Multimodal Display Rationale

High-workload, fast-paced, and degraded sensory environments (e.g., during EVA and telerobotic operations) are the likeliest to benefit from multimodal displays that can:

- Enhance situation awareness and task performance by maximizing the effectiveness of different sensory channels in an appropriate interaction between modalities.
- Play an important role in informing interface guidelines for long duration exploration missions (LDEMs) requiring greater crew autonomy with increased dependence on spacecraft information systems for both routine and time/safety critical tasks.

Benefits of Multimodal Displays

- Increased bandwidth: Increase in the amount of information that can be presented over a fixed time period.
- Cross-modal: Perception from sense information in more than one sensory modality (e.g. critical alarms).
- Adaptability: Information from different sensory channels is integrated into an overall view.
- Multisensory: Integrating sensory channels based on their suitability for presenting particular kinds of information (e.g., auditory for voice recognition, visual for visual focus).
- Complementarity: Presenting related information in different sensory modalities to form a unified perceived object or event.
- Substitutability: Presenting information in an alternative modality when other sensory channels become temporarily or permanently unavailable.

Multisensory Integration

Evidence from both behavioral and neuroscience research demonstrates an extraordinary cross-modal link between visual, audition, and touch:

- Modality specificity: top-down influence on attention allocation. Attention allocation was increased in the expected channel.
- Modality shifting: Performance degradation when attention is shifted from the expected modality to an unexpectedly used channel. It's slower for events in less frequent modalities.
- Crossmodal spatial and temporal time lags: delay in the integration of stream of information across the brain's different locations and the expected time delay. Crossmodal spatial links lead to enhanced facilitation of responses when simultaneous stimuli are at the same location or in response suppression for stimuli at different locations or that are presented in time. Perfect spatial and temporal alignment is not required for multisensory integration to occur as long as the modalities are presented within close spatial and temporal proximity (e.g., as defined by psychophysical studies).

Literature Review: Applied Studies of Multimodal Displays

Multimodal display research covers:
- Other developed in a trial and error manner.
- Don't consider basic mechanisms of human multisensory integration and cross-modal attention.
- Equivalence between stimuli in each sensory channel (e.g., comparable detection thresholds) is newly established prior to a study.
- Performance measures not always directly compared among all possible combinations of auditory, visual, and haptic displays.
- Clear influences about relative multisensory benefits can be problematic.

Examples of Applied Studies of Multimodal Displays

A-VIEW Mixed Reality System: Mars Surface

NASA Ames Human Systems Integration Division (courtesy Kenji Kato)

Modality appropriateness:

- Multimodal autonomous interface such as collision event warnings (visual, auditory and/or tactile) display the source and spatial location of potential collisions.
- Research results are inconsistent regarding whether multimodal displays produce better performance compared to unimodal displays. Performance varies considerably depending on factors like the spatial congruency/(physical location) of the different display modalities.

Modality appropriateness:

- A simulated ground vehicle study compared the effectiveness of auditory, visual, and haptic threat warning systems.
- When all three cues were spatially congruent, threat acquisition was significantly better for a trimodal (visual-auditory-haptic) display than for the tri-modal threat warning systems.

Modality appropriateness:

- Similar benefits observed for multimodal directional alerting systems under conditions such as high workload or induced visual occlusion, in the presence of Keplerian noise, and during all traffic control.

Modality appropriateness:

- Studies show multimodal displays produce differential effects depending on workload, e.g., multimodality may become more effective than unimodal displays when selecting a smaller region of interest.

Modality appropriateness:

- Unilateral agreement in the threshold that fixates alignment of multialarms to tasks or types of information across all devices is not a desirable or even possible. Multimodal interfaces must accommodate possible changes in the needs, abilities and experience level of the user, and the type of tasks being performed, the level of attention, and the level of workload.

Modality appropriateness:

- Adaptive display techniques are developed for detecting and/or predicting operator state or task conditions. Considerable debate remains regarding whether multimodal interface flexibility should be taken to the form of system-controlled adaptivity (automatically) and/or user-controlled adaptivity (modified by user preferences).

Adaptive Multimodal Information Displays

- Simple approaches based on user preference are not likely to be sufficient in complex task environments such as LDEMs where crew members will require at least some degree of automated support.

Multimodal Displays in Space Environments

- Although the effect of microgravity is relatively well documented for individual sensory systems, less is known about interactions between the senses.

- The normal contribution (weight) of each sensory modality to multimodal perception experienced on Earth will not be relevant in space, since the reliability of the different senses will change. For example, the usual dominance of visual cues in multisensory perception may decrease, and the role of auditory and tactile cues may increase.

- Some conclusions may be drawn from studies on conditions during altered gravity but investigation in true space environment will remain the best test of display effectiveness.

Current Standards & Guidelines

Significantly more consistent guidance directly addressing multimodal displays is currently available in the form of standards and guidelines.

- May be essentially unstructured, addressing the properties and preferable use of individual sensory channels.
- May focus on very specific type of displays for a very specific task such as multimodal warning signals for driver-vehicle interactions.
- Are high-level design principles that can apply independent of modality, such as complementarity, consistency, and redundancy of information presentation either within or across sensory channels.
- May be more general guidelines concerned with the effective combination and integration of sensory channels, but they are primarily based on research using bimodal information and free directly available trimodal (or beyond) information.
- NASA 3001 standards for crew interfaces are either very specific or model-based and recommend guidelines tend to be high level. Neither specifically addresses multimodal displays.

Examples of Current Standards & Guidelines

- ISO 9241-111 (2002): International standard of multismedia design principles that focus on the impact of each visual, auditory, and/or tactile selection per se, rather than modality selection, in extraneous, tactual, and unpredictable. Comprehensible, manageable information being presented, complementarily, consistency & redundancy.
- Sarter (2017, 2018) reviews and critiques current guidelines for multimodal displays and outlines questions that should be addressed in formulating guidelines.
- Brown et al. (2015) is an oft-cited review article that addresses the development of guidelines. Requirements Specifications, Designing Multimodal Information, and/or user-adaptive displays and cross-modal perception
- Geng, et al. (2015) is a comprehensive document published by Defence Research and Development Canada that addresses a variety of topics related to the design of multimodal interfaces.

Recommendations for NASA

- Incorporate multimodal (MM) guidelines into HMD as mid-level guidelines that elaborate high-level recommendations (this should be done for a number of topical areas in HMD).
- Clarify what are the multimodal guidelines and their underlying rationale.
- Provide pointers to other HIDH sections for guidelines that are not specific to multimodal interface design or that focus on the choice of individual sensory channels for given tasks and contexts.
- Develop user guidelines for each area of multimodal displays and cross-modal perception
- NASA, DOD, industry personnel with interface development experience in both applied research & operational simulation contexts
- Experts in MM software/hardware architecture, e.g., MM experience in virtual/augmented displays
- Significantly invest in research to validate proposed guidelines and multimodal prototypes.

Reference