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Track 8: C^2 Architectures

Track 1: C^2 Concepts, Theory, and Policy

Track 7: Network-Centric Experimentation and Applications

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Abstract

The U.S. Navy is developing new maritime strategies and command structures to guide transformation efforts, to ensure the security of the global maritime commons in the new network-centric era, and to fit the challenges of the 21st century. The addition of an intelligence, surveillance, and reconnaissance (ISR) commander is one such innovative structural innovation that is under consideration. To empirically investigate different conceptualizations of ISR officers, we contrasted an ISR officer who coordinated--but did not own—ISR assets with an officer that coordinated—and owned—all ISR assets under low and high intensity mission conditions. Four teams comprised of three active duty officers were assigned to coordination or command ISR conditions and participated in two 90 minute experimental sessions using the Distributed Dynamic Decision-making simulator. The findings show that when task intensity was high the percentage of tasks correctly processed was higher when the ISR officer was a commander than a coordinator. We also found attack accuracy to be higher and action latency lower when mission intensity was high and the ISR officer was a commander. Implications for command and control organizations are discussed.

Introduction

Organizational design and related strategies are undergoing dramatic changes in form and function within the U.S. military. The creation of Expeditionary Strike Groups (ESGs) is one example of the transformational vision provided in the Naval Operating Concept (2002) where Strike Groups offer the potential to revolutionize naval warfare in the littoral region. The ESG provides a flexible force package, capable of tailoring itself to accomplish a wide variety of missions.

ESGs present a new way of organizing Navy and Marine Corps assets and personnel to accomplish a broad range of missions. A joint Navy and Marine Corps Naval Operating Concept (2003) describes a transformational vision for the future employment of U.S. Naval forces, which includes the development of ESG, Carrier Strike Group (CSG), and Expeditionary Strike Force (ESF) organizational constructs (Callahan, 2005). Operational deployment of these newly formed units began in 2003. This realignment of naval assets under the Strike Group concept provides the Amphibious Squadron/Marine Expeditionary Unit (PHIBRON/MEU) with significantly more offensive and defensive capability. ESGs have recently undergone proof of concept testing in which they were deployed under different command arrangements to test and validate various command and control (C^2) constructs for organization.

We are particularly interested in investigating how ESGs with alternative structures and processes are able to perform their mission tasks. For this effort we focus on the incorporation of an intelligence, surveillance, and reconnaissance (ISR) officer and how the definition of that position can impact performance and information flow in an information rich planning and execution environment. Specifically, the issues we investigated involved the C^2 responsibilities of the ISR officer in terms of resource allocation, coordination efficiency, and performance/execution of the mission. Observations and analyses reported by Weil et al. (2006) underscore the Navy's interest in the role of an ISR officer and the effect such a position would have on the ESG's performance effectiveness. Based on these observations it seems that the inclusion of an ISR officer would be beneficial to an ESG as such an organization strives to perform the myriad of tasks comprising its mission. The question is how the ISR position should be defined and empowered.

A study reported by Baker et al. (2004) manipulated the presence and absence of an ISR coordinator with two other independent variables, information load (low, high) and time. The ISR coordinator was conceptualized as a new command position that would coordinate all theater sensors and maintain situational awareness for the organization. The researchers, drawing on modeling results that indicated a 25% increase in mission performance when an ISR coordinator was present (Serfaty et al., 2002), hypothesized that an organizational structure that included an ISR coordinator would perform at a higher level—particularly when information load was high—than an organizational structure that did not include an ISR coordinator. Results did not appear to support this hypothesis. Despite the lack of performance results, however, during periods of high information load, teams with an ISR coordinator processed more critical email/intelligence messages and demonstrated a better understanding of message criticality. This indicates superior situational awareness. Results also revealed that teams with an ISR coordinator exhibited a steeper improvement in performance over time compared to teams without an ISR coordinator. By the end of the study, teams with an ISR coordinator caught up to the performance of the teams without an ISR coordinator in both low and high information load conditions. This led the researchers to speculate that the presence of an ISR coordinator may facilitate performance improvements and with more experience and practice teams with an ISR coordinator would surpass the performance of the teams without an ISR coordinator.

The Baker et al. (2004) study provides some support for the inclusion of an ISR officer as part of the Navy's Composite Warfare Commander (CWC) organization. Although Baker et al. refer to the ISR officer in their study as a coordinator, in fact the ISR officer was defined and empowered as a commander and owned the primary theater ISR assets. Alternatively, the ISR officer could be defined as a true coordinator and empowered to facilitate information gathering and flow within the ESG organization without actually owning the ISR assets. The use of coordinators within naval organizations or command and control in general is not without precedence (see Naval Doctrine Publication 1, 1994; Allard, 1996). Generally speaking coordinators are seen as facilitators that can increase the efficiency and effectiveness of an organization by specializing in some specific area or across specified areas and maintaining high situational awareness.

This paper focuses on empirically investigating the differences between an ISR coordinator's and an ISR commander's impact on the efficiency and effectiveness of a command and control organization. Based on the effectiveness of commanders within the CWC doctrine, we hypothesize that an ISR commander will be generally more effective in fostering efficiency and effectiveness within a command and control organization than an ISR coordinator. From another aspect of the Baker et al. (2004) study we also hypothesize that the ISR commander will be particularly superior in performance to the ISR coordinator when workload in terms of mission tasks is higher than lower.

Method

Participants

The 14 participants for this experiment were active duty military officers drawn from classes at the Naval Postgraduate School, Monterey, CA. Although the Naval Postgraduate School draws from all services, the participants in this study were predominately naval officers and ranged in rank from 01 to 03. The participants were organized into four teams of 3-persons and one team of 2-persons.

Independent Variables and Experimental Design

The primary experimental condition was the responsibilities and authority of ISR position at two levels and a control condition. The *self-synchronized* condition (Level 1), conducted only as a control, had no single person responsible for coordination of ISR assets—the responsibility for ISR coordination was diffused over two participants. At Level 2 an *ISR Coordinator* was responsible for pushing/pulling information among the participants and for coordinating use of ISR assets based on the Commander's Intent. Level 3 involved an *ISR Commander*, who had the same responsibilities as the ISR Coordinator plus "owned" all the unmanned air vehicles (UAVs; a primary theater ISR asset). This independent variable was manipulated as between-subjects. One team of two participants was assigned to the self-synchronized condition as a control—the two participants decided amongst themselves how best to employ the scarce ISR resources. Two teams were allocated to the ISR Coordinator condition and the participant designated as the ISR coordinator managed asset usage by managing the information flow between all players but did not own/control ISR assets. Lastly, two teams were assigned to the ISR commander condition and the participant designated as the ISR commander in addition to managing the flow of information and directing use of ISR assets, owned the primary ISR assets that were allocate on a case by case basis. For a more detailed discussion of this independent variable, as well as other method-related topics, we recommend the reader see Hutchins et al. (2007).

The second independent variable was mission or task intensity manipulated over two levels: low and high. Drawing on Baker et al. (2004) and Entin, Entin, & Hess (2000) two scenario intensity conditions were derived manipulating mission workload in terms of tasks per unit time. The high intensity task condition presented 50% more tasks to be completed than the low intensity condition. Due to scheduling and resource constraints it was not possible to counter-balance the two task intensity conditions. Thus, all teams experienced the low intensity condition followed by the high intensity condition as a within-subjects variable.

The three levels of the between-subjects ISR type independent variable were crossed with the two levels of task intensity to produce a mixed-design of six experimental conditions illustrated in Table 1.

Table 1: Number of Groups in Each Experimental Condition

		Workload (Within-Subjects)	
		Low Intensity	*High Intensity*
ISR Position (Between-Subjects)	*Self-Synchronized*	1	1
	ISR Coordinator	2	2
	ISR Commander	2	2

Dependent Variables

Three types of dependent variables were derived from the simulation environment. All of the dependent variables related to tasks completed by the mission teams. Tasks varied on the number of information attributes required to be discovered before action could be taken. For example, a fishing boat could have a hostility attribute (e.g., hostile/not hostile) and a weapons attribute (e.g., weapons/no weapons). Participants could discover attribute values by employing ISR assets. About a third of the tasks required no attributes to be measured, another third required one attribute to be measured, and the last third required two attributes to be measured. Once the attribute values were determined, participants had to make a decision regarding processing of that task. Some attribute combinations required further processing (e.g., if a fishing boat is hostile and has weapons, a "Vessel Board, Search, & Seizure" was to be performed), while other attribute combinations required no further action (e.g., if a fishing boat was not hostile and had no weapons). Participants were given clear instructions regarding the proper action to take given different attribute value combinations. Given these constraints, three dependent measures were examined.

1. The percentage of tasks a team correctly attacked (that is, tasks in which the team took action only when task attributes warranted action). Two types of errors eroded the percentage of tasks correctly attacked, (1) failure to attack a task in which attribute values required an attack and (2) attacking a task that did not have the attribute values to require an attack.
2. The percentage of tasks that were attacked with correct resources (attack accuracy – bringing the correct type of resources to bear).
3. The latency, or reaction time in seconds, related to four activities. *Detection latency* measured the length of time between the instant a task appeared on the simulation screen and the time it was detected by the participants. *First measurement latency* assessed the length of time from task detection until the first

attribute measurement. *Second measurement latency* calculated the time between the first measurement and the second measurement, if the task required a second measurement. The final latency variable referred to as *attack latency* measured the length of time from the last attribute measurement until the task was attacked.

Scenario

The scenario illustrated a humanitarian effort and included tasks indicative of the ESG mission set. Teams working in the Dynamic Distributed Decision-making (DDD; Kleinman and Serfaty, 1989) simulation environment were required to perform a variety of mission tasks. These tasks included surveillance of fishing boats and fishing villages for refugees, terrorists, and/or weapons. Tasks also included vessel boarding, aiding refugees, or performing rescues. The scenario was designed to create tension over the use of ISR assets because of limited supply, time pressure, or task difficulty. Conflicts over the use of ISR assets forced choices to be made regarding allocation of resources. This, in turn, encouraged communication among participants and motivated the need for adjudication by the ISR officer.

The scenario narrative began with a description of a situation in which a tsunami had negatively affected life in a region that included both countries friendly and unfriendly to the United States. The participants were instructed to provide security, logistical support, humanitarian aid, and security to in-land refugees, littoral force protection, and open sea anti-piracy operations. These tasks required teams to constantly monitor fishing villages and small boats with ISR assets and to quickly react to unexpected events.

Procedure

All teams participated in two training periods. The first lasted for two hours and the second for an hour and a half. During training, participants received instruction on how to use the DDD simulation and how to function as a team performing mission tasks.

Prior to the training all participants were given a “read ahead” packaged that described the background leading up to the current humanitarian mission, the assets that Blue forces possessed, the commander’s intent, the rules of engagement, and intelligence describing more of the current picture. Following training, each team received a short brief about the mission, was afforded some time to plan, and then completed the first of two 90 minute data collection sessions.

Results

The means for the percentage of tasks correctly attacked are depicted in Figure 1. There was no main effect for experimental condition, but the significant main effect for task intensity revealed that all conditions attained a higher percentage of correct attacks in the low (mean = 91.61%) verses the high (mean = 89.22%) intensity treatment, $F(1, 2) = 153.69$, $p < .007$. As expected, the higher task intensity imposed a higher workload that eroded performance. The ANOVA also revealed a significant interaction between experimental condition and task intensity, $F(2, 2) = 22.58$, $p < .05$. As we can see from Figure 1, the self-synchronized control performed about the same as the ISR coordinator condition, thus in keeping with the primary thrust of this research we performed an *a priori* planned comparison that focused on the differences between the ISR coordinator and ISR commander conditions. We performed a second ANOVA, similar to a simple effects analysis, omitting the self-synchronized condition. The implication of the self-synchronized control condition's outcome and its relationship to the other experimental levels is addressed in the Discussion Section below. This second analysis showed that while the performance of the two ISR conditions was about the same when task intensity was low, the ISR commander achieved a higher percentage of correct attacks than the ISR coordinator condition when task intensity was high, $F(1, 2) = 13.88$, $p < .07$. Having ownership of a key ISR resource appears to facilitate higher performance.

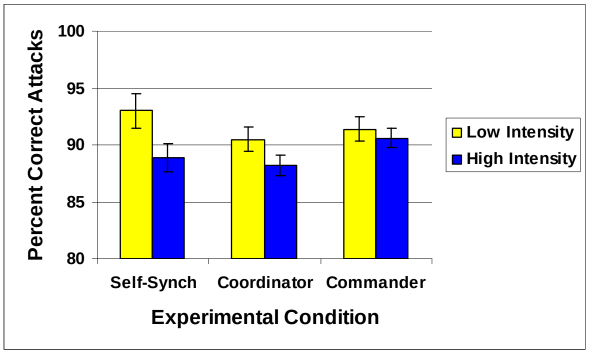

Figure 1. Percentage of Tasks Correctly Processed (Correctly Attacked) by Experimental Condition and Task Intensity

Percent attack accuracy is the next dependent measure analyzed and the means for this analysis are shown in Figure 2. For this analysis the factors were experimental condition, task intensity, and task attributes with the latter two factors analyzed as within-subjects variables. A significant three-way interaction was revealed by the ANOVA, $F(4, 2) = 209.14$, $p < .01$. Inspection of the means showed that the self-synchronized control condition means were again similar to one of the ISR condition, thus we computed an *a priori* planned comparison in the form of an ANOVA omitting the self-synchronized condition to sharpen the focus on the two ISR conditions. Once again the three-way interaction proved significant, $F(2, 2) = 165.29$, $p < .01$. From Figure 2 we see that the patterns of results for the zero-attribute and one-attribute tasks are quite similar and different from the results for the two-attribute tasks. For the zero-attribute and one-attribute tasks both ISR conditions have higher percent attack accuracy in the high than low task intensity treatment, whereas, for two-attribute tasks the ISR coordinator attained higher percent attack accuracy in the low intensity treatment and ISR commander achieve perfect attack accuracy in both task intensity treatments. Once again there appears to be an advantage to owning a key ISR asset when it comes to performing tasks.

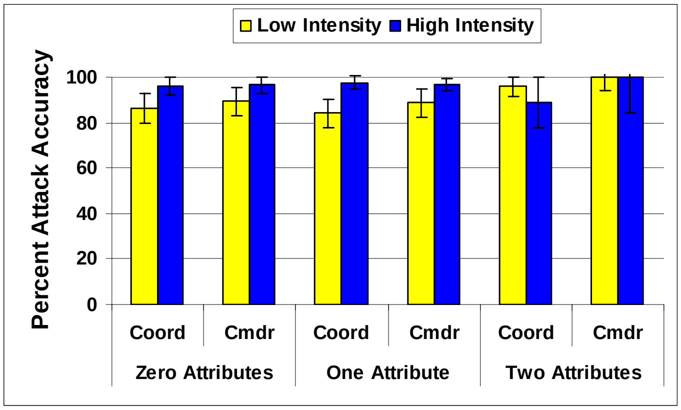

Figure 2. Percent Attack Accuracy by Experimental Condition and Task Intensity for Zero, One, and Two Attribute Tasks

Analyses of the four latency variables for tasks with either zero attributes to measure or one attribute revealed no reliable differences. Thus, only tasks requiring two attributes to be measured are discussed. The means for detection latency can be found in Figure 3. A main effect for intensity indicates that latency was shorter when task intensity was high rather than low, $F(1, 2) = 343.43$, $p < .005$, most likely due to the higher density of tasks in the high intensity treatment. The interaction between experimental condition and intensity was also significant, $F(2, 2) = 64.55$, $p < .02$. To focus specifically on the two ISR officer types, an *a priori* planned comparison ANOVA was computed with the self-synchronized experimental condition omitted. The interaction still proved to be significant, $F(1, 2) = 96.62$, $p < .02$. Perusing the means in Figure 3, we can see that the ISR coordinator was almost four times faster detecting the task than the ISR commander when task intensity was low, but only 1.6 times faster when task intensity was high. When it comes to detecting tasks owning the UAVs does not appear to be an advantage.

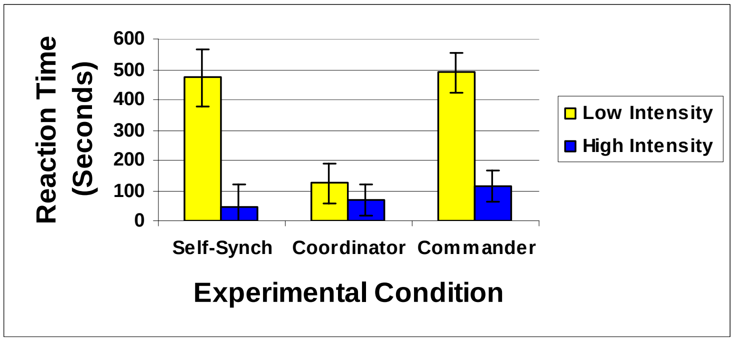

Figure 3. Detection Latency as a Function of Experimental Condition and Task Intensity for Tasks Requiring Two Attribute Assessments

The means for first measurement latency in Figure 4 show that reaction time still tends to be shorter when task intensity is high than low, $F(1, 2) = 15.51$, $p < .06$. There is no significant interaction or a significant main effect for experimental condition—the latencies for the two types of ISR officers are not reliably different when it comes to make the first attribute measurement after the task has been detected.

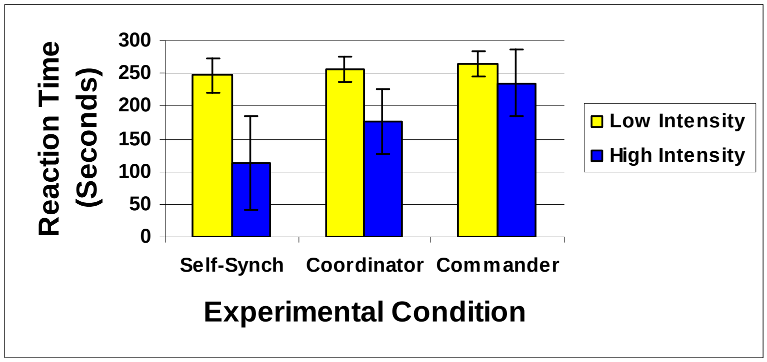

Figure 4. First Measurement Latency as a Function of Experimental Condition and Task Intensity for Tasks Requiring Two Attribute Assessments

The means for the second measurement latency can be found in Figure 5. The interaction between experimental condition and intensity is significant, $F(2, 2) = 19.99$, $p < .05$. As before we computed an *a priori* planned comparison dropping the self-synchronized condition to allow us to concentrate on the two ISR conditions. The recomputed ANOVA reveals a main effect for intensity, $F(1, 2) = 20.47$, $p < .05$ indicating high intensity (mean = 369 sec.) produced longer latencies than low intensity (mean = 190 sec.). The mean latency for the ISR commander condition (mean = 191 sec.) was significantly shorter than the latency for the ISR coordinator condition (mean = 369 sec.), $F(1, 2) = 93.49$, $p < .02$. Most telling, however, was the significant interaction, $F(1, 2) = 34.14$, $p < .03$ (Figure 5). The ISR coordinator produced exceptionally longer latencies than the ISR commander when task intensity was high. When task intensity was low the latencies of the two ISR conditions was about the same. Not having control over critical ISR resources when task intensity is high and the tasks to be dealt with require two assessments appears to take a toll in reaction time.

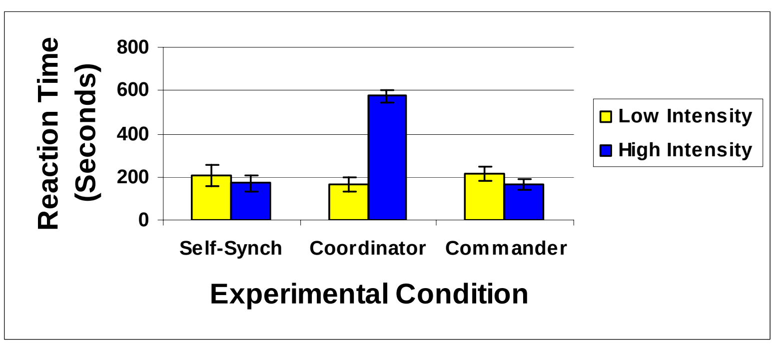

Figure 5. Second Measurement Latency as a Function of Experimental Condition and Task Intensity for Tasks Requiring Two Attribute Assessments

Inspection of the means for attack latency, calculated as the time between the last attribute measure and the attack, showed no significant main effects or interactions. One final overall analysis looking collectively across the four latency variables revealed that the ISR commander tended to have a shorter reaction time than the ISR coordinator when latencies were averaged over the two task intensities, $F(1, 2) = 14.12$, $p < .065$. These means can be seen in Figure 6.

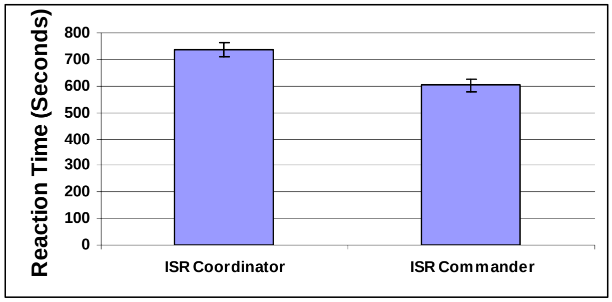

Figure 6. Overall Reaction Time for the ISR Coordinator and Commander Conditions across the Three Latency Variables and Task Intensity

Discussion

The inclusion of an ISR officer in the ESG organization—in one fashion or another—is currently being considered by the Navy. Observations from ESG-1 missions, modeling results (see e.g., Serfaty et al., 2002), and the promise that the ISR picture will only get more complex (Callahan, 2005) have all but convinced the Navy that ISR management cannot be left in its current state. The issues on which this study focused were the definition and authority of that ISR position. We addressed these by contrasting two ISR officer positions, the first a coordinator who facilitated information flow within the organization, but did not own any ISR assets and the second a commander who facilitated information flow and also owned critical theater ISR assets. Based on previous literature and observations made within an ESG organization, we hypothesized that the ISR commander would foster more efficient and effective performance than the ISR coordinator doing ESG-like mission tasks. The results from this study lend support to this hypothesis. We also argued that the ISR commander condition would be superior to the ISR coordinator condition particularly when task intensity, in terms of the number of tasks to be done, was high. There was support for this hypothesis as well.

The function of the self-synchronized control was to serve as a benchmark, a way to observe whether the outcomes of the two ISR conditions were within realistic bounds. We therefore expected that the self-synchronized control outcomes would be similar to one or the other ISR conditions, which they were, but never significantly different from both of them. This was substantiated; the self-synchronized control was never significantly different from both ISR conditions. Moreover, in concert with the Navy's interests, the design and scenario of this study were optimized to reveal differences between the ISR coordinator and ISR commander conditions. As such we never intended to contrast the self-synchronized control with either of the two ISR conditions. With adjustments in the design and scenario, a self-synchronized condition could be contrasted with the two ISR conditions.

Examining the results for the percentage of tasks attacked correctly, we observed that it was when intensity was high that the ISR commander condition was superior to the ISR coordinator condition. When intensity was low the performance of the two ISR conditions was not different. The results also showed that, in general, the higher workload conditions of the high intensity treatment are detrimental to performance. So it is particularly significant that ISR commanders performed better than the ISR coordinators in the high intensity condition. We suspect that owning an important ISR theater asset enabled the ISR commanders to obtain information needed to decide if and how to process a task. This is a key finding because it implies that owning the ISR assets needed to perform a mission task reduces coordination overhead, thus allowing more attention to be allocated to do the task correctly. These results dovetail nicely with the attention allocation literature (see Wickens, 1996).

Results from the analysis of percent attack accuracy also lends support to the hypothesis that ISR commanders' performance will be better than ISR coordinators' under higher workload conditions. In fact, the ISR commanders' performances proved to be perfect for the high task intensity treatments and when tasks required two attribute assessments. When the tasks required zero or one attributes to be assessed, the ISR commanders did well: better in the high than low task intensity treatments, but not better than the ISR coordinators. The real advantage of controlling one's own ISR assets appears to come when many tasks have to be attended to and multiple attributes must be assessed to learn how a task is to be attacked. Controlling at least one of the needed ISR assets lowers the coordination overhead. A lower coordination overhead probably does not matter much when workload and task demands are manageable. But when workload or task demands or both are high, a lowered coordination overhead could be the difference between having sufficient attention resources to allocate to correct task execution and not having sufficient attention resources and poor task execution.

Examining the latency results we see that although ISR commanders tended to have shorter latencies overall, this was not true for certain latency conditions. ISR coordinators exhibited faster reaction times for detection and for performing the first measurement. Owning/controlling one's own ISR assets does not appear to speed up reaction time when detecting a task or assessing the first attribute of a task. These finding make sense and fit with our argument of coordination overhead - there is not much coordination overhead to manage when detecting or making a single attribute assessment. Adding two attribute assessments, each perhaps requiring a different ISR asset, plus high workload and the advantage to the lower coordination overhead afforded the ISR commander becomes apparent in reaction time.

Our study contrasted an ISR coordinator conceptualized as one who facilitates information flow, but does not own/control ISR assets, to an ISR commander operationally defined as one who facilities information flow and owns/controls an important ISR theater asset. The findings show that when workload and task demands are high the ISR commander performs at a higher level and exhibits shorter latencies than the ISR coordinator. We offer lower coordination overhead for the ISR commander as an explanatory mechanism. There are, however, some caveats and cautions that accompany our results. Although we used active duty officers in our study to increase operational relevance, our results rest upon a small number of teams. We also acknowledge that in addition to replication with more teams, we need to more richly define the position of our ISR officers and provide more operationally complex mission tasks to produce more robust findings. Thus, as usual, we call for more systematic observations under controlled experimental conditions.

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