Multimodal Alert Design

Kritina Holden, Leidos
Ian Robertson, KBR
Ryan Lange, Geologics
Durand Begault, NASA
Tyler Duke, Leidos
Ryan Z. Amick, KBR

Safety-Critical Alerts at NASA

- Alert Types
  - **Emergency** - time-critical event that requires immediate action and crew survival procedures (Fire, Pressure Loss, Rapid Depress, Toxic Atmosphere)
  - **Warning** - an event that requires immediate action
  - **Caution** - an event that needs attention, but not immediate action
  - **Advisory -** A message that imparts information for routine action purposes
- Auditory and Visual Annunciation
  - When an alert tone is annunciated, a message with more detail is displayed on a hardware panel or a computer display

Alert Requirements across Artemis

- Artemis Vehicles
  - **Orion** – exploration vehicle that will carry the crew into space
  - **Gateway** – outpost or space station that will orbit the moon and serve as a staging point for future deep space exploration
  - **Human Landing System (HLS)** – vehicle to land humans on the moon
- Alert Tones for Orion, Gateway and HLS
  - Emergency (Fire: siren, Pressure Loss/Toxic Atmosphere: klaxon)
  - Warning – alternating tone
  - Caution – continuous tone
  - Advisory – 2 beeps, self-terminating (optional tone for select use)
- Gateway and HLS requirement to allow for tone and speech alerts

Speech Alerts

- Past NASA HRP research (2009/2010) on speech alerts found:
  - Speech alerts were recognized more quickly and were preferred
  - Crew advocacy for speech alerts
  - Too late in the Orion development cycle for inclusion
- In recent years, ISS crew have asked for enhanced alerting, including voice
  - Tones are hard to distinguish in first seconds, especially when waking up
  - To gain situation awareness, they must float to a panel or computer for more information, potentially losing critical response time
  - Crew running on treadmill or in visiting vehicle could miss the signal

HRP Alert Design Research

- Project Team
  - HRP team plus Artemis stakeholders
  - Informal partnership with Embry-Riddle
- Research Questions
  - How does performance with a multimodal alert (tone + speech) compare to performance with a tone alert?
    - How is addition of a speech component impacted by type of task? (computer-based, speech-based)
  - Do context-specific tones (different set for each location) or a common set of tones (across all locations) yield faster and more accurate responses?

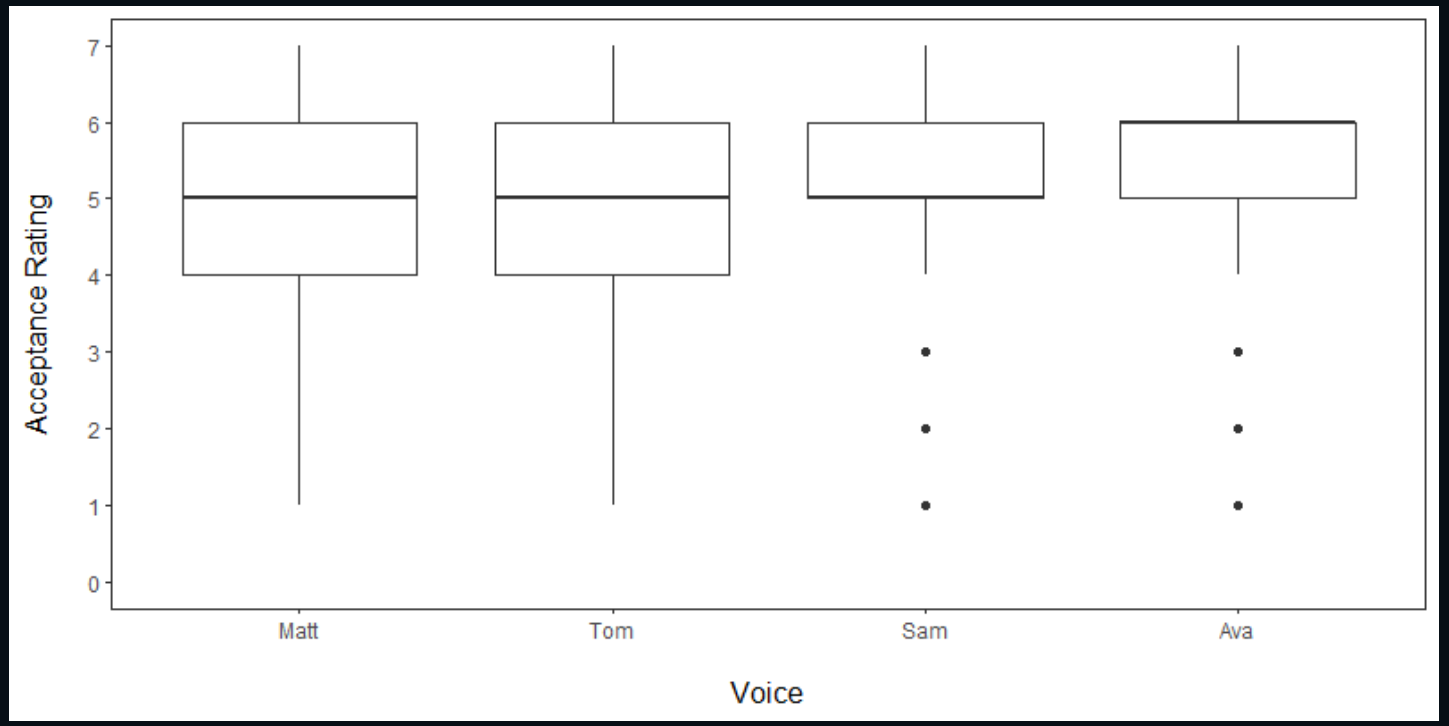
Experiment 1 – Speech Alerts

How does performance differ when using Tone-only alerts vs. Tone+Speech alerts?

Voice Type and Exemplar Messages

- Exemplar Messages
  - Collaborated with Stakeholders to develop representative alert messages
- Voice Type
  - Synthetic speech – because easiest to modify
  - Speech messages with realistic (e.g., fan) background noise
  - Used accessibility features – macOS “VoiceOver” utility, edited with Adobe Audition
    - Team selected 2 male and 2 female voices for use in exemplar messages (*Matt, Tom, Sam, Ava*)
- Preference test with 21 stakeholders
  - Listen to each speech alert message as many times as you want
  - Focus on the sound, not the content (although you can comment on that)
  - Provide ratings about suitability and intelligibility, and provide free-form comments

Preference Test Results



- Participants preferred female voices to male voices
  - Easier to hear in noisy environments due to higher pitch (Ji et al. 2019)
  - May have advantage in portraying varying levels of urgency (Edworthy et al., 2003)
- Overall preference for the *Ava* voice

Decision: Proceed with use of Ava voice for alert studies.

Opportunity!

Gateway and HLS Requirements Documents Opened for Revision

Detailed Speech Alert Requirements

- Opportunity: provide more specific speech alert requirements to Gateway and HLS
- Content based on literature, talking with stakeholders and experts, and preference test
- Alert message structure recommended:
  - Tone + signal word + type of emergency and location + repetition of key information + repetition of entire alert string until terminated by crew

Example:

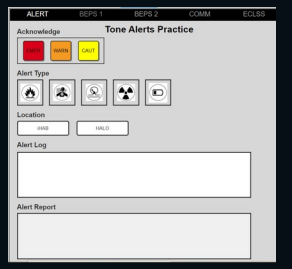
- *tone* – Warning – Radiation HALO – Radiation HALO / Warning – Radiation HALO – Radiation HALO

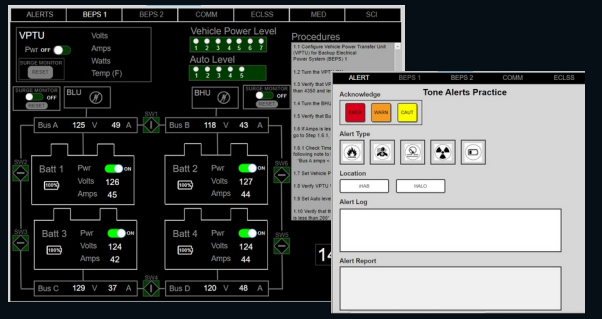
Alerts Study 1 – Speech Alerts

- 25 Crew-like participants
- Semi-realistic, procedure-driven task – configuring a backup Electrical Power System
  - Time pressure
  - Alerts were triggered at certain points in the procedure, with delays (unknown to the participant)
- 2X2 within subject design – participants used two types of alerts and two types of procedures
- Alert conditions
  - Tone-only condition – alert message details shown on the computer
  - Tone+Speech condition – alert message details only heard in speech alert message
- Procedures conditions
  - Electronic procedures shown on the display
  - Procedures read by MCC (confederate) – (potential interference with speech alerts)

Experimental Session Agenda (2 days)

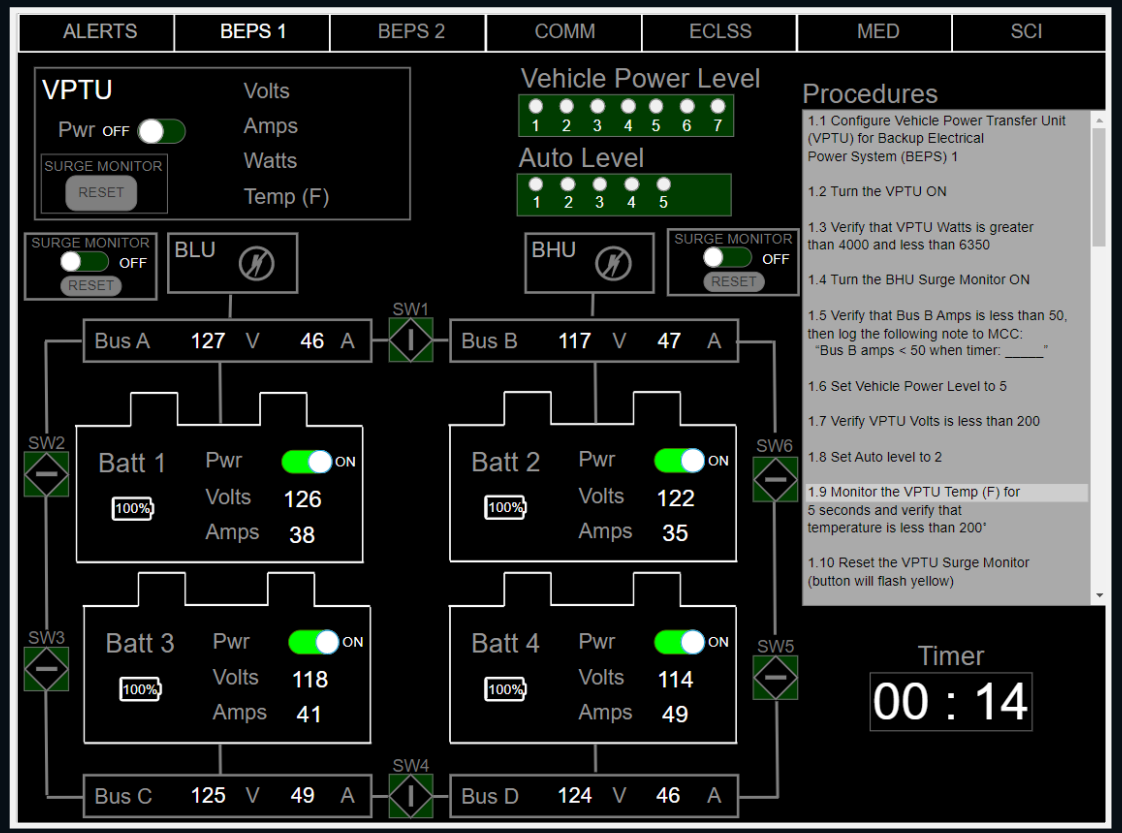
- Familiarization – Learn the alert tones and messages, and how to respond by clicking on the relevant icons.
- Training – Learn how to respond to alert messages using the Alerts display.
- Experiment Trials – Perform procedure-based Electrical Power System configuration task and respond to alerts as they arise.



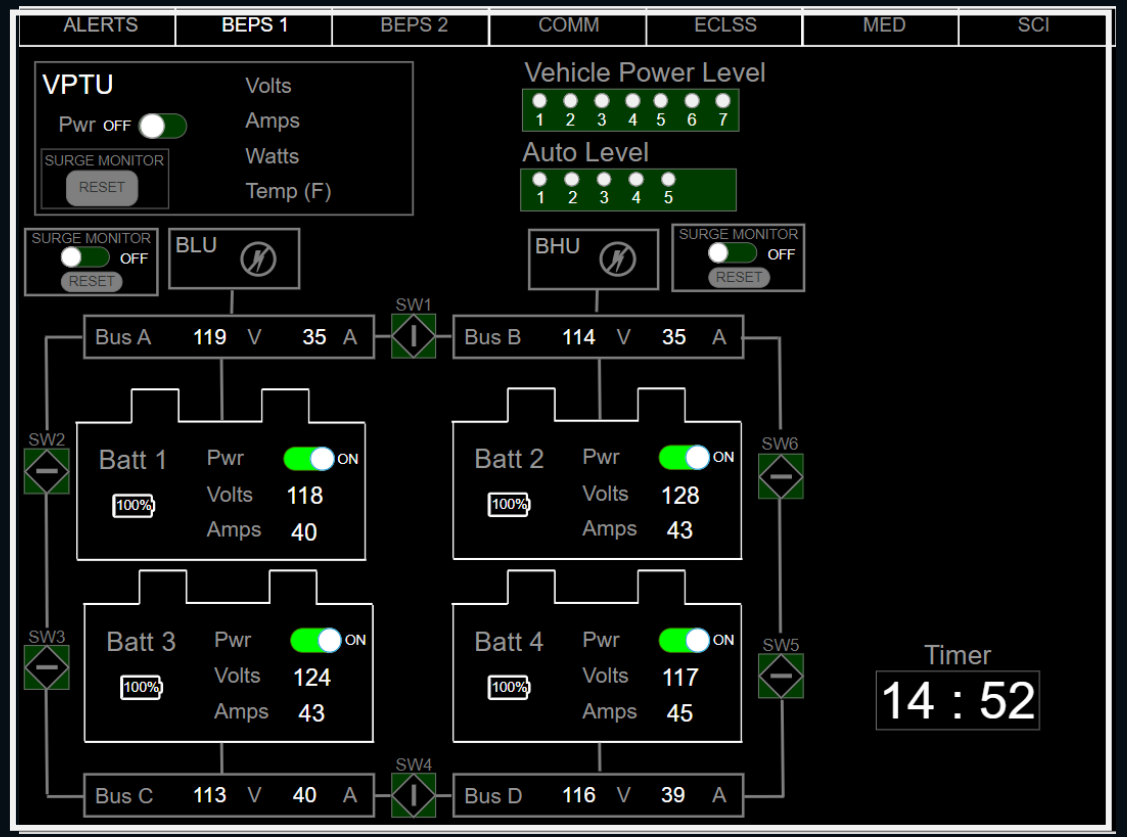


Experimental Task Displays

Electronic Procedures (Eproc)

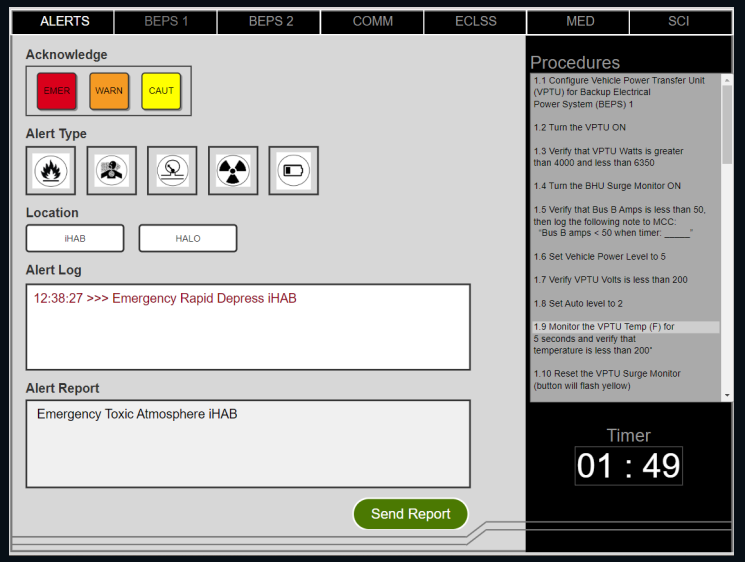


MCC-read Procedures

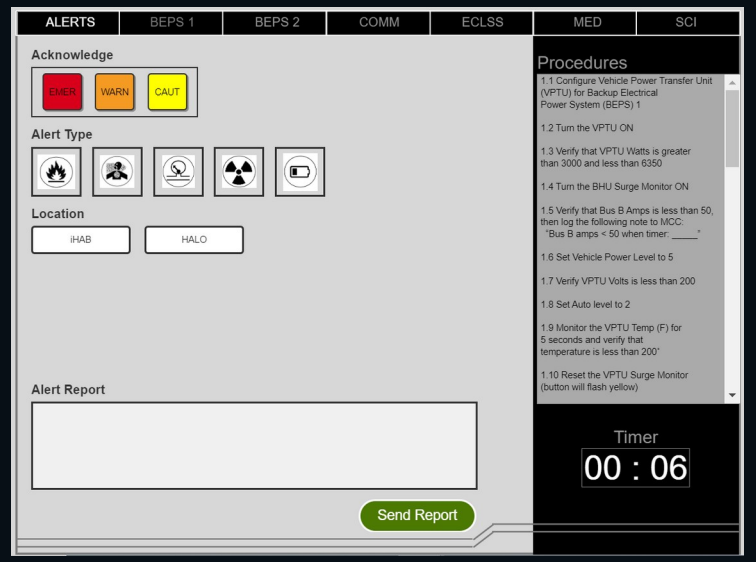


Alert Response Differences

Tone-Only



Tone+Speech



Response rules:

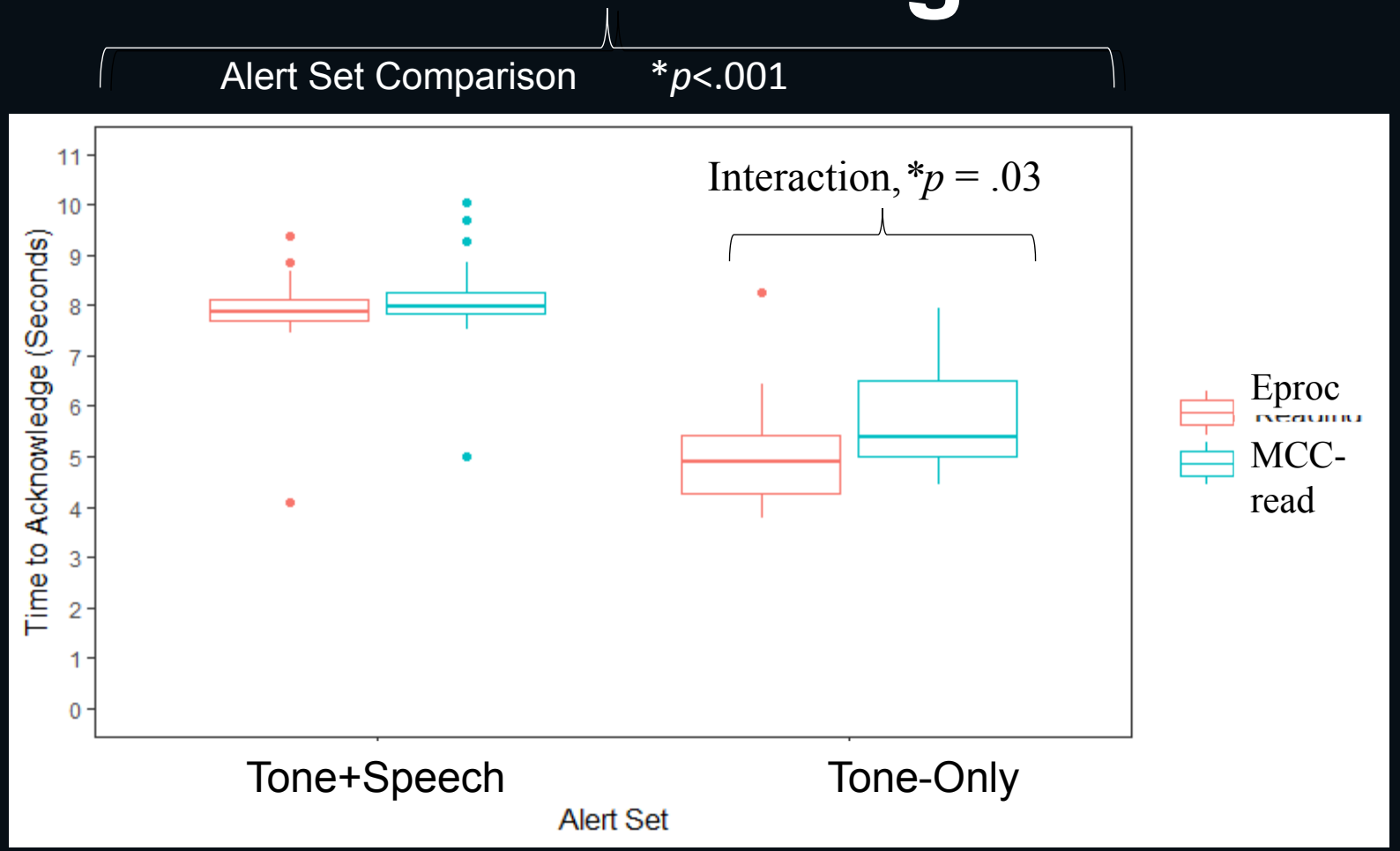
- Press Ack button to indicate class of alert. If Caution – no report/action is required.
- Press button/icon associated with type of alert, then location of alert.
- Press Send to send the report generated by the button presses.

Study 1 – Results Summary

	Overall Task Time (In minutes)		Overall Accuracy
	Eproc	**MCC-read**	
Tone+Speech	5.18 (1.18)	5.54 (0.81)	95%
Tone-Only	4.88 (1.42)	5.48 (1.18)	92%

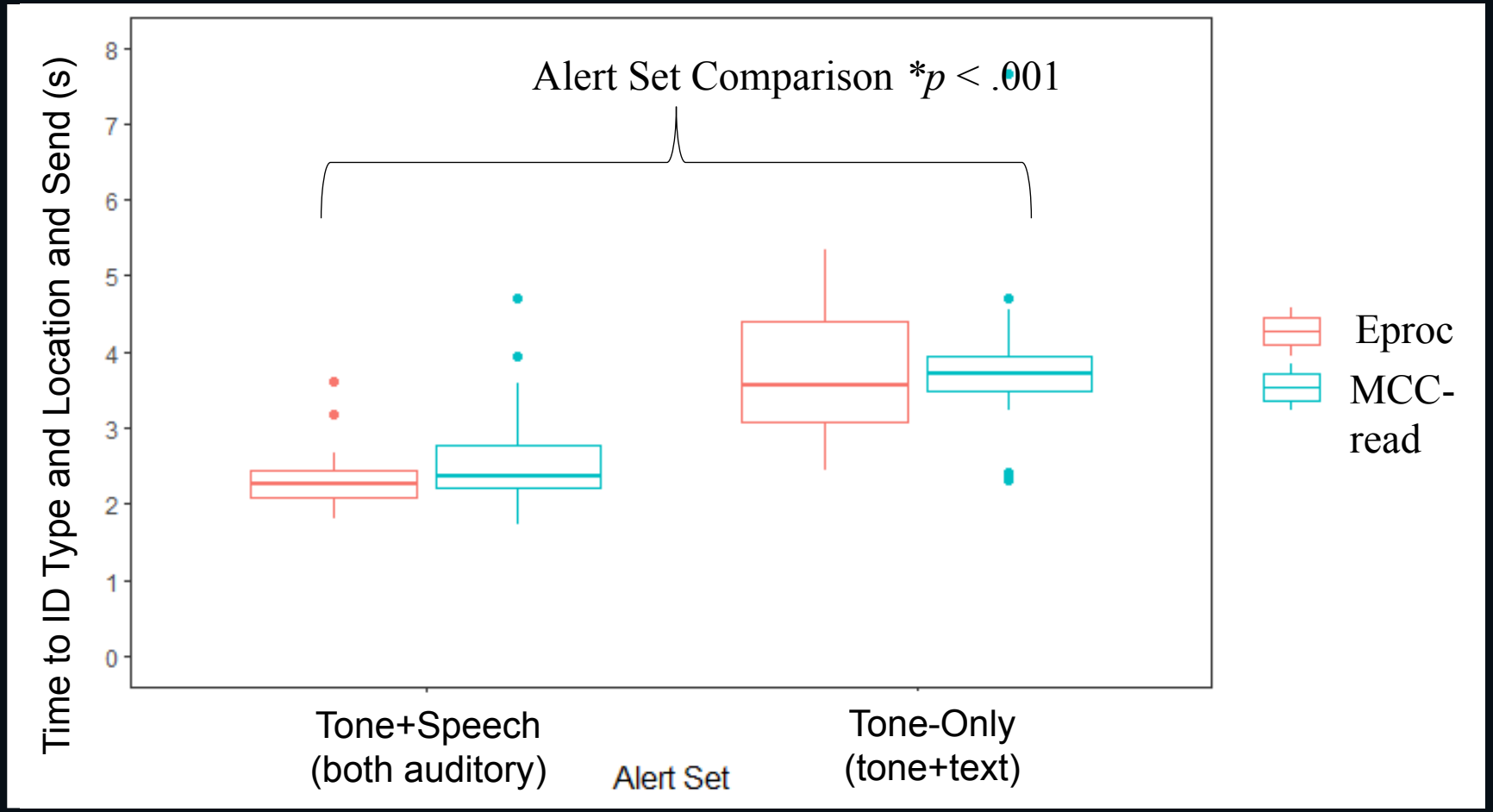
- 20 of 25 preferred Tone+Speech
- Tone+Speech – slightly slower task time, but slightly more accurate.
- Reminder: Tone+Speech requires listening to the entire message at least once before responding.

Time to Acknowledge Alert



- Tone+Speech slower to acknowledge
- Reminder: Tone+Speech requires listening to the entire message at least once before responding.

Time to Categorize Alert and Send Report



Tone+Speech condition faster to correctly identify event and location.

Select Participant Comments

- Tone+Speech vs. Tone-only Alerts
  - “Workload is greatly increased when there is not a voice notification with the alerts”
  - “Too focused on trying to remember what each tone meant”
  - “The amount of time taken to mentally switch back to recall meaning behind the alert took an undesirable amount of time and effort”
  - “The additional auditory information allowed me to reduce workload while I was shifting between tasks”
- Electronic procedures vs. MCC-read procedures
  - “Easier when reading the procedure vs. waiting for MCC to read it to me”
  - “Quicker to perform reading from a list, I think mostly because verification steps were quicker”
  - “Having the list of instructions makes it easier for me to jump back into the task after leaving the page”

Conclusions

- Tone+Speech Alert Messages
  - Slightly longer task time, but slightly higher accuracy
  - Faster interpretation/understanding of the alert situation, once acknowledged
  - Overwhelmingly preferred by participants (20 of 25)
- Realizations and Surprises
  - It takes longer to listen to a message than to hear a tone
  - Mixing alerts that have messages with those that don't (e.g., Caution) may cause delays/annoyance as it is difficult to break the response pattern.
- Operational advantages of speech
  - When not in front of computer – allows crew to mentally prepare or take action prior to getting to a computer to see details

Experiment 2 – Alert Commonality and Context

How does performance differ when using a common alert set across vehicles vs. multiple alert sets?

Alerts Study 2 – Commonality and Context

- Participants (19) drawn from first alert study to decrease training time
- Between subject design
- Groups/Conditions
  - Common set of alert tones across two “vehicles” (Vehicle A and Vehicle B)
  - Multiple tone sets – one for A and a different set for B
- Data collected
  - Response time
  - Errors
  - Bedford Workload Scale
  - Comments

Experimental Task Details

- Task
  - Electrical Power System configuration task and alert reporting – highly similar to Study 1
- Task locations
  - One room had signage that said “Vehicle A” – and interfaces had a black/green theme
  - One room had signage that said “Vehicle B” – and interfaces had a blue theme
- Primary difference from Study 1: the decision making and responding instructions - based on location (A vs. B)
  - If an alert occurs in a vehicle where you are located:
    - Acknowledge alert, log alert type, and send to MCC (as in Study 1)
  - If an alert occurs in the other vehicle or is a Caution:
    - Acknowledge the alert, and then send to MCC (no logging of details)

Study 2 - Alert Sets

Common Alert Set

- Same as in Study 1, whether in Vehicle A or Vehicle B
  - Emergency
    - Fire – siren
    - Pressure Loss/Toxic Atmosphere – klaxon
  - Warning – alternating tone
  - Caution – continuous tone

Multiple Alert Sets

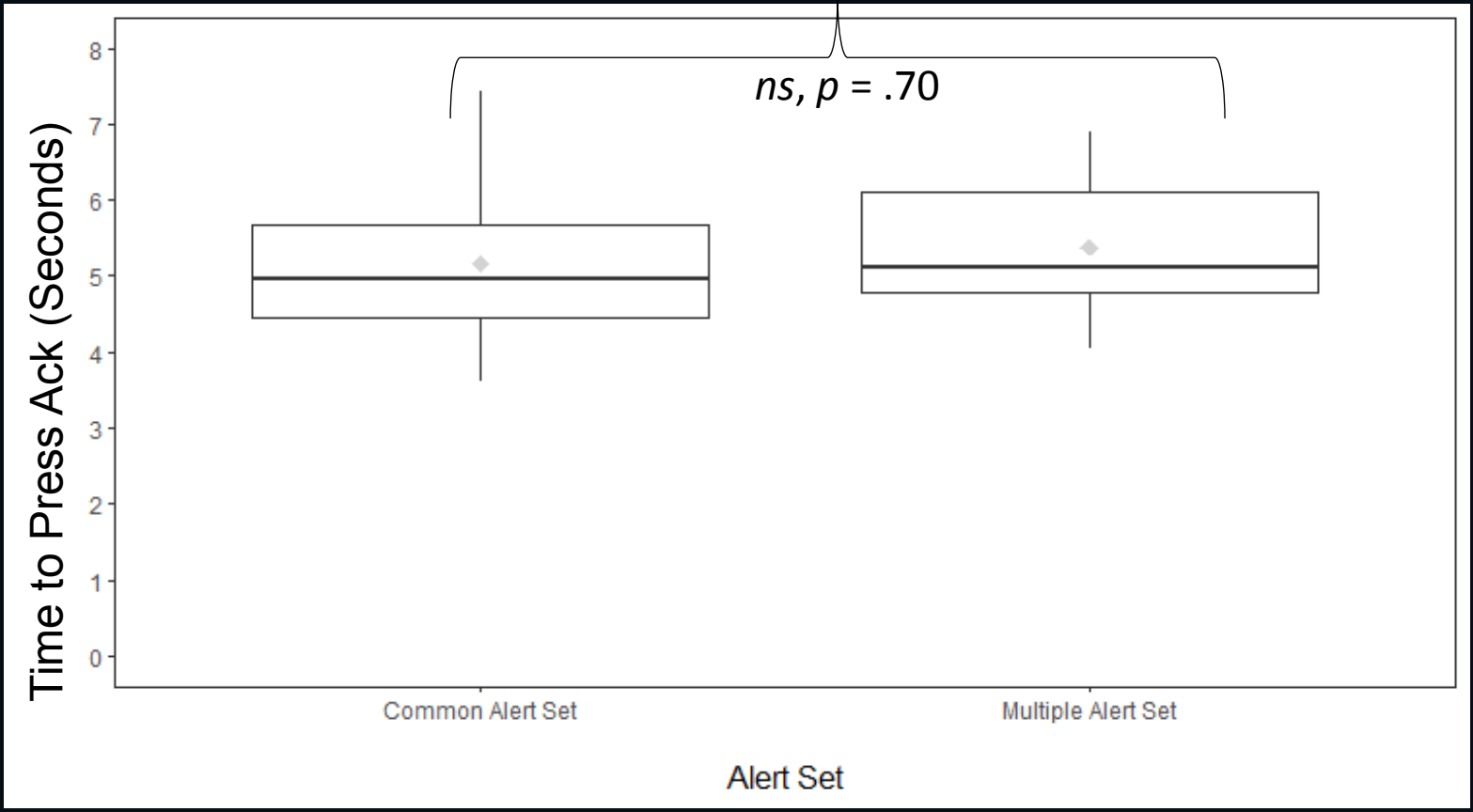
- In Vehicle A – Alert Set A (same as Experiment 1)
  - Emergency
    - Fire – siren
    - Pressure Loss/Toxic Atmosphere – klaxon
  - Warning – alternating tone
  - Caution – continuous tone
- In Vehicle B - Set B (new alert set)
  - Emergency – low-pitched beeps
  - Warning – higher pitched beeps
  - Caution – continuous tone

Study 2 – Results Summary

	Overall Task Time (In minutes)	Accuracy to ID Alert
Common Alert Set Group	4.6 (1.63)	93%
Multiple Alert Sets Group	4.16 (1.07)	90%

High accuracy for both tone sets

Time to Acknowledge Alert

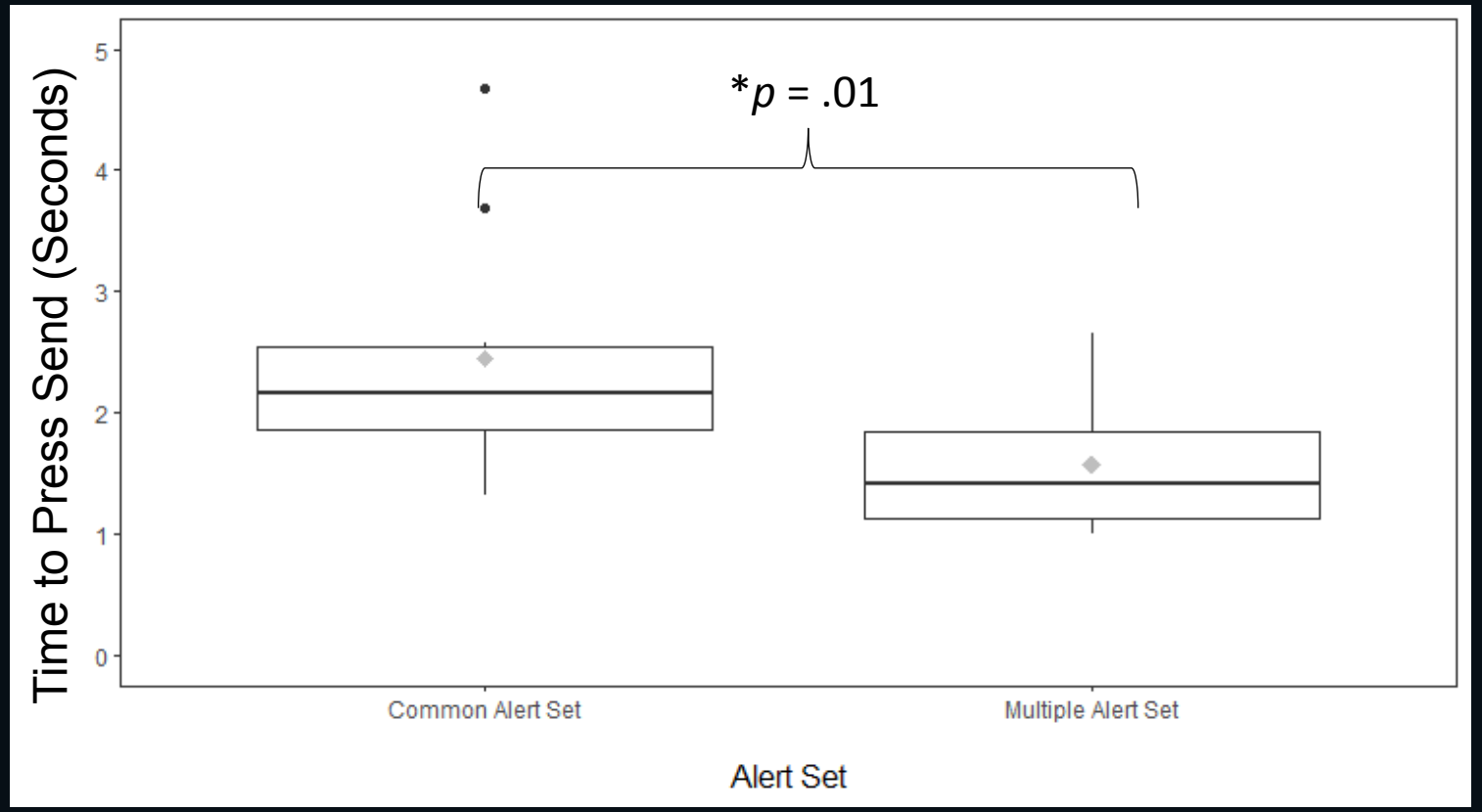


Common set was slightly faster to Acknowledge

Time to Identify Alert Type - Their Location

Common alert set slower to ID Alert Type (alert in their location)

Time to Recognize Alert from Other Location



Common alert set slower to determine location and press Send

Select Comments

- Workload and lack of speech alerts
  - “There was a lot of cognitive workload having to recall information about how to respond to two different tone sets
  - “Mental capacity was mostly differentiating between the two sets. I miss the speech alerts from last time. Those would be helpful in determining the module you are currently in.”
  - “I think having the same alerts for each vehicle would be helpful with the added spoken alert of which vehicle it was in”
- Multiple sets of alerts
  - “I like that the alerts were distinguishable”; they had good differentiation
  - “Just the two alert sets was manageable, but more than that may get difficult.”
  - “The more information you are asking crew to assimilate into a pattern of behavior, the higher the probability of them making a mistake”

Conclusions

- Common and Multiple tone sets provided for accurate performance and equal workload
- Common Alert Set – slightly faster to acknowledge and slightly more accurate
- Multiple Tone Set condition – faster to identify alert type and recognize location
- Realizations and Surprises
  - Working with two tone sets did not significantly increase workload or negatively impact performance
    - Two distinct alert sets provided an additional bit of information “for free” – location
    - Those using the common set had to read location information from the alert message
- Overall, results indicate that the effect of using multiple alert sets is dependent on multiple factors
  - Number of different sets of tones (only 2 tested in this study)
  - Distinctiveness of the different sets (not manipulated in this study, but the sets were distinct)

Remaining Questions

- Alert Tone Sets
  - What is the limit of number of different alert sets that can be successfully used in a spaceflight environment?
  - How can distinctiveness or other techniques be used to mitigate multiple alert sets and indicate source of the alert?

As the number of unique spacecraft grows, further research is needed to address these important questions.

Questions?