Supporting Situation Awareness Under Data Overload in Command and Control Visualizations

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Abstract

Overcoming information overload is a central challenge for supporting information dense environments, such as military operations, some process control systems, and real-time data analysis tasks. This paper describes a study which evaluated concepts for supporting military personnel's ability to quickly assess needed information in very cluttered Common Operating Picture (COP) displays. The effort focused on the presentation of four possible unit representations on a digitized COP based on ethnographic observations of the way in which Army officers seek to deal with the proliferation of large, overlapping battlespace objects on dense displays. Sixteen U.S. Army Reserve Officer Training Corps (ROTC) cadets monitored a 28 minute simulation that depicted a developing military advance. Cadets viewed each of the four modalities with presentation order counterbalanced between subjects using a Latin squares design. For each modality, cadets responded to a rapid battery of questions about their SA using the Situation Awareness Global Assessment Technique (SAGAT). At the end of the study, participants completed a subjective questionnaire about their representation preferences. While participants prefer current MilSTD 2525B representations, objective SA measures do not support the superiority of this representation.

Keywords: experimental study, Situation Awareness, cognition, human computer interaction, usability, Command and Control

1. Introduction

We are living in the midst of a revolution of information technology. With the proliferation of data sources and the increasing digitization of data, operators in many domains are expected to monitor dynamic, constantly updating data from a wide array of sources covering a broad spectrum of operations. This increased information flow is provided to enhance decision-making and human-system performance, yet often, the high flow of data has a deleterious effect on the operator's understanding of the relevant aspects of the situation. The tools provided to support task performance are no longer simple tools; they are often amazingly complex, requiring significant amounts of training and experience to master. The challenges are not simply in learning to physically perform a task and mastering the motor skills required for performance, but rather in perceptual and cognitive task mastery.

Just as the Industrial Revolution wrought changes in the way people lived and worked, so too is the current Information Revolution producing changes in the way people work and interact with systems. In many workplaces, this has meant a huge increase in systems, displays and technologies. The problem in this environment is no longer lack of information, but finding, within the mass of data available, those precise bits of information that are needed to make an informed, reasoned decision. A widening gap exists between the tons of data being produced and disseminated, and the individual's ability to find the right, disparate bits and process them together to arrive at the actual information sought. If we examine research on aviation accidents and performance under demanding battlefield conditions, we see that operators have no difficulty physically performing their tasks, and no difficulty choosing the correct action once they understand the situation, but they struggle with the task of developing and maintaining an understanding of the situation [1, 2]

For this reason, researchers are interested in understanding, evaluating and improving the situation awareness (SA) of individuals. Endsley [3] formally defines SA as "…the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future."

The definition encompasses several concepts that are central to understanding the SA construct. First, SA is comprised of three levels: perception, comprehension and projection. Level 1 SA, perception, involves the sensory detection of significant environmental cues. Perception is an active process whereby individuals extract salient cues from their environment. By selectively directing attention to the incoming stimuli, important/essential information is attended to while nonessential items are disregarded. Level 2 SA, comprehension, involves integrating information to understand how it will impact upon the individual's goals and objectives. This includes developing a comprehensive picture of the world, or of that portion of the world of concern to the individual. Level 3 SA, projection, consists of extrapolating this information forward in time to determine how it will affect future states of the operational environment [4]. Level 3 SA combines what the individual knows about the current situation with their mental models or schemata of similar events to predict what might happen next. For instance, a driver approaching a red light might predict that ignoring the light and proceeding into the intersection would result in a car accident. Thus, mental models help ease the cognitive workload required to develop level 2 and 3 SA.

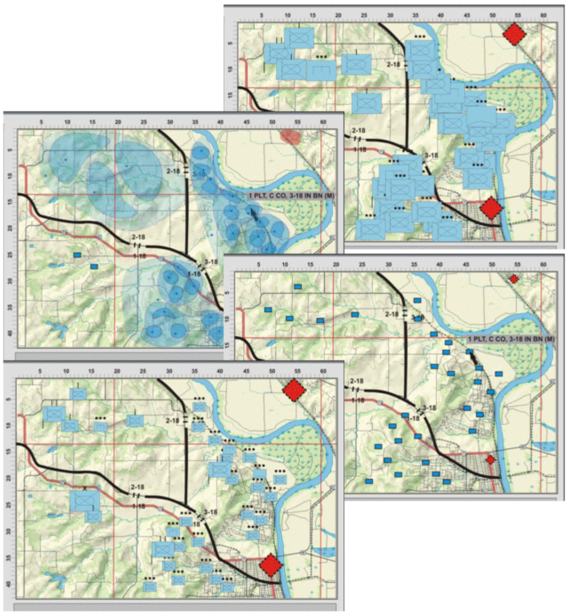

Figure 1. Display modalities investigated were (clockwise from top right) standard, miniature, proportional, and blobs.

The current research investigated the issue of information overload in a military command and control (C2) environment. In a fast-paced, dynamic environment such as military C2, it is often difficult to develop a clear picture of emerging events. One significant source of confusion is the density of units being displayed on cluttered Common Operating Picture (COP) displays and the difficulty this information density causes for operators seeking a clear picture of the situation. In particular, current military C2 displays are often difficult to "read" because of stacked and occluded icons on the COP. This phenomenon can be seen in the standard display shown in Figure 1 above.

The current research focused on the presentation of unit representations (icons) on the digitized COP. A comparison was undertaken of the effectiveness of current MilSTD 2525B symbology, the military standard for display symbology, with other unit representation options. The options selected for this study, in addition to standard, are miniature icons - smaller versions of the standard icons, without the detailed information contained in standard icons, proportional icons - icon size is proportional to unit size (e.g. larger units have larger icons), and blobs depicting physical unit boundaries and dispersion, developed by the U.S. Army Research Lab's

Computer Information Systems Directorate (see Figure 1 for sample displays).

Modalities were selected for investigation based on ethnographic observations of the ways in which officers seek to deal with the proliferation of large, overlapping battlespace objects on dense COPs. The operator needs easy ways to understand relationships among and between units, such as which are headquarter units, which the current military standard does not readily support. They also need to be able to tradeoff the detail of MilSTD 2525B for simpler representations that reduce the substantial symbol overlap and occlusion associated with units in close proximity that render viewability of unit symbols virtually impossible.

This study examines the utility of several new approaches that do not "declutter" in the traditional sense (simply eliminating some symbols, thus creating potentially hazardous loss of SA). Instead this effort seeks to convey meaning through variable sizes and proportions, or through the blobology concept developed by the U.S. Army Research Lab's Computer Information Systems Directorate. The goal is to determine if these other approaches can retain critical battlespace object location and identity information while also reducing clutter and adding much needed data on unit relationships and importance.

2. Method

2.1 Participants

Sixteen United States Army Reserve Officer Training Corps (ROTC) students at the University of Central Florida volunteered for participation in the study. An honorarium was paid into the ROTC student fund as compensation for their participation. Student ages ranged from 18 to 27 years, with a mean age of 22.8 years. Seven participants had no prior military experience, while nine participants had some prior military service time. For those with military experience, the time in service ranged from two years, five months, to seven years. Six of the nine participants with military service time had been operationally deployed, with number of deployments ranging from one to six. Four participants were excluded from the analysis as they did not complete the SA queries at all halts, thus it was not possible to tell which experimental condition they completed immediately prior to testing when they did respond to the queries.

2.2 Materials

Background for the experimental scenario was provided to participants on paper copies of excerpts from a standard format, U.S. Army Operations Order. A laptop computer with a mouse was employed for presentation of the simulation scenario. The 28 minute simulation was divided into four, seven-minute segments. Icon modality was changed in each segment, so each participant viewed each display modality – standard, miniature, proportional and blobs, for one seven-minute segment.

In order to provide the broadest possible array of information regarding the quality of participant SA, SA data was collected using the Situation Awareness Global Assessment Technique (SAGAT), a validated, objective measure, along with a subjective assessment of SA. Additionally, NASA-TLX was used to collect subjective workload data; however, that data is not reported here.

1. ***Participant Biographical Questionnaires.*** Relevant biographical data was collected from each participant with information about age, rank, educational background, and pertinent military experience and training (see Appendix 1B.)
2. ***SAGAT.*** Situation Awareness Global Assessment Technique (SAGAT) was used to measure participant SA during the simulation [5]. Four freezes were inserted into the simulation, one at the end of each segment, to collect SAGAT data. At each freeze, the simulation was stopped, SAGAT queries were administered on the same laptop PC as the simulation, and responses were collected electronically. Response accuracy to the SAGAT queries yields an objective measure of participant SA at the end of each presentation segment. SAGAT queries presented are shown in Table 1, with the possible responses, and the level of SA (1-perception, 2-comprehension, and 3-projection) of the query. Queries about the status of unit assets were placed into a separate category.
3. ***Subjective Assessment Forms.*** SA will also be measured using subjective evaluations forms to determine participants' subjective assessments of the different visual displays.

Table 1
SAGAT queries administered

SA level	Query	Response
1	How many companies in your battalion are in contact?	#
1	How many platoons in your battalion are in contact?	#
1	How many enemy elements has your battalion engaged?	#
1	How many sensors are in OBJ Gold?	#
1 - 2 Status	What companies are not green on vehicles?	A, B, C, D, NA
1 - 2 Status	What companies are not green on troops?	A, B, C, D, NA
1 - 2 Status	What companies are not green on weapons?	A, B, C, D, NA
1 - 2 Status	What companies are not green on supplies?	A, B, C, D, NA
2	What is your current battalion effectiveness?	100%, 90 %, 80%, 70%, 60%, 50%, <50%
2	Which enemy locations are strongest?	Use map items
2	Which enemy locations are weakest?	Use map items
2	Which friendly locations are strongest?	Use map items
2	Which friendly locations are weakest?	Use map items
3	What do you expect the enemy to do next?	Attack, defend, move, retreat, nothing, other

These subjective assessments consisted of queries concerning which modality participants liked best, which they liked least, which was easiest for monitoring friendly forces, and which was easiest for monitoring enemy forces. In addition, participants were asked to write in what they liked and didn't like about each icon modality. Finally, they were asked if there was any additional information they would like to tell us about the different icons.

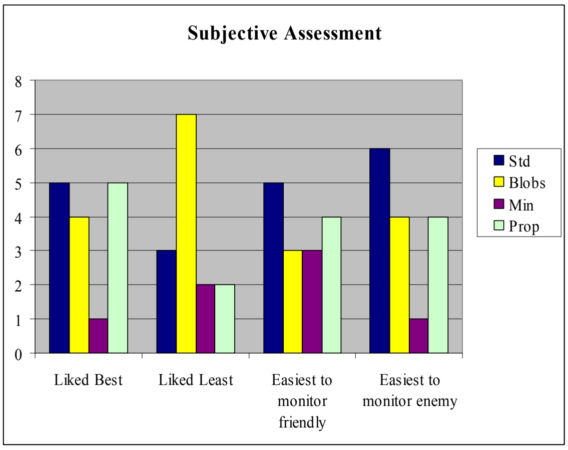

Figure 2. Subjective assessment of icon modalities

2.3 Procedure

Each participant completed one scenario trial. Biographical information was completed prior to study participation. Study instructions were provided prior to the start of the trial, including instructions regarding SAGAT, real-time probes, and subjective evaluations.

The 28 minute scenario was divided into four sever-minute segments. Display modality varied among the seven-minute segments, with each of the four modalities shown in only one of the four segments for each participant. Presentation order was varied between participants using a Latin Squares design. A halt in the action occurred between each segment to collect SAGAT data, and a final SAGAT data collection on completion of the scenario. Participants were not informed of the number or timing of the freezes. At the end of the scenario, participants completed the NASA-TLX and the subjective evaluations.

3. Results

3.1 Subjective Assessment

Participant responses are shown in the bar chart above. No statistical analysis was done on these data; they are simply reported here as collected. Overall, more participants preferred the standard icons and the

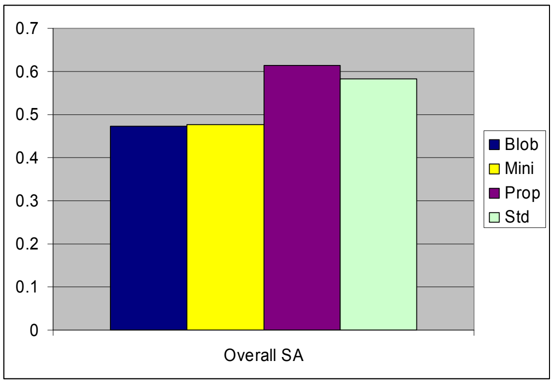

Figure 3. Overall SA across display conditions

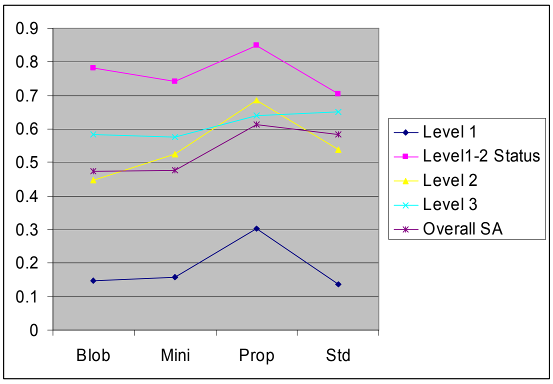

Figure 4. Levels of SA and overall SA for each condition

proportional icons, although four participants (only one less than the five who preferred standard and proportional) preferred blobs. Only one participant indicated a preference for miniature icons. Blobs, however, were the icons selected by the largest number of participants as being least preferred. More than twice as many participants identified blobs as the least preferred icon than the next higher icon, which was standard. Finally, more participants indicated that they felt it was easiest to monitor friendly elements, and easiest to monitor enemy elements, in the standard condition.

3.2 SAGAT

SAGAT data was analyzed using analysis of variance (ANOVA). As the purpose of the experiment was to compare the information afforded to operators by different unit representation modalities, and as there was only a single SAGAT halt per participant for each of the four modalities, the analysis deemed most appropriate was an analysis of combined SA for all queries, coupled with an analysis of SA for each level of SA listed in Table 1. Only one significant difference was found using this method; there was a significant difference for display type for the overall SA score, $F(3, 42) = 4.430$, $p<.01$. Means for overall SA are shown in Figure 3. Post hoc analysis using Fischer's PLSD indicates a significant difference between individual modalities in some cases. For Level 1 SA, a significant difference was found between the proportional and standard condition ($p<.05$), a significant difference was found for Level 2 SA between proportional and blobs ($p<.05$), and a significant difference was found for Overall SA between proportional and all other display conditions.

The direction of the difference in each case can be seen in Figure 4 above. With the exception of Level 3 SA (a single query concerning what actions the enemy will take next), participant SA is at least slightly higher in the proportional condition than in all other conditions.

4. Discussion

The results of this analysis offer an interesting view of the differences between subjective and objective SA. In the subjective evaluation, participants indicated a slight preference for the current MilSTD 2525B symbology, and indicated that it was easiest to monitor both friendly and enemy forces using this display modality. Results from SAGAT, a well-validated objective measure of SA, however, do not support this assessment.

There are several possible reasons for this discrepancy. Nine of the study participants have either current or prior military experience, and are likely to have at least some familiarity with MilSTD 2525B icons. Even the participants who have no prior military service time are likely to have been exposed to MilSTD 2525B icons as ROTC cadets. It is not unusual to find a preference, in subjective evaluations, for the familiar.

In addition, some of the screen clutter and occlusion issues this experiment was designed to address were actually minimised by the experimental interface, which uses concepts of SA-oriented design developed for military operations. Because the experimental display was an individual display, which could be zoomed in or out, issues of screen clutter and stacked icons could be addressed by zooming in to view a smaller area of the map. Wile this is not an unacceptable solution to the problem, as long as individual displays are available, it has some potential shortcomings. First, it may slightly increase operator workload, due to the dynamic need for resizing the area of interest on the map. To get the big picture of the area, the operator would have to zoom out; however, to prevent icon stacking, the operator would have to zoom in to find the units of interest. Even relatively small increases in operator workload can have an impact on SA in high demand tasks.

In considering why the proportional condition would provide superior SA for virtually every SAGAT query, we must consider what information proportional icons add to the display. In every respect other than size, proportional icons are identical to standard icons. For the current study, even miniature icons were identical to proportional and standard icons, although the detail on the icons may have been more difficult for participants to distinguish due to small icon size. The only information that is made more salient for proportional icons is the size of the unit being represented. Although this information is present in standard icons, it is more easily distinguishable in proportional icons. It is possible that by making this information more salient, participants were able to acquire this information with less effort, thus leaving more cognitive capacity for other evaluation tasks.

It is important to note that the participants in this study are not all military personnel, and perhaps the findings would be different with active duty personnel intimately familiar with the nuances of MilSTD 2525B. It is possible that these personnel would perform better with the existing display condition, although initial advantages for the familiar system might also be overcome in time.

5. Conclusions

This experimental study found qualitative differences in SA assessed by subjective and objective measures of SA. Subjective measures of SA have tremendous appeal, as they are quite simple to develop, administer and analyze. The current study, though, indicates that there are tradeoffs for this ease of application. Objective measures of SA are generally more sensitive and diagnostic of true differences between experimental conditions. Wherever possible, the use of objective measures of SA is indicated.

This research also demonstrated that relatively minor design differences can have a significant impact on operator SA. By changing icon size, we allow the operator to easily glean valuable information with minimal effort, thus increasing the available cognitive capacity which can be directed toward other tasks.

This research effort should be repeated with active duty military personnel to determine whether the results can be replicated in this group. Analysis of subjective workload in each condition would also be valuable in determining whether the improved SA in the proportional condition is truly the result of reduced workload, or whether there are other factors at work.

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