HI-SEAS: 20m, NEEMO: 0s,50s,5m, 20m, ISS/Palinkas: 0s, 50s

HRP Research – Selected Communication Delayed Studies	0s	~10s	~1m	5m	10m	20m
Task Types						
Nominal Ops (DRATS*, DSH*, NEEMO*, ISS**, ISTAR*, ECLSS SIM†)	x		x	x	x	x
EVA (DRATS, DSH, NEEMO)			x	x	x	x
Medical/Emergency (DSH, NEEMO)	x		x	x	x	x
Maintenance (DRATS, DSH, ISS, ISTAR, ECLSS SIM)	x		x	x		
Contingency (DRATS, DSH, ECLSS SIM)	x		x	x		
Troubleshooting (DSH, ECLSS SIM)	x		x	x		

*Rader et al., 2013 **Kintz, 2016 † Fischer & Mosier, 2014

Note: For safety/time-critical tasks, metrics must assess task execution, not just the quality of communication.
The way tasks are structured is important because we're not just trying to solve an interface problem; we're trying to support particular interaction and integration.

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Aims of Study and Approach

- Investigate the effects of different time delays in the range of 0-12 sec one-way
  - Document impacts on ground and flight crew, using a flight-realistic problem-solving task.
  - Identify any “breakpoints” where performance and other factors are significantly affected.
  - Identify any workaround strategies used by participants that may suggest potential countermeasures.
- EIHSO risk team focused on:
  - Implementation of a communication delay technology infrastructure
  - Development of nominal and off-nominal spaceflight-relevant experimental tasks and prototypes
  - Identification of EIHSO-related performance measures and outcomes
- TEAM risk team focused on:
  - Identification and recruiting of appropriate crew-like subjects
  - Development of Qualtrics surveys for data collection
  - Identification of Team-related functioning and performance measures and outcomes

Method

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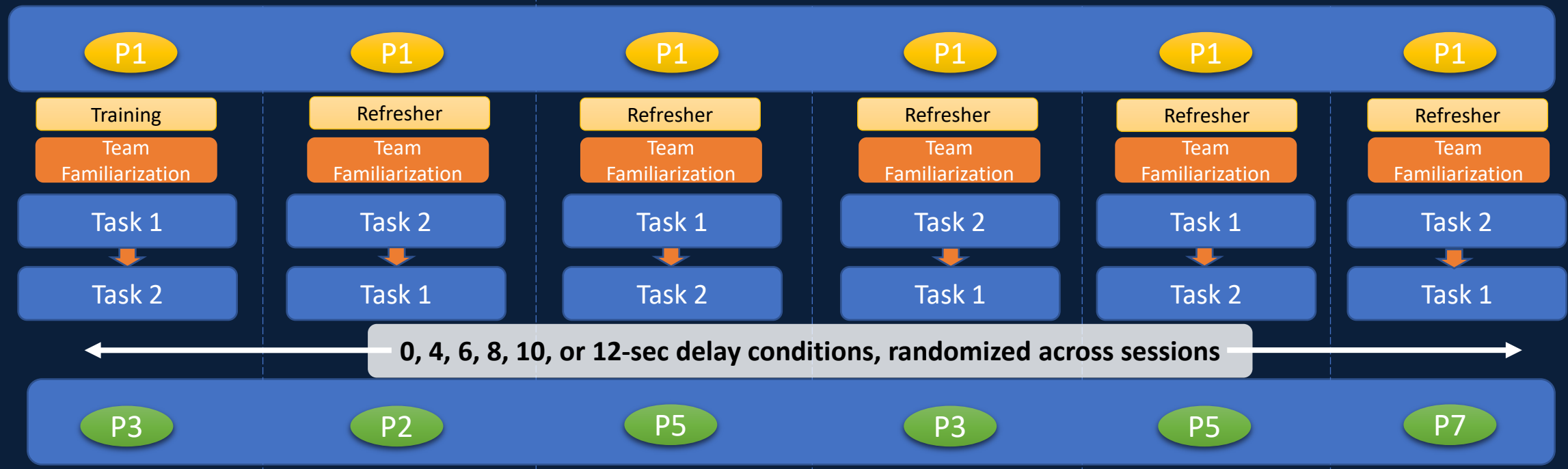
Repeated Measures Experimental Design

- 6 sessions, 1st session at 0s/4s/6s delay
- Each participant assigned to one role across all sessions (Crew or MCC); random partners
- Comm: Audio/Video (delayed), with option for Texting (delayed)



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Participants and Roles

- Participants
  - *Planned*: 24, 2-person teams planned (48 individuals) complete 6 sessions
  - Actual: 48 individuals
    - 10 teams completed 6 sessions
    - 9 teams completed 3-5 sessions
    - 4 teams completed <3 sessions
  - Recruited to be "astronaut-like"
    - Mean age ~41 years old; all had STEM education/background
    - 18 participants were current or former NASA flight controllers
    - 35 had comm delay experience; 37 had remote comm exper
    - Personality (IPIP-NEO-120) was comparable to astronaut / analog crew profiles
- Roles
  - Randomly assigned as MCC or Crew – kept the same role throughout
  - MCC/Crew pairs randomized – partners not always the same
  - MCC/Crew pairs performed the tasks in separate rooms

Final number of datapoints

	Participants	Teams
Delay 0s	37	19*
Delay 4s	32	16
Delay 6s	39	20*
Delay 8s	24	12
Delay 10s	30	15
Delay 12s	40	20

*excludes dropouts

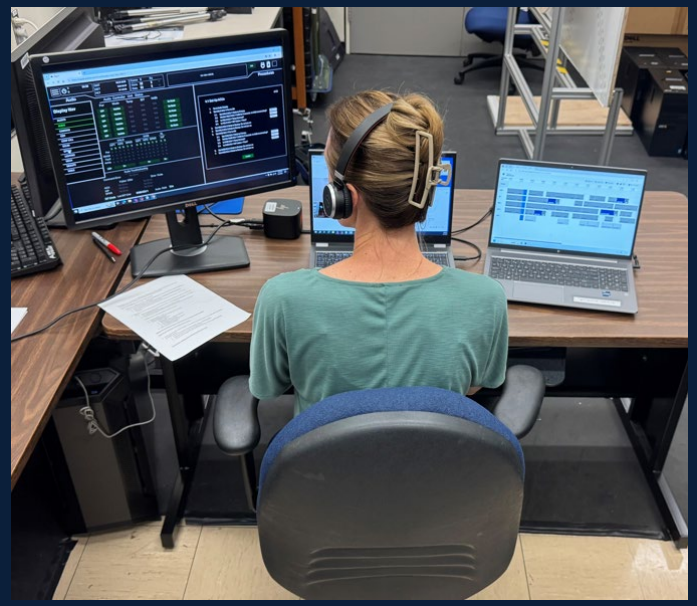
Experiment Task Characteristics

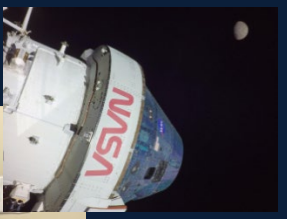
- ***Study back story**: MCC and crew are working through task procedures together. Due to a technical issue, MCC displays are not updating reliably. Data are considered "stale," forcing MCC to rely on Crew for up-to-date task information, feedback, and alert details, while MCC leads them through the procedures with changing information.*

- Nominal and off-nominal task activities
- Imperfect procedures and vehicle faults resulting in alert messages and auditory alarms
- Requires MCC-Crew problem-solving and communication

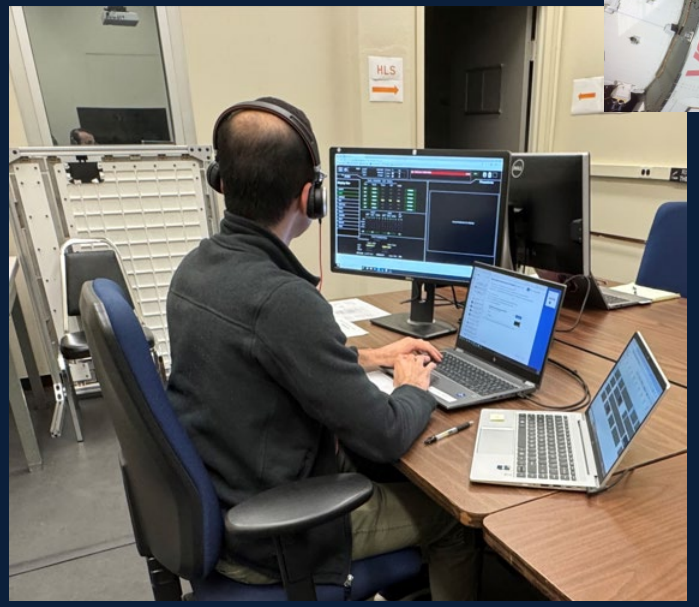
Experiment Setup

Mission Control Center (MCC)





Crewmember in Lunar Transit



- Prime for directing the tasks
- MCC displays are “stale” - not receiving reliable vehicle data, so crew must communicate what is happening

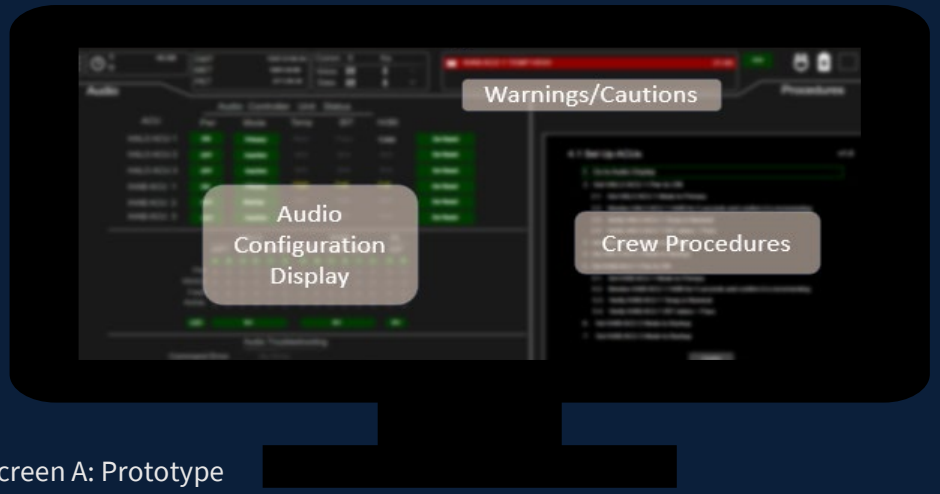
- Responsible for performing hands-on display interaction and commanding
- Most reliable vehicle data - inform MCC of alerts, sig events

Participant Training- 1st Session + Refreshers

- Roles and responsibilities for “MCC” vs. “Crew”
- Training on how to use task displays and procedures
- Training on speaking with their partner and texting with them using Playbook
- Best practice guidelines for good communication
- Supplemental resources available
  - Paper and pen for notes
  - Supplemental reference information and procedures for MCC
  - Ability to contact test conductor for issues during the test run

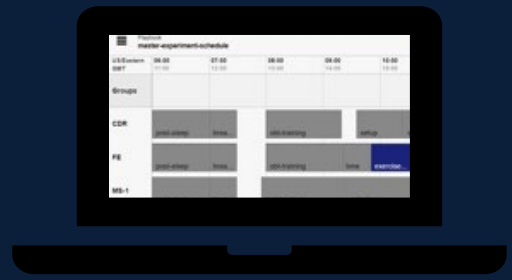
Experiment Task Displays

- MCC and Crew each have display monitors for:
  - System/task information- system display, procedures, alerts
  - Audio/video of team member
  - Playbook software (text messaging, activity scheduling)
- Vehicle display tasks
  - Nominal - setting up an audio conference call, scheduling an activity with Playbook
  - Off-nominal - setting up audio devices, resolving alerts, noting procedural inconsistencies, etc., with small variations



Screen A: Prototype

Screen B: Partner a/v



Screen C: Playbook

(text messaging, activity scheduling)

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Experiment Implementation

- Comm Delay implemented with OBS and virtual audio cable software
- Interactive prototypes implemented with Axure RP Pro
- Tasks and displays based on Gateway and Orion
- Problems to be solved based on realistic faults from vehicle SMEs, and procedure mismatches or incomplete information

Measures

- Demographics
  - Selected to be crew-like – age, education
  - Personality
  - Experience with remote comm
  - Familiarity with teammate
- BHealth and Team
  - Sleep
  - Stress self-report
  - Mood
  - Communication quality
  - Frustration – with task, latency, partner
  - Perceived autonomy
  - Team processes
  - Shared mental models
  - Cohesion
  - Team performance (self-report)
- Physiological
  - Heart rate (Garmin watch)
- Human Factors
  - Usability - NASA Modified SUS
  - Workload - NASA TLX and Bedford Workload Scale
  - Acceptability scale
  - Situation Awareness
  - Perception of Difficulty
- Communication techniques and countermeasures
  - Use of texting
- Performance (objective)
  - Task completion time – nominal vs. off-nominal
  - Success / Productivity measures

Questions?

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