

Wireless Collaboration Technology to Support Distributed Teams

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Small tactical teams require sophisticated technologies to support distributed teamwork. In this article we discuss a field study of a tool designed to support distributed and mobile collaboration. This tool, SLATE, was designed to support a number of cognitive processes thought to be challenged during distributed teamwork. First we discuss the factors of team cognition that SLATE supports, then we describe a field study with U.S. Navy warfighters in which SLATE was fielded on tablet PCs that communicated over the internet via cell phone broadband and wireless networks. We report our findings from this field study and describe the design modifications it elicited to improve the cognition and coordination of small, distributed, tactical team collaboration.

KEYWORDS: Collaboration, Communication, Team Cognition, Human-Computer Interaction, Groupware Design

Small tactical teams occur in a wide variety of domains, including Special Forces operations, reconnaissance posts and patrols, border and facility security, civil emergency operations, wild fire fighting, and maritime interdiction operations. These highly skilled teams must coordinate information gathering, tactical planning, direct action, fire support, logistics, and after action review. These tasks must be coordinated across both time and space, since distributed team members are often out of view of each other, are often busy acting, and only check in periodically with each other, command centers, and reach-back (i.e., nonlocal team members who perform support functions such as intelligence analysis).

Given the complexity of their interaction, these teams have a number of specific requirements for collaboration technology that go well beyond mere connectivity. In this article we outline these team cognitive and collaborative requirements (e.g., Fiore & Salas, 2004) and describe a wireless collaboration software application developed to support these requirements. We then report a field study in which teams of military experts used this tool and subjectively assessed how well the software met these requirements compared with other common collaboration tools. We illustrate how technologies supporting both cognition and collaboration within teams can be developed by exploiting findings from cognitive science, human factors, and related fields.

Tactical Team Requirements

Our initial efforts in this project involved in-depth interactions and interviews with experts in tactical teams. Our experience observing and interviewing SEAL teams

helped us to identify the following collaboration requirements. First, tactical team members are often distributed in space, out of face to face contact. This distribution places a great burden on communication technology to support team situation awareness and coordinated activity. Communication and collaboration tools must help team members share their situation awareness of the operational context (e.g., awareness of current threats, achievement of objectives, team member locations, etc.) as well as collaborate in order to share knowledge, solve problems, review and critique plans, and build consensus in spite of their distribution across space. Yet, as Holland and Stornetta (1992) put it, the goal should be not to recreate face-to-face communication but to go “beyond being there.” In particular, rather than just recreating interaction environments that mimic standard face-to-face settings, information technologies should be designed to augment and improve upon such interactions.

Second, team members are responsible for a variety of complementary roles. These includes staffing reconnaissance posts, command centers, and reach-back analysis centers, as well as being responsible for maneuvers and the performance of direct tactical actions. This distribution of roles means that the team as a whole can be viewed as a “transactive memory system” where team members exchange individual expertise and perspectives on the situation (see Moreland, 1999; Moreland & Myaskovsky, 2000). A common problem for transactive memory systems is that members often fail to share private information and only discuss information they hold in common (Stasser, Taylor, &

Hanna, 1989). One goal for our collaboration tool was to support the sharing of more private information by providing a shared situation context to which team members can contribute. Moreover, if the situation display is well organized, then team members can share their information more effectively by knowing where to add it within the organizational structure and where to look for other team member's additions. Such organizations of situation information have been called "coordinating representations" (Alterman & Garland, 2001) in that they represent the externalizations of team member knowledge in a representation and organization that facilitates coordinated interaction.

The shared situation awareness also provides a "common ground," that is, information believed to be shared among the team members, which in turn facilitates communication (e. g., Clark & Brennan, 1991; Clark & Krych, 2004). Linguistically, new statements are typically composed of a topic and comment, with the topic serving to remind the audience of the context of the statement and the comment providing the new information. But the team's common ground of the shared situation means that authors can abbreviate the topic component and move to the comment component more quickly, thereby making the communication more efficient.

A third collaboration requirement arises from the fact that tactical teams are often distributed in time as well as space. Team members may only collaborate intermittently, doing so when they are not maneuvering or performing other actions away from collaboration tools and situation displays. Therefore, collaboration is often interrupted, intermittent, and asynchronous, with one team member communicating while another is maneuvering or acting, and vice versa. But, while users are away from their collaboration tools and situation displays, the situation continues to evolve, and messages from teammates accrue. When users return to the situation display, they must "come back up to speed" with the situation and their teammates' communications. The complexity and interactivity of tactical team information can make it challenging to follow these distributed and often asynchronous conversations. Team members need clear information about the chronology and authorship of accrued messages – who said or drew what, when. Especially for shared whiteboard displays, returning from an interruption may present a "visual spaghetti" of annotations that are difficult to parse and interpret. Annotations can also grow stale and clutter a display with outdated information. Therefore, the tool must provide an appropriate means for guiding attention to messages and annotations, and effective control over

clutter on their common operating picture, so that new messages can be seen and understood efficiently.

Designing displays to better support this situation awareness recovery process is an important issue for collaboration tools. Recently, St. John and Smallman (2008) described four design principles for helping users recover situation awareness following interruptions, including automating change detection, unobtrusively notifying users of changes and new messages, providing change and message overview information so that users can prioritize their reviews, and providing access to details only on demand in order to minimize clutter on busy displays. Especially for busy displays with high potential for clutter, we found that this control increases the usability of the tool and users' situation awareness of the operational context (see St. John, 2008 for a discussion).

A fourth collaboration requirement arises from the fact that tactical teams frequently discuss spatial information, such as locations, routes, and the layout of buildings and encampments, that are difficult to describe verbally – and, more to the point, inefficient to describe verbally given the time-stressed nature of this work. Because of this difficulty, providing a tool that supports spatial cognition for the team, such as the ability to exchange graphic annotations, can significantly enhance communication efficiency. For example, Heisser, Tversky, and Silverman (2004) found that when participants were able to interact over a common map to plan an emergency rescue route, annotations such as pointing and tracing improved collaboration. Gergle, Kraut, and Fussel (2004) found similar benefits in a spatial puzzle task. Kirsh (2008) found that annotations improved participants' ability to convey the current situation and issues involved in a video war game to a collaborator taking over the task. Building upon this research, within SLATE, team members can point to locations rather than finding and spelling out coordinates, and team members can draw rather than verbally describe a path or landmark. This natural communication improves the speed of composition through the use of low effort drawing rather than laborious text entry. Further, it facilitates accurate comprehension through the use of integrated, direct co-referencing on maps rather than placing the burden on the reader to interpret coordinates and locate them on maps.

A fifth collaboration requirement arises from the variety of pacing throughout operations. During periods of direct action, such as engaging an enemy or maneuvering, operators' hands and eyes are busy, and there is no time to interact with a collaboration tool. Under these conditions, only hands-free radio, voice, and hand

gestures are appropriate. In between direct actions, however, there is time to interact with collaboration tools to report locations and intelligence, plan routes, and coordinate activities. The SLATE tool is designed to support these more contemplative periods that occur periodically throughout operations.

Finally, a sixth collaboration requirement is that tactical teams require collaboration tools that are easy to use, mobile, and use little network bandwidth, because bandwidth is often at a premium in field settings. Ease of use is important in field settings, since operators have limited time and may have to share attention to the tool with the attention to the local situation and teammates. Our approach to this usability constraint has been to provide core functionality and minimize the amount of interaction required to use the tool. For instance, SLATE is not meant to compete with desktop drawing tools or desktop shared whiteboards. Instead, it is meant to perform as a pared-down, field-ready collaboration tool, yet still support semantically rich communication and team situation awareness.

In the next section we describe how these design requirements were built into our tool. We illustrate how technologies designed with the underlying cognitive processes of the operator in mind can lead to usable and effective tools for interaction in complex operational settings.

THE SLATE DESIGN

Over the past two years, we have developed a collaboration concept and software prototype called Shared Lightweight Annotation Technology (SLATE; St. John & Smallman, 2008). Essentially, SLATE is a cross between a shared whiteboard and email but which incorporates the aforementioned design requirements in a way that supports operators' cognitive and collaborative processes. Users can import and annotate a variety of mission documents such as maps, imagery, and timelines, and they can share those documents and annotations with team members. Each annotation message is encapsulated as a separate information object, or "infob," and it is treated much like an email message that can be listed, opened, and closed.

The key innovations of SLATE are that it provides the ability to: a) draw rather than verbally describe spatial information, b) convey the context for messages by embedding annotations on mission documents, much like an acetate overlay, c) manage message notification and clutter to support asynchronous collaboration and interruption recovery, and d) switch contexts easily and monitor multiple missions. Below, we describe the components of SLATE, their principled design

rationales, and tie them back to the collaboration needs of tactical teams outlined above.

Mission documents are imported into SLATE as images that become SLATE "canvases." Users can then draw and send annotation messages on each canvas. Thumbnails of the canvases appear in a column on the left side of the interface (see Figure 1, Label 1). Selecting a canvas thumbnail displays the canvas on the canvas pane and displays the list of messages drawn on that canvas.

Users may import and share additional canvases at any point during a mission. Importing a canvas causes it to be shared immediately with all team members, and once shared, any team member may then annotate it, just as with any other canvas. Users may also create and share blank whiteboards, and use them to draw layouts, maps, or any other spatial information. The set of canvases essentially acts as an overall coordinating representation (Alterman & Garland, 2001) for planning and sharing situation awareness about a mission because it provides an organizational structure for placing and retrieving information about a mission.

The infobs for the selected canvas are listed in chronological order in the column next to the canvas column (Figure 1, Label 2). Each infob displays a thumbnail of its annotation message and its author. This information can be used as a preview or topic to scan for relevant messages, much like the subject line of an email, but it is created automatically with no effort from the author of the message. Rolling over an infob reveals a timestamp as a tool tip and highlights the annotation on the canvas pane. This highlighting feature can help users find the annotation associated with the infob, and it can also be used to search for the infob that controls any given annotation on a canvas by watching an annotation and rolling over successive infobs until the annotation becomes highlighted.

This representation of messages as a list of infobs follows from the notion of information encapsulation in the computer supported collaborative work literature (see Keele, 2007; 2008). The idea of information encapsulation is that fairly complex concepts can be represented as simple cards on a bulletin board that provide overview information. This encapsulation makes it easy to organize concepts in various ways (e.g., columns or networks) and to display their interrelationships. In SLATE, the chronological ordering of infobs for each canvas organizes messages with their mission context and in the order in which they were composed and receive.

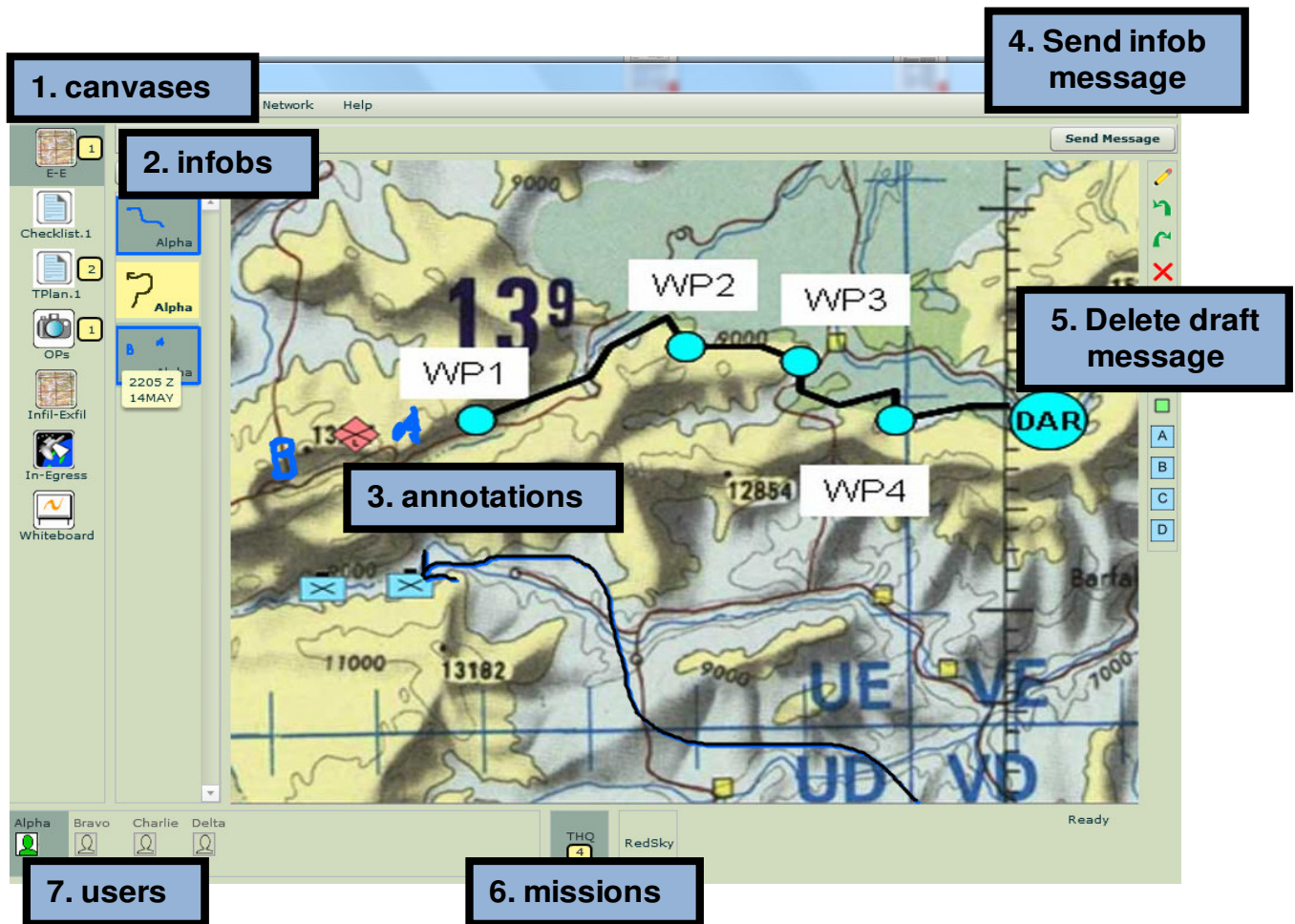


Figure 1. SLATE Interface. Mission documents are listed in the left column (label 1) and individual messages pertaining to that canvas are listed to the right (label 2) and displayed on the currently selected canvas in the middle of the display (refer to text for theoretical and practical rationale for tool features).

Selecting an infob displays its annotation on the canvas pane. Selecting it again hides the annotation. This ability to view and hide annotations on an individual basis provides fine-tuned control over clutter, and it allows users to tailor their view of message information and the common operating picture.

Annotations appear as black lines with a blue drop shadow to make them visible against a wide variety of canvas backgrounds (Figure 1, Label 3). We investigated black-white lines, but found they are not perceived as a coherent line, making it difficult to parse complex lines or read handwritten text. Annotations are created simply by drawing on the canvas pane, either with a mouse or a stylus – there is no need to pick a pen tool. Importantly, the drawing tool is less sophisticated than a typical desktop drawing application. There is no ability to create or modify drawing objects, for example, and there is only one pen color and width. Instead, our objective for field

collaboration was simplicity and minimal user interaction with the interface.

From the standpoint of effective cognition and collaboration, the advantage of annotations, compared with radio or chat, is two-fold. One, annotations easily convey spatial information, such as locations, routes, and layouts, which are common and important information for tactical teams. Two, they reside directly on mission documents (the canvases). In this way, when marking up mission documents, the documents provide the context that facilitates common ground, that is, they automatically provide the context or reference for the messages for both authors and recipients. To illustrate, a team member might start a new whiteboard canvas, draw the side of a building under surveillance, and then indicate the locations of windows and fortifications. This drawing then becomes the common ground for future collaboration. Another user could indicate the likely location of a covert meeting or information about the

interior by referring to the original drawing and simply adding the new information. Further, by numbering the windows in the drawing, users can then verbally discuss the building more easily (“there’s a figure behind window 1”), because the canvas provides the shared references. By providing this common ground on which to build annotations, SLATE makes communication more efficient. The common ground of the documents also provides an implicit organization of mission topics that supports the sharing of information across the transactive memory system of the team. Through such features, SLATE not only scaffolds coordination, it augments the team’s cognition by offering a capability over and above what would be feasible in its absence. Chat, by comparison, does not have this ability to integrate with mission documents because it occurs in a separate window, and users must integrate the stream of information for themselves.

Selecting the send message button sends the message to a server, which in turn sends the message to all members of the team (Figure 1, Label 4). This concept of operations (conops) simplifies message composition since no specific recipients have to be identified or selected. It also supports situation awareness amongst team members since everyone receives all messages and, therefore, have the same shared knowledge. Although one might suggest that this conops could lead to information overload, it works because the missions are specific (so that the objectives and goals are clear to all team members), the teams are small (so that the amount of information shared is not extensive), and all messages tend to be relevant (which minimizes message traffic). As with the drawing tool, our objective was to simplify the interface overhead for composing and sending messages. Large missions with many team members would likely require a different conops and a different interface design.

Users are notified of new messages via a yellow counter box on each canvas that indicates the presence and number of new, unviewed messages on that canvas. Additionally, the infobs for new messages are shown with a yellow fill. Selecting a new infob displays the annotation, changes the fill to green, and decrements the counter on the canvas. This method of notification informs users of the presence of new messages, but it does not distract significantly from other on-going tasks (St. John & Smallman, 2008). Users can prioritize which messages to review first according to which canvas they appear on, since some canvases may be more relevant to particular users than other canvases. Users can also use the author and topic information on each infob to further refine their prioritization.

The ability to collaborate over multiple missions is provided by tabs along the bottom of the interface (Figure 1, Label 6). This ability supports command center operators as they track multiple missions. If a new message arrives from any mission, the counter on the tab indicates the new message. Selecting a tab displays the canvases for that mission in the canvas column. Users can then navigate to the canvas containing the new message. This system is designed to support context switching among missions by providing easy access to the canvases and context for each new message.

Team member presence information is displayed in the lower left corner of the interface (Figure 1, Label 7). The current user is indicated by a green fill on the square (team member “Alpha” in Figure 1). Other logged-in team members are indicated by a highlight. SLATE also indicates the length of time since the last interaction with the tool. After preset times elapse, the team member symbol turns from green to orange to red. This information indicates whether other users are currently interacting with SLATE or are performing other activities and are unaware of recent messages. In this manner, SLATE uses simple attentional devices that are easy to comprehend and which provide information about other team members’ likely level of situation awareness; that is, it helps team member infer other teammates’ awareness based upon the colors indicating how long they have been away from their collaboration tool.

From the standpoint of the software and hardware of our tool, SLATE is an internet application developed in Adobe Air. It compiles as a Windows application that can be run on any Windows device (or any other device that supports Adobe Air Runtime), from wall-size screens in command centers, to mobile laptops and even palm top devices for field use. However, the interface is currently designed for a screen resolution of 1024x768 pixels. Smaller resolution screens would require a redesign of the interface. For connectivity, SLATE uses a socket connection to communication via the internet. Display devices can be connected to the internet by a variety of means, including Ethernet, wireless networks, and cell phone broadband or, if needed, secure military networks.

FIELD STUDY

In this next section we describe a field study of SLATE in the context of complex collaborative cognitive activity. The US Navy’s Trident Warrior 08 (TW08) fleet experiment provided an opportunity to evaluate SLATE with experienced Navy operators and realistic scenarios. Trident Warrior is an annual navy exercise and

experiment where innovative and experimental systems are evaluated. We evaluated SLATE, in comparison with other contemporary tools such as radio, chat, and shared whiteboards, for a) its ability to convey spatial information, b) manage messages and clutter, and c) support situation awareness and collaboration among team members.

Method. The field study was conducted at three venues, with three different groups of participants, and two different scenarios. All groups were administered the same survey (see Table 1). The first group was composed of four participants: three US Navy SEAL petty officers – two senior chiefs (E-8) and one first class petty officer (E-6) – and one analyst who was a retired special forces Ranger. The field test was held in the Small Combatant Joint Command Center Laboratory at the Naval Undersea Warfare Center, Newport, RI as part of a larger exercise involving a larger group of SEAL mission planners. The participants performed a series of realistic training exercises involving mission planning that were devised by the SEALs. Three SLATE “nodes” were worked into the exercises, one for a rear command component, one for a field command component, and one for a tactical component. SLATE was used to share imagery, annotate, and ask and answer questions. SLATE was supplemented by a web portal, chat, and voice communications.

The second group was composed of five US Navy reserve officers, one captain (O-6), two commanders (O-5), one lieutenant commander (O-4), and one lieutenant (O-3). The field test was held in a conference room in San Diego. The participants performed a simulated tactical scenario designed by us to demonstrate SLATE’s capabilities. There were four SLATE “nodes” representing a command center, a reconnaissance unit, a direct action unit, and a secondary reconnaissance mission. The participants were distributed among the nodes, and they exchanged messages via SLATE as they followed a script for the scenario. No other communication channels were available.

The third group was composed of two consultants from Wexford Group International. Both were retired SEALs with over 20 years of experience. The field test was held in the Cognitive and Automation Research Laboratory, Naval Air Systems Command, Patuxent River, MD. The participants performed the same tactical scenario as group two. The participants were assigned to two nodes, and confederates were assigned to the other two nodes. No other communication channels were available.

All participants were briefed on SLATE, trained on its features, performed the test scenarios, and then they completed the survey.

Results. Table 1 reports the mean ratings for all eleven participants (scale of 1 to 5, with 1 as “very poorly” and 5 as “very well”). Significant differences between ratings of SLATE and other tools are indicated with asterisks. These comparisons were computed as one-tailed, paired t-tests, $p < .05$. Below we discuss the primary findings of our field test.

Not surprisingly, SLATE was rated as better at conveying location, route, and layout information than radio or chat. SLATE was also rated as better than a whiteboard, despite its spatial nature, presumably because SLATE supports annotating directly on maps, imagery, and other mission documents.

SLATE was rated as better for maintaining an uncluttered common operating picture (COP) than sticky notes and grease pencils, a common method for maintaining multiple messages on a COP. SLATE was also rated as better for archiving and retrieving relevant messages than either a whiteboard or sticky notes. The survey did not ask about radio or chat for these questions because they do not provide a COP. Presumably, these ratings derived from SLATE’s control over the presenting and hiding of individual annotations and the distribution of messages among canvases. Whiteboards make erasing specific annotations difficult, and neither whiteboards nor grease pencils support retrieval of messages once erased.

SLATE was rated superior to a shared whiteboard for helping users prioritize messages, but not superior to sticky notes, despite the large numerical difference in ratings. Presumably, SLATE’s advantage over the whiteboard is due to its listing of individual messages as a column of infobs that can be scanned. The thumbnail sketches of the annotations and the author information on the infob may also have provided useful prioritization information. In recent laboratory studies of the SLATE concept, the thumbnails did help users find relevant information more quickly than did whiteboards or chat (St. John, Smallman, & Manes, 2007; St. John, 2008). However, the thumbnails in the laboratory experiment were carefully constructed in these experiments to be meaningful, while the thumbnails in the present field study were generated automatically by miniaturizing what participants drew. It is not clear how informative these thumbnails actually were. Future field testing could specifically investigate this issue to determine the informativeness of the thumbnails actually produced during a live exercise, as well as investigate how well they support prioritization after many messages have accrued.

Table 1. Survey Questions and Ratings

Question	SLATE	Radio	Chat	Shared Whiteboard	Sticky notes and grease pencils
Spatial Information					
How well does _____ convey location information?	4.6	3.6*	3.6*	3.9*	NA
How well does _____ convey route information?	4.5	3.3*	3.1*	3.4*	NA
How well does _____ convey layout information?	4.4	2.8*	2.7*	3.6*	NA
Manage Messages					
How well does _____ help you maintain an uncluttered and clear COP?	4.6	NA	NA	3.6	2.4*
How well does _____ help you archive/retrieve potentially relevant mission information?	4.6	NA	NA	2.9*	2.2*
How well does _____ help you prioritize messages after an interruption?	3.5	NA	NA	2.7*	2.4
Situation Awareness					
How well does _____ help you recover SA after an interruption?	4.8	NA	NA	3.4*	2.0*
How well does _____ help you understand the context of an incoming message?	4.0	3.4*	3.6	4.0	NA
Collaboration					
How well does _____ help you collect and integrate new information for your mission re-planning tasks?	4.4	3.3*	3.5*	3.8	NA
How well does _____ help you build consensus for your mission re-planning tasks?	4.0	3.3	3.3	3.8	NA
How well does _____ review and critique alternative plans for your mission re-planning tasks?	4.2	2.9*	3.3*	3.6*	NA

* Indicates statistically significant difference between SLATE and other tool, $p < .05$

SLATE was rated better than either a shared whiteboard or sticky notes for supporting interruption recovery. Presumably, SLATE’s advantage is due to its listing of messages in the infob column as well as the yellow counters indicating the number of new messages on each canvas so that users know when new messages have arrived and where to find them. These results were

obtained despite the fact that interruptions in the scenarios tended to be short and infrequent, and few messages accrued.

While we have not explicitly documented the frequency and length of interruptions during tactical tasks such as special forces operations, or the accrual of messages

during interruptions, we maintain that interruptions are significant issues for these tasks. SLATE's support for interruption recovery is likely to be even greater for longer interruptions, when more messages accrue and more prioritization is required. Future studies could measure and document interruptions, as well as carefully measure any SLATE advantage.

SLATE was rated better than a radio for helping users understand the context of a message. SLATE's advantage over a radio is presumably due to a radio providing no permanent record of a context. However, SLATE was not rated better than chat or a shared whiteboard for understanding the context of a message. This lack of an advantage for SLATE compared with chat was surprising. While chat provides a permanent record of text messages, they are disjoint from the maps, imagery, and other mission documents to which they refer. The similar ratings for SLATE and a shared whiteboard are more understandable because both tools allow users to annotate directly on mission documents, thereby providing the context for each message. Note, though, that older whiteboard systems, that only offer a true "whiteboard," are also disjoint from the mission context. Still, we expected an advantage from SLATE due to its greater control over annotations and mission context.

The difficulty appears to be due to two limitations of the current design of SLATE. First, it became apparent during the exercises that linguistic communication, either chat or voice, provides an important complement to annotations. Writing text via the annotation tool is too cumbersome for text lengths beyond a few words. We are currently working to integrate a chat component in SLATE. Our goal is to integrate text with the infob concept in order to provide a text capability, but design it in a way that provides a tighter coupling between text and annotations than that provided by a disjoint chat window. The second limitation of the current SLATE design involves conversational threads. There were moments, for example, when one participant confirmed a message and another participant became confused about which message was being confirmed. An explicit representation of conversational thread could remedy this problem by illustrating the mapping between messages and replies to those messages. However, if a conversational thread bounced among multiple canvases, it still might be difficult to follow.

Other communication tools have addressed the problem of conversational threads with a variety of designs. For example, chat windows address this problem by providing a single window, and a single linear sequence, for all messages. Replies always follow questions in the

list. Still, if multiple threads are on-going, they may become interwoven and difficult to follow. Again, more explicit illustrations of threads would be useful.

Email programs address the problem of conversational threads in part by providing subject lines. Even if conversations are interwoven, the subject lines provide information that can be used to follow a thread. Additionally, some modern email programs, such as Gmail, explicitly organize messages into threads based on their subject lines. However, this solution comes at the price of higher interaction overhead, since the subject lines have to be composed and typed in.

Addressing this threading issue without increasing interaction overhead may be difficult. An alternative solution is to develop a concept of operations or protocol for authoring SLATE messages that addresses this issue. For example, there could be a protocol that all replies, and especially all confirmations, be written on the same canvas as the question. We are currently looking into both design and protocol solutions to this issue.

The collaboration questions were designed to address stages of complex collaborative problem solving; that is, processes associated with macrocognition in teams - integration, consensus building, and reviewing/critiquing (see Warner & Letsky, 2008). SLATE was rated better than radio and chat for collecting and integrating information. This result is understandable since radio messages are ephemeral, and chat messages are solely textual and more difficult to integrate with mission documents. However, SLATE was not rated significantly better than a whiteboard for collecting and integrating information. A closer look at the data indicates that several users did not notice collection and integration during the scenarios. In future studies, better definitions of integration as well as stronger methods for evaluating integration may yield differences.

All three tools were rated equally for consensus building. Participants may have focused on achieving agreement and felt that even radio and chat provide good opportunities for discussion and agreement. Providing a text capability within SLATE may also improve its ability to support consensus building since it would allow for richer explanations and discussions than annotations alone provide.

SLATE was rated as better than the other tools for reviewing and critiquing plans with distributed teammates. Reviewing and modifying plans was a focus of the SLATE scenario at the second and third venues, therefore, there were good opportunities to demonstrate this capability. SLATE's ability to present and hide individual annotations and maintain an uncluttered COP

may also have contributed to the superior ratings for SLATE.

Finally, SLATE was rated as easy to learn and use. Given that new technologies need to be integrated and adopted rapidly, this finding is not trivial. In particular, given the cognitive and coordinative complexity inherent in distributed tactical team missions, adding a new technology to augment cognition and collaboration must not present its own set of challenges for the user, particularly in mobile, field settings.

SUMMARY AND CONCLUSIONS

The results emerging from our field study suggest that SLATE has much potential to support communication, awareness, and collaboration – factors foundational to team cognition (e.g., Fiore & Salas, 2004). The annotation capability of SLATE provided an effective way for users to convey spatial information. Since spatial information is a major concern for tactical teams, this capability provides important support for tactical team collaboration. The methods for logging and displaying individual annotations supported new message notification, prioritization of messages for review, and the ability to archive and retrieve annotations as desired. SLATE's ability to support this variety of attention management and interruption recovery processes is important for tactical teams, where situations and missions may evolve quickly. The ability to annotate and draw alternative plans, as well as the ability to control their display, and thereby maintain an uncluttered COP, also supported reviewing and critiquing. Together, these capabilities produced a collaboration tool that was highly regarded by the military experts who used it. Finally, we found evidence that an integrated text component was needed to enrich the communication medium, and we found that better support for conversational threads was needed. Such data represent an important addition to our ongoing research program in that they highlight the need to provide more explicit scaffolding for exchanges of messages beyond how individual messages are represented and organized.

In sum, our field study suggests that SLATE provides a number of the collaboration capabilities that meet the requirements imposed by the high stakes situations in which tactical teams operate. SLATE offers support over and above connectivity by providing capabilities that help to manage attention and spatial cognition, while supporting a team's need to develop a common operating picture of their tactical environment.

SLATE was developed specifically to meet the collaboration requirements of Special Forces operations.

But the SLATE design is quite general and potentially valuable for a wide range of small distributed tactical team domains including security operations, disaster relief, and emergency response. For example, in wild fire fighting, team members could annotate and share the locations of fire fronts, the movements of water trucks, and plans for evacuations and the building of fire lines. Going forward, our goal is to strengthen the capabilities and representations of SLATE for supporting distributed collaboration while maintaining the simplicity of its interaction for field users.

REFERENCES

- Alterman, R. & Garland, A. (2001). Convention in joint activity. *Cognitive Science*, 25, 1-23.
- Clark, H.H., & Brennan, S.E. (1991). Grounding in communication. In L. B. Resnick, R.M. Levine, & S.D. Teasley (Eds.), *Perspectives on Socially Shared Cognition* (pp. 127-149). Washington, DC: APA.
- Clark, H.H. & Krych, M.A. (2004). Speaking while monitoring addressees for understanding. *Journal of Memory and Language*, 50(1), 62-81.
- Fiore, S.M. & Salas, E. (2004). Why we need team cognition. In E. Salas & S.M. Fiore (Editors). *Team Cognition: Understanding the factors that drive process and performance* (pp. 235-248). Washington, DC: American Psychological Association.
- Gergle, D., Kraut, R.E., & Fussell, S.R. (2004). Language efficiency and visual technology: Minimizing collaborative effort with visual information. *Journal of Language and Social Psychology*, 23, 491-517.
- Hollan, J.D., & Stornetta, S. (1992). Beyond Being There. In *Proceedings of the ACM CHI'92 Conference on Computer-Human Interaction* (Monterey, CA, 3-7 May 1992), pp. 119-125.
- Keel, P.E. (2007). EWall: A visual analytics environment for collaborative sense-making. *Information Visualization*, 6, 48-63.
- Keel, P. (2008). EWall – a computational tool for knowledge building. In M. Letsky, N. Warner, S. M. Fiore, & C. Smith (Eds.). *Macro-cognition in Teams: Theories and Methodologies* (pp. 187-208). Hampshire, UK: Ashgate Press.
- Kirsh, D. (2008). The theory and practice of augmenting video to improve situational awareness in distributed collaborative environments. In M. Letsky, N. Warner, S.M. Fiore, & C. Smith (Eds.). *Macro-cognition in Teams: Theories and Methodologies* (pp. 165-186). Hampshire, UK: Ashgate Press.

- Moreland, R.L. (1999). Transactive memory: Learning who knows what in work groups and organizations. L. L. Thompson, J.M. Levin, & D.M. Messick (Eds.) *Shared Cognition in Organizations: The Management of Knowledge*. Mahwah, NJ: Lawrence Erlbaum Associates, 3-31.
- Moreland, R.L. & Myaskovsky, L. (2000). Exploring the Performance Benefits of Group Training: Transactive Memory or Improved Communication? *Organizational Behavior and Human Decision Processes*, 82, 1, 117-133.
- Rensink, R.A. (2002). Change detection. *Annual Review of Psychology*, 53, 245-277.
- St. John, M. (2008). Designing a better shared whiteboard: Interruption recovery, message prioritization, and decluttering. In *Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society.
- St. John, M. & Smallman H.S. (2008). Staying up to speed: Four design principles for maintaining and recovering situation awareness. *Journal of Cognitive Engineering and Decision Making*, 2, 2, 118-139.
- St. John, M., Smallman, H.S. & Manes, D.I. (2007) Interruption recovery tools for team collaboration. In *Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society.
- Warner, N.W., & Letsky, M.P. (2008). Empirical model of team collaboration: Focus on macro-cognition. In M. Letsky, N. Warner, S.M. Fiore, & C. Smith (Eds.). *Macro-cognition in Teams: Theories and Methodologies*. Hampshire, UK: Ashgate Press.

AUTHOR NOTES

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