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**EFFECTS OF A NETWORK-CENTRIC MULTI-MODAL
COMMUNICATION TOOL
ON A COMMUNICATION MONITORING TASK**

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14. ABSTRACT Multi-Modal Communications tool suite was developed to better equip C2 operators to manage the high workload and complex communication environments in which they work. This integrated system captures, displays, records and archives radio and text-based chat communications. This study examined the performance associated with monitoring communication channels, with access to different tools. Operators monitored and responded to the occurrence of critical phrases presented during a 27-min communication monitoring task. Communication performance was analyzed in regard to message detection, response accuracy, and time. Data showed that MMC provides a balance between the speed of radio listening and the accuracy and data-capturing capabilities of chat displays. MMC can be a beneficial tool to operators in its ability to increase intelligibly, while providing a persistent, searchable display that reduces perceived mental workload.					
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1.0 SUMMARY

Communication remains a critical component to mission success. With the shift towards network-centric warfare, standard radio communication needs to meet the needs of today's warfighter. A net-centric communication management suite called Multi-Modal Communication (MMC) had been developed. This integrated system captures, displays, records, and archives radio and text-based communication to better equip the warfighters. This study examined the performance associated with monitoring communication channels, with access to different tools. Communication performance was analyzed in regard to message detection, response accuracy, and time. Data showed that MMC provides a balance between the speed of radio listening and the accuracy and data-capturing capabilities of chat displays. MMC can be a beneficial tool to operators in its ability to increase intelligibility, while providing a persistent, searchable display that reduces perceived mental workload.

2.0 INTRODUCTION

Chief of Naval Operations Admiral Jay Johnson stated, "the fundamental shift from what we call platform-centric warfare to something we call network-centric warfare will prove to be the most important revolution in military affairs in the past 200 years" (Cited from Cebrowski & Garstka, 1998). The motivation for this transformation is to increase mission effectiveness with the use of vast networks of state-of-the-art sensor and weapon platforms. The theory is that instant access to information from dispersed resources will increase the speed of command and self-synchronization of all active operators, thus improving military capabilities (Cebrowski & Garstka, 1998). These benefits are a result of advanced collaborative tools that allow distributed teams to communicate and share information, thus increasing each other's situation awareness of the ever-changing mission (Vidulich, Bolia, & Nelson, 2003). It is important to point out that although advanced collaborative tools will aid in the sharing of information, accurate communication between operators can never be replaced (Nelson, Bolia, Vidulich, & Langhorne, 2004). Communication will continue to be the central tool for Command and Control (C2) operators. However, current radios are still analog and are not fully integrated into modern day collaborative networks.

The effects of dated technology can be seen in situations confronting C2 operators who monitor communications from multiple assets to build a real-time picture of the dynamic battlefield and direct them as needed to carry out the mission. This communication-intensive environment imposes high workload on the operators, who typically monitor and transmit on eight or more simultaneous channels (Bolia, 2003). A major cause of the high mental workload is the issue that multiple operators can speak at the same time, thus reducing the intelligibility of essential messages. An additional problem is the transient nature of radio transmissions, in that the recipient has one chance to extract crucial information or is required to request that it is repeated. Not only is missed information a problem during the mission, but the operators must take detailed notes to ensure the correct information is relayed to the appropriate asset. This added step to relay the information to the correct asset opens up the possibility for error and may place the mission in jeopardy.

In an attempt to better equip C2 operators with collaborative tools that could aid in their mission, a survey of air battle managers from the United States Air Force, United States Navy, and the Royal Australian Air Force assessed the perceived usefulness of current commercial-off-the-shelf collaborative tools (Nelson, Bolia, Vidulich, & Langhorne, 2004). The two highest ratings for most potential technologies were data capture/replay tools and chat/messaging tools. Based on this information and research on communication intelligibility, researchers at the Battlespace Acoustics Branch in the Air Force Research Laboratory developed a network-centric communication management suite to help improve communication performance for network-centric warfare. This program, called Multi-Modal Communication (MMC), combines mature communication

technologies into an integrated communication system, see Figure 1. This combination fosters collaborative decision-making by providing operators with full access to voice and text-chat communication data from the distributed operator.

MMC allows operators to manage communication from voice as well as text-based systems in a single dynamic display. To combat the issue with radio intelligibility due to multiple operators talking, MMC spatially separates each of the voice channels to virtual locations around the operator via their headphones. Digital filters, called head-related transfer functions, take advantage of binaural cues that normally occur when competing talkers are spatially separated, and display the sounds over headphones in a similar manner. These types of auditory displays can produce virtual sounds that are as localizable as sounds produced in the free field and have been shown to increase speaker intelligibility by 30-40% for headphone-based multi-talker communication, and to reduce listeners' perceived mental workload (Bolia, 2003; Bolia & Nelson, 2003; Brungart & Simpson, 2005; Ericson, Brungart, & Simpson, 2004; Nelson, Bolia, Ericson, & McKinley 1998).



Figure 1. Two MMC displays. 1) Spatial location of audio channel; 2) Chat input field; 3) Control buttons; 4) Playback, edit/annotate controls, and flag icon tags; 5) Flagged/Transcribed text; 6) Find control; 7) Keyword highlight.

As stated earlier, a major problem with voice communication is that it is perishable in that operators only have one chance to extract critical information from a transmission and retain it before it is gone. Two features within MMC address that issue. The repeat function allows operators to replay the last 10 seconds of communication to clarify any missed information. The other feature that combats this issue is the use of automatic speech recognition (ASR), which captures and displays voice communication as text, thus making a once perishable message persistent. All voice communication is textually displayed and time stamped to aid operators in message detection and recall. In addition to capturing the message as text, the audio file is also captured and attached, allowing the operator to select the text and relisten to the original message or group of messages.

MMC also accepts and transmits chat messages from most multi-user chat programs. MMC follows a client-server framework where a user sends a chat message via the client to a server. The server then distributes the chat message to the connected clients, which stores the chat data, audio messages and their transcriptions in time order, thus maintaining a complete log of all communication during a mission. Operators who join the communication channels after the start of the mission, who have been disconnected or who take over a shift, now will have access to all verbal and written messages, thus allowing them to gain situation awareness by reviewing the log. Currently, there is a lengthy exchange between the oncoming and outgoing operators during shift change. Since the data is stored as text, MMC allows operators to highlight or flag important transmissions

so they stand out for easy review. In addition, the flags can be categorized to allow messages to be easily organized.

The information being passed from one operator to another can be a matter of life or death, thus the accuracy of that data is of the utmost importance. Given that ASR is not always perfect or that there can be typos in chat entries, MMC allows messages to be edited to reflect accurate information. Human- based computation can be employed here, as proofreaders for all transcribed messages in that operators not directly related to the mission can hear and read transcribed messages and make necessary corrections. These edits then can be reprocessed to improve the ASR program. Another advantage of displaying transcribed messages is that they can be formatted and presented to the operators so they can clearly review the material. An additional feature in MMC to help reduce transmission errors is the ability to copy a message and paste it to the appropriate channel for dissemination.

Operators can configure MMC to alert them to the occurrence of keywords. The keywords are highlighted to an operator's preference so that messages containing these keywords stand out and are clearly visible. In addition to highlighting keywords, MMC provides operators with the full capability to search and find critical information. The "Find" function allows them to search for keywords or flagged items, while the "History" function provides operators with the ability to jump to specific times and review past information.

These features have been integrated into a single unified system to allow for interoperability of verbal and chat communication. The idea behind the design of MMC is to give operators full access to all current and past information, thus allowing them to make quick and accurate decisions while decreasing the mental workload associated with a C2 task.

The goal for this study was to assess the potential utility of the MMC suite as a network-centric communication- management tool when compared to radio communication with or without 3D spatial audio, and chat. It was expected that the combination of communication tools would aid operators in their ability to quickly and accurately detect and reply to critical messages as well as reduce their perceived mental workload. In addition to manipulating Comm. Format, the amount of information each participant monitored was varied. The Easy message detection condition did not require working memory of critical (hostile) information, signal since it was composed of the call sign and the word "Hostile". The Hard message detection condition required operators to monitor and respond with all of the hostile's location information, thus requiring more of a working memory load. The second expectation was that the combination of communication tools would aid operators in their response to the hard message detection conditions. Performance was measured by the ability of operators to detect the critical messages, the accuracy of their responses, and the time they took to reply. Finally, it was expected that the use of communication tools would reduce the perceived mental workload, associated with the MMC task as compared to the other more traditional communication formats as described below.

3.0 METHODS, ASSUMPTIONS, AND PROCEDURES

Participants

Fourteen paid participants, eight male and six female, ranging in age from 18 – 26 years old served as operators in this task. All operators had normal hearing, as well as normal or corrected-to-normal vision.

Design

A within-subject design study was employed, with two levels of Signal Difficulty (Easy & Hard) combined factorially with four different Communication Formats (Radio, 3D Audio, Chat, & MMC). The Radio condition had audio from all six channels presented monaurally. The 3D Audio condition spatially separated each audio channel, so that each one virtually came from a different location in space around the operator. For the Chat condition, sound was not transmitted. Instead, text transcriptions of the signals were displayed (messages were identical to verbal messages) for the six channels. Although operators were reading these messages, they still responded via voice communication. Finally, in the MMC condition, both 3D Audio and ASR capabilities were combined. The operators were able to hear each of the channels localized in space and see the speech-to-text transcription of all audio signals. In addition, several other tools were made available to the operators, including the playback, find, mute, and isolate functions, while the highlighting of keywords was disabled during the study.

Apparatus

In all experimental conditions, operators were presented with a 27-min communication-monitoring task in which they were required to simultaneously monitor six radio/chat channels for the occurrence of critical phrases from the “Cowboy” call sign. The critical and neutral phrases for each call sign were recorded by six different voices (four male and two female). Critical signals were defined by the presence of the word “Hostile” from the “Cowboy” call sign. In the Easy condition, the critical phrase contained the “Cowboy” call sign followed by the phrase “ID hostile” (i.e. “Cowboy one ID hostile”). The critical phrase for the Hard condition was the “Cowboy” call sign, followed by the word “Hostile” and location information (i.e. “Cowboy one hostile north lead group 25 miles”). The neutral phrases were modified phrases from the Air Force Tactics, Techniques, and Procedures communication brevity document.

Phrases for each of the six channels were updated independently from each other with the restrictions of 30 messages per min and that they would be equally distributed across channels (810 overall events; 5 events/min/channel). Neutral signals for each channel were generated at random over a range of 10 – 30 seconds, with the restriction that there were approximately 4.6 neutral signals per channel per minute (126 neutral signals/channel). The message length for the neutral signals ranged from 1 – 8 sec in length ($M = 3.85$). Critical signals were presented at random over a range of 10 – 60 seconds, with the restrictions that two critical signals were generated per minute and occurred equally often across the six channels (9 critical signals/channel; signal probability = .067). The message lengths for the Easy critical signals were 1 sec long while the Hard signals ranged from 3 – 5 sec with an average of 4.3 sec. In all conditions, operators responded to a critical signal by pressing the “push-to-talk” button on the correct channel and repeating the message back. Responses occurring within 50 sec of a critical signal were recorded and all responses beyond were considered a missed signal.

Procedure

All operators took part in the computer-based training, which explained that their task was to monitor communication channels for the occurrence of a hostile entity that required a response. The training, which was comprised of two separate 60 min sessions, allowed operators to familiarize themselves with the different communication interfaces and the task itself. The order in which operators experienced the eight experimental conditions was determined by a Latin Square. Data were collected in a series of sessions, with each session lasting approximately 30 min. Each operator typically observed one session a day, until the completion of all eight conditions. Operators were stationed at a computer, where they experienced the presentation of neutral and critical signals through the communication interface. Headphones were used to present the auditory signals and responses were recorded through an attached microphone. Immediately following each session, observers completed the NASA-Task Load Index (NASA-TLX; Hart & Staveland, 1988) which is a validated measure of perceived mental workload.

4.0 RESULTS AND DISCUSSION

Correct Detections. Mean percentage of correct detections for all combinations of response Difficulty and Comm. Format are presented in Figure 2.

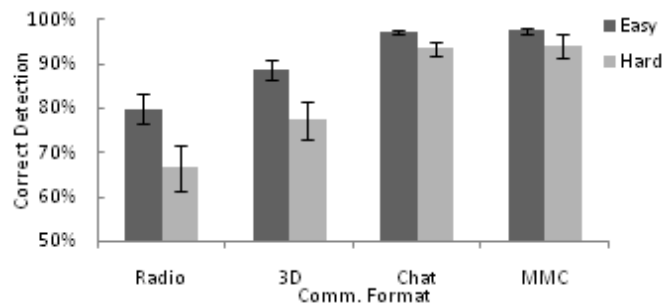


Figure 2. Percentage of correct detection for all combinations of task Difficulty and Comm. Formats. Error bars are standard errors.

Data from Figure 2 were tested for statistical significance by means of a 2 (Difficulty) $\times$ 4 (Comm. Format) within subjects analysis of variance (ANOVA). A significant main effect was found for Difficulty, $F(1, 13) = 21.11, p < .05$; the overall level of detections was greater in the Easy ($M = 90.9$) than in the Hard condition ($M = 82.9$). A significant main effect was also found for Comm. Format, $F(1.81, 23.51) = 27.35, p < .05$. Post hoc Tukey test found that the MMC ($M = 95.8$) and Chat ($M = 95.4$) formats did not differ significantly from each other, the scores for both were significantly higher than those in the 3D Audio ($M = 83.0$) and Radio ($M = 73.3$) formats. In addition, detection scores were significantly higher in the 3D Audio format than in the Radio format.

Along with the significant main effects, the Difficulty $\times$ Comm. Format interaction in the ANOVA was also significant, $F(1.68, 21.79) = 3.68, p < .05$. To explore this interaction Tukey tests were performed on the differences between Difficulty levels within each Comm. Format. Detection scores were significantly greater in the Easy than Hard condition for the Radio and 3D Audio formats; there were no significant differences in difficulty in the Chat and MMC format. In this and all subsequent ANOVAs, Box's epsilon was used to correct for violations of the sphericity assumption (Maxwell & Delaney, 2004).

Verbal Response Accuracy. Mean verbal response accuracy scores for all combinations of response Difficulty and Comm. Format are presented in Figure 3. Accuracy scores were calculated as percentages of the number of words in the verbal response that were identically matched to the words in the critical phrase.

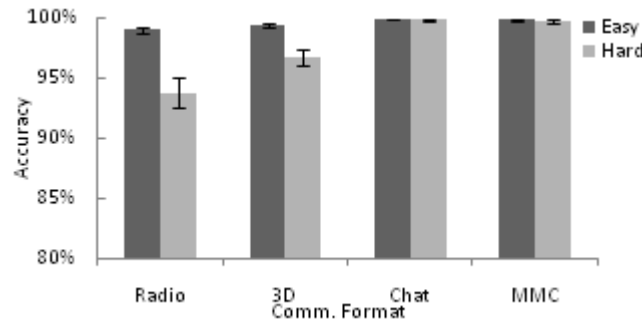


Figure 3. Verbal response accuracy scores for difficulty and comm. formats. Error bars are standard errors.

A 2 (Difficulty) $\times$ 4 (Comm. Format) within subjects ANOVA revealed a significant main effect for Difficulty, $F(1, 13) = 22.61, p < .05$; verbal response accuracy in the Easy condition ($M = 99.6$) was greater than in the Hard condition ($M = 97.5$). A significant main effect was also found for Comm. Format, $F(1.56, 20.29) = 22.83, p < .05$. Supplementary Tukey tests indicated that while the verbal response accuracy scores in the MMC ($M = 99.8$) and Chat ($M = 99.9$) formats did not differ significantly from each other, the scores in both of these formats were significantly greater than those in the Radio ($M = 96.4$) and 3D audio ($M = 98.1$) formats which in turn, did not differ significantly from each other.

In addition to these main effects, the interaction between Difficulty $\times$ Comm. Format was also significant, $F(1.37, 17.84) = 15.09, p < .05$. Similar to the correct detection results, post hoc Tukey tests revealed that verbal response accuracy was greater for the Easy than Hard phrases in the Radio and 3D Audio formats but that there were no differences in difficulty for the Chat and MMC conditions.

Reaction Time. Response times for the detected critical signals for all combinations of response Difficulty and Comm. Format are presented in Table 4.

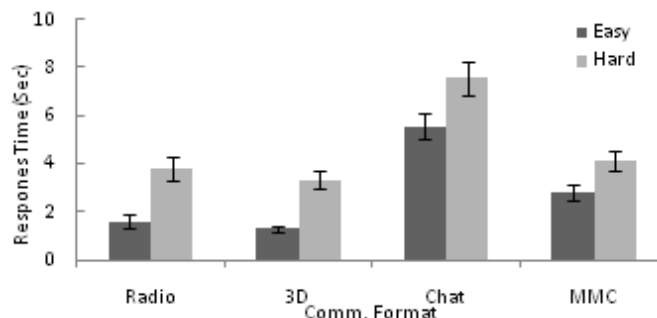


Figure 4. Mean response times in sec for all combinations of task difficulty and comm. format. Error bars are standard errors.

A 2 (Difficulty) $\times$ 4 (Comm. Format) within subjects ANOVA of the response time data found a significant main effect for Difficulty, $F(1, 13) = 35.12, p < .05$; response time was faster the Easy ($M = 2.82$ sec) than the Hard condition ($M = 4.70$ sec). A significant main effect was also found for Comm. Format, $F(1.68, 21.85) = 34.85, p < .05$. Supplementary Tukey tests indicated that response times for the 3D Audio ($M = 2.31$ sec) and Radio ($M = 2.69$ sec) formats were equivalent and that in both formats, the response times were faster

than for MMC ($M = 3.47$ sec) and Chat ($M = 6.56$ sec) formats. In addition response times in the MMC format were faster than the Chat format. The interaction between Difficulty and Comm. Format was not statistically significant, $p > .05$.

Perceived Mental Workload. Mean global workload scores on the NASA- TLX for all combinations of response Difficulty and Comm. Format are presented in Table 5.

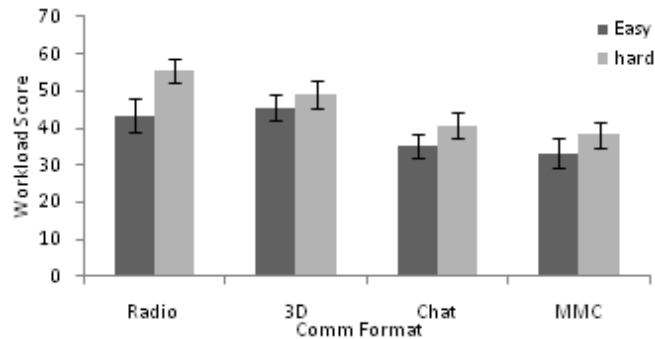


Figure 5. Mean NASA-TLX scores for difficulty and comm. format. Error bars are standard errors.

A 2 (Difficulty) $\times$ 4 (Comm. Format) within subjects ANOVA revealed that perceived mental workload was significantly greater for the Hard ($M = 45.94$) than Easy ($M = 39.33$) condition, $F(1, 13) = 16.86$, $p < .05$. A significant main effect was also found for the Comm. Format condition, $F(2.48, 32.29) = 15.24$, $p < .05$. Supplementary Tukey tests revealed that perceived mental workload was higher in the Radio ($M = 49.52$) and 3D Audio ($M = 47.38$) formats than in the Chat ($M = 37.83$) and MMC ($M = 35.80$) formats. The difference between the two highest workload conditions was not significant and the same was true of the difference between the two lowest workload conditions. The Difficulty $\times$ Comm. Format interaction lacked statistical significance, $p > .05$.

5.0 CONCLUSION

This study evaluated the effectiveness of a recently developed tool by researchers at AFRL's Battlespace Acoustic Branch, to aid C2 operators in managing communication data. The assumption was that the MMC suite provides operators with net-centric, collaborative tools to accurately monitor multiple communication channels and make quick and effective decisions. The study was designed to evaluate different communication tools in their ability to aid operators in monitoring and replying to critical messages. Operators' ability to detect critical messages and to quickly and accurately reply to those messages was used to evaluate their performance with each of the Comm. Format with two levels of Difficulties.

Operators detected significantly more messages using MMC and Chat than Radio and 3D Audio, however in support of previous research, operators detected more messages with 3D Audio than Radio (Ericson, Brungart, & Simpson, 2004). There were no differences between the Easy and Hard messages for the MMC and Chat conditions, however there were more detections for the Easy than Hard messages for Radio and 3D-Audio. This suggests that the persistent nature of the messages aids in the monitoring of communication, independent of message difficulty. The accuracy of the responses to the detected messages was greater for the Easy than Hard phrases, as well as greater for the MMC and Chat formats as compared to Radio and 3D-Audio formats. The interaction between signal Difficulty and Comm. Format for response accuracy was similar to message detection. Response accuracy for the Easy phrases was greater than the Hard phrases for the Radio and 3D-Audio condition, however there were no differences between message difficulty for MMC or Chat. Again, this

suggests persistent information aids participants in accurately recalling messages as compared to perishable, auditory signals. The third measure of operator performance was response time. Operators' replies were faster for the Easy than Hard phrases and for the Radio and 3D- Audio formats as compared to MMC format, which was also faster than Chat format. Along with the performance data, scores from the NASA-TLX support the belief that MMC reduces the perceived mental workload of a communication- monitoring task over Radio and 3D Audio.

The two most common types of communication systems in current use are Radio and Chat. The results shown here clearly indicate that messages were easier to detect and could be read back more accurately with a Chat system, but listeners were able to respond more rapidly to critical information with a Radio display. Thus, in choosing to present information through either a Chat or a Radio display, there is a clear speed/accuracy tradeoff between these two alternatives. MMC offers a compromise between these two extremes - it provides a level of accuracy comparable to that achieved with a Chat display, but with a much faster response time. The MMC suite not only utilizes the speed of Radio listening but also increases the intelligibility of the audio signals by spatializing them, as well as providing the necessary tools to find, replay, annotate, or edit messages that were once perishable or hard to find.

Another important finding was that there were no differences in correct detections and response accuracy for difficulty in the Chat and MMC conditions whereas there were differences in the Radio and 3D Audio conditions. This suggests the availability to find and read messages aids in the monitoring of communication, independent of message complexity. Situations such as the ones confronting C2 operators, where the transmission of complex data is of the utmost importance, the availability of persistence transcriptions of Radio communication and the ability to easily retrieve pertinent information could be a matter of mission success or failure.

A key limitation of this study is that it used a simple detection task to evaluate a communication tool that would be used for more complex communication environments where operators would also have to integrate information from other sources such as tactical visual displays. Studies, however, have shown that tasks that require operators to compile data from multiple visual displays to properly perform multiple tasks, often result in poor management and suboptimal performance as operators will focus the majority of their time on the Chat display, rather than the more important tactical display (Cummings & Guerlain, 2004). In theory, MMC will help combat this issue and provide advantage over Chat because it utilizes multiple modalities so when an operator must focus on a visual display the communication data is still presented aurally. Future studies will examine this as well as direct testing of the MMC format on the operator's situation awareness and use in team tasks. MMC is continually being modified to meet the warfighters needs thus continuation of the research will explore further capabilities and interface designs.

Although this was a simple message detection task, there is evidence the integration of communication tools aids operators in their ability to monitor multiple communication channels. These results suggest that MMC provides a balance between the speed of radio listening and the increased intelligibility of 3D Audio display with the data capturing capability of text only displays.

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7.0 LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

3D	Three Dimensional
ANOVA	Analysis of Variables
ASR	Automatic Speech Recognition
C2	Command and Control
Comm	Communication
ID	Identification
MMC	Multi-Modal Communications
NASA	National Aeronautics and Space Administration
NASA-TLX	National Aeronautics and Space Administration – Task Load Index
Sec	Second