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Memo on Speech Alarms: Replication and Validation of Results

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Acronyms and Definitions

ANOVA ....Analysis of Variance
C&W..........................caution and warning
CCD ....Cursor Control Device
FY ....Fiscal Year
HERA ....Human Exploration Research Analog
HRP............................Human Research Program
HSIR ....Human Systems Integration Requirements
IBC.............................International Building Code
ISO ....International Standards Organization
ISS..............................International Space Station
JSC ....(NASA) Johnson Space Center
ms...............................millisecond
NASA ....National Aeronautics and Space Administration
NFPA ....National Fire Protection Association
RT ....response time
s ....second
SAE............................Society of Automotive Engineers
SHFH ....Space Human Factors and Habitability
Voice Evac ....Voice Evacuation Systems

Memo on Speech Alarms: Replication and Validation of Results

Anikó Sándor[1], Haifa Moses[2], John Sprufera[3], and Durand R. Begault[4]

1. Introduction

Caution and warning (C&W) alarms help people to quickly and efficiently identify situations that are of immediate danger or would escalate to a safety critical level. Tones are highly salient and have been traditionally used for caution and warning alarms. However, research shows that tone alarms can have an unwanted startle effect that hinders operator decision making (Stanton & Edworthy, 1999). Speech alarms are good alternatives to tone alarms because they require less training and are less startling. They have been in use for decades for caution and warning systems in commercial airplanes and in buildings (International Building Code, 2015, Stanton & Edworthy, 1999).

Speech alarms have been considered for space flight use by the National Aeronautics and Space Administration's (NASA) Astronaut Office and by its Orion Program. To investigate whether performance with various types of speech alarms was similar to performance with the currently used tone alarms, a study was conducted in 2010 (Sándor, Begault, & Holden, 2010). The results showed faster identification times of speech alarms as well as higher acceptance rates from participants. However, the presentation of the alarms had a variable onset time due to software. The current research project was funded to address this issue by collecting new data with alarms having non-variable onset time and to validate the alarms in the Human Exploration Research Analog (HERA).

This report describes the two studies: a laboratory experiment comparing tone and speech alarms, and an evaluation in the HERA facility.

2. Background

Studies conducted in FY08 and FY09 (Begault, Godfroy, Holden, & Sándor, 2008; Begault, Godfroy, Sándor, & Holden, 2007) evaluated auditory alarms currently in use with NASA flight deck displays along with proposed candidate alarms for fire, depressurization, warning, and caution categories. In the FY09 study, 11 non-crewmember and 3 crewmember participants were asked to rate 6 candidate alarms relative to the current alarm in each category on perceived suitability for each category. Five of the candidate alarms were designed based on the current alarm or the runner-up alarm sound from the FY08 study. The sixth alarm sound included a speech component appended

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after the tone, termed a "speech suffix," which gave additional information about the cause of the alarm. Each alarm was also rated in terms of perceived urgency level, overall satisfaction, and the perceived value of including a speech suffix. The results showed that the inclusion of a speech suffix was preferred by both crewmember and non-crewmember subjects.

The purpose of a later study (Sándor, Begault, Holden, 2010) was to investigate how quickly various types of auditory alarms with and without a speech suffix could be identified. Since the previous study found that a speech suffix was preferred by all participants, the 2010 study included four types of speech alarms that were composed of combinations of warning tones, spoken warnings, and speech suffixes that provide brief additional information related to the alarms' cause or location. An additional purpose of the study was to gather subjective impressions regarding interference caused by playing the speech alarms simultaneously with radio communications.

The results of the 2010 study indicated that alarms starting with a speech component were identified faster than alarms starting with a tone. This result could be due to an increased cognitive processing time to correctly recognize an abstract tone compared to speech. For example, the duration of a siren tone requires 5 s to complete its full modulation cycle, whereas the word "fire" can be spoken in less than 1 s. Even though many of the alarm tones were familiar to the crewmembers from training or from direct mission experience, familiarity did not insure the fastest recognition times. This result is supported by the subjective comments as well: speech is immediate, and easy to recognize; whereas tones need to be memorized. Crewmembers are very familiar with the alarm tones, and although they noticed the faster identification of speech, they still ranked tone and tone-speech combinations higher than speech alarms. Non-crewmembers ranked the alarms starting with speech higher than the ones starting with tone. As expected, when the alarms were played over radio communications, identification times increased. Otherwise the results were very similar to the results obtained without radio communications.

When speech alarms are heard over headsets in combination with spoken radio conversation, there is a greater overlap in spectrum and temporal envelope that may cause the speech alarms to be masked or misidentified. This effect can be mitigated somewhat by the prosody of the spoken alarm; for example, the synthetic speech used in aviation flight decks has a unique timbre and declamatory style that allows it to be more easily separated from radio communications. Spatial separation of the spoken alarm (e.g., by playing it over one ear of the headset) can also allow a "cocktail party" effect advantage. Ultimately the decision whether to use speech alarms or tone alarms or a combination of these should take into account the context of their use.

As a result of these studies, the alarm requirements in the Human Systems Integration Requirements (HSIR) document were updated with the option to use speech alarms when available. For example, the Orion hardware architecture has the capability to support speech alarms. Although human space flight work for the Orion program was halted in 2010, it resumed in 2013. The Space Human Factors and Habitability (SHFH) program determined at that time that the current follow-on study with updated speech alarms was warranted.

The goals of a follow-on study were intended to serve as a decision point for the use of speech alarms:

- Are the alarms ready for transition to operations?
- Is additional research required via a Human Research Program (HRP) solicitation?

The current study sought to replicate the results of our prior studies but using improved versions of the alarms with non-variable onset times in a laboratory setting. In addition, we wished to evaluate the efficacy of the alarms in an analog environment (HERA) while participants were involved in tasks that increased their workload.

3. Phase 1: Speech Alarms Experiment

3.1 Method

3.1.1 Participants

Twenty-four participants from the NASA Johnson Space Center's Human Test Subject Facility completed the study. All had normal or corrected-to-normal vision and normal hearing.

3.1.2 Stimuli

At the beginning of the study, participants were presented with the definitions for the four categories of alarms from the current NASA Human Systems Integration Requirements Revision E, as follows:

> *Emergency*: Specifically identified life threatening warning event that requires immediate action.
>
> *Warning*: Event that requires immediate action because it is or has the potential to become a life/mission threat.
>
> *Caution*: Event that needs attention, but not immediate action.

There are two types of emergency situations: fire and depressurization. Thus, the four categories of alarms used in the study were: fire emergency, depressurization emergency, warning, and caution.

Each type of alarm was presented in either a tone or speech version (see description of each in Table 1):

- Tone only: a single iteration of the current fire alarm of 7 to 10 seconds duration.
- Speech only: two iterations of the alarm word, e.g., "Fire Fire."

All alarms were played in three conditions of background noise:

1. No background noise.
2. Communication loop noise: communication loop recorded from the ISS between ground control and crew.
3. Fan noise: fan noise recorded from the International Space Station (ISS).

The alarms and background noise were calibrated to comply with HSIR requirement 3.2.6.3.5 "Loudspeaker Alarm Audibility" so that alarms exceeded the masked threshold by at least 13 db per International Standards Organization (ISO) 7731 (see Appendix A).

The two types of sounds (speech and tone) with the three types of background noise (no noise, com, and fan) resulted in six conditions. All participants experienced all conditions in counterbalanced order using a within-subjects experimental design.

Table 1. Description of Stimuli Used in Study.
(The tone alarms were created based on the current HSIR requirements.)

Stimulus Name	*Description*
Fire Category	
Tone	5 s tone (single period of siren frequency modulation); 1 s silence; repeat tone.
Speech	Speech “FIRE FIRE;” 1 s silence; repeat.
Depressurization Category	
Tone	2 s tone (klaxon iterated 8 times); 1 s silence; repeat tone.
Speech	Speech “DEPRESS DEPRESS;” 1 s silence; repeat.
Warning Category	
Tone	6.7 s tone (3 iterations of 1.5 s alternating tones); 3 s silence; repeat.
Speech	Speech “WARNING WARNING;” 1 s silence; repeat.
Caution Category	
Tone	1 s tone (2 iterations); 2 s silence; repeat.
Speech	Speech “CAUTION CAUTION;” 2s silence; repeat.

3.1.3 Procedure

The study had two types of tasks: a detection task and an identification task. We hypothesized that detection times would be shorter than identification times. Trials were blocked by type of sound, within that by type of task, and then by type of background noise. Before the experiment, participants had 16 practice trials with the alarms without background noise, with both detection and identification tasks.

Icons were used to represent the alarm types (see Figure 1) to avoid the facilitation effect of words for speech alarms (i.e., hearing and seeing the word “Fire” would facilitate choice). Participants had training with the icons until they were able to quickly identify each of them.

3.1.4 Detection Task

After participants completed the familiarization session with the icons, alarms, and task, they were presented with a Start button on the center of the computer screen. When they clicked the Start button, an alarm played (see Figure 1). The subjects then clicked the Stop button as soon as they could identify the alarm. After pressing the Stop button to confirm they heard the sound, subjects were presented with the icons representing the four categories of alarms. They had to indicate their choice without being timed on this part of the task. Feedback ("correct" or "incorrect") was provided on the accuracy of the choice. Here are the instructions displayed for the participants:

> *"When you click the Start button, an alarm sound will be played. Your task is to identify that you heard the sound as quickly as possible. As soon as you realize a sound is played, click the Stop button in the center of the screen. Then identify which sound played by clicking on the appropriate icon, into one of the four categories: fire, depressurization, warning, and caution. You will receive feedback on your selection. Please try to be as fast as possible in identifying that an alarm played, meaning that you do not need to listen to the whole duration of the sound before indicating you heard it. However you may take your time in identifying that a sound had played. Your response time is recorded and is measured as the time between your click on the Start button and the click on the Stop button. You may take a break after any of your choices, before clicking on the Start button again."*

Figure 1 Screen sequence for the detection task in the study. Clicking the Start button started the sound, the Stop button stopped it. The participant were asked to identify the four categories by clicking on the corresponding icon.

The four categories of alarms were presented four times with each sound type and background noise, for a total of 96 trials in the detection task. Within each condition, the stimuli were randomized and the conditions were counterbalanced.

3.1.5 Identification Task

In the identification task, subjects had to categorize the alarms as quickly as possible. The task was very similar to the detection task, except participants responded with clicking one of the four icons as soon as they could identify the alarm played (see Figure 2). Subjects were instructed to respond to the sounds as soon as they identified the sounds, without listening to the sound for its full duration. Feedback was provided on the accuracy of the choice.

Subjects received the following instructions:

> *"When you click the Start button, an alarm sound will be played. Your task is to categorize the sound as quickly as possible, by clicking on the appropriate button, into one of the four categories: fire, depressurization, warning, and caution. You will receive feedback on your selection. Please try to be as fast and as accurate as possible, meaning that you do not need to listen to the whole duration of the sound before making a choice. Your response time is recorded and is measured as the time between your click on the Start button and the click on the button of your choice. You may take a break after any of your choices, before clicking on the Start button again."*

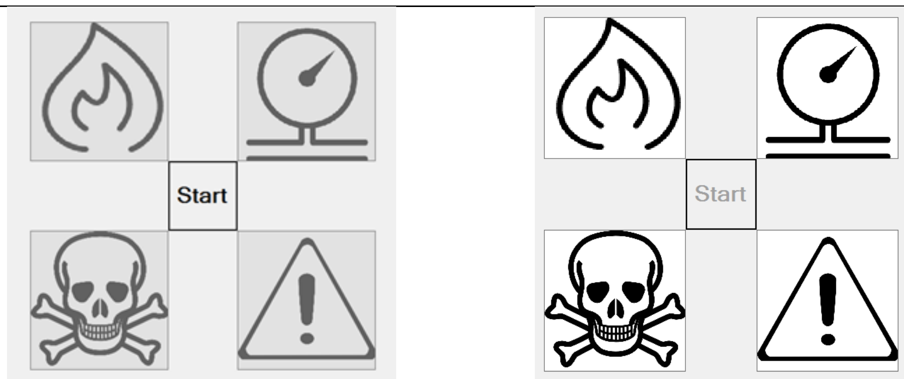

Figure 2. Screen sequence for the identification task in the study. Clicking the Start button started the sound. The sound stopped playing as soon as the participant clicked on one of the icons.

Similar to the detection part, in this task the conditions were counterbalanced, and the alarm stimuli were randomized within each condition. In each condition there were 32 stimuli for a total of 192 trials in this task. The software recorded response times and errors.

3.2 Results

3.2.1 Response Time (RT) Analysis

For the response time analysis, the incorrect trials were removed from the data set (276 trials out of 6912 trials, 3.99% of all trials). The analysis of errors will be presented in the next section of the report. Response times (RT) longer than 5000 ms (12 trials out of 6636 correct trials, 0.18% of correct trials) were excluded as well.

A 2 x 3 x 2 repeated measures ANOVA, Alarm Type (Speech, Tone) x Noise Type (None, Fan, Com) x Task Type (Identification, Detection) was conducted on the RT.

There was a significant Alarm Type x Noise Type interaction, $F(2,46) = 3.7$, $p = 0.03$, response times to tone alarms were more affected by background noise (fan or com loop) than speech alarms, that is, RTs were longer (see Figure 3).

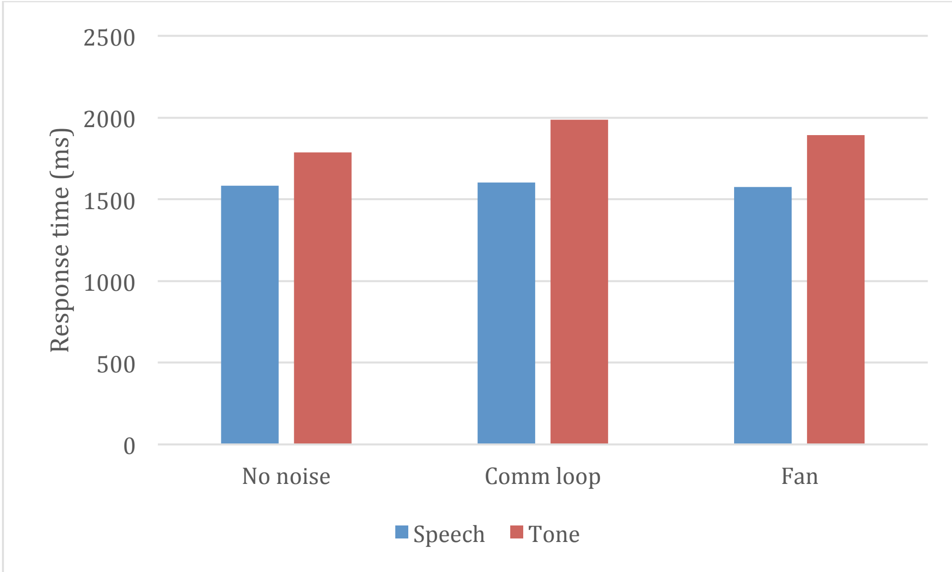

Figure 3. Mean response times as a function of alarm type and noise.

Interestingly, response times in the detection task were longer than in the identification task. It appeared that participants were faster identifying the alarm when the icons representing the types of alarms were on the screen than when the icons were not displayed. This difference was larger for tone than for speech alarms, pointing to more difficulty recognizing the tone alarms than the speech alarms. The analysis found a statistically significant Alarm Type x Task Type interaction: $F(1,23) = 6.9$, $p = 0.015$; (see Figure 4).

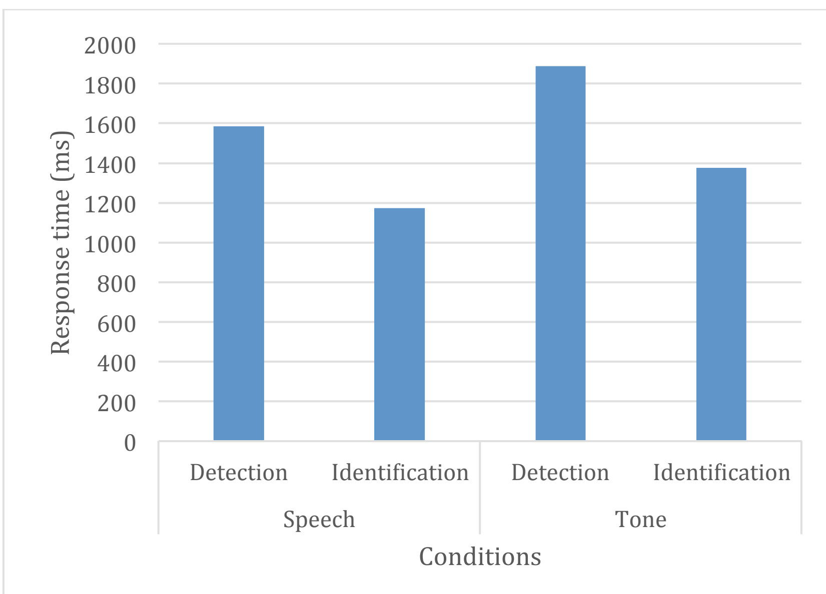

Figure 4. Mean response times as a function of alarm type and task type.

3.2.2 Accuracy

Overall, participants were more accurate identifying speech alarms than tone alarms, $t(22)$, $p = 0.004$, mean difference of 3 errors.

The results of this study are consistent with the literature and our previous study: speech alarms are identified faster and more accurately than tone alarms.

4. Phase 2: Speech Alarms Evaluation in the Human Exploration Research Analog (HERA)

The purpose of Phase 2 was to validate the speech and tone alarms in a more realistic setting. The Human Exploration Research Analog at NASA JSC was used for this purpose (Figures 5 and 6).

4.1 Method

4.1.1 Participants

All participants (N = 6, female = 3) were volunteers with normal hearing recruited through the NASA JSC Human Test Subject Facility.

Figure 5. Human Exploration Research Analog (HERA) at the NASA Johnson Space Center.

Figure 6. Inside HERA. (Note: The equipment pictured was not used in the evaluation.)

4.1.2 Stimuli

The stimuli were the same as the ones used in the lab experiment. The tone and speech alarms were presented to participants over the ambient noise of the analog. The sound levels of the alarms were calibrated to comply with the HSIR requirement (see Appendix A).

4.1.3 Equipment and Setup

The alarms were presented through speakers stationed on opposite walls of the analog with the participant positioned at a workstation between the speakers.

The participants completed their tasks on a laptop with Internet connection. They had access to all of the task materials, including the Alarm Response survey (Appendix B), the Morae Recorder© software, the electronic task list (Appendix C), pattern blocks and cards (Appendix D), and the Cursor Control Test Battery software (Sándor and Holden, 2008).

The test conductor sat at a workstation adjacent to the participant's workstation. Morae Observer© was used to monitor the participant's progress through the task list and to document alarm onset times.

4.1.4 Procedures

Participants received facility training and familiarization with test alarms and tasks prior to testing. Familiarization with the alarms was completed with the familiarization part of the software used in the laboratory study. Informed consent was obtained during the familiarization session. Participants completed two test sessions in HERA: one with speech alarms and one with tone alarms. The order of the sessions was counterbalanced across participants.

For each test session, the participants met the test conductor at the HERA facility to review the study and answer any remaining questions. They then entered HERA and took a seat at the workstation in front of a laptop and a task list.

The task list contained two kinds of tasks: a mock assembly task (completing a pattern block card using written and auditory instructions) and a computer-based task with the Cursor Control Device (CCD) Test Battery software that consisted of mouse pointing and dragging tasks. The pattern block card task was completed twice during each session, with the instructions in written and then spoken form.

Alarm onset intervals were based on task rather than time to ensure that participants were engaged in a task when presented with an alarm. Participants heard an alarm at least once during each type of task.

When an alarm began, participants were instructed to stop their current task and indicate the type of alarm (caution, warning, fire, or depressurization) using the Alarm Response survey. After identifying the type of alarm, participants received instructions to retrieve a code in a specified location in the HERA habitat and enter the code in the Alarm Response survey. After entering the code, the participant resumed the interrupted task.

4.1.5 Measures

Response time to identify the alarm was defined as the time between alarm onset and identification of the alarm type. These were recorded by the test conductor using specialized software[5]. Alarm identification accuracy was determined based on participant responses on the Alarm Response survey. Qualitative feedback about the alarms was collected by the test conductor during the verbal debrief (Appendix B).

4.2 Results

The task times and total time are shown in Table 2.

Table 2. Minimum, Maximum, Mean Task Times, and Total Session Time in Minutes

Time on Task (Minutes)	*CCD Test Battery*	*Pattern Block Instructions (Written)*	*Pattern Block Instructions (Spoken)*	*Total Time*
Minimum	2.98	5.84	4.64	42.81
Maximum	7.76	8.71	10.54	86.01
Mean (sd)	5.14 (1.19)	6.70 (0.79)	6.38 (1.80)	58.57 (11.47)

Response time and accuracy were analyzed as a function of alarm type.

Five out of six participants responded faster to speech than tone alarms with a mean difference of 4.8 seconds (see Figure 7). The sixth participant had almost the same response time to both types of alarms.

[5] "Morae Observer" distributed by TechSmith Corporation.

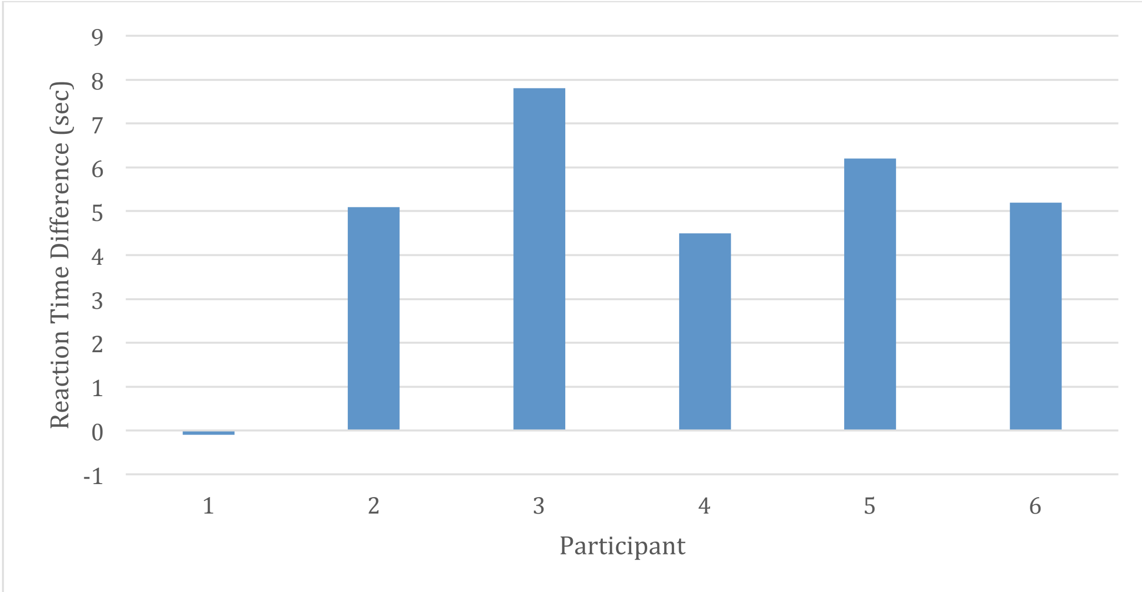

Figure 7. Reaction time difference (sec) to tone and speech alarms for each participant. Positive values indicate a faster response to speech alarms (slower response to tone).

A 2 x 4 repeated measures ANOVA, Alarm Type (Speech, Tone) x Category (Caution, Warning, Fire, Depressurization) was conducted on the response time to the alarms. There was a significant main effect of Alarm Type, $F(1,5) = 19.29$, $p = 0.007$, indicating faster responses to speech than to tone. There was no significant main effect of category and no Alarm Type x Category interaction, meaning that the category of the alarm did not significantly impact response time.

Participants made no errors when identifying speech alarms. However, there was one error for identifying caution, warning, and depress alarms.

Qualitative feedback was analyzed to determine recommended changes to the speech alarms. Four out of six participants preferred the speech alarms over the tone alarms. They commented that speech alarms seemed easier and faster to identify, increased the awareness for the situation, and conveyed more urgency than the tone alarms. Participants recommended improving the indication of the level of urgency of the alarms (e.g., vocal emphasis), using a combination of speech and tone, and including a brief description of the problem.

5. Discussion

An experiment in controlled conditions and an evaluation in a flight analog environment were conducted to investigate tone and speech alarms. Both studies show that speech alarms are identified faster and more accurately than tone alarms. The study results show that speech alarms are ready for transition to operations. Furthermore, the research investigating speech and tone alarms is conclusive showing advantage of speech alarms in space flight relevant conditions.

Speech alarms have a well-established performanc record in aviation and other domains. Speech alarms, or Voice Evacuation Systems (Voice Evac), are used in combination with tones in newly constructed buildings. International Building Code (IBC) and the National Fire Protection Association's (NFPA) Life Safety Code included Voice Evac systems as early as 2003 (NFPA, 2003). The 2015 IBC (IBC, 2015) Section 907.5.2.2 (see Appendix A) specifies that automatic fire detectors "shall automatically sound an alarm tone followed by voice instructions." The combination of tone alarm and voice instructions is considered safer in the industry for evacuating large volumes of people during emergency situations because the voice instructions help people remain calm and provide additional information about evacuation routes and emergency protocols.

Half of the participants in the HERA study recommended evaluating alarms combining tone and speech including a brief message providing additional information about the alarm. Previous speech alarm studies investigated the combination of tone alarms with speech suffix in a lab setting, but did not find a difference in reaction time or accuracy when compared to tone alarms alone. Because of this result, the combination alarms were not evaluated during this study.

Based on the successful use of combinations of tone and speech alarms in aviation and buildings, and the results of the current study, we find compelling evidence for the use of combination speech-tone alarms in space vehicles for caution-warning systems. In situations when identifying the details of the problem is as important as detection, speech alarms with detail information regarding the warning may provide additional advantages. Future research is recommended to investigate combination of speech and tone alarms in other operational settings.

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Appendix A. Requirements

HSIR Requirement and Verification for Alarm Types and for Loudspeaker Alarm Audibility.

Caution and Warning: Alarm Annunciations		
Alarm Type	*Priority*	*Alarm Annunciation*
Emergency: Fire Time critical warning event that requires immediate action due to life/mission threat.	1	Siren: square wave frequency modulated over a period of 5 s from 650 Hz – 1,500 Hz – 650 Hz; followed by 2 s silent interval; repeat until terminated. Notes: 1, 2, 3, 4, 5, 6 (Corresponds to red symbology on display and lights.)
Emergency: Pressure Loss Time critical warning event that requires immediate action due to life/mission threat.	2	Klaxon: 2,560 Hz tone, 2.1 ms on, 1.6 ms off, mixed with 256 Hz tone. Two digital pulse trains shall be logically OR'ed and the DC component removed. The first pulse train shall be a 50% duty cycle square wave at 2,560 Hz which is enabled for 2.1 ms and set to logic "0" for 1.6 ms. The second pulse train shall be a 50% duty cycle square wave at 256 Hz which is enabled for 210 ms and set to logic "0" for 70 ms. Sequence contains 4 iterations of 280 ms on-off pulse (210 ms ON, 70 ms OFF), followed by 280 ms silence. This sequence is, repeated 3 times separated by 1.5 s silent interval; repeat until terminated. Notes: 1, 4, 5, 6 (Corresponds to red symbology on display and lights.)
Warning Event that requires immediate action because it has the potential to become a life/mission threat.	3	Alternating tone (square wave), 400 Hz and 1,024 Hz at a 2.5 Hz modulation rate (400 Hz for 0.4 s then 1,024 Hz for 0.4 s, total 0.8 s); sequence contains two pairs of alternating square wave tones with total 1.6 s duration; sequence followed by 1 s silent interval; repeats 3 times followed by 3 s silent interval; repeat until terminated. Notes: 1, 2, 4, 5, 6 (Corresponds to red symbology on display and lights.)

Catuion and Warning: Alarm Annunciations (continued)		
Alarm Type	*Priority*	*Alarm Annunciation*
Caution Event that needs attention, but not immediate action.	4	Continuous tone triangle wave (odd harmonics at amplitude reciprocal to harmonic number) 512 Hz of duration 1 s. Subsequent repetitions consist of 1 s of silent interval followed by the 1 s tone. Number of repetitions (or total duration) may be set by the crewmember, from 1 to 30 repetitions (or 1 s to 60 s). Notes: 1, 2, 3, 4, 5, 6 (Corresponds to yellow symbology on display and lights.)
Advisory Message describing a routine event, situation, or action, or an off-nominal event that does not meet the criteria for a Caution.	5	No audio. (Corresponds to blue symbology on display)

NOTES:

1. To prevent 'startle effect,' the onset of all alarms should be preceded by a 'pre-alarm,' whereby the same alarm is enunciated 10 dB lower than its final calibrated level (e.g., +15 dB(A) with respect to the level of the background noise). This may be accomplished using separate start and loop start addresses to the digital buffer (see Appendix K of the HSIR document, figure Pre-Alarm and Alarm Start/Loop Start for Non-Startle).
2. To prevent 'startle effect,' the onset of the amplitude envelope of alarms should have a rise time from 0 to maximum amplitude of 200 ms (see Appendix K of the HSIR document, figure Onset of the Amplitude Envelope of Alarms for Non-Startle).
3. This siren is based on the standard 'wail' siren used by law enforcement that mimics historical 'wind-up' sirens. Frequencies have been adjusted to conform to recommended practice "Emergency Vehicle Sirens-SAE J1849 August 1995," Society of Automotive Engineers (SAE).
4. Rather than sounding continuously, the alarms have silent intervals in between sound bursts to aid problem solving under high-stress conditions. The lower the priority of the alarm, the longer the 'inter-burst silent interval' (ranges from 2–4 s).
5. Alarms shall be prioritized per the second column so that higher priority annunciations postpone or cancel any lower priority alarm from sounding at the same time.
6. Any verbal annunciation used must have NASA approval.

Loudspeaker analysis:
The alarms were analyzed against the 1/3 OB spectral requirements per 4.2.6.3.5 Loudspeaker Alarm Audibility [HS3111V] (at least 13 dB above ambient for frequencies between 300 to 3k Hz 1/3 OBs).

4.2.6.3.5 Loudspeaker Alarm Audibility
[HS3111]
Loudspeakers shall produce non-speech auditory annunciations that exceed the masked threshold by at least 13 dB in one or more one-third octave bands where the alarm resides, as measured at the crewmember's expected work and sleep station head locations.
Rationale:
The 13dB signal-to-noise ratio ensures that non-speech auditory annunciations are sufficiently salient and intelligible, according to ISO 7731, Ergonomics - Danger signals for public work areas - Auditory danger signals. ISO 7731 is an accepted standard for ensuring the ability to detect and discriminate non-speech alarms and alarms.

4.2.6.3.5 Loudspeaker Alarm Audibility
[HS3111V]
The loudspeaker non-speech auditory annunciation levels shall be verified by test. The measurements shall be made within the vehicle in the flight configuration with integrated GFE, stowage, vehicle installations, and closeouts installed. Hardware shall be operated across the expected range of operational settings (including settings corresponding to the expected highest noise levels). Sound pressure measurements shall be made within each one-third-octave band, with center frequencies ranging from 300 Hz to 3 kHz, using a Type 1 integrating-averaging sound level meter using a peak hold function with a fast (125 ms) exponentially-weighted time averaged response.
Measurements shall be made at expected work and sleep station head locations. The ambient noise level shall be measured via a 20-second Leq (slow time weighting). The verification shall be considered successful when the test indicates that, for each temporal component of the annunciation, the level in at least one one-third-octave band is more than 13 dB above the ambient noise level at each expected work and sleep station location.

International Building Code requirement on voice alarms (2015)

[F] 907.5.2.2 Emergency voice/alarm communication systems.
Emergency voice/alarm communication systems required by this code shall be designed and installed in accordance with NFPA 72. The operation of any automatic fire detector, sprinkler waterflow device or manual fire alarm box shall automatically sound an alert tone followed by voice instructions giving *approved* information and directions for a general or staged evacuation in accordance with the building's fire safety and evacuation plans required by Section 404 of the *International Fire Code*. In high-rise buildings, the system shall operate on at least the alarming floor, the floor above and the floor below. Speakers shall be provided throughout the building by paging zones. At a minimum, paging zones shall be provided as follows:

1. Elevator groups.

2. *Interior exit stairways*.

3. Each floor.

4. *Areas of refuge* as defined in Chapter 2.

Appendix B. Alarm Response Survey

1.	Alarm Category:	[- Select One -]

2.	Please enter the code found in the **Airlock**	______________________________

2.	Please enter the code found in the **Hygiene Module**	______________________________

2.	Please enter the code found in the **Main Area**	______________________________

2.	Please enter the code found in the **Galley**	______________________________

Please answer the following questions. Your responses will remain anonymous, results will be presented in aggregate. Please select "No Reply" on questions that you do not want to answer.

3.	The alarm was easy to identify.					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	No Reply
	¡	¡	¡	¡	¡	¡

4.	The alarm was startling.					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	No Reply
	¡	¡	¡	¡	¡	¡

5.	The alarm was appropriate for the problem.					
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	No Reply
	¡	¡	¡	¡	¡	¡

Appendix C. Participant Task List as Used in the HERA Evaluation

Task List

1. Complete one session of Cursor Control Device Test Battery on laptop
    1.1 Open Test Battery Software
    1.2 Select "Run Participant"
    1.3 Select "Speech_Alarms_HERA" for Experiment Name
    1.4 Select Participant number 001
    1.5 Select "Run Participant"
    1.6 If an Alarm goes off during this task, selt Alt + Tab to exit the software

2. Comple Card 1 in order listed below. Return tiles to container after completing the card.
    - 5
    - 20
    - 24
    - 44
    - 4
    - 22
    - 34
    - 3
    - 30
    - 45
    - 27
    - 39
    - 42
    - 9
    - 48
    - 33
    - 10
    - 38
    - 37
    - 15
    - 2
    - 11
    - 14
    - 13
    - 41
    - 47
    - 35
    - 7
    - 46
    - 26
    - 32
    - 6
    - 18
    - 29
    - 16
    - 28
    - 21
    - 25
    - 43
    - 23
    - 49
    - 40
    - 31
    - 19
    - 17
    - 8
    - 1
    - 36
    - 12

3. Complete one session of Cursor Controld Device Test Battery on laptop
    3.1 Open Test Battery Software
    3.2 Select "Run Participant"
    3.3 Select "Speech_Alarms_HERA" for Experiment Name
    3.4 Select Participant number 002
    3.5 Select "Run Participant"
    3.6 If an Alarm goes off during this task, selt Alt + Tab to exit the software

4. Complete Card 2 in order described in this recording. Return tiles to container after completing the card.

5. Complete one session of Cursor Control Device Test Battery on laptop
    5.1 Open Test Battery Software
    5.2 Select "Run Participant"
    5.3 Select "Speech_Alarms_HERA" for Experiment Name
    5.4 Select Participant number 003
    5.5 Select "Run Participant"
    5.6 If an Alarm goes off during this task, selt Alt + Tab to exit the software

6. Complete Card 3 in order listed below. Return tiles to container after completnig the card.
    - 28
    - 35
    - 18
    - 4
    - 30
    - 40
    - 32
    - 41
    - 38
    - 42
    - 34
    - 25
    - 5
    - 14
    - 23
    - 1
    - 15
    - 10
    - 12
    - 6
    - 3
    - 33
    - 16
    - 37
    - 24
    - 8
    - 19
    - 48
    - 43
    - 11
    - 29
    - 26
    - 2
    - 39
    - 46
    - 21
    - 47
    - 45
    - 44
    - 36
    - 13
    - 9
    - 22
    - 7
    - 17
    - 27
    - 20
    - 31

7. Complete one session of Cursor Control Device Test Battery on laptop
    7.1 Open Test Battery Software
    7.2 Select “Run Participant”
    7.3 Select “Speech_Alarms_HERA” for Experiment Name
    7.4 Select Participant number 004
    7.5 Select “Run Participant”
    7.6 If an Alarm goes off during this task, selt Alt + Tab to exit the software

8. Complete Card 4 in order described in this recording. Return tiles to container after completnig the card

9. Complete one session of Cursor Control Device Test Battery on laptop
    9.1 Open Test Battery Software
    9.2 Select “Run Participant”
    9.3 Select “Speech_Alarms_HERA” for Experiment Name
    9.4 Select Participant number 005
    9.5 Select “Run Participant”
    9.6 If an Alarm goes off during this task, selt Alt + Tab to exit the software

10. Complete Card 5 in order listed below. Return tiles to container after completnig the card
    - 30
    - 27
    - 29
    - 37
    - 3
    - 34
    - 38
    - 10
    - 32
    - 24
    - 23
    - 17
    - 33
    - 31
    - 9
    - 21
    - 35
    - 11
    - 25
    - 14
    - 19
    - 22
    - 40
    - 2
    - 18
    - 6
    - 5
    - 4
    - 12
    - 26
    - 39
    - 16
    - 8
    - 20
    - 36
    - 15
    - 7
    - 13
    - 28

Appendix D. Pattern Blocks and Card Example

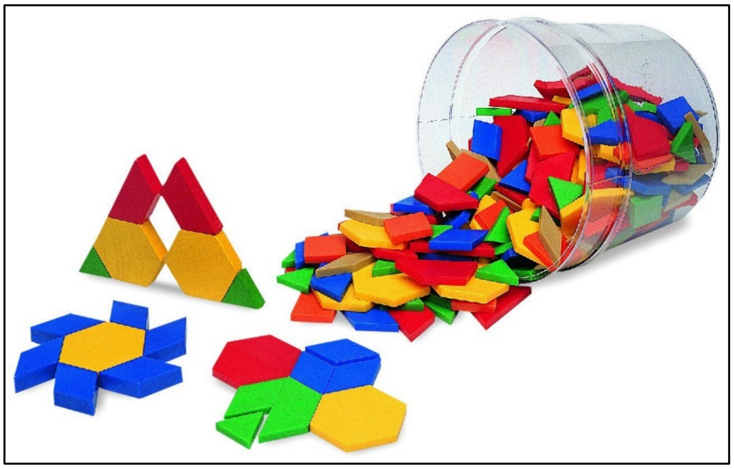

Figure D1. Pattern blocks used to build the pattern card shown below.

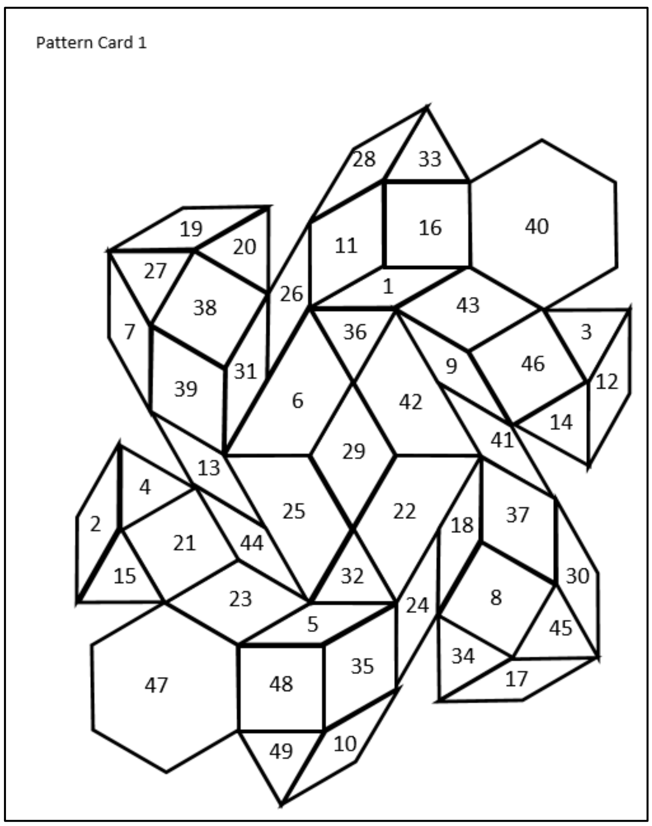

Figure D2. Pattern Card example used during the evaluation.