Effects of Information Availability on Command-and-Control Decision Making: Performance, Trust, and Situation Awareness

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Objective: We investigated how increases in task-relevant information affect human decision-making performance, situation awareness (SA), and trust in a simulated command-and-control (C2) environment.

Background: Increased information is often associated with an improvement of SA and decision-making performance in networked organizations. However, previous research suggests that increasing information without considering the task relevance and the presentation can impair performance.

Method: We used a simulated C2 task across two experiments. Experiment 1 varied the information volume provided to individual participants and measured the speed and accuracy of decision making for task performance. Experiment 2 varied information volume and information reliability provided to two participants acting in different roles and assessed decision-making performance, SA, and trust between the paired participants.

Results: In both experiments, increased task-relevant information volume did not improve task performance. In Experiment 2, increased task-relevant information volume reduced self-reported SA and trust, and incorrect source reliability information led to poorer task performance and SA.

Conclusion: These results indicate that increasing the volume of information, even when it is accurate and task relevant, is not necessarily beneficial to decision-making performance. Moreover, it may even be detrimental to SA and trust among team members.

Application: Given the high volume of available and shared information and the safety-critical and time-sensitive nature of many decisions, these results have implications for training and system design in C2 domains. To avoid decrements to SA, interpersonal trust, and decision-making performance, information presentation within C2 systems must reflect human cognitive processing limits and capabilities.

Keywords: information, situation awareness, trust, decision making, command and control, network enabled operations

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INTRODUCTION

Technological advances drive information growth and transform the ways that people share information (Gleick, 2011). The emergence of networked forms of organization lies at the core of economic, military, political, and social operations of the 21st century (Castells, 1996). In networked organizations, the number of potential collaborations is virtually limitless, as is the potential for information sharing. Consequently, there is a need to understand how the transition to networked environments affects human cognition, particularly, decision making.

This question is especially relevant in command-and-control (C2) domains, such as military operations, emergency response, air traffic control, and others in which information from various sources and of varying quality must be quickly assimilated and shared among distributed team members to make critical decisions. The concept of information overload has been recognized for many years as a potential problem for decision makers in these domains (e.g., Bateman, 1998; Curts & Campbell, 2001; Eagen, 1998; Entin & Serfaty, 1990), and there has been substantial work developing and testing training interventions to enable decision makers to avoid and mitigate the effects of information overload and other related stressors, such as time pressure and workload (Freeman, Cohen, & Serfaty, 1997; Serfaty, Entin, & Johnston, 1998). As increases in networking and integrated communications continue, allowing for exponential increases in the amount of relevant information available to the individual decision maker, understanding the relationship between information volume and human decision-making processes remains a critical question.

Furthermore, previous research suggests that cognitive limitations can constrain the amount of information that can be used (e.g., Gigerenzer & Selten, 2002; Simon, 1972) and that information can be processed inappropriately and with systematic biases (e.g., Kahneman, 2011). Increased information sharing may raise the quantity of available information without a corresponding quality improvement, which presents a challenge as cognitive resources must be devoted to separating the relevant information (signal) from the irrelevant or redundant information (noise). Even when information sharing increases the volume of relevant information, the sheer volume and rapid pace of information can be overwhelming. Indeed, previous research shows that task workload and time constraints interact with and can impair an individual's cognitive processing abilities (Gonzalez, 2004, 2005b).

Research on complex, dynamic decision-making tasks suggests that more information does not necessarily lead to better decisions (e.g., Gonzalez, 2005a); and many times a robustly networked force may result in poorer shared situation awareness (SA; Saner, Bolstad, Gonzalez, & Cuevas, 2009). For example, Nadav-Greenberg and Joslyn (2009) asked their participants to make repeated decisions as to whether or not to salt the roads in a town, based on their prediction of whether or not it would freeze on a given night given the expected overnight temperature. The researchers manipulated what additional information items the participants received: no additional information, the lower bound of the 80% confidence interval (CI) on expected temperatures, the lower and upper bound of the CI, the probability of freezing, or the option to request any or all of these pieces of information. Participants in this last condition, with all types of information available to them upon request, actually performed worse than those in the other information conditions. The data showed that the majority of participants in this condition did in fact request multiple types of information throughout the course of the task, although many narrowed down the types of information requested as they learned which were most useful. In a different study, participants predicted a firm's financial distress on the basis of four, six, or eight different information cues (Chewning & Harrell, 1990). The researchers found that approximately one third of their participants showed signs of information overload, choosing not to use all the available information cues and making less consistent decisions overall.

Similar effects have been found in simple judgment tasks: Participants given additional relevant information about cities in the United States and Germany were not more accurate in ranking the cities by size (Goldstein & Gigerenzer, 2002). In addition, participants were less accurate in predicting the outcome of professional basketball games when they received additional information about the team name than when they lacked that information (Hall, Ariss, & Todorov, 2007).

Much of the previous work exploring the relationship between information volume and decision making has used abstract judgment tasks in a laboratory environment; however, in C2 environments, decision makers not only make judgments but also choose courses of action, work in a dynamically changing environment, and make use of feedback on their performance. Thus, it is unclear how well findings from abstract environments would apply to a C2 environment.

Simulated C2 environments or microworlds are a useful way of exploring decision-making processes in these more complex domains while still maintaining the benefits of experimental control and have been used successfully to study many aspects of C2 decision making for individuals (e.g., Hall, Shattuck, & Bennett, 2012; Rovira, McGarry, & Parasuraman, 2007) and teams (e.g., Lafond, Jobidon, Aubé, & Tremblay, 2011; Serfaty et al., 1998). Here, we focus on simulation to specifically investigate how information volume and reliability affect objective decision making in individuals and teams in a military C2 context of locating high-value targets (HVTs). This context provides a clear, easily grasped objective for experimental participants while also representing a real problem domain for military decision makers. In contrast to many previous studies of information volume and decision making, we use a task with an objective ground truth to assess the speed and

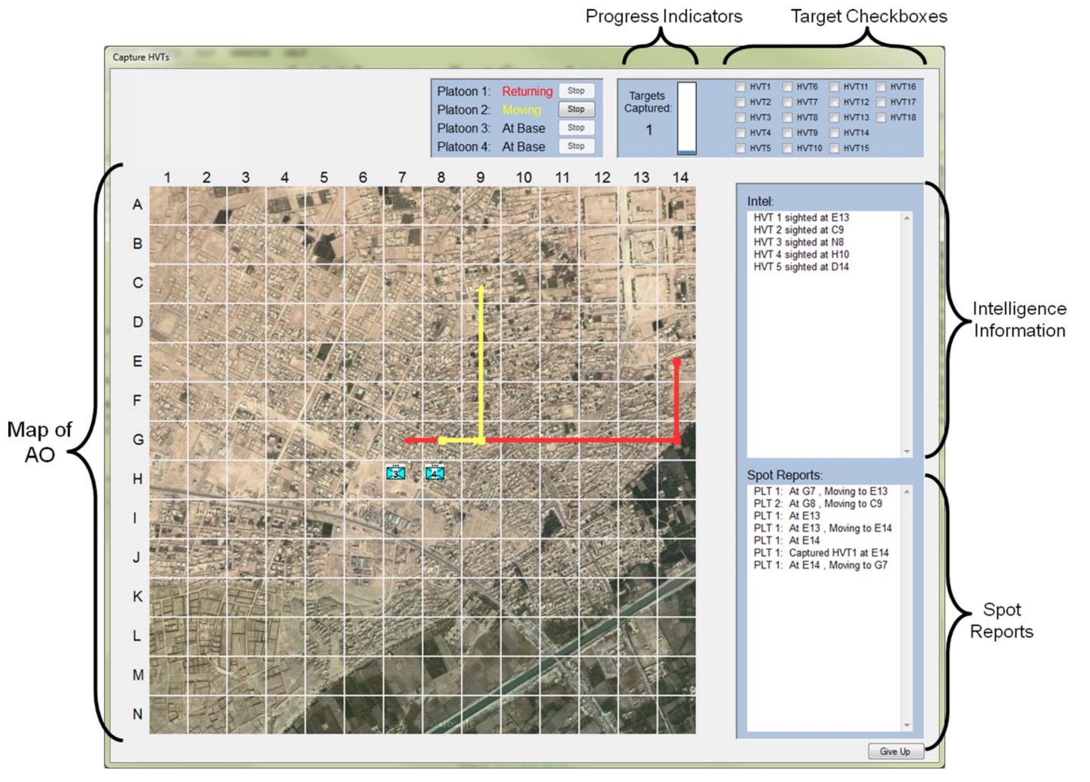

Figure 1. Screen capture of the single-player task display used in Experiment 1.

accuracy of participants' decisions, and all information provided is task relevant. This approach allowed us to systematically manipulate variables, such as volume of displayed information, and to collect objective data on decision making and task performance.

In Experiment 1, we examine the impact of task-relevant information volume upon the decision-making performance of single participants operating individually in a simulated C2 environment. Experiment 2 builds upon Experiment 1, using two-player teams instead of single players. The goal of Experiment 2 is to explore the effects of information volume and information reliability upon decision-making performance in distributed operations and additionally upon SA and interpersonal trust.

Simulated C2 Task

The goal of the experimental task was to find and capture HVTs within a given area of operations (see Figure 1). Participants received text-based intelligence information about the location of HVTs, and they had control over the movements of four identical assets that could be assigned to travel to any location on the map to capture HVTs. Friendly unit icons based on standard military symbology (Department of Defense, 2008) were used to represent the assets. An HVT was considered "captured" if a unit icon was moved to the same map location as the HVT. Objective decision-making performance was operationalized as the time to capture the HVTs.

Experiment 1 was a single-player task: Participants controlled unit movements to capture targets, based on incoming intelligence information, all of which was relevant. Information volume was manipulated through the number of these intelligence updates provided for each HVT. Experiment 2 was a two-player task: Participants worked collaboratively in pairs, one responsible for unit movements and the other for intelligence reports. In Experiment 2, we examined decision making given varying source reliability information and limited versus self-selected information sharing. Additionally, we investigated the relationship between decision making and self-reported measures of informational and interpersonal trust and SA. The two versions of the task are described in more detail in each experiment's Method section.

Our task involved several simplifications from real-world C2 scenarios. We limit the interaction to one or two roles rather than the multiple interacting roles of a command staff. In addition, this task focused on one well-defined mission rather than a more complex combination of operations and events. These simplifications allowed for systematic and controlled manipulation of variables of interest while avoiding potential confounds (e.g., quality/relevance of information, information modality, network bandwidth, system availability) that occur in the real world.

Using a controlled experimental task also allowed for direct, objective measurement of task performance. In a real scenario, performance is notoriously difficult to measure, whether quantitatively or qualitatively. Even mission success is often ambiguous. Under our more controlled task, we operationalized task performance as the time to capture each target. The proficiency in interpretation and integration of intelligence information determined how quickly participants were able to move assets to the correct target locations. Thus, target-capture times served as a useful quantitative measure of task performance.

Hypotheses

In Experiment 1, using the single-player task, we manipulated the number of location updates presented to participants about each HVT. Based on the decision-making literature cited earlier, we expected to find that large increases in information, even when task relevant, would generate diminishing returns in performance or perhaps even decrements in performance due to information overload.

Because this initial study was largely exploratory, it was critical that we be able to understand and interpret the human performance data we obtained. To assess human performance against a standard, we developed an ideal observer model. The purpose of an ideal observer is "to determine the optimal performance in a task, given the physical properties of the environment and stimuli" (Geisler, 2006, p. 825). Our ideal observer model is an information fusion algorithm that performed the experimental task by perfectly integrating all of the provided information. The ideal observer model is not meant to characterize the cognitive processes of human decision making; instead, it simulates the performance data that optimized decision making might generate in this task. This model is a useful representation of ideal information fusion performance against which we can compare human performance. We can determine what perfect information fusion would look like in the data generated from this particular task and compare this to the data our human participants actually generate.

In Experiment 2, using the two-player C2 task, we investigated the effects of information volume by manipulating whether players had access to the information primarily used by their partners. Information sharing within teams is necessary for shared mental models and for mission effectiveness (e.g., Cannon-Bowers, Salas, & Converse, 1993; Gorman, Cooke, & Winner, 2006); however, as the amount of information available to be shared has grown vast in today's networked environments, it is to be expected that there may be diminishing returns or perhaps performance decrements with unlimited increases in information sharing. We examined the effects of making all information available to both partners versus providing access only to information relevant to each partner's assigned role. Conceivably, making all information available to both partners may help facilitate a shared situational model and improve performance compared to a more limited-information condition. Conversely, this access to additional information could lead to information overload and poorer task performance. Similarly, we anticipated one of two possible outcomes of the effect of information volume upon interpersonal trust. The transparency of shared information may promote trust; however, the corresponding opportunity to second-guess a partner's decisions may actually decrease trust.

We also added an additional manipulation of source reliability in Experiment 2. In Experiment 1, all intelligence updates had an equal probability of being accurate. In an effort to represent additional complexity of decision making in real C2 domains, where information often arrives from multiple sources of varying reliability, we included intelligence sources that differed in their probability of informational accuracy. We also manipulated the knowledge provided about the reliability of these intelligence sources with three conditions:

1. None: No information about source reliability
2. Congruent: Accurate representation of source reliability (e.g., a 90% accurate source is labeled "90% accurate")
3. Incongruent: Inaccurate representation of source reliability (e.g., a 90% accurate source is labeled "10% accurate")

We hypothesized that task performance would be best in the congruent condition, followed by none, and worst in the incongruent condition.

EXPERIMENT 1: HVT SINGLE PLAYER

Experiment 1 was designed to assess the effects of information volume upon task performance in a military-relevant C2 task. This experiment also provided insight into individual performance on this task, informing the design and analysis of Experiment 2, in which two players completed a similar task in pairs.

Single-Player Task

In the single-player task, the display contained a map of the area of operations (AO), a text box that displayed incoming intelligence information about the location of HVTs, another text box that showed spot reports from the four units, a progress bar indicating how many targets had been captured, and checkboxes that participants could use to mark which targets had been captured (see Figure 1). The map was divided into a two-dimensional grid. To reference particular locations on the map, the x-axis of the grid was marked with numbers 1 through 14, and the y-axis was marked with letters *A* through *N*.

During the task, new HVTs activated at a randomized location every 15 s and remained in the same location until captured. When a new HVT activated, participants received intelligence information about the possible location of that target in the "Intel" text box (e.g., "HVT 1 sighted at D2"), but they were not shown the HVT on the map. Using this information, the participant could click on one or more of the four unit icons and assign them to travel to map locations to capture the targets. While a unit was traveling, its icon disappeared, and a yellow arrow appeared showing the path of travel. Units traveled by taxicab geometry, moving only vertically or horizontally to reach the target. Whether units initially traveled horizontally or vertically was determined randomly for each unit movement. If a unit entered the same location as an active target, it automatically captured the target and returned to the base location in the center of the map. A returning unit was indicated on the map by a red arrow showing the path of travel back to the base location. If a unit reached its assigned destination without finding an HVT, the unit icon reappeared in the destination location and became available for reassignment. Participants had the ability to stop a moving unit (if it was not returning with a captured target) and reassign it. Units always traveled one block every 3 s.

The spot reports presented to the participants contained information about the units (*platoon* is abbreviated PLT) and their location (e.g., "PLT 1: At G4"), unit movement ("PLT 2: At G8, Moving to A14"), and target captures ("PLT 1: Captured HVT1 at J2"). These reports were always 100% accurate.

The intelligence updates presented to the participants were 50% accurate, meaning they were 50% likely to provide the correct location of a target, which was always stationary. If the update was not accurate, it was off by only one square in the horizontal or vertical direction (see Figure 2). As a result of these constraints, multiple intelligence updates allowed for the possibility of pinpointing the actual location of a given target with certainty. For example, if one update read, "HVT 1 sighted at C7," and another read, "HVT 1 sighted at C9," it could be inferred with certainty that the target was at C8 (see Figure 3). In addition, if the same location appeared in multiple intelligence updates, this information could be taken as increased support for that specific location.

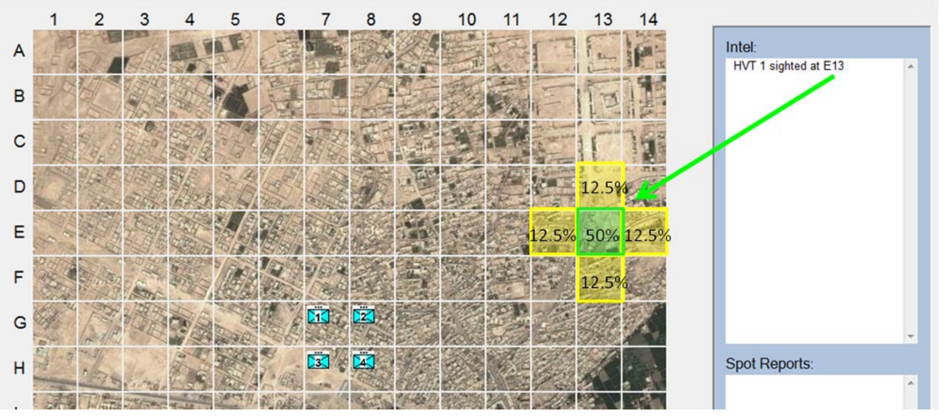

Figure 2. Illustration of the probabilities of possible high-value target locations, given a single intelligence update. This illustration was shown to participants during the tutorial phase but was not part of the experimental display.

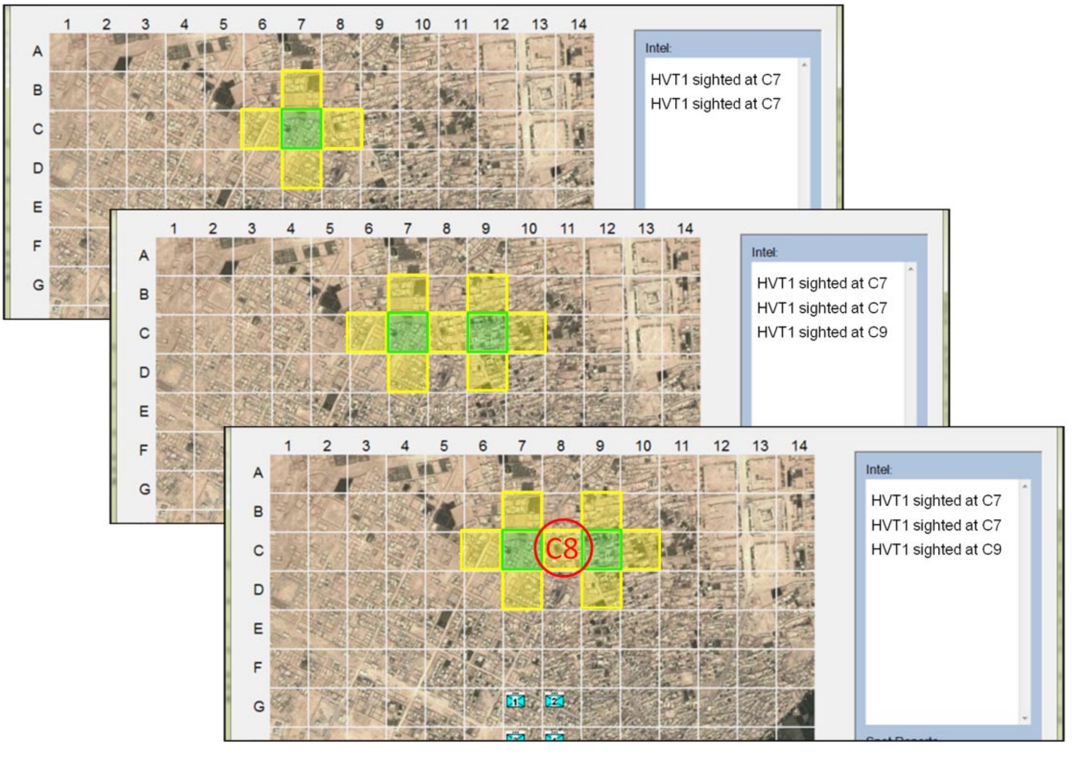

Figure 3. Illustration of integrating multiple intelligence updates to determine the true target location. Given the two unique updates displayed, the only possibility is C8. These illustrations were not part of the experimental display.

All updates about a single target appeared within a 16-s window, with new targets activating every 15 s (see Figure 4). Participants were able to assign units to capture a target at any time during or after this 16-s updating window. Pilot studies indicated that the small amount of

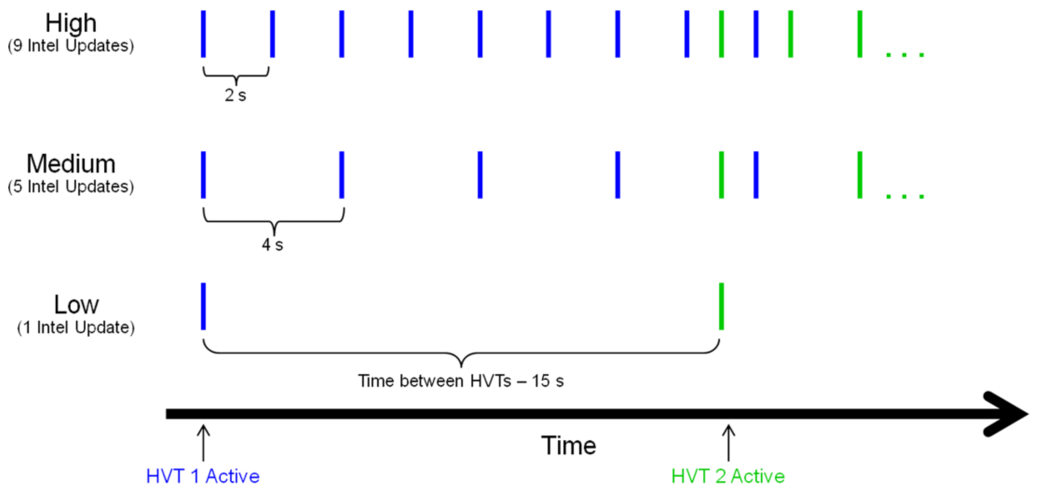

Figure 4. Illustration of the timing of intelligence updates in Experiment 1.

overlap between the reporting windows of successive targets would provide a challenging, but not completely overwhelming, task for participants. During the course of the task, new intelligence updates were added to the bottom of the scrolling "Intel" text window, but all previous updates remained available above to be referenced by participants as needed. An HVT remained active until it was captured, even if subsequent HVTs activated before this capture occurred.

Method

Participants. Twenty-four participants (16 male, eight female) completed this study. All were between the ages of 18 and 60 years. Participants were recruited through e-mail solicitation of civilian employees at the U.S. Army Research Laboratory, and they received no compensation for participation.

Experimental design. The within-participant independent variable was information volume, operationalized here as the number of intelligence reports (one, five, or nine) presented about the location of a single HVT. Information volume varied by experimental block, and the order of blocks was counterbalanced across participants. The dependent variable was the time it took participants to capture an HVT after presentation of the first intelligence report about that HVT.

Procedure. The study took place in a dimly lit experimental room on a single-monitor computer. Participants completed a self-paced tutorial, which provided an overview of the purpose of the task and allowed them to step through each of the actions required of them in the task (reading intelligence updates, assigning a unit to a new location, and marking a checkbox to indicate target capture). The accuracy contingencies of the intelligence updates were also described in the tutorial using both text and diagrams. Participants then completed a practice block, in which they captured six HVTs. Each of the three intelligence volume conditions was presented twice in this practice block. After successfully completing the practice, participants completed three test blocks of 18 HVTs each.

Ideal observer model. We assessed human performance against a standard using an ideal observer model. The model receives the same intelligence updates in the same sequence with the same timing as the human participants. After the first update, the algorithm assigns the closest platoon to the grid location specified by that update. With each new update, the model combines the information provided in the current and previous updates to generate an optimal prediction of the target's most likely location (see Figures 2 and 3).

In some cases, multiple updates provide enough information to know the target location

TABLE 1: Results From Experiment 1 in Capture Time and Standardized *Z* Scores

Result	Low Volume	Medium Volume	High Volume
Capture time in seconds	19.05 (9.87)	21.10 (9.31)	21.14 (10.72)
Z score	–0.07 (0.32)	0.04 (0.34)	0.02 (0.33)

Note. Means shown with standard deviations in parentheses.

with certainty. In other cases, more than one location is equally likely; in these cases, the algorithm randomly selects one of these locations for its prediction. If a unit is en route to one location, and subsequent updates have confirmed with certainty that the target is in a different location, the model will stop and reassign the unit. If a unit arrives at a predicted location and does not capture a target there, the algorithm updates its list of possible target locations and tries each remaining possibility in turn until the target is captured.

Analysis and Results

In this study, task performance was operationalized as target-capture time. Each HVT remained active until it was captured, and participants were able to assign and reassign one or more units to locate each target; as a result, there is no simple measure of trial accuracy in these data as would typically be collected in a forced-choice paradigm. For each participant, the time between activation of an HVT (the time of the first intelligence update) and the capture of that HVT was calculated. This time was divided by the distance in blocks of the HVT's location to the base location, to account for the longer travel time required by farther-away targets, generating a rate (time to capture / distance traveled). Because there was substantial variability in overall speed across participants, these rates were converted to standardized *z* scores for each participant. We then calculated the average *z*-score rate in each information volume condition for each participant and compared across participants. The means for each volume condition in both capture times and *z* scores are shown in Table 1. The condition with the fastest capture times was the low-information-volume condition (see Figure 5), but this difference was not significant, $F(2, 46) = 0.49$, $p = .62$, $\eta^2 = .02$.

As a comparison, an ideal observer model was designed to have the same movement constraints but could perfectly integrate all intelligence updates. The purpose of this model was to discover if additional information objectively conferred an advantage, given optimal information processing. The ideal observer model was run on the exact set of intelligence updates received by each participant. If the ideal observer model did not perform better in the five- and nine-update conditions than in the one-update condition, it would indicate that the human participants were not necessarily overwhelmed by additional information but that they were making a possibly rational decision to use only a single update, no matter how many were available. However, if the ideal observer did perform better in the five- and nine-update conditions, it would indicate that the human participants were unable to take advantage of the benefits of additional information.

As with the human data, the rates were converted to *z* scores and then averaged (see Figure 5). The resulting pattern of data shows the ideal observer's *relative* performance differences in each of the three information volume conditions. The relevant comparison between the human and ideal observer data is not in the absolute scores for each condition but, rather, in the patterns of relative differences among the three conditions. The human data show relatively similar performance across the three volume conditions, with slightly faster performance in the lowest information condition. In contrast, the ideal observer performed much faster with additional intelligence updates, relative to the lowest information condition. There is some evidence of diminishing returns in model performance as the number of updates increases from five to nine, indicating that in this task, an intermediate number of updates is often sufficient to determine target location. More updates allow even

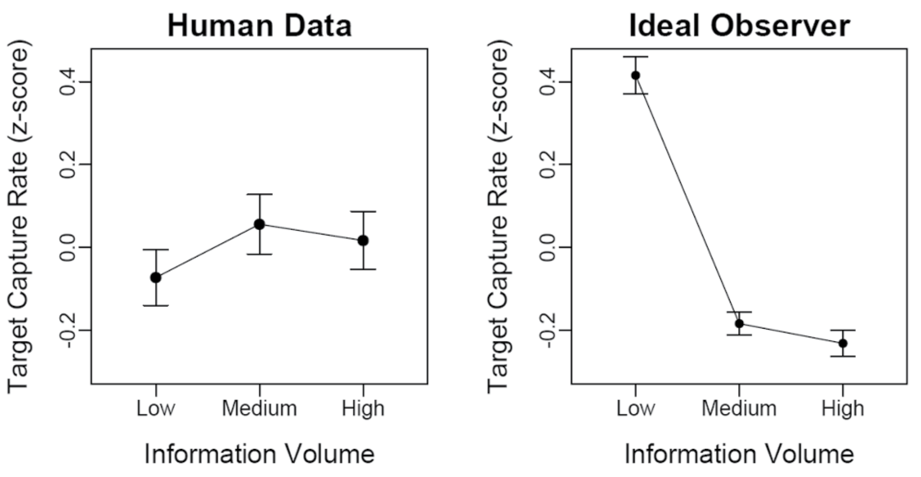

Figure 5. Comparison of results from human participants and simulated results from the ideal observer model in Experiment 1. Larger *z* scores represent relatively slower target-capture times, whereas smaller *z* scores represent relatively faster target-capture times. Humans performed better in the low-information condition, whereas performance of a data fusion algorithm (ideal observer model) improves with increasing information volume. Error bars represent standard error of the mean (*SEM*).

more certainty of target location but also increase the probability of redundant information.

Discussion

In this study, we manipulated the volume of task-relevant information provided to participants and measured the resulting time to find and capture HVTs. We did not find significant effects of increasing the volume of task-relevant information on task performance. In contrast, an ideal observer, which perfectly integrated all information provided, performed much faster with increasing information. Thus, whereas the results of the ideal observer suggest that computational performance can be improved by integrating all available information, human participants did not seem capable of using this information. This finding suggests that participants may have been at their limits in integrating information in the HVT task.

The exact relationship between information volume and performance will depend on many things, including individual differences and the nature of the task being completed. For example, we would expect that performance in a simple task with no multitasking requirements or time pressure could show steady improvement even with fairly large increases in information volume. The C2 domain, on the other hand, is typically a time-stressed, multitasking environment that requires critical decisions to be made continuously. Given the finding that observers were not able to use all available useful information in our relatively simplified experimental task, there is reason to believe this finding would also be true in an even more complex real-world C2 environment (something we explore further in Experiment 2).

Psychological research has shown that people are indeed limited by how much information they can process, given finite working memory capacity (Anderson, Reder, & Lebiere, 1996; Baddeley, 1992; Miller, 1956). Even when demands on working memory are minimized, as in our task where information was maintained in the visual display ("knowledge in the world" vs. "knowledge in the head"; Norman, 1988), processing limitations, such as information fusion, remain. These limitations, in turn, have been linked to our ability to perceive, comprehend, and make projections about the environment we are facing—referred to more generally as SA (Endsley, 1995a, 1995b).

However, the promise of an integrated network is not limited to information volume; it also extends to better, more distributed information processing. In particular, multiple people integrated into the efforts of Mission Command allows for both increased capacity and flexibility in evaluating the environment. Yet, while dividing information-processing tasks can reduce the cognitive demands on individuals in the network, it may also introduce the risk that the right information might not reach the right people at the right time, particularly when information reliability varies. The critical question emerges of how to most effectively share this information across the network. Additionally, interpersonal dynamics become increasingly important. Whether distributed efforts can be consolidated to coherent and effective solutions may depend upon the interpersonal trust between operators. When trust is low, judgments made by colleagues might be discounted or ignored, leading to either missing, redundant, or delayed action.

EXPERIMENT 2: HVT TWO-PLAYER

In this study, we explored issues of interpersonal dynamics and information volume using the two-player version of the C2 task. We manipulated both information volume and source reliability information and assessed the impact on human performance, SA, and interpersonal trust.

Trust is the willingness to accept vulnerability to others for a potential common benefit (Mayer, Davis, & Schoorman, 1995). Conceivably, increased transparency and information awareness across teammates may promote trust, as one can verify another person's work (e.g., Saner et al., 2009; Martin, Gonzalez, Juvina, & Lebiere, 2014). Conversely, such verification may itself signify distrust, and observed mistakes in another's work may be overweighted.

SA forms the basis for decision making and task performance (Endsley & Garland, 2000; Strater & Bolstad, 2008; Strater, Endsley, Pleban, & Matthews, 2001). Although it is possible for an individual with an incomplete or inaccurate understanding of the situation to make the right decision and perform well by chance, good outcomes are far more likely with an accurate picture of the situation. In this study, we measure SA to have a better understanding of the behavior exhibited by the individual, including trust and performance. SA measurement also helps interpret findings by providing insight into the individual's cognitive state preceding decision making. As suggested by Study 1, one potential risk of increasing available information is that we might actually decrease rather than increase SA if there is information overload.

Two-Player Task

In the two-player task used in Experiment 2, each of two players was assigned to either the role of the intelligence officer (Intel) or the operations officer (OPS). The display in this version of the task was very similar to the display used in the single-player version. An additional display element in the two-player task was a chat window, which allowed the two participants to communicate directly with one another if they chose to do so. Some of the display elements, including intelligence updates and unit spot reports, were visible to participants depending on their assigned role and experimental condition. The goal of the task was the same as in the single-player version: to use text-based intelligence information to find and capture HVTs.

Intel. The responsibilities of the participant assigned to the Intel role were to read and process the incoming intelligence updates and to use this information to mark probable HVT locations on the grid map. This task was done by dragging target icons to the map, and these icons were automatically shared with the other player in all conditions.

OPS. The responsibilities of the participant assigned to the OPS role were to use the available information on probable target locations to assign the four units to find and capture the targets and to keep track of which targets had been captured. As in the single-player task, this task was done by clicking on individual units and either clicking on the grid space or typing in the grid location to assign a goal location. The yellow and red arrows indicating unit movement were visible to both players in all conditions.

In this version of the task, the intelligence updates were provided by two sources: Source A and Source B. In each experimental block, one source was randomly assigned to be 90% likely to be accurate, and the other was only 10% accurate. As in the single-player version, inaccurate

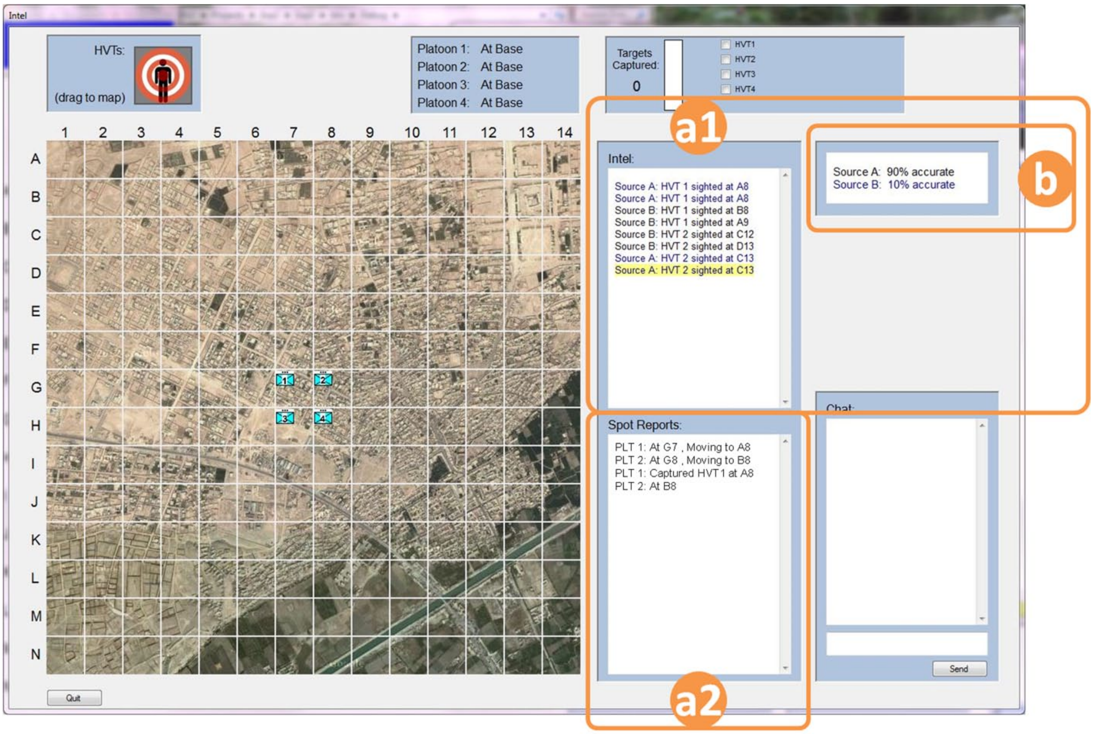

Figure 6. Screen capture of the intelligence officer (Intel) role's display in Experiment 2, with the two experimental manipulations highlighted. (1) In the shared condition, a1 and a2 are shown to both players. In the limited condition, a1 is shown to only the Intel player and a2 is shown to only the operations officer player. (2) In the *none* condition, b is hidden. In the *congruent* condition, the information in b is true. In the *incongruent* condition, the information in b is false.

information was off by only one square, either horizontally or vertically. Four updates appeared for each target, with two from Source A and two from Source B. The order of presentation reversed on each target (AABB, BBAA, AABB, etc.). Updates for the same target were presented every 4 s, and new targets activated every 18 s.

An additional display element in this version of the task provided source reliability information (see Figure 6, Region b). In some conditions, this information accurately represented the actual reliability of the two sources; in other conditions, the information provided was the opposite of the actual source reliability.

Method

Participants. Twenty-eight complete pairs of participants (56 participants total: 24 male, 32 female) volunteered for this study through the subject pool in the Psychology Department of the University of California, Santa Barbara. Participant ages ranged from 18 to 31 years.

Experimental design. Participant pairs completed three rounds of game play in this study. There were two manipulations, one between subjects and one within. The first was a between-participants manipulation, whether the role-specific information was shared or limited to the relevant role (see Figure 6). In the limited condition, only the Intel player was able to see the intelligence updates and source reliability information (Region a1 of Figure 6), and only the OPS player was able to see the spot reports about unit movement and target captures (Region a2 of Figure 6). In the shared condition, all of these elements were visible to both players. Participant pairs were randomly assigned to either the shared- or limited-information condition, which was constant across all three rounds of their participation in the task.

The second manipulation was within participants, and it determined what information was provided to the participants about source reliability. In the *none* condition, no information was provided. In the *congruent* and *incongruent* conditions, an additional display element (Figure 6, Region b) provided information about source reliability. This display element was always visible to the Intel player and visible to the OPS player in the shared-information condition. In the *congruent* condition, the source reliability information correctly indicated which source was 90% accurate and which was 10%. In the *incongruent* condition, the information was reversed. For example, if Source A was actually 90% accurate in that round, the display would show Source B as 90% accurate and Source A as 10% accurate. Participant pairs completed one round of the task in each of the three source reliability conditions. Within a single round, the accuracy of the two sources, as well as the source reliability condition (congruent, incongruent, or none), remained constant.

In all conditions, we collected data on task performance (measured by target-capture times), subjective SA, players' trust in their partners (both measured by questionnaires completed after each round of the task, described next), and chat communications between partners.

Questionnaires

Pretest questionnaire. Before beginning the experimental task, participants completed the pretest questionnaire, which included questions about demographic information (e.g., "What is your age?"), propensity to trust ("In your opinion, how trusting are you?"), and familiarity with the concepts presented in the main study ("Are you familiar with the concept of Situation Awareness?"). Most of the questions used a 3-point Likert scale for responses.

Round questionnaire. This questionnaire was given to participants after each experimental block (see appendix). The first part of the questionnaire was the Mission Awareness Rating Scale (MARS), a subjective measure designed to assess SA content and SA workload adapted from the Crew Assessment Rating Scale (CARS; McGuiness & Foy, 2000) to the military domain. These scales have been validated by Matthews, Beal, and Pleban (2002) and used to assess SA in various military-relevant experiments and exercises (e.g., Bowman & Thomas, 2008; Eid, Meland, Matthews, & Johnsen, 2005; Strater et al., 2004). MARS assesses participants' perceptions of their SA. It was selected due to its origins in the military domain and its unobtrusiveness for this experiment.

MARS consists of two subscales. Each subscale consists of four questions, on a 4-point scale, that address the three levels of SA as defined by Endsley (1988): perception, comprehension, and projection. A fourth question is about mission goals. The first subscale assesses SA content, meaning how well participants believe they understand the current situation. The second subscale assesses SA workload, or how many (or few) mental resources participants believe they used to understand the situation. According to Matthews et al. (2002), it is important to include perceived mental workload in an assessment of SA, citing an example of individuals who may have "high levels of SA, but most of their attentional capacity is required to achieve that level of SA. This would leave little mental workspace left to allocate to other, perhaps equally critical, processes" (p. 4).

MARS questions were adapted to our experiment by making minor wording changes to the questions. In addition, three more questions about the teammate (awareness of the teammate's activities, sharing decision making, and communicating) were added to assess shared SA. Higher scores on the MARS indicate higher levels of SA.

The second part of the round questionnaire assessed the participant's self-reported trust in the other player ("How much did you trust the other player?"), also on a 4-point scale. This relatively simple assessment of trust was chosen to avoid overwhelming participants, as this questionnaire was presented on three occasions.

Posttest questionnaire. After the main study, participants completed a short poststudy questionnaire. The purpose of this questionnaire was to gauge participants' understanding of the game and their perspective on the utility of the user interface (UI) components and to assess each player's feeling about his or her partner player's competence. This questionnaire comprised both 5-point rating scales and open-ended items.

Procedure. Each pair of participants was randomly assigned to either the shared- or limited-information condition, and roles were randomly assigned within pairs at the start of each session. The two members of a pair completed the study on single-monitor computers in separate experimental rooms. Participants first completed the prestudy questionnaire. They then performed a self-paced tutorial that provided an overview of the purpose of the task and the responsibilities of each role and that allowed them to step through each of the actions that would be required of them in the task. Participants then completed three test blocks corresponding to the three source reliability conditions (none, congruent, incongruent). Block order was counterbalanced across pairs. Each block contained a four-target practice, an 18-target test, and an after-round questionnaire. After all three blocks, participants completed the poststudy questionnaire.

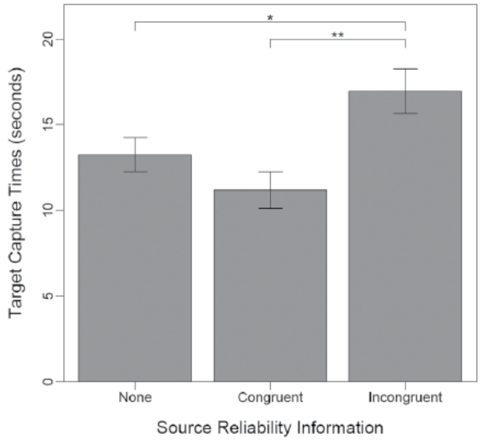

Figure 7. Mean target-capture times across the three source reliability information conditions in Experiment 2. Error bars represent standard error of the mean (*SEM*). Tukey's HSD is indicated by $*p < .05$, $**p < .01$.

Results

Task performance. A two-way mixed analysis of variance (ANOVA) showed a significant main effect of source reliability information upon task performance, measured by target-capture times, $F(2, 52) = 7.96, p = .001, \eta^2 = .14$. Because participants in Experiment 2 demonstrated much less variability in overall speed than those in Experiment 1, capture times were not converted to standardized z scores in this analysis. Post hoc tests using Tukey's honestly significant difference (HSD) test indicated significantly slower target-capture times in the *incongruent* condition (M = 16.97, SD = 6.93) than in either the *none* (M = 13.24, SD = 5.19) or the *congruent* (M = 11.20, SD = 5.63) condition (see Figure 7). There was no significant main effect of the between-participants limited/shared manipulation upon task performance, nor was there a significant interaction between the two independent variables.

SA. A two-way mixed ANOVA showed a main effect of the limited/shared manipulation upon SA levels, measured by MARS, $F(1, 54) = 8.29, p = .006, \eta^2 = .08$ (see Figure 8), with lower SA scores in the shared condition (M = 3.04, SD = 0.40) than in the limited condition (M = 3.32, SD = 0.33).

In addition, there was a main effect of source reliability information upon SA, $F(2, 108) = 7.14, p = .001, \eta^2 = .06$ (see Figure 8). Post hoc Tukey HSD tests showed that SA scores were significantly lower in the incongruent condition (M = 3.04, SD = 0.45) than in the congruent condition (M = 3.33, SD = 0.54).

Trust. There was a main effect of the limited/shared manipulation upon self-reported trust in one's partner, $F(1, 54) = 6.40, p = .02, \eta^2 = .08$ (see Figure 9), with lower trust scores in the shared condition (M = 3.42, SD = 0.66), than in the limited condition (M = 3.76, SD = 0.48). The main effect of source reliability information upon self-reported trust in one's partner was marginal, $F(2, 108) = 2.49, p < .09, \eta^2 = .01$, with the lowest levels of trust reported in the incongruent condition (see Figure 9).

Communication volume. We measured the communication volume between partners as the number of words transmitted over chat during a single round. Participants were not restricted as to the frequency or content of their communications. The two primary types of chat communication were sharing the probable location of targets and indicating which targets had been captured. As would be expected, partner chat volume was higher in the limited condition (M = 31.11, SD = 34.95) than in the shared condition (M = 17.74, SD = 25.32), although this difference was only marginally significant, $F(1, 54) = 2.79, p = .10$,

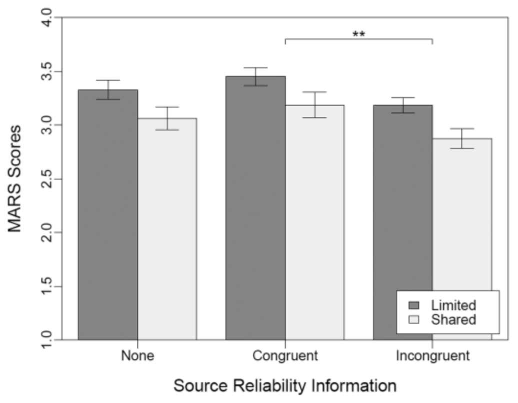

Figure 8. Self-reported situation awareness (SA), as measured by Mission Awareness Rating Scale (MARS) scores in Experiment 2. Error bars represent standard error of the mean (*SEM*).

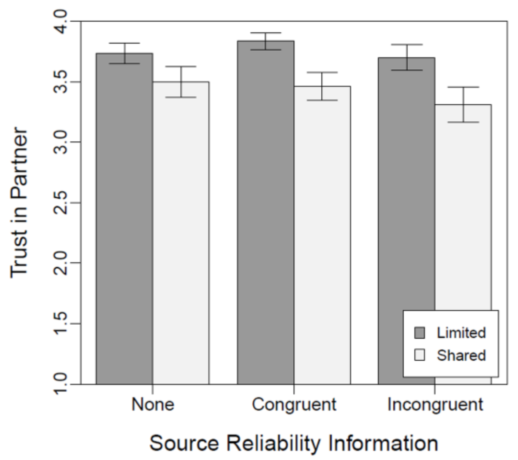

Figure 9. Self-reported trust in partner. Error bars represent standard error of the mean (*SEM*).

$\eta^2 = .05$. There was no significant main effect of the source reliability information manipulation upon chat volume, $p = .31$.

Discussion

We found that both the between-participants limited/shared manipulation and the within-subjects source reliability information manipulation affected participants' experience on the simulated C2 task. Although participants in the shared condition did not exhibit significantly slower target-capture times than those in the limited condition, they did report lower SA and lower trust in their partners. It seems that when users have access to the information their partners are using to perform their duties, they may "second-guess" their partners' decisions and consequently feel less trust in their partners. It is possible that this additional information may also cause a degree of overload in users, especially if they spend substantial time using it to check their partners' work, resulting in lower levels of SA.

As discussed earlier, we measured SA using MARS, a subjective measure based on self-ratings. Although this method was minimally intrusive to participants, several aspects of self-ratings may affect how we interpret our findings. MARS was administered as a posttrial questionnaire after each round of the task, and people are generally poor at reporting detailed information about past mental events (Endsley, 1995a). Also, participants' ratings may reflect confidence rather than actual SA. Our results showed significantly lower reported SA in the shared condition. It is possible that actual participant SA was not lower but rather that participants' confidence in their own SA was lower, driven by lower trust or by having to process additional information. This possibility is partly supported by the fact that target-capture times were not significantly slower in the shared condition. For future studies, we will consider integrating objective measures of SA, such as Situation Awareness Global Assessment Technique (SAGAT; Endsley 1988), for a better understanding of the observed behavior.

One consequence of the design of this task is that in the shared conditions, the OPS players can go beyond simply attending to the additional information available in the shared condition to actually using the information to perform both roles, ignoring the work of their (Intel) partner partially or completely. In cases in which the Intel player is performing poorly, this strategy may be effective. However, it can easily result in worse overall performance, as a result of information and task overload. We examined the data for evidence of this type of behavior in the OPS players. We noted the time at which the Intel player communicated a target location to the OPS player, through either the map interface or the chat window. We then noted the time that the

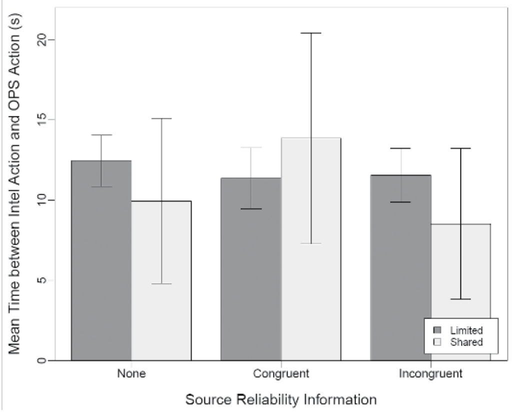

Figure 10. Elapsed time after intelligence officer action before operations officer action on a given target. Error bars represent standard error of the mean (*SEM*).

OPS player first assigned a unit to capture that target. If the OPS action preceded the Intel action, it provided evidence that the OPS player was appropriating the Intel player's duties. We found that timing differences in the shared condition were not significantly reduced, compared to the baseline timing differences observed in the limited condition (see Figure 10).

However, there was a wider range of values in interpair capture times, with large variability even within a single round of play of some pairs. This finding indicates that in some pairs, the OPS player acted both much earlier than the Intel player and much later, as compared with pairs in the limited condition. In fact, we find that the magnitude of this variability within a single round of game play predicts task performance. That is, in rounds with high variability in the time difference between actions, participants took longer to capture targets (see Figure 11). The implication is that the strategy of taking over for one's partner in this task may result in faster performance for some trials, but the additional task demands will cause overload and lead to much slower performance on many other trials.

This deeper analysis shows that no single condition performs the best in all cases. As follow-on research, this observation may point to an opportunity for exploring adaptive systems that change the UI based on underlying conditions. An adaptive system may be able to exploit the fact that in some cases, shared condition can offer a benefit (taking over for one's partner for faster performance for certain scenarios), whereas in general, the limited condition has better overall performance. An interesting research question would be to investigate whether the benefits of an adaptive interface outweigh the additional complexity and overhead introduced by it (Woods, Patterson, & Roth, 2002).

The team nature of this task allowed us to explore effects upon interpersonal trust. We were also interested in manipulating reliance upon and trust in information sources and assessing the effects upon task performance. We found that providing participants with false information about the reliability of the two information sources (the incongruent condition) resulted in slower target-capture times, lower self-reported SA, and possibly lower self-reported trust in players' partners. We did not find evidence that having correct information about the source reliabilities (the congruent condition) resulted in better performance, higher SA, or higher trust, as compared to having no information about source reliabilities. This finding indicates that, at least in this task, the cost of false information about source accuracy is greater than the benefit of true information.

CONCLUSIONS

As technological advances and the widespread transition to networked forms of organization give rise to an explosion of available information in C2 environments, it is critical to understand the impact of information volume upon human decision making, SA, and interpersonal trust. To this end, we designed two empirical studies that explored information volume in a decision-making task relevant to military C2. The first experiment investigated how varying the amount of task-relevant information influenced the time it took single participants to find and capture targets. The second experiment added the element of team dynamics; two interacting participants collaborated to complete a version of the same HVT task.

The general findings from these two studies indicate that increasing the amount of available task-relevant information is not necessarily beneficial to human decision-making performance,

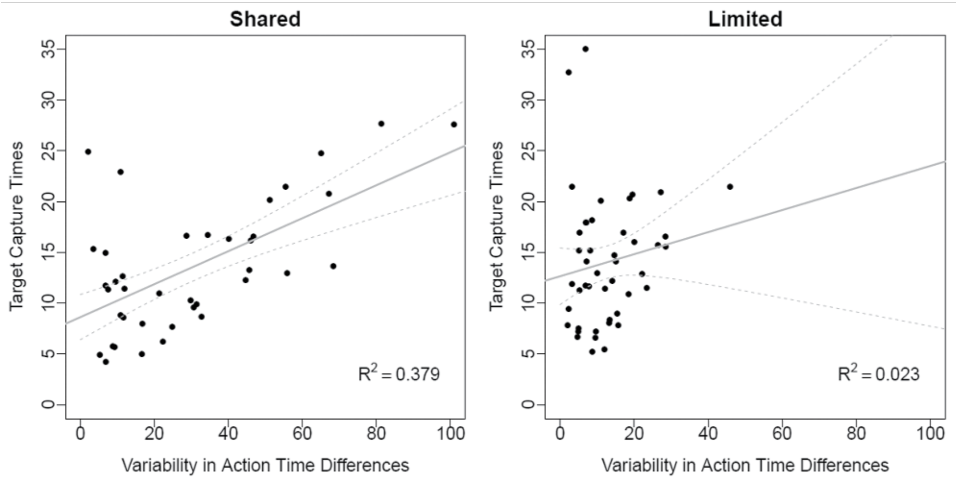

Figure 11. Scatterplot showing the relationship between differences in action times and task performance (target-capture times). There is a strong positive correlation in the shared conditions. Dashed lines indicate 95% confidence intervals.

in agreement with previous findings (e.g., Chewning & Harrell, 1990; Goldstein & Gigerenzer, 2002; Gonzalez, 2005a; Hall et al., 2007; Nadav-Greenberg & Joslyn, 2009; Saner et al., 2009). Furthermore, Experiment 2 provides evidence that access to increased information can reduce reported SA and trust in team members. These are important findings, particularly in the C2 domain, where decisions are made in time-pressured, safety-critical situations. In these environments, human decision makers may be easily overwhelmed with high information volume, even when that information is potentially useful.

The trade-off between experimental control and ecological validity entails both benefits and limitations for the experimental work reported here. One benefit is that stronger causal inferences can be made from experimental evidence than from observational data (e.g., Shadish, Cook, & Campbell, 2002). In addition, our experiments were designed to create ideal conditions for decision makers to improve their performance with increased information volume: Participants received training, clear task goals, and performance feedback; all information provided was task relevant; and working memory demand was minimized by displaying all information throughout the task. The implication is that increased information does not necessarily improve decision-making performance, even under ideal conditions. Ideal conditions in lab experiments provide a litmus test for strong causal inference (Mook, 1983).

The corresponding limitation to our design is that it excluded a multitude of real-world factors for the military and C2 domains, including fatigue, stress, time pressure, training, experience, skills, abilities, doctrine, availability and capabilities of technical systems (computers, software, networks, and communications equipment), resources, time of day, and stability of the operational environment, among many others (also see Bakdash, Pizzocaro, & Preece, 2013). The current work allowed us to isolate the effects of a small number of variables upon decision-making performance; however, it is important to note that these effects are likely to also interact with a number of the additional factors listed previously.

A popular applied perspective for C2 domains is that increased networking, and thus information sharing, leads to greater availability of information, resulting in improved decision quality and efficiency. The framework of Alberts and Garstka (2004) formalizes this perspective as the tenets of network-enabled operations. These tenets posit that robust networking and information sharing act as a positive feedback loop for raising mission effectiveness in military operations, although these claims are primarily based on observational, and not experimental, data (Bakdash, 2012; Wilson, 2007). From a policy viewpoint, enhancing information sharing within and across organizations has become a major priority and investment for the United States military (Alberts & Garstka, 2004) and other departments (Department of Homeland Security, 2013; Federal Aviation Administration, 2014). Our findings suggest that a general organizational policy or system for sharing all relevant information may not necessarily be beneficial for human decision makers. Even when presenting useful information, C2 system designers should be cognizant of human cognitive processing limits and capabilities.

APPENDIX

Round Questionnaire

Please answer the following questions about the mission you just completed. Your answers to these questions are important in helping us evaluate the effectiveness of this exercise. Check the response that best applies to your experience

Please enter your ID number:___________

The first four questions deal with your ability to detect and understand important cues present during the mission.

Please rate your ability to identify critical cues relevant to your task in this mission.

- ☐ very easy - able to identify all cues
- ☐ fairly easy - could identify most cues
- ☐ somewhat difficult - many cues hard to identify
- ☐ very difficult - had substantial problems identifying most cues

How well did you understand what was going on during the mission?

- ☐ very well - fully understood the situation as it unfolded
- ☐ fairly well - understood most aspects of the situation
- ☐ somewhat poorly - had difficulty understanding much of the situation
- ☐ very poorly - the situation did not make sense to me

How well could you predict what was about to occur next in the mission?

- ☐ very well - could predict with accuracy what was about to occur
- ☐ fairly well - could make accurate predictions most of the time
- ☐ somewhat poor - misunderstood the situation much of the time
- ☐ very poor - unable to predict what was about to occur

How aware were you of how to best achieve your goals during this mission?

- ☐ very aware - knew how to achieve goals at all times
- ☐ fairly aware - knew most of the time how to achieve mission goals
- ☐ somewhat unaware - was not aware of how to achieve some goals
- ☐ very unaware - generally unaware of how to achieve goals

The next four questions ask how difficult it was for you to detect and understand important cues present during the mission.

How difficult - in terms of mental effort required - was it for you to identify or detect critical cues relevant to your task in the mission?

- ☐ very easy - could identify relevant cues with little effort
- ☐ fairly easy - could identify relevant cues, but some effort required
- ☐ somewhat difficult - some effort was required to identify most cues
- ☐ very difficult - substantial effort required to identify relevant cues

How difficult - in terms of mental effort - was it to understand what was going on during the mission?

- ☐ very easy - understood what was going on with little effort
- ☐ fairly easy - understood events with only moderate effort

- ☐ somewhat difficult - hard to comprehend some aspects of situation
- ☐ very difficult - hard to understand most or all aspects of situation

How difficult - in terms of mental effort - was it to predict what was about to happen during the mission?

- ☐ very easy - little or no effort needed
- ☐ fairly easy - moderate effort required
- ☐ somewhat difficult - many projections required substantial effort
- ☐ very difficult - substantial effort required on most or all projections

How difficult - in terms of mental effort - was it to decide on how to best achieve your goals during this mission?

- ☐ very easy - little or no effort needed
- ☐ fairly easy - moderate effort required
- ☐ somewhat difficult - substantial effort needed on some decisions
- ☐ very difficult - most or all decisions required substantial effort

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The next three questions ask about your teammate in the mission.

How aware were you of your teammate's activities during this mission?

- ☐ very aware - knew teammate's activities at all times
- ☐ fairly aware - knew teammate's activities some of the time
- ☐ somewhat unaware - was not aware of some of the teammate's activities
- ☐ very unaware - generally unaware of teammate's activities

How difficult - in terms of mental effort - was it to share decision making responsibilities with your teammate during this mission?

- ☐ very easy - could share decision making with little effort
- ☐ fairly easy - could share decision making, but with moderate effort
- ☐ somewhat difficult - effort was required to share decision making
- ☐ very difficult - sharing decision making required substantial effort

How difficult - in terms of mental effort - was it to effectively communicate with your teammate while completing the tasks in this mission?

- ☐ very easy - could effectively communicate with little effort
- ☐ fairly easy - could effectively communicate, but with moderate effort
- ☐ somewhat difficult - effort was required to effectively communicate
- ☐ very difficult - effectively communicating required substantial effort

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The next three questions ask how much you trust the other player and information sources present during the mission.

How much did you trust the other player?

- ☐ Completely
- ☐ Moderately
- ☐ A little
- ☐ Not at all

How much did you trust Source A?

- ☐ Completely
- ☐ Moderately
- ☐ A little
- ☐ Not at all

How much did you trust Source B?

- ☐ Completely
- ☐ Moderately
- ☐ A little
- ☐ Not at all

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KEY POINTS

- As command-and-control (C2) organizations and other entities transition to network-enabled operations, the amount of information available to the individual decision maker grows rapidly; it is critical to understand how information volume affects decision making in these environments.
- In a simulated C2 task, neither individual nor pair decision-making performance improved with increasing task-relevant information.
- Increased information led to lower situation awareness and lower partner trust within pairs.
- Receiving incorrect information about the reliability of information sources led to poorer decision-making performance, lower situation awareness, and marginally lower partner trust within pairs.

REFERENCES

Alberts, D., & Garstka, J. (2004). *Network centric operations conceptual framework version 2.0* (Tech. rep.). Washington, DC: U.S. Office of Force Transformation and Office of the Assistant Secretary of Defense for Networks and Information Integration, U.S. Department of Defense.

Anderson, J. R., Reder, L. M., & Lebiere, C. (1996). Working memory: Activation limitations on retrieval. *Cognitive Psychology*, *30*, 221–256.

Baddeley, A. (1992). Working memory. *Science*, *255*, 556–559.

Bakdash, J. Z. (2012). The human dimension of network enabled operations: Cognitive performance in mission command. In *Proceedings of the Annual Conference of the International Technology Alliance*. Retrieved from https://www.usukita.org/sites/default/files/P4_jbakdash_human_dimension_cognitive_performance.pdf

Bakdash, J. Z., Pizzocaro, D., & Preece, A. (2013). Human factors in intelligence, surveillance, and reconnaissance: Gaps for soldiers and technology recommendations. In *Military Communications Conference, MILCOM 2013* (pp. 1900–1905). Retrieved from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA608006

Bateman, R. L., III. (1998). Avoiding information overload. *Military Review*, *78*, 53.

Bowman, E. K., & Thomas, J. A. (2008, June). *C2 of unmanned systems in distributed ISR operations*. Paper presented at the 13th International Command and Control Research and Technology Symposium (ICCRTS), Seattle, WA.

Chewning, E. G., & Harrell, A. M. (1990). The effect of information load on decision makers' cue utilization levels and decision quality in a financial distress decision task. *Accounting, Organizations and Society*, *15*, 527–542.

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. (1993). Shared mental models in expert decision making teams. In N. J. Castellan Jr. (Ed.), *Current issues in individual and group decision making* (pp. 221–246). Hillsdale, NJ: Lawrence Erlbaum.

Castells, M. (1996). *The information age: Economy, society and culture. Vol. 1: The rise of the network society*. Oxford, UK: Blackwell.

Curts, R. J., & Campbell, D. E. (2001). *Avoiding information overload through the understanding of OODA loops, a cognitive hierarchy and object-oriented analysis and design*. Annapolis, MD: C4ISR Cooperative Research Program.

Department of Defense. (2008). *MIL-STD-2525C: Common warfighting symbology. U.S. Department of Defense interface standard*. Washington, DC: Author.

Department of Homeland Security. (2013). *DHS information sharing and safeguarding strategy*. Retrieved from http://www.dhs.gov/sites/default/files/publications/12-4466-dhs-information-sharing-and-safeguarding-strategy-01-30-13–fina%20%20%20.pdf

Eagen, M. M. (1998). *Advanced C4I and operational decision making: Panacea or Pandora's box?* Newport, RI: Naval War College, Joint Military Operations Department.

Eid, J., Meland, N. T., Matthews, M. D., & Johnsen, B. H. (2005). Dispositional optimism and self-assessed situation awareness in a Norwegian military training exercise 1. *Perceptual and Motor Skills*, *100*, 649–658.

Endsley, M. R. (1988). Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors and Ergonomics Society 32nd Annual Meeting* (pp. 97–101). Santa Monica, CA: Human Factors and Ergonomics Society.

Endsley, M.R. (1995a). Measurement of situation awareness in dynamic systems. *Human Factors*, *37*, 65–84.

Endsley, M. R. (1995b). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*, 32–64.

Endsley, M. R., & Garland, D. J. (2000). *Situation awareness analysis and measurement*. Mahwah, NJ: Lawrence Erlbaum.

Entin, E. E., & Serfaty, D. (1990). *Information gathering and decisionmaking under stress* (No. TR-454). Burlington, MA: Alphatech.

Federal Aviation Administration. (2014). *NextGen implementation plan*. Washington, DC: Author.

Freeman, J. T., Cohen, M. S., & Serfaty, D. (1997, June). *Information overload in the digital army: Simulator-based training for prevention, detection and cure*. Paper presented at the 1997 Command and Control Research and Technology Symposium, Washington, DC.

Geisler, W. S. (2006). Ideal observer analysis. In L. Chalupa & J. Werne (Eds.), *The visual neuroscience* (pp. 825–837). Cambridge, MA: MIT Press.

Gigerenzer, G., & Selten, R. (2002). *Bounded rationality: The adaptive toolbox*. Cambridge, MA: MIT Press.

Gleick, J. (2011). *The information: A history, a theory, a flood*. New York, NY: Random House.

Goldstein, D. G., & Gigerenzer, G. (2002). Models of ecological rationality: The recognition heuristic. *Psychological Review*, *109*, 75–90.

Gonzalez, C. (2004). Learning to make decisions in dynamic environments: Effects of time constraints and cognitive abilities. *Human Factors*, *46*, 449–460.

Gonzalez, C. (2005a). Decision support for real-time dynamic decision making tasks. *Organizational Behavior and Human Decision Processes*, *96*, 142–154.

Gonzalez, C. (2005b). The relationship between task workload and cognitive abilities in dynamic decision making. *Human Factors*, *47*, 92–101.

Gorman, J. C., Cooke, N. J., & Winner, J. L. (2006). Measuring team situation awareness in decentralized command and control environments. *Ergonomics*, *49*, 1312–1325.

Hall, C. C., Ariss, L., & Todorov, A. (2007). The illusion of knowledge: When more information reduces accuracy and increases confidence. *Organizational Behavior and Human Decision Processes*, *103*, 277–290.

Hall, D. S., Shattuck, L. G., & Bennett, K. B. (2012). Evaluation of an ecological interface design for military command and control. *Journal of Cognitive Engineering and Decision Making*, *6*, 165–193.

Kahneman, D. (2011). *Thinking, fast and slow*. New York, NY: Macmillan.

Lafond, D., Jobidon, M. E., Aubé, C., & Tremblay, S. (2011). Evidence of structure-specific teamwork requirements and implications for team design. *Small Group Research*, *42*, 507–535.

Martin, J. M., Gonzalez, C., Juvina, I., & Lebiere, C. (2014). A description-experience gap in social interactions: Information about interdependence and its effects on cooperation. *Journal of Behavioral Decision Making*, *27*, 349–362.

Matthews, M. D., Beal, S. A., & Pleban, R. J. (2002). *Situation awareness in a virtual environment: Description of a subjective assessment scale*. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Mayer, R. C., Davis, J. H., & Schoorman, F. D. (1995). An integrative model of organizational trust. *Academy of Management Review*, *20*, 709–734.

McGuinness, B., & Foy, L. (2000). A subjective measure of SA: The Crew Awareness Rating Scale (CARS). In D. B. Kaber & M. R. Endsley (Eds.), *Human performance, situation awareness and automation: User centered design for the new millennium*. Atlanta, GA: SA Technologies.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 81–97.

Mook, D. G. (1983). In defense of external invalidity. *American Psychologist*, *38*, 379–387.

Nadav-Greenberg, L., & Joslyn, S. L. (2009). Uncertainty forecasts improve decision making among nonexperts. *Journal of Cognitive Engineering and Decision Making*, *3*, 209–227.

Norman, D. (1988). *The design of everyday things*. New York, NY: Basic Books.

Rovira, E., McGarry, K., & Parasuraman, R. (2007). Effects of imperfect automation on decision making in a simulated command and control task. *Human Factors*, *49*, 76–87.

Saner, L. D., Bolstad, C. A., Gonzalez, C., & Cuevas, H. M. (2009). Measuring and predicting shared situation awareness in teams. *Journal of Cognitive Engineering and Decision Making*, *3*, 280–308.

Serfaty, D., Entin, E. E., & Johnston, J. H. (1998). Team coordination training. In J. A. Cannon-Bowers & E. Salas (Eds.), *Making decisions under stress: Implications for training and simulation* (pp. 221–245). Washington, DC: American Psychological Association.

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for general causal inference*. Boston, MA: Houghton Mifflin.

Simon, H. A. (1972). Theories of bounded rationality. *Decision and Organization*, *1*(1), 161–176.

Strater, L. D., & Bolstad, C. A. (2008). Simulation-based Situation Awareness Training. In D. A. Vincenzi, J. A. Wise, M. Mouloua, & P. A. Hancock (Eds.), *Human factors in simulation and training* (pp. 129–148). New York, NY: Lawrence Erlbaum.

Strater, L. D., Endsley, M. R., Pleban, R. J., & Matthews, M. D. (2001). *Measures of platoon leader situation awareness in virtual decision-making exercises*. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Strater, L. D., Reynolds, J. P., Faulkner, L. A., Birch, D. K., Hyatt, J., Swetnam, S., & Endsley, M. R. (2004). PC-based tools to improve infantry situation awareness. In *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting* (pp. 668–672). Santa Monica, CA: Human Factors and Ergonomics Society.

Wilson, C. (2007). *Network centric operations: Background and oversight issues for congress*. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA466624

Woods, D. D., Patterson, E. S., & Roth, E. M. (2002). Can we ever escape from data overload? A cognitive systems diagnosis. *Cognition, Technology & Work*, *4*, 22–36.

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