Distributed Mission Environments: Effects of Geographic Distribution on Team Cognition, Process, and Performance

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In this chapter we empirically examine the effects of geographic distribution on team performance, process, and cognition in a command-and-control setting. The particular command-and-control setting in which our investigation takes place is that of UAV (Unmanned Aerial Vehicle) ground control. Teams in this setting are heterogeneous with respect to their knowledge, skills, and abilities; the task is highly complex and dynamic; and interactions are synchronous. These factors make this setting different from many of the scenarios typically tested by social and organizational psychologists who use homogeneous groups and relatively simple tasks (e.g., Hinsz, 1999) and lend ecological validity in terms of the characteristics of distributed team task performance.

Highly complex tasks often involve a unique division of labor, often covering a global terrain of operations coordinated by specialized team members distributed across the landscape. Distributed teams pervade the military. Although individuals may be distributed in space, distributed teams can make decisions, communicate, and share information over an interconnected network. Warfare in this environment has been termed "network centric", such that the battlefield is not only geographically dispersed over terrain, but is also dispersed over the internet, or some other communication network, as well as individual team member competencies (cf. "heterogeneous" teams). Thus in the military, team tasks are performed by individuals who may have never met, who are not sitting in the same room, who may only share information by computer or other media, such as radios or telephones, and who may come from rather distinct backgrounds in terms of training or knowledge. In addition these arrangements apply not only to teams of individuals, but to teams of teams as well (i.e., hierarchical layers of teams) in which the task is shared by an intricate *distributed* network of collaborating individuals who are required to coordinate voluminous amounts of information.

However heterogeneous groups interacting in a distributed manner to perform complex tasks are not unique to the military. This type of team task is increasingly common in venues ranging from business meetings and emergency operations, to remote telemedicine and collaboratories in distance education. The degree to which geographically distributed, as opposed to co-located work environments impact team performance and cognition in these settings has critical implications for training and design in support of distributed work. Another characteristic that these complex distributed tasks have in common is that most, if not all, of the work entails cognitive, rather than physical, activity. The performance of cognitive activities at the team or group level gives rise to the concept of *team cognition* (Cooke, Salas, Cannon-Bowers, & Stout, 2000; Salas & Fiore, 2004).

What is Team Cognition?

Teams think, make decisions, assess situations, remember, plan, and solve problems as an integrated unit. These cognitive activities are increasingly prevalent in team tasks in general and dominate activities in distributed mission environments. We assume that team cognition provides the psychological basis for team performance and therefore is a prime target for training or design interventions to improve team performance. Similarly, we assume that factors such as geographic distribution can have profound effects on team cognition.

Traditional views of team cognition are *collective* in that they assume that team cognition is a linear, or additive, byproduct of the knowledge residing in each team member's head (cf. Steiner, 1972). In some sense, the collective model predicts that team member cognition is less than or equal to the sum of its parts, in this case, individual team member knowledge. This view is represented in Panel A of Figure 1. Measures of team cognition (e.g., shared mental models) based on aggregating individual cognitive measures across team members reflect the collective view (e.g., Langan-Fox, Code, & Langfield-Smith, 2000).

There are two main limitations to the collective view and measures derived from it. First aggregation and its associated constructs and metrics (e.g., shared mental models) assume homogeneous cognition (i.e., identical or at least similar parts), a view that does not strictly apply to heterogeneous teams (Cooke & Gorman, in press). For example, the assumption that we can compare the (task) effective knowledge of a surgeon to the knowledge of an anesthesiologist, or somehow sum the two together in order to estimate the knowledge of the two in coordination is a collective assumption. Second, collective views and metrics omit, or at least oversimplify, the processing component of team cognition and therefore do not accurately reflect team cognition (Cooke, et al., 2000). Thus a linear, or additive factors approach to understanding team cognition belies the intrinsic importance of team member interactions to team cognition; such that the team's parts as well as their interactions are important in generating an emergent whole (Figure 1b). Traditionally, the shared mental models view of team cognition has been a collective view that may be limited especially for heterogeneous teams.

In general, we define team cognition as the emergent product of the interplay between the local cognition of each team member and team process behaviors (Cooke, et al., 2000; Cooke, Salas, Kiekel, & Bell, 2004). That is, team members each have a unique responsibility for their own particular labor division: a local environment, which they perceive, maintain, and act on. Through interaction team members can share changes in their own local environments with other team members, potentially making significant contributions to the information available in the environments of other, reciprocating team members. In this case, the emphasis is on the act of sharing knowledge as opposed to the collective knowledge product often referred to as a shared mental model. Team members interact with respect to time through communication, coordination, and other process behaviors, thereby building actionable team knowledge. Thus, no one team member is responsible for the global patterns underlying team cognition, rather team cognition emerges from the interplay of the parts, each responsible for their own local environments. In terms of understanding complexity, this viewpoint is called self-organization, but here we use the terminology of Cooke et al. (2000), referring to it instead as a “holistic” perspective.

Metrics of team cognition applicable at the group or team level should also be relevant in terms of a holistic view of team cognition. For example, team members in a military aviation setting may *individually* have information about an impending threat, but without adequate communication that helps to produce the integration or fusion of the pieces of information at a very global level, the *team’s* knowledge would be lacking and the *team* would fail to act on the impending threat. In this case, collective knowledge metrics would inaccurately represent the team as having knowledge about the impending threat, whereas holistic metrics would better reflect the team’s actual knowledge.

One of our approaches to measuring team cognition has focused on obtaining and comparing collective and holistic measures of team cognition. Collective measurements can be obtained using a number of aggregation procedures such as averaging individual responses. Holistic measurement requires assessing team knowledge at the team level. We have explored the use of communication data as a holistic approach to measuring team cognition (Kiekel, Cooke, Foltz, Gorman, & Martin, 2002). Communication can actually be viewed as cognitive processing at the team level, but has the benefit of being

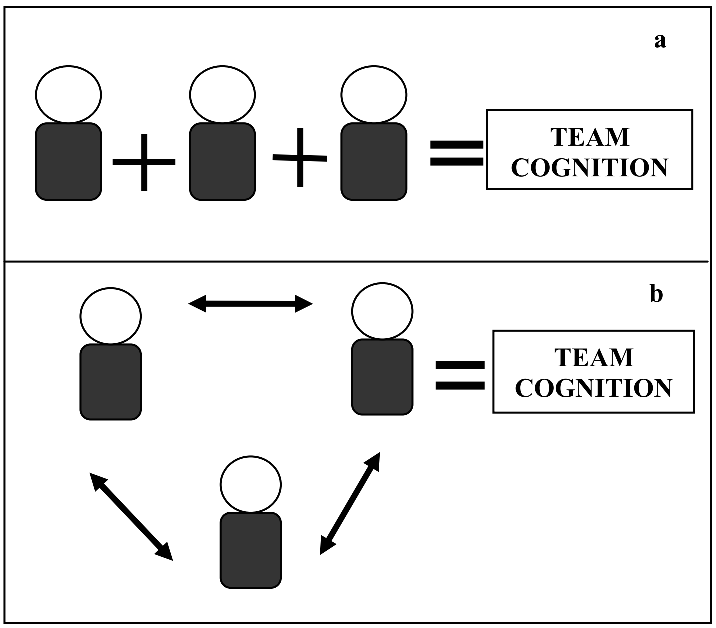

Figure 1. Panel A represents traditional collective views of team cognition. Panel B represents a more process-oriented holistic view of team cognition.

a natural byproduct of most team interactions. Another approach to assessing team knowledge at the holistic level is to present the same measurement tasks used at the individual level to the group as a whole (Cooke, Salas, Kiekel, & Bell, 2004). For instance, we have asked team members to discuss material over headsets and come to a consensus on the team's responses to questions about taskwork. We assume that the team interaction that is required to come to consensus involves some of the same team process behaviors that the team exercises in the operational environment and that the output of this measure is post-processed knowledge.

In much of the remainder of this chapter we empirically examine the effects of geographic distribution on team process behaviors, team cognition (both collective and holistic views), and team performance in a command-and-control UAV setting.

Predicted Influences of Geographic Distribution on Team Cognition and Performance

Very little research has been conducted that examines the effects of DMEs (distributed mission environments) on team performance, process behaviors, or cognition. Although Kleinman and Serfaty (1989) studied a military-based synthetic task environment that represented a geographically distributed AWACS environment, there were no direct comparisons of team behavior, performance, and cognition between this setting and a co-located environment.

Whereas there has been little or no research on the impact of geographic distribution on team performance or cognition in military settings, research in the human-computer interaction community has addressed mode of communication, a topic relevant to distributed work. This research has compared face-to-face or audio communication with computer-mediated communication, such as e-mail, GDSS (Group Decision Support Systems), or other tools. Several of these studies have found problems with computer-mediated communication. For example, Mantovani (1996) found that computer-mediated communication can hinder the creation of meaning, though Hedlund, Ilgen, and Hollenbeck (1998) found that computer-mediated communication can lead to lengthy decision-making compared to face-to-face communication. Unfortunately, these studies did not measure the performance of heterogeneous teams working on complex tasks for an extended period of time during which team member familiarity may confer an advantage. Some researchers have found that specific group norms are critical when higher team member familiarity among co-located teams produces better performance compared to distributed teams (Postmes & Spears, 1998; Postmes, Spears & Lea, 1998; Contractor, Seibold, & Heller, 1996).

Team members in distributed environments are less likely to be familiar with each other, as they must often communicate in ways that are less direct (i.e., never face-to-face), and may not be able to share displays or convey information visually through gestures or facial expressions. This opacity is likely to affect team process behaviors (e.g., communication, coordination, and planning) that in turn affect team performance during initial team missions and when workload is high (Fiore, Salas, Cuevas, & Bowers, 2003; Levine & Choi, 2004; Robertson & Endsley, 1997). These factors may also affect the acquisition of a team member's knowledge about the task or team with co-located team members better able to acquire interpositional knowledge than distributed team members (Fiore, et al., 2003). For instance, team members in distributed environments may have less of an understanding of the tasks of other team members simply because they cannot view the work environment of their teammates. In addition, communication limitations can affect the ability of team members to develop a shared understanding of the task or of the immediate situation. This knowledge difference at the individual level can ultimately affect knowledge at the team level.

To summarize, we hypothesize that process limitations of a distributed learning and work environment will lead to deficits in the development of team cognition and ultimately, team performance.

Examining the Impact of Geographic Distribution on Team Performance and Cognition

In order to investigate the effect of geographic distribution on team performance, process, and cognition, a study was conducted in the context of the Cognitive Engineering Research on Team Tasks Lab Unmanned Aerial Vehicle Synthetic Task Environment (CERTT UAV-STE; Cooke & Shope, 2004). The CERTT UAV-STE task is an abstraction of the Air Force's Predator Unmanned Aerial Vehicle ground operations task (Cooke, Rivera, Shope, and Caukwell, 1999). The team's goal is to fly the UAV to designated target areas in order to take acceptable photos of the areas.

This comprises a heterogeneous task environment in which there are three distinct roles of Air Vehicle Operator (AVO; pilot), Payload Operator (PLO; photographer), and Data Exploitation, Mission Planning and Communication Operator (DEMPC; navigator). Thus the UAV STE is a good example of a heterogeneous task in that each team member performs different, though interdependent functions: The AVO controls airspeed, heading, and altitude, and also monitors UAV systems. The PLO adjusts camera settings (in accord with airspeed and altitude), takes photos, and monitors the camera equipment. And the DEMPC oversees the mission and determines the flight paths under various constraints. Thus each team member has unique, yet interdependent roles and is provided with distinct, though slightly overlapping training and information during the mission. In order to complete the mission, the team members need to coordinate information with one another in a timely and adaptive fashion. Most communication is done via microphones and headsets, although some involves computer messaging.

In the experiment discussed in this chapter twenty teams engaged in seven 40–minute missions in either a co-located or geographically distributed team environment. Co-located team members worked at individual consoles in the same room and though they could see each other, during missions they communicated over headsets. Distributed team members, on the other hand, could not see each other as they were separated for the entire experiment by partition walls, or in the case of the DEMPC, by separate rooms. (Note that this manipulation is subtle in that communication mode [i.e., over headsets and microphones] remains constant.) The first four missions were low workload in that there were nine targets to photograph. Missions five through seven were "high workload" missions with twenty targets each and additional scenario constraints.

Based on extant literature (e.g., Mantovani, 1996; Hedlund et al., 1998) we hypothesized that distributed teams would exhibit impaired process behaviors compared to co-located teams and that this in turn would impact team cognition and performance negatively for distributed teams compared to co-located teams. We also hypothesized that the impact of distribution would be greater under high workload than low.

Measures

The study presented here is part of a larger project which investigated not only the effects of distributed vs. co-located mission environments on team performance and cognition, but also various techniques for measuring aspects of team cognition and performance. Thus, a variety of measures were taken including SART (subjective situation awareness), SPAM (situation awareness; Durso, Hackworth, Truitt, Crutchfield, Nikolic, & Manning, 1998), NASA TLX (subjective workload), social desirability, teamwork knowledge measures, experimenter ratings of team process behavior, and working memory measures. The analyses presented in this chapter focus on the measures that are most central to our hypotheses (i.e., team performance, team knowledge, and team process behavior). Measures of team performance and process were taken unobtrusively during each mission. The taskwork knowledge measure was taken apart from the mission in two sessions: one immediately following training and another after the last mission (i.e., Mission 7).

Team performance was measured using a composite score based on several mission outcome variables most relevant to the team objective including time each individual spent in an alarm state (e.g., airspeed beyond an acceptable range – pilot), time each individual spent in a warning state (e.g., camera battery low – photographer), rate with which critical waypoints were visited, and the rate with which targets were successfully photographed. Penalty points for each of these components were weighted *a priori* in accord with importance to the task and subtracted from a maximum score of 1000. Team performance data were collected for each of the seven missions.

Team process behavior was scored independently by each of two experimenters who attended to specific process behaviors at critical events and thus is referred to as Critical Incident Process (or CIP). For each mission the experimenters observed team behavior and responded to a series of six questions. Three of these items concerned team behaviors that did or did not occur at designated event-triggers in each mission (e.g., within five minutes after the end of the mission, the team discusses and assesses their performance). These items were scored as either present or not present. The other three items also assessed team behaviors that did or did not occur at designated event-triggers in each mission, but these items were scored on a scale that ranged from very poor/none (0) to good (2) (or to very good [3] in the case of one item). The sum of scores on these six items was expressed as a ratio of total possible points out of 10 for a given mission. This ratio formed the CIP score for each mission.

A *taskwork knowledge measure* was administered by presenting 55 concept pairs, one pair at a time, to participants. Items for each pair were drawn from eleven task related terms, such as "altitude" and "airspeed". Team members made relatedness ratings of the 55 concept pairs on a six-point scale that ranged from unrelated to highly related. Based on these ratings, the Pathfinder network scaling procedure (Schvaneveldt, 1990) was used to develop an individual knowledge network for each of the team members on a team. Network similarities were computed that ranged from 0 to 1 and represented the proportion of shared links between two networks.

Intrateam similarity was based on the mean of network similarity values for all pairs of team member networks. An overall accuracy value was computed for each team member by computing the similarity between the individual network and an overall knowledge referent (derived from task expert ratings). These similarities were averaged across the three team members for a collective measure of taskwork accuracy. Individual taskwork knowledge was also scored against referents specific to each role (Cooke, Salas, Kiekel, & Bell, 2004). Thus each individual obtained a score reflecting accuracy relative to the AVO, PLO and DEMPC positions. From these scores, estimates of positional and interpositional knowledge accuracy could be determined (e.g., each DEMPC was scored against a DEMPC key for positional accuracy and interpositional accuracy was estimated as the average when scored against the PLO and AVO keys).

A holistic measure of taskwork accuracy involved having teams reach consensus on the items that were presented to individual team members. For each pair, the rating entered in the prior session by each team member was displayed on the computer screen of each team member. The three team members discussed each pair over their headsets until consensus was reached. As a team, the individuals had to agree on relatedness ratings for the concepts. The team was scored for holistic accuracy on the same scale used for overall individual accuracy, by comparison of the team's network to a referent.

Participants

Twenty three-person teams of New Mexico State University students voluntarily participated in two five-hour sessions separated by 48 hours. Forty of the participants were male. Individuals were compensated for their participation by payment of $6.00 per person hour to their organization. In addition, the three team-members on the team with the highest team performance score were each awarded a $50.00 bonus. At the beginning of each experiment, the participants were randomly assigned (with constraints of three persons per team) to teams and to roles (with the constraint of one AVO, PLO, or DEMPC per team), with the teams randomly assigned (but maintaining equivalent number of teams per condition) to either the co-located or distributed mission environment.

Procedure

Each experimental sessions was overseen by two experimenters. Communication occurred mostly over headsets with some minimal computer messaging (e.g., DEMPC could send AVO a current route plan). Participants were first given a brief overview of the task and then started training. During training, all of the participants were separated by partitions regardless of the condition they were assigned. Team members studied three PowerPoint training modules at their own pace and were tested with a set of multiple-choice questions at the end of each module. Once all team members completed the tutorial and correctly answered the test questions, skills were tested. Experimenters had participants practice aspects of the individual tasks, checking off skills that were mastered (e.g., the AVO needed to change altitude and airspeed, the PLO needed to take a good photo of a target) and assisting in cases of difficulty. This continued until all skills were mastered. Training took a total of 1.5 hours.

After a short break, the taskwork measure was administered, after which the partitions were removed for co-located teams and the first 40-minute mission was begun. The first experimental session contained three low workload missions. The second session (48 hours later) contained one low workload mission and three high workload missions. Team performance and process measures were administered during each mission. The taskwork knowledge measure was again administered at the end of the second session (after Mission 7).

Each mission was completed at the end of a 40-minute interval or when team members believed that their mission goals had been completed. Immediately after each mission, participants were shown their individual and team performance scores and were able to compare these scores to the means of previous teams in the same experiment.

Results

Team Process

We hypothesized that distributed teams should have more trouble with communication, coordination, and planning, compared to co-located teams because of the inability to see each other and view team members' computer screens. As discussed in the measures section, the sum of scores on the six CIP items was expressed as a ratio of points out of 10. When the team did not reach a designated event-trigger, and therefore had missing data for that item, the ratio was calculated without that item. In this way, the team's process score was not affected by an event that is better captured by the team's performance score. Thus the CIP ratios range from 0 to 1.

A 7 (mission) x 2 (distribution condition) ANOVA was conducted with mission manipulated within teams and distribution manipulated between teams. The main effect of mission was significant, F (6,108) = 4.77, $p < .01$, implying that CIP scores were statistically different across the seven missions. The main effect of condition was also significant, F (1, 18) = 18.41, $p < .01$. Figure 2 illustrates that co-located teams had significantly higher CIP over missions. Figure 2 supports the statistical finding that distribution effect was largely independent of mission, F (6, 108) < 1.

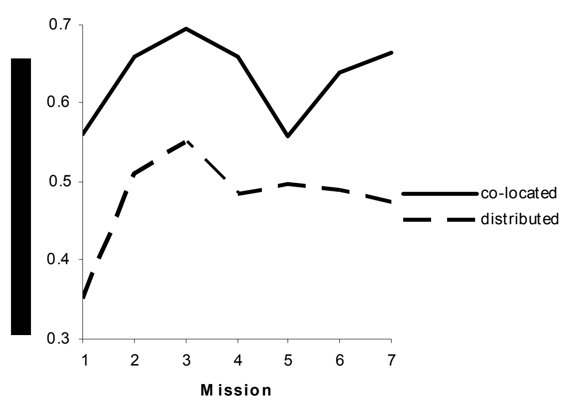

Figure 2. Mean co-located and distributed CIP scores over missions.

A planned comparison between Missions 4 and 5 was conducted to examine the impact of the increase in workload from Mission 4 to 5. As expected, results indicate a significant main effect of condition, $F(1, 18) = 5.53$, $p < .05$, between these missions, with co-located continuing to earn higher CIP scores. The main effect of mission however was not significant, $F(1, 18) = 1.86$. However inspecting Figure 2, the reason this main effect was not significant is likely due to the fact that the process of distributed teams was not impaired by the higher workload. A *post hoc* simple comparison revealed that co-located teams did show significant decrease on critical incident process between Missions 4 and 5, $F(1, 9) = 4.37$, $p = .07$. (Note that in this study we consider α-levels of $\leq .10$ statistically significant, opting to err in the direction of increased Type I errors in order to identify any potentially interesting measures or effects.) It is not surprising then that the planned interaction contrast using Missions 4 and 5 was also significant, $F(1, 18) = 3.01$, $p = .10$. Apparently co-located and distributed teams' critical incident process scores were differentially impacted by the transition from low to high workload between Missions 4 and 5. In Figure 2 this difference is illustrated by the sharp drop in co-located critical incident process at Mission 5 relative to the steady, albeit low, level of critical incident process at Missions 4 and 5 for distributed teams.

In order to more deeply explore the source of the process differences between co-located and distributed teams, a discriminant analysis model was fit using the critical incident items as predictors and co-located (0) or distributed (1) as the dependent grouping variable. Wilks' Lambda and the *F* analogue of the weights assigned to each item in the discriminant function are presented in Table 1.

Table 1
Results of Discriminant Analysis

Process Item	Wilks' Lambda	*F*	*df*num	*df*den	Sig.	Standardized Weights
1	.90	13.31	1	124	.00	.16
2	1.00	.00	1	124	.99	-.11
3	.94	7.38	1	124	.01	.28
4	1.00	.50	1	124	.48	-.06
5	1.00	.01	1	124	.92	-.11
6	.34	244.84	1	124	.00	.98

Notes: *df*num = numerator degrees of freedom; *df*den=denominator degrees of freedom; Sig.=p value

Clearly CIP Item 6 is the largest discriminator, followed by Items 1 and 3 in that order. It is interesting to note that these items involve communications that are not explicitly necessary to accomplish their task. For example, Items 6 and 1 involved teams discussing their performance after and at the beginning of, respectively, their missions. Item 3 concerned whether or not teams explicitly noted called-in (i.e., *ad hoc*) targets before getting to a called-in ROZ (Restricted Operating Zone) area. All of the other Items, 2, 4, and 5, involve communications that are explicitly necessary during the course of a mission (e.g., AVO and PLO coordinating on a specific target). We thus theorize that the significantly better process behaviors exhibited by co-located teams were due to teams' differences in assessing performance prior to and after each mission (Items 1 and 6), and to some extent, *explicitly* noting mission parameters that emerge during the course of a mission (Item 3).

To summarize, the results suggest that teams in the co-located condition exhibit better team process behaviors at our pre-defined trigger points and thus support our hypothesis. Given that our participants in the co-located condition are geographically proximal, the simple explanation is that something about being located in the same room facilitates certain types of process behaviors. The specific process behaviors exhibited by co-located teams but not by distributed included pre- and post-mission process planning and adaptive process behaviors. In terms of CIP, although co-located teams exhibited a more drastic decrease at the onset of high workload, they still displayed higher CIP scores than distributed teams under the same conditions.

Team Performance

Team performance scores across the seven missions are displayed in Figure 3. Teams steadily improved during the initial four missions and then performed more poorly at the point at which the high workload manipulation was introduced. A two-factor ANOVA with mission as the repeated measure and distribution as the between-teams variable revealed a detectable effect of mission $F(6, 108) = 19.10$, $p < .01$, but no effect of distribution (i.e., co-located or distributed) $F(1, 18) < 1$. There was also an interaction between mission and distribution, $F(6, 108) = 1.94$, $p = .08$.

Further exploration of the mission by distribution interaction for the transition from low to high workload (Mission 4 to 5), indicated that increased workload produced a decline in performance between the last low workload mission (Mission 4) and the first high workload mission (Mission 5), $F(1, 18) = 31.47$, $p < .01$, with a detectable interaction between distribution and mission $F(1, 18) = 6.05$, $p = .02$, suggesting that the decline in performance was affected by distribution. Means in this single degree of freedom interaction revealed that the direction of the distribution effect changed from Mission 4 to Mission 5, with distributed teams performing better than co-located in Mission 5 and with co-located teams suffering the most from increased workload.

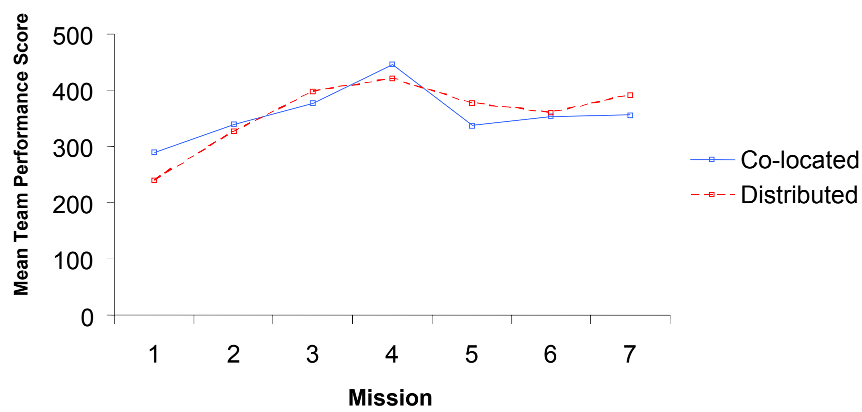

Figure 3. Co-located and distributed team performance across missions.

We also compared co-located to distributed teams on Mission 4, the last low workload mission, and Mission 7, the last high workload mission, to see whether teams recovered from the workload manipulation by the end of the experiment. There was a main effect of mission F (1, 18) = 13.74, $p < .01$, with teams performing worse in Mission 7 than in Mission 4. Also, there was an interaction between distribution and mission, F (1, 18) = 3.65, $p = .07$, indicating a change in valence for the distribution effect between Mission 4 and Mission 7 with distributed teams outperforming co-located teams in Mission 7, but not in Mission 4.

In sum our hypotheses regarding performance deficits of distributed teams were not supported by our findings. Co-located and distributed teams performed nearly equivalently and co-located teams, but not distributed, were negatively impacted by the workload change. In fact, the minimal differences between high workload Missions 5 and 7 attribute workload deficits more so to the *co-located teams*.

Taskwork Knowledge

The means and standard deviations as well as the minimum and maximum scores for the various taskwork knowledge metrics can be seen in Table 2. Taskwork data collected during Knowledge Session 2 was missing for one team (Team 7). With regard to *overall taskwork accuracy*, a two-factor ANOVA revealed a significant interaction between distribution condition (between subjects) and knowledge session (within subjects), $F(1, 17) = 5.17$, $p = .04$. A main effect of knowledge session was also found, $F(1, 17) = 4.05$, $p = .06$, where overall accuracy was higher in Knowledge Session 2. There was no main effect of distribution $F(1, 17) < 1$. As *post hoc* tests reveal, co-located teams improved in overall accuracy from Knowledge Session 1 to Knowledge Session 2, $F(1, 8) = 6.62$, $p = .03$, but distributed teams' overall accuracy scores did not change, $F(1, 9) < 1$.

Table 2 also displays the descriptive statistics for *taskwork positional knowledge*. A two-factor ANOVA revealed no significant interaction between distribution and knowledge session, $F (1, 17) < 1$ nor a significant effect of distribution, $F (1, 17) < 1$. There was no significant difference across knowledge sessions in terms of positional knowledge, $F (1, 17) = 1.97$.

Taskwork interpositional knowledge was also analyzed for both sessions as a function of the co-located/distributed manipulation (see Table 2). As with overall accuracy, there was a significant interaction between knowledge session and distribution, $F (1, 17) = 3.29$, $p = .09$, as well as a significant main effect of knowledge session, $F (1, 17) = 6.09$, $p = .03$. No main effect of distribution was found, $F (1, 17) < 1$. Again, *post-hoc* tests confirmed that co-located teams improved in interpositional knowledge across knowledge sessions, F (1, 8) = 8.86, p = .02, while distributed teams' interpositional knowledge did not significantly improve from Knowledge Session 1 to Knowledge Session 2, F (1, 9) < 1.

Table 2

Descriptive Statistics on Taskwork Knowledge Metrics in Co-located and Distributed Conditions for Knowledge Session 1 and Knowledge Session 2

Metric and Knowledge Session	Mean		Standard Deviation		Minimum		Maximum	
	Col.	Dist.	Col.	Dist.	Col.	Dist.	Col.	Dist.
Overall Accuracy								
1	.44	.48	.06	.04	.37	.41	.56	.53
2	.50	.47	.05	.04	.39	.40	.59	.54
Positional Accuracy								
1	-.19	-.07	.55	.60	-.96	-.96	.52	.57
2	.15	.13	.56	.65	-.51	-.94	1.18	1.15
Interpositional Accuracy								
1	-.20	-.08	.55	.40	-.70	-.84	1.24	.62
2	.32	.00	.46	.43	-.62	-.90	.68	.49
Intrateam Similarity								
1	.36	.38	.06	.06	.30	.28	.49	.47
2	.43	.41	.07	.07	.34	.27	.56	.53
Holistic Accuracy								
1	.53	.59	.07	.05	.39	.50	.63	.69
2	.62	.56	.06	.08	.52	.44	.71	.71

We also examined *taskwork intrateam similarity* (the descriptive data are displayed in Table 2). There was no significant interaction between distribution and knowledge session, F (1, 17) = 2.67, but a significant effect of session was found, F (1, 17) = 14.39, p < .01 with both co-located and distributed teams becoming more similar over time. The distribution main effect not significant, F (1, 17) < 1.

The final taskwork variable we examined was *holistic taskwork accuracy*. Descriptive data are displayed in Table 2. For this variable, there was a significant interaction between distribution and session, F (1, 16) = 12.27, $p < .01$. A significant main effect of session was detected, F (1, 16) = 3.07, $p = .10$, indicating that across teams, holistic accuracy was higher at Knowledge Session 2. There was no significant main effect of distribution, F (1, 16) < 1. *Post hoc* tests indicated that co-located teams became more accurate from Knowledge Session 1 to Knowledge Session 2 on the holistic measure, F (1, 8) = -17.99, $p < .01$, while distributed teams' holistic accuracy did not significantly change across sessions, F (1, 8) = 1.24.

In summary, with the exception of positional knowledge, there was general improvement in taskwork knowledge scores from Session 1 to 2. This improvement is mostly attributable to co-located teams (however both co-located and distributed teams became more similar over sessions). The pattern of results suggests that co-located teams acquired interpositional knowledge (i.e., knowledge about the tasks of their fellow team members), which also influences overall accuracy and holistic accuracy scores.

Discussion of the Geographic Distribution Study

As predicted, geographic distribution of team members affected team process and team cognition. Specifically, teams that were co-located as opposed to distributed engaged in more pre- and post-mission process communication behaviors. These behaviors involved adaptation and planning. Indeed some preliminary analyses of communication data collected in the same study indicate that co-located teams spend more time, in general, communicating compared to distributed teams. Particularly, team members in every role made more utterances in the co-located condition, than in the distributed (see Table 3)

Table 3
Statistics for the Comparison of the Number of Utterances Between Co-located and Distributed Conditions

	M_{col}	M_{dist}	F	df_{num}	df_{den}	Sig.	η^2
AVO	99.11	68.31	11.349	1	16.12	.004	.412
PLO	81.61	55.65	5.459	1	16.13	.033	.253
DEMPC	93.74	71.13	5.000	1	16.18	.040	.236

Note: M*col* = mean co-located; M*dist* = mean distributed; *df*num= numerator degrees of freedom; *df*den= denominator degrees of freedom; Sig. = p-value

Some have tied these kinds of pre- and post-mission process behaviors theoretically to the building of shared knowledge (Fiore, et al., 2003; Levine & Choi, 2004). There is support for the connection between process and knowledge in that the co-located teams more readily acquired knowledge about the task from the perspective of other team members than distributed teams. This pattern suggests that the process behaviors favored by co-located teams may have facilitated a common understanding (i.e., shared mental model) of the task.

However, we found no evidence to support the notion that geographic distribution affected performance on the UAV team task. So, although distributed teams appear to be scoring lower on team process than co-located teams and failing to acquire knowledge of the others' tasks, they maintain performance equivalent and in some cases better than co-located teams (e.g., during the switch to high workload). How do we explain such process and knowledge differences with no concomitant performance effects? What about the finding that common knowledge mitigates the detrimental effects of high workload (e.g., Stout, Cannon-Bowers, Salas, & Milanovich, 1999)? This is puzzling unless we take the view that teams in each of these two conditions can adapt differently given the constraints of their special environments and that differences in team behavior and team cognitions that result are appropriate for their unique setting; that there exists a principle of equifinality, with different teams taking different routes to what comprises qualitatively the same outcome.

A co-located environment allows team members to interact more directly and share computer displays, which means that co-located teams can develop interpositional taskwork knowledge. In turn, this kind of broadly overlapping understanding of the task environment allows team members to anticipate what other team members need or will do (Stout et al., 1999; Entin & Serfaty, 1999) enabling them to coordinate their activities appropriately, further enhancing team process.

However, in this study, distributed teams successfully adapted to an environment that more readily constrained team member interactions (e.g., there were no opportunities for face-to-face interactions). Unlike co-located teams who interact more freely outside of what their task dictates, and who thereby acquire interpositional knowledge, distributed teams interact only as the task necessitates (or perhaps exhibited different process behaviors that were not anticipated and thus, not captured by our CIP measure). Along with this highly constrained medium of interaction, distributed team members became more similar over time in their understanding of the task however this did not necessarily entail a better understanding of the nuances of other task roles (inter-positional knowledge). We might think of this form of adaptation as developing a much more rigid but efficient team cognition, while co-located teams have more "play" in the system, from which they can develop expectancies about what it means to play a different role on the team. However this was clearly not always adaptive, given the findings of performance decrement under high workload. Indeed, the distributed modes of interaction seemed to be most impervious to the demands of high workload compared to the easier-going interaction of co-located teams.

Other results from our lab similarly support the adaptation explanation. In a previous study that manipulated the ability to share knowledge in the same UAV task environment, we found that teams with different knowledge structures did not differ in terms of team performance (Cooke, Shope, and Kiekel, 2001). On the other hand, team members who were allowed to freely share knowledge had more accurate taskwork knowledge scores than those who were restricted from information sharing.

Overall these results suggest that there is not a single form of team cognition to which teams should aspire. Rather team cognition, like individual cognition, is more parsimoniously considered an adaptation to the environment.

One other possibility is that there may be a cost associated with the co-located condition that overrides any potential benefits of pre- and post-processing. According to Penner and Craiger (1992), the presence of others can produce higher levels of arousal, which in turn may produce poorer performance on a complex task. Although co-located team members may have a richer understanding of the task, the presence of others may also increase evaluative pressures or produce a distraction that prevents individuals from fully attending to the task. Interestingly we have some evidence in our secondary measures to support this cost of co-location in our task. Specifically, based on the NASA TLX results DEMPCs experienced greater workload demands than distributed DEMPCs during Mission 4, $F(1,19) = 8.62$, $p < .01$, and Mission 5, $F(1,19) = 6.82$, $p < .05$. There was also a significant relationship between scores on a working memory task and

DEMPC performance during Mission 5 for co-located teams, $t = 2.79$, $p < .05$, $B = .55$, but not for distributed teams, $t = .28$.

Implications for Distributed Learning

Distributed team environments have many advantages, from dispersing assets on the battlefield and minimizing the risks of concentrating resources in a single location that may be attacked to reducing the logistical problems of bringing team members to a single location for a business meeting. But what are the costs? The results from our experiment in a UAV command-and-control environment suggest that teams are able to adapt their interactions to these environments to achieve successful performance. Our research suggests that team performance will not necessarily suffer when team members are geographically dispersed, and in fact, they may demonstrate superior performance when compared to co-located teams through differential mechanisms of learning and team member interaction.

Our research suggests that distributed teams are different from co-located teams in terms of their process behavior and taskwork-relevant knowledge. Although these differences seem adaptive for the situations tested in our experiment, it may be the case that they would not be for other novel situations. In fact, the co-located teams who displayed more pre- and post-mission process behaviors and more interpositional knowledge were less able to adapt to a more intense high workload task. In other cases, the distributed mode of interaction may be more difficult to adapt, for example when team members must be completely interchangeable. Future work should be directed at identifying factors that facilitate or inhibit the adaptiveness of certain team process behaviors as well as team member knowledge. Accordingly, research should also be conducted that addresses the relative importance of team process and team knowledge in this adaptation.

It is also possible that knowledge differences were simply a byproduct of different process behaviors, but not critically tied to team performance. For instance, the development of interpositional knowledge by co-located teams may not produce significant benefits in performance compared to distributed teams when all team members in both settings are allowed to freely communicate thereby “sharing” knowledge in real-time (Stout, Cannon-Bowers, and Salas, 1996). Put differently, interpositional knowledge may not always be critical, given for example a highly specialized division of labor, as found in an operating room context. Given the other extreme however, in which team members are highly interchangeable, communication restrictions such as requiring team members to communicate by computer messaging or restricting the amount of communication allowed may produce a greater decline in performance for distributed teams compared to co-located teams, who presumably can develop expectancies about the needs of other team members.

These results also suggest that distributed teams may derive benefits from interventions targeting pre- and post-mission process coordination behaviors. If interpositional knowledge *is* necessary for adapting to some settings, then this type of intervention might foster the types of process behaviors that facilitate the development of this sort of knowledge in distributed teams, for example through instituting pre- and post-mission planning sessions.

From a more global perspective, our conclusions pertain to the kind of distributed scenario characterized by our UAV-STE. Communication took place primarily over headsets even in the co-located condition, the task was a highly structured command-and-control task, and there was significant interdependence among team members. Therefore differences in process and cognition should not be attributed to mode of communication, but rather to the subtle differences associated with co-presence.

Although various methodological concerns may prevent us from generalizing broadly to other task environments, we can conclude that geographic distribution changes team cognition and team process, but apparently has little effect on team performance. Whereas in this task the benefits of using distributed teams appear to outweigh any minor costs of geographic distribution, in another task in which communication is hampered or interpositional knowledge is critical, the costs may be significant. In the present chapter we hope to have at least provided researchers in applied domains such as command and control and particularly network-centric warfare with some theoretical footing in terms of the issues, factors, and considerations in assessing the effects of distributed mission environments on team cognition, process and performance.

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