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Communication in Command and Control teams

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Abstract

An important factor affecting team performance in Combat Information Centers is communication. Previous research has shown that high-performing teams use effective communication patterns, such as limiting idle chatter during high workload conditions, and sharing information before it is needed. Although the existence of these communication patterns is well-established, less is known about the conditions under which the various patterns are effective. The goal of the current research was to examine the impact of the predictability of the task environment. A two-person team task was used in which communication could be manipulated directly, that is, the task could be performed both with and without overt auditory communication between team members. The predictability of the task environment was manipulated by presenting team members either with situations they were trained on, or with situations for which they had to develop new strategies in real time. The results showed a positive effect of communication on team performance during novel situations, but no effect during routine situations. Given well-trained teams, who have shared mental models of their task, teammates, and equipment, our results would suggest designing for minimal communication interdependency among team members.

Effective teamwork is critical in a number of work environments, such as military command centers, fire fighting, aircraft cockpits, and emergency medicine. In these environments, teams are faced with high risks, and errors or delayed reactions may have serious consequences. It is, therefore, important to determine the factors that make teams successful. One of those factors is communication. The way teams communicate has received considerable attention of team researchers in recent years. Some researchers assert that performance is positively affected when teams communicate extensively to develop a shared understanding of the team, task and situation, plan activities, and cooperatively solve unexpected problems (Blickensderfer, Cannon-Bowers, and Salas, 1997a; Orasanu, 1990; Rasker, Post, and Schraagen, 2000; Rochlin, LaPorte, and Roberts, 1987; Seifert and Hutchins, 1992; Stout, Cannon-Bowers, Salas, and Milanovich, 1999). Other researchers claim that performance improves when team members limit their communication by coordinating implicitly, that is, providing each other information before being asked (Cannon-Bowers, Salas, Blickensderfer, and Bowers, 1998; Kleinman and Serfaty, 1989; Stout et al., 1999).

The goal of the present study is to shed light on these claims, and to gain a better understanding of the conditions under which communication in teams affects performance. We are especially interested in the role of communication for the development and use of shared mental models. Shared mental models allow team members to generate explanations and predictions about task and team demands. In turn, this allows team members to engage in implicit coordination, which refers to a communication and coordination process in which team members anticipate on each other's informational needs and provide each other relevant information in advance (e.g., Cannon-Bowers et al., 1998; Kleinman and Serfaty, 1989; Orasanu, 1990; Volpe, Cannon-Bowers, Salas, and Spector, 1995). This is supposed to be especially beneficial during conditions of high workload, because there is no need for team members to request information constantly or to communicate extensively to coordinate.

Although shared mental models may result in efficient communication (Cannon-Bowers, Salas, and Converse, 1993; Orasanu, 1990; Rouse, Cannon-Bowers, and Salas, 1992), communication is also important for the development and maintenance of shared mental models (Blickensderfer et al., 1997a; Orasanu, 1990; Stout, Cannon-Bowers, and Salas, 1996). Hence, communication serves two important functions. First, communication during task execution refines team members' shared mental models with contextual cues, which may result in more accurate explanations and predictions of the team task demands (Stout et al., 1996). Second, for maintenance purposes, communication is needed to keep the shared mental models up-to-date with regard to the changes that occur during task execution. Especially in dynamic or novel situations, communication is needed to maintain an up-to-date shared mental model of the situation and to adjust strategies or develop new ones to deal with the situation.

In the present study, we attempted to capture several dimensions of shared mental models that have received less attention in empirical studies conducted so far. First, besides team knowledge, we investigate situation knowledge in shared mental models. Second, instead of investigating communication because of having shared mental models, we investigate communication during task performance as an antecedent of shared mental models. Third, we focus on strategic knowledge in a shared mental model. Before we arrive at the hypotheses, we will first delineate how communication is related to these dimensions of shared mental models.

Communication during task execution is important for developing and maintaining team and situation knowledge in shared mental models. Furthermore, communication is especially important for developing strategic knowledge. With respect to team knowledge, communication supports team members to develop a common understanding of who is responsible for what task and what the information requirements are. With respect to situation knowledge, communication is important for maintaining an up-to-date understanding of the situation. Especially in novel situations, team members must communicate to respond to environmental cues, explain to each other why previous strategies do not work in the novel situation, jointly determine new strategies, and predict future states (Orasanu, 1990).

Based on the concepts discussed above, communication can be classified in different categories. First, team members communicate to exchange the information that they need from each other to complete their tasks successfully. When this information is exchanged in time and without explicit requests, teams coordinate implicitly. Second, for performance monitoring, team members inform each other what they are doing and provide each other feedback about each other's task performance. Third, team members evaluate and analyze performance outcomes. Fourth, team members communicate to determine strategies and optimize their task performance. Fifth, to develop and maintain up-to-date team knowledge, team members communicate about the team task, team members' tasks, and each other's informational needs. Finally, to develop and maintain up-to-date situation knowledge, team members communicate about the current developments in the environment. Table 1 gives an overview of the categories and their definitions.

TABLE 1

Communication analysis, overview of the categories and definitions

Category	Definition
Information Exchange	The necessary information exchange about the status of buildings (i.e., fire, extinguished, burnt down), number of units needed, units available, units in transport, and the threatened building
Performance Monitoring	Communication about the tasks team members execute during the scenario that they are engaged in. That is, explicitly telling each other what one is doing at that moment, giving advice what to do, and giving feedback about each others performance
Evaluation	Evaluative utterances or judgements concerning the activities of the scenario just played. Analyses of why things went well or wrong
Determining Strategies	Information that expressed intentions to adjust the way the team should engage in the task, deliberations about alternatives, rationalizations of the strategy adopted so far
Situation knowledge	Information about the present situation, the pattern or changes in the pattern of a series of small buildings, and the prediction of the endangered building
Team Knowledge	Information about learned facts of the task, each others' task and roles, and when and how information must be exchanged
Remaining communication	Information exchange that was unclear or social in nature

Some studies (e.g., Smith-Jentsch, Johnston, and Payne, 1998; Waller, 1999) have shown that the timely collection and exchange of information regarding situational changes is crucial in effective team performance. There have been no studies, however, that directly compare the effects of routine and non-routine situations on the possibility for overt strategizing.

We equipped team members with a team knowledge schema that represented a shared mental model comprising team knowledge (i.e., a schematic representation of team member's interdependencies, each other's tasks, and informational needs in time). With this schema, we expected that communication would improve team performance only when team members encountered novel situations, not when they encountered routine situations. This is because communication is not needed to the same extent to develop team knowledge (as this knowledge could be obtained from the schema), whereas in novel situations, communication is needed to maintain an up-to-date shared mental model (and the schema provided no guidance in this respect).

Hypotheses

1. No positive impact is expected of communication during routine situations.
2. In novel situations, teams that can communicate are expected to perform better than teams that cannot communicate.
3. There will be an interaction between communication and the type of situation, such that the teams that can communicate will be able to maintain their performance in novel situations to a greater extent than teams that cannot communicate.
4. Team members that can communicate are expected to have more utterances in the category situation knowledge and determining strategies in novel situations than in routine

situations.

Method

Participants. The data were obtained from 80 students in teams of two participants. Each team consisted of either two male or two female participants. In each of the two conditions, 20 teams (10 male and 10 female) performed the task. The participants were paid Dfl. 60, = for their participation.

Task. The team task consisted of an interactive computer simulation in the form of a fire-fighting game played by a team of two members. The fire-fighting task is situated in a virtual city where different buildings are set on fire by an arsonist. The goal of the team was to extinguish these fires in order to save as many lives as possible. Fires could be extinguished by assigning fire-fighting units to the fire. The number of units available was limited and more units were needed for large than for small building types. Scenarios (three minutes each) were developed that defined when the fires took place and in which building. The way fires developed in reaction to the deployment of units was determined by pre-programmed algorithms.

In each scenario, there were several small fires and one large fire. The large fire could be extinguished only when sufficient units were present at the onset of the fire. A series of small fires at the beginning of each scenario could be used to predict the location and the type of the large fire near the end of the scenario. The city was divided into four sectors, with all building types being represented in each sector. When three small buildings in one sector were set on fire, a large building would be set on fire later in the opposite sector. A particular sequence of small fires in one sector was considered a "pattern". Teams were trained to determine this pattern in the series of small fires so that they could make a prediction of the expected large fire and could allocate units in time. In order to develop a novel situation, the pattern in a series of small fires in a scenario was changed. In novel scenarios, the large fire was set in another section and in another building than team members would expect based on the pattern in a small series of fires they learned in their training. If, for instance, a hospital was expected in the diagonally opposite section, a factory would in fact be in danger next to the diagonally opposite section. Hence, these situations posed maximum uncertainty to the teams. In routine scenarios, the pattern in a series of small fires always predicted the large fire, in the way team members would expect based on the pattern they learned in their training.

A *team knowledge schema* was developed that represented a team member's shared mental model containing team knowledge. The schema consisted of a sheet of paper with a simplified event-handling model that represented team member's tasks, and the information that should be exchanged by each team member at particular points in time. Hence, the schema represented a form of explicit cross training that would induce a shared mental model of the team's informational needs.

In the task, different activities were assigned to the two team members (an observer role and a dispatcher role). The observer took care of the fire detection and identification of the buildings in the situation. Information on buildings needed to be exchanged with the dispatcher who determined the type of building, number, and time of the allocation of units. Subsequently, the system took care of the transport of units and the extinction of fires. When a building was on fire, the observer watched the building for possible status changes. When a series of fires in small buildings took place, both the dispatcher and the observer attempted to predict the building type and its location. Subsequently, the observer performed a search for the expected fire. In the meantime, the dispatcher predicted the onset time of the expected fire and determined the number of units needed. When the threatened building was found, the observer needed to send this information in time to the dispatcher. If not, the dispatcher would not be able to dispatch units. Along with this information, the dispatcher transferred the decision to the units.

The observer and dispatcher worked with different displays. They exchanged information electronically through standardized electronic messages that did not require any typing. The electronic message exchange was always required; in some conditions (see below), participants were also allowed to speak to each other through headsets.

Design. There were two experimental conditions in which the possibility to communicate was varied systematically. Team members were placed in separate soundproof rooms. In the no communication condition, team members could not communicate verbally, whereas in the communication condition, team members could communicate both during and between scenarios through headsets. Scenario type was counterbalanced across the communication conditions, such that in each condition half of the teams started with the novel scenarios, whereas the other half started with routine scenarios.

Procedure. Participants were briefly informed on the purpose of the research and were randomly allocated to the role of dispatcher or observer. The instructions and five simple training scenarios were followed by five training scenarios that contained a pattern in a series of small fires. In this session, team members had the team knowledge schema at their disposal. After the training, participants received two one-hour experimental sessions of 16 scenarios each. The participants were asked to use the team knowledge schema during the experimental sessions.

Dependent variables. Performance was measured by the percentage of potential casualties saved. A high performance score could only be obtained if the observer had been made aware by the dispatcher of the importance of sending the message about the threatened building in time. Although the observer and dispatcher did not need to share all knowledge, at least they needed to have shared knowledge of the importance of when to send what information. In this sense, a high-performing team had necessarily established this shared mental model.

Results

Performance. A repeated measures ANCOVA was performed. The repeated measures design consisted of two sessions (routine and novel scenarios) with 16 scenarios each. Because there were differences in the performance of teams on the training scenarios, the mean score on the training scenarios containing a pattern was included as a covariate. Separate analyses were carried out depending on the type of scenarios participants started with, as this influenced performance on the novel scenarios in particular. Performance on the novel scenarios was significantly lower when participants started with these scenarios as compared to when they started with the routine scenarios (in the communication condition, the means on the routine and novel scenarios were, respectively, 66% and 45%, $F(1,17) = 13.54$, $p = 0.002$; in the no communication condition, the means were 56% and 35%, $F(1,17) = 5.34$, $p = 0.034$). Performance on the routine scenarios was not dependent on the order in which they were performed in the restricted condition, $F(1,17) < 1$, but was dependent on the order in the unrestricted condition (74% versus 85%), $F(1,17) = 6.96$, $p = 0.017$. The results are shown in figure 1.

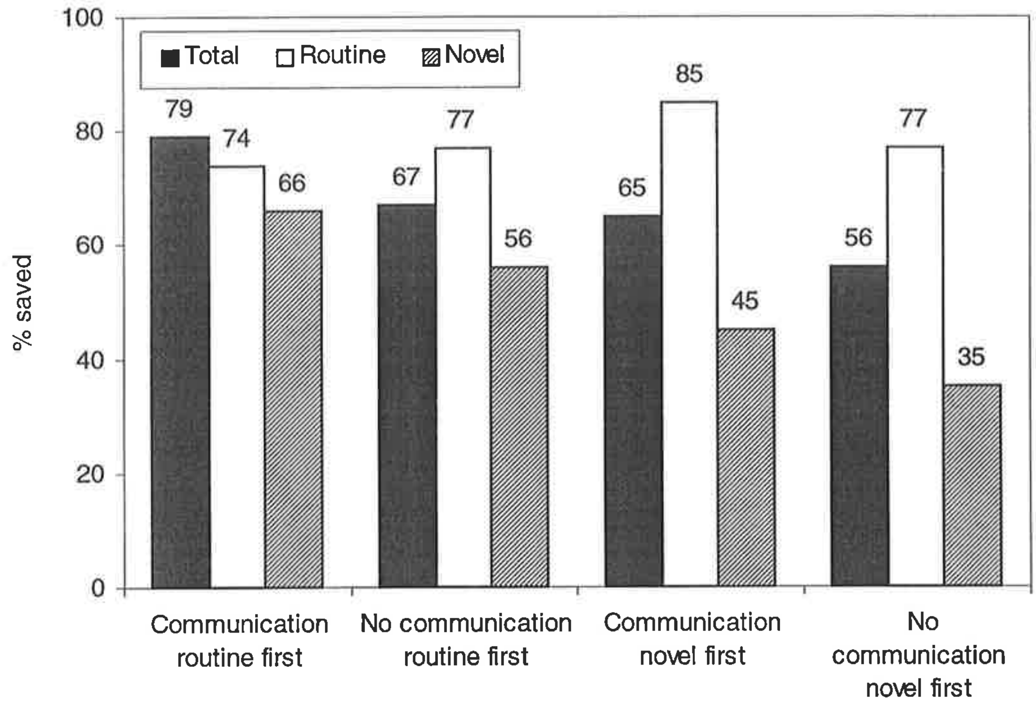

Figure 1. *Mean percentage of casualties saved in the communication and the no communication condition that started either with the routine session or with the novel session first for both sessions and the routine and the novel session separately.*

As there was an order effect of scenario type, the hypotheses will be discussed separately depending on whether teams started with the routine or the novel scenarios.

Routine session first. Hypothesis 1 received support; there was no significant difference between the communication and no communication condition during the routine session, $F(1,17) < 1$. Hypothesis 2 also received support. Figure 2 shows that teams in the communication performed better (66%) than teams in the no communication condition (56%), $F(1,17) = 4.93$, $p = 0.040$. The interaction between communication and session, as predicted in hypothesis 3, was also significant, $F(1,18) = 5.00$, $p = 0.038$. This interaction was as predicted: teams in the communication condition performed only slightly worse when confronted with novel situations (a non-significant drop from 74% to 66%, $F[1,17] = 3.88$, $p = 0.065$), whereas the teams in the no communication condition showed a sharp decrease in their performance (a drop from 77% to 56%, $F[1,17] = 10.04$, $p = .006$).

Novel session first. This first hypothesis received support; there was no significant difference between the conditions in the routine session, $F(1,17) < 1$, $p = 0.704$. Hypothesis 2 also received support. Figure 2 shows that teams in the communication condition performed better (45%) than teams in the no communication condition (35%), $F(1,17) = 5.34$, $p = 0.034$. The interaction between communication and session that was predicted by hypothesis 3, was not significant, $F(1,18) < 1$.

Communication analysis. The communication that took place in the communication condition was rated into the categories as described in table 1. With respect to the scenarios that both coders rated, the agreement level was 79%. This was considered sufficiently high such that the data obtained from the first coder (the one that scored all scenarios for all teams) were used for further analysis. To test whether teams communicated differently in the routine and novel scenarios as a function of the order in which they received these scenarios, we made a comparison between the teams that started with the routine session and the teams that ended with the routine session, and between the teams that started with the novel session and the teams that ended with the novel session. The results of this analysis revealed that there were no order effects. Therefore, we collapsed across different orders in which routine and novel scenarios were presented.

To test whether there were differences in the communication between the routine and the novel session, the mean number of utterances in a team for each condition was examined for each category. An ANOVA was performed, comparing the routine and the novel session within the communication condition. The results of this analysis are shown in table 4. As predicted by hypothesis 4, the teams communicated more in the categories determining strategies and situation knowledge during novel than during routine scenarios, $F(1,38) = 5.25$, $p = 0.028$ and $F(1,38) = 4.79$, $p = 0.035$ respectively.

TABLE 4

Mean number of utterances for each team for the routine and the novel session in the communication condition

Communication	routine session	novel session	F(1,38)=
Information Exchange	212	185	1.09
Performance monitoring	92	80	1.19
Evaluation	40	37	<1
Determining strategies	16	28	4.79*
Situation knowledge	26	39	5.25*
Team Knowledge	26	26	<1
Remaining Communication	18	19	<1
Total	430	413	<1

$p < 0.05$

Discussion

The results supported hypothesis 1, which predicted that communication is not beneficial in routine situations, when team members are provided with a schema representing a shared mental model containing team knowledge. In novel situations, however, we expected that communication is needed to develop a shared mental model that contains situation knowledge. The results supported this second hypothesis. The expected interaction that asserted that teams that could communicate would be able to maintain their performance during novel situations, whereas teams that could not communicate would show a performance decrease, is partially supported by the results. For the teams that started with the routine situation and ended with the novel situation, the interaction occurred as expected. For the teams that started with the novel situation and ended with the routine situation, however, there was no interaction. Whether teams could communicate or not, teams performed worse during novel situations than during routine situations. This asymmetry may be explained by noting that team members can better practice their teamwork skills when starting with routine rather than novel scenarios. This practice effect is of the same magnitude, whether teams could communicate or not. However, on top of this general practice effect, there is a significant advantage associated with being able to communicate that shows up on novel scenarios.

General discussion

In novel situations, teams communicated considerably about the changing situation itself and how to deal with it. Compared with the teams that could not communicate, this type of communication led to a performance improvement, independent of whether teams had had practice on routine scenarios or not. The updated shared mental model containing situation knowledge, allowed team members to determine strategies in cooperation. Because teams were presented with a series of novel scenarios that conformed to the same underlying principle, they could discover effective strategies to deal with these scenarios and perform better than teams that could not communicate, and could not discover those strategies.

Our studies have also pointed to the potential costs of communication. Communication does not seem to have any added value once teams have developed a shared mental model, as long as they are confronted with routine situations. In our task, teams could suffice with exchanging pre-formatted information electronically under the conditions mentioned. Obviously, in constantly changing situations, such as on aircraft carriers (Rochlin et al., 1987), constant overt communication may be required to keep team members up-to-date. This corroborates our results on the value of communication in novel situations.

Our results have practical implications for the design of effective teams in particular on designing communication structures in teams. Given well-trained teams, who have shared mental models of their task, teammates, and equipment, our results would suggest designing for minimal communication interdependency among team members. This would leave team members free to perform their own tasks as well as they can, while at the same time leaving as much spare communication capacity available for dealing with novel events, or for providing redundancy during routine events.

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