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Team Cognition in the Cockpit: Linguistic control of shared problem solving

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Abstract

Communication of professional air transport crews (2- and 3-member crews) in simulated inflight emergencies was analyzed in order to determine (1) whether certain communication features distinguish high-performing from low-performing crews, and (2) whether crew size affects communication used for problem solving. Analyses focused on metacognitively explicit talk; i.e., language used to build a shared understanding of the problem, goals, plans and solution strategies. Normalized frequencies of utterances were compared during normal (low workload) and abnormal (high workload) phases of flight. High-performing captains, regardless of crew size, were found to be more metacognitively explicit than low-performing captains, and effective captains in 3-member crews were found to be most explicit. First officers' talk complemented their captains' talk: First officers in low-performing crews tended to be more explicit than first officers in high-performing crews.

A string of recent disasters (e.g., the Vincennes incident in which an Iranian passenger jet was shot down, mistaken for a military plane; the Exxon Valdez oil spill in Alaska; and the Avianca jet crash in New York due to fuel exhaustion) has stimulated public concern for team problem solving and performance. They have also sensitized the research community to how little we know about team problem solving, decision making, and performance. A large literature exists on group problem solving (Steiner, 1972; McGrath, 1984), but much of this work was based on college students performing laboratory tasks in ad hoc groups (see Orasanu & Salas, in press, for a review; Ilgen et al., 1991). The relevance of much of this early group problem solving research to present applied problems has been called into question by recent findings on the role of expertise in individual problem solving performance (Chi, Glaser, & Farr, 1988). Yet we know little about the role of knowledge in expert team problem solving.

Recent efforts in the area of socially-shared cognition have focused on the role of shared knowledge in coordinating actions (see Resnick et al., 1991). For example, Hutchins and Klausen (1991) have analyzed 2 minutes of talk in a simulated air transport cockpit and have shown how shared knowledge gave meaning to ambiguous and cryptic gestures, glances, and utterances. Shared knowledge evidently provided the basis for mutual expectations and interpretations that allowed a 3-member crew to function as a single cognitive unit.

Teams of professionals in any area share considerable background knowledge--for their tasks, systems, artifacts, procedures, and the roles of various team members (Canon-Bowers, Salas, Converse 1990). Thus, when a problem arises, they should be well primed to cope with it. But the fact that tragic accidents occur means that something more is needed besides shared background knowledge. Orasanu (1990) suggested that a team must create a shared model for the current problem situation so that all members have the same understanding of what the problem is, what environmental cues mean, what solutions might be tried, and what is expected of various team members. The elements of the shared model are the same elements that research on metacognition has identified for effective individual problem solvers (e.g., Brown, Armbruster, & Baker, 1986; Flavell, 1981). That is, the shared situation model should include a clear goal, should be based on an accurate interpretation of the situation, should specify appropriate strategies to reach that goal, and should be updated by continuous progress monitoring. Knowledge and problem models held by individual crew members do not contribute to the common team effort unless they are shared. Team members need to communicate to each other how they understand the situation. Through communication they build a common model of the problem situation.

We propose that the degree to which a team establishes a shared mental model for a problem and the degree to which it is made explicit in communication will determine the team's effectiveness in coping with the problem. The fundamental issue addressed in this study was whether differences in how well crews coped with complex problems were associated with systematic differences in language use. Specifically, we sought to determine whether the language of more effective crews was more metacognitively explicit.

Explicitness is a slippery concept, because following Grice (1957), one does not want to say more than is useful. One can be explicit at the lexical level--that is, by using concrete referents rather than implicit ones or various forms of ellipsis. One can assure all participants share common terms of reference (c. f., Garrod & Anderson, 1987). One can also be explicit at a more abstract level, letting others know one's views of a problem and approach to its solution. The second aspect is addressed in this paper. Certain language functions were identified as relevant to metacognitive aspects of problem solving. They included goals, plans, strategies, predictions or warnings, and explanations. These were identified using a speech act theory approach (Austin, 1960; Searle, 1969). Utterances were coded in terms of the most prevalent function they performed within the context of preceding utterances and the given state of the task environment. For example, "Can you get me some ride reports," in the context of turbulence was taken as a comment on the deteriorating state of the weather, not simply as a question or even as a request. Obviously, utterances could be coded at many levels.

The present study examined the language used by teams of experts (cockpit crews) as they solved dynamic problems in a familiar work environment. Crew performance was observed in a high fidelity full-mission simulator. This environment is highly realistic and offers at the same time experimental control. Each crew can be presented with exactly the same scenario, pre-flight information, en route conditions (e.g., turbulence) and system malfunctions. This presents an opportunity to examine how each crew handles realistic emergencies in a safe environment, but one that is familiar to them and calls upon their domain-relevant knowledge.

In order to establish the generality of our findings, two different simulation studies were compared, one involving 2-person crews, the other 3-person crews. This between-study replication enabled us to address the following two hypotheses: (1) High-performing groups, regardless of crew size, show higher levels of explicit metacognitive talk than low-performing crews. (2) Three-member crews use more explicit metacognitive talk than 2-member crews. The second hypothesis is based on the fact that 2-member crews share a visual space and little ambiguity exists as to what is being addressed. The third crew member in a cockpit sits behind the other two and faces a different direction. This difference in visual field increases the need for explicitness.

Method

This study used videotapes from two simulator studies run at the NASA-Ames Man-Vehicle Systems Research Facility (Foushee et al., 1986; Chidester et al., 1990). These studies were selected because both involved the same scenario during one flight leg, with minor differences reflecting the aircraft systems (B-727 and B-737). The scenario involved a 1 to 1 1/2 hour flight characterized by a normal take-off and cruise to the destination. Weather deteriorated at the destination, which required crews to abort the landing. They had to decide whether to try again to land at the original destination, to go to their designated alternate, or to choose another alternate. During climb out, one of the hydraulic systems failed. This initiated a high workload period during which the decision had to be made about the alternate, now complicated by constraints imposed by the system failure. In addition, crews had to lower the gear and flaps manually, a time consuming and low frequency task.

There were 18 2-member crews (captain and first officer), who flew B-737s; 24 3-member crews flew B-727s, an older plane. The third crew member was the second officer, whose main duty is to monitor systems and attend to navigation. Communications of the second officers were not included in this study in order to maintain comparability with the 2-member crews. The captain designates himself or the first officer as pilot-flying, whose duty it is to fly the plane and watch out for traffic. The pilot-not-flying handles radio communication, checklists, and other procedures as needed.

As this was an exploratory study, the five highest performing and 5 lowest performing crews from each simulator study were selected for comparison. Performance was judged on the basis of operational errors, mainly dealing with adherence to standard procedures and aircraft handling (e.g., failures to obtain clearances, to complete checklists, or altitude deviations). Crews were not selected on the basis of their problem solving performance. Performance judgments were made by a check pilot (whose usual job is to evaluate pilots' cockpit performance). This was done on-line during the simulator run, and then two other observers made identical judgments from the videotapes. Videotapes were made of all crews in the simulator. Their talk was transcribed and served as the primary data for the present analyses.

Coding. A coding scheme that characterized the cognitive functions of cockpit discourse was developed (Orasanu, 1990). In brief, that scheme distinguished among three types of communication in the cockpit: Standard Operating Procedure talk (SOP), which is standard formulaic communication that is part of flying the plane; Housekeeping talk, which is sharing non-system information and allocation of tasks; and Metacognitive/Problem Solving talk, which is used to talk about problems. It is not formulaic or prescribed and is most variable across crews.

Because of our interest in the explicitness between 2- and 3-member crews, only certain functions were examined in this study. These include the following types of Metacognitive/ Problem Solving utterances: Goals, Plans/Strategies, Predictions, and Explanations. In addition, two other categories were included that are inherently explicit: Task Allocation and Commands. These served as anchors for the other measures.

Utterances were coded by assistants who were knowledgeable about aircraft systems and procedures, but who were blind to the conditions or performance levels of the crews. A reliability check indicated .86 agreement on scoring, which involved deciding on the unit of analysis, as well as the code.

Design. Separate analyses were run on data for each crew position (captains and first officers) using the same 2 (B) x 2 (B) x 2 (W) design. High and low-performing crews were compared within each crew size (2-member and 3-member). The within-crew variable was phase of flight: Normal vs. Abnormal. The abnormal phase began when the hydraulic system failed, causing the problem solving and coordination demands to escalate. Utterance frequencies for each crew member were normalized as rates per minute by dividing the observed frequencies by the amount of time the crew spent in the normal and abnormal phases, as appropriate. This normalization allowed comparisons across crew sizes and phases. All results reported here are significant at the $p<.05$ level or better, unless indicated otherwise.

Results

1. Do high and low-performing groups differ in the metacognitive explicitness of their talk? First, the total amount of task relevant talk was computed for each group. High- and low-performing captains did not differ in amount of total talk. Similarly, no significant effect of performance on first officers' task relevant talk was observed. This pattern forms the baseline against which to examine differences in types of talk.

Overall, captains of high-performing crews stated more plans and strategies than those in low-performing crews (see Figs. 1 and 2). In contrast, first officers in low-performing crews suggested more plans (M_{low} = .40) than those in high-performing crews (M_{high} = .31), seeming to compensate for the lack of planning by their captains. High-performing captains issued more commands than their low-performing counterparts, but only in 3-member crews. Commands may be considered the ultimate in explicitness. High- and low-performing captains in 2-member crews did not differ in commands. A marginally significant main effect suggests that high-performing captains also are more explicit in allocating tasks. The only other significant difference involving crew performance level was a 3-way interaction with crew size and phase of flight, which will be discussed in the next section.

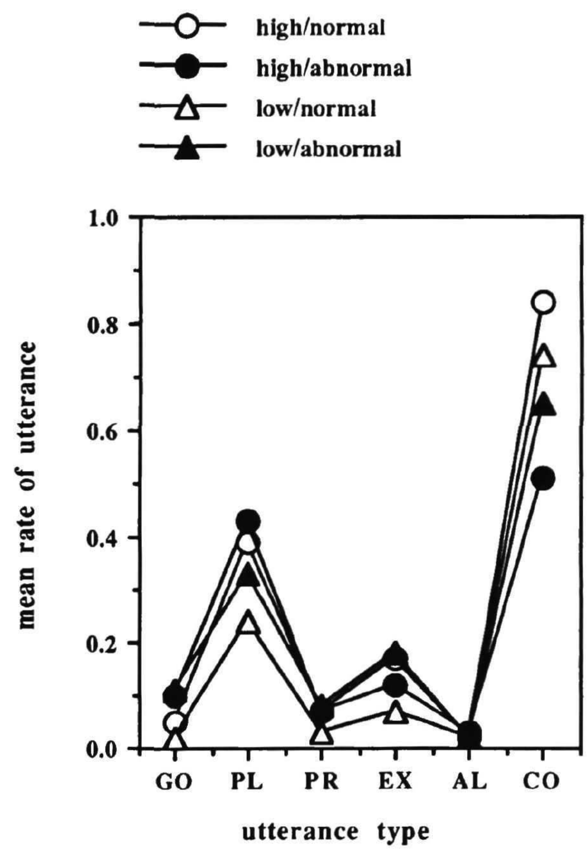

Figure 1: Mean rate of utterances by Captains of 2-member crews

Legend:

GO	Goal utterances
PL	Planning utterances
PR	Predictions
EX	Explanations
AL	Task allocating utterances
CO	Commands

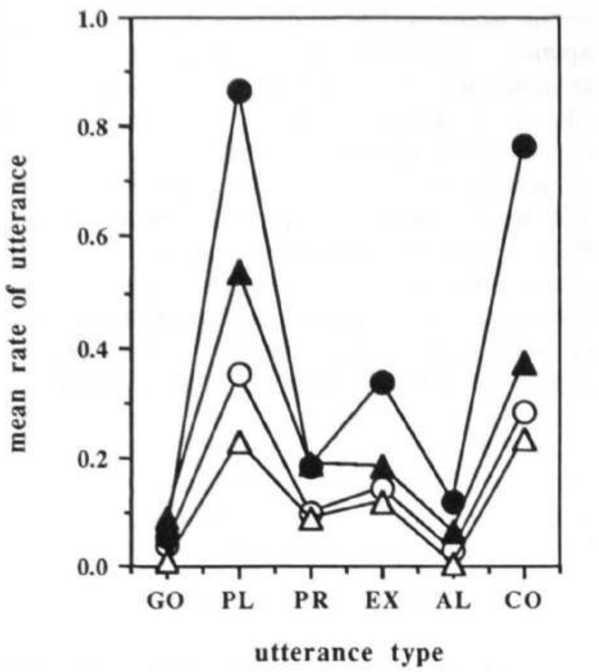

Figure 2: Mean rate of utterances by Captains in 3-member crews

2. Does crew size make a difference in the use of explicitness features in crew problem solving talk? First, it should be noted that the overall rate of talk in the abnormal phase was greater than in the normal phase for both 2- and 3-member captains. However, this effect was exclusively due to high-performing 3-member and low-performing 2-member captains. No significant phase effect on rate of talk was observed for high-performing 2-member and low-performing 3-member captains. In effective 3-member crews, captains' task-relevant talk rate almost doubled in the abnormal phase. For first officers, the reverse pattern was found: high-performing 3-member and low-performing 2-member first officers did not change their rate of talk significantly in the abnormal phase. High-performing 2-member and low-performing 3-member first officers, in contrast, talked more in the abnormal than in the normal phase.

Several main effects and interactions indicate that captains of 3-member crews were more explicit than captains of 2-member crews. In 3-member crews, captains more explicitly assigned tasks, particularly during the abnormal phase when workload was high. The significant phase effect for task assignment was due exclusively to the 3-member crews. They also were more explicit in alerting other crew members about things to watch out for or to expect. Essentially, they were the metacognitive crew monitors. The main effect of crew size was marginally significant for planning, with 3-member captains stating more plans and strategies, especially during the abnormal phase. Regardless of crew size, all captains stated more explicit goals during the abnormal phase than in the normal phase, as might be expected. The picture is somewhat complicated for commands, our bellwether of explicitness, reflecting different patterns associated with crew size. In 2-member crews, high-performing captains gave fewer commands during the abnormal phase than in the normal phase. The reverse was true for low-performing captains: they gave more commands in the abnormal phase. In 3-member crews, high-performing captains issued many more commands during the abnormal phase than during the normal phase. For low-performing crews there was no difference across phases.

First officers' utterances in many ways complemented those of their captains. Like the captains, they made more plans during the abnormal than the normal phase of flight, when coordination demands were high. Overall, first officers in 2-member crews made more plans than first officers in 3-member crews. A marginally significant interaction suggests they do this during the abnormal phase. No other effects were significant for first officers, although several were marginally significant and all of those were in the direction of supporting more explicit contributions by the first officers during the abnormal phase, specifically: stating goals, giving explanations, and allocating tasks.

Discussion

This pattern of findings paints a picture that shows some overriding commonalities in language use among high-performing crews. Two aspects of captains' talk cut across crew size: More effective captains explicitly state their plans and explicitly allocate tasks among crew members. By stating their plans, they let all crew members know what they want to accomplish. This allows other crew members to offer contributions and take actions that are consistent with the captain's intentions.

Other effective behavior patterns reflect the size of the crew. An effective captain communication strategy in a 2-member crew is different from what is effective in a 3-member crew. These differences appear to reflect possible task allocations, mainly with respect to who is flying the plane. In 2-member crews the captain has to make do with fewer cognitive resources. Effective captains exploit low-workload periods to do contingency planning and rehearsal for events that might occur (like the aborted landing). This enables the crew to be prepared when difficulties in fact strike; they are primed and are not just beginning to think about what they might do. Preplanning appears to save cognitive energy. The overall level of high-performing captains' talk drops in the abnormal phase. He is the one flying the plane under difficult circumstances. After he states his goals, plans, and priorities, he turns over the troubleshooting and checklist review to the first officer, allowing him to manage his own workload. He does not micromanage with frequent commands. In contrast, low-performing captains in 2-member crews do little preplanning and find themselves overwhelmed by work during the abnormal phase. They issue many commands and are reactive to problems, but do little overall planning.

In 3-member crews the patterns are quite different, because of the presence of the third person. Effective captains immediately shift flying responsibilities to the first officer, freeing themselves to manage the problems. This results in a high level of talk by effective captains, including many plans, commands, explanations, and explicit allocation of workload. In contrast, captains in low-performing crews fly the plane themselves and assign the first officer to work on trouble shooting and other manual tasks. However, the captain is still in charge of managing the problem and prioritizing tasks. From these captains we see few commands, little planning, and overall a lower level of talk.

First officers appear to be reactive to the style of their captains. If the captain has everything in hand, the first officer just does his job, which in the abnormal phase is to trouble shoot, monitor systems, and to assess progress. If the first officer is flying the plane, that's basically all he does, and talks very little. If the captain has not taken charge of the situation, the first officer is more likely to suggest plans and strategies, as shown by the higher level of plan utterances made by first officer in 2-member low-performing crews.

This pattern of findings suggests that differences in overall crew effectiveness, measured by commission of errors, reflects two things: how well the captain has managed the crew's workload by distributing tasks among himself and his first and second officers, and how explicit he is in letting the crew know what he wants to do. Interestingly, first officers' and captains' levels of explicit metacognitive talk seem to work inversely. If the captain's is high, the first officer's is low and vice versa. It is not the case that some crews appear to use categorically more metacognitive talk. The captain seems to set the lead. The finding that first officers in low-performing crews do not succeed in their efforts to compensate for their captains' lack of metacognitive talk needs further investigation. We suspect that low-performing captains do not sufficiently acknowledge the validity of first officers' suggestions. This interpretation is in line with previous research by Torrance (1954), who found that suggestions and solutions offered by low-status crew members were frequently rejected even when correct. In contrast, high-status members' contributions were accepted even when wrong. Also, Goguen, Linde, & Murphy (1986) showed that first officers' speech is more mitigated and perceived as less forceful than captains'.

Our analysis demonstrates that it is possible to identify classes of utterances that are related to overall quality of crew performance. Crews that use more explicit metacognitive talk when faced with in-flight emergencies perform more effectively than those whose talk is less explicit. Exactly how performance differences are brought about cannot be discerned from this study, which is a post hoc analysis. But the relations suggest directions for future efforts to tease out causal links between crew metacognition, communication and performance effectiveness.

References

Austin, J. L. 1960. *How to do things with words*. Oxford: Clarendon Press.

Brown, A. L., Armbruster, B. B., & Baker, L. 1986. The role of metacognition in reading and studying. In J. Orasanu ed., *Reading Comprehension: From research to practice*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Cannon-Bowers, J. A., Salas, E., & Converse, S. 1990. Cognitive psychology and team training: Training shared mental models of complex systems. *Human Factors Society Bulletin* 33(12):1-4.

Chi, M. T. H., Glaser, R., & Farr, M. J. 1988. *The nature of expertise*. Hillsdale, NJ: Lawrence Erlbaum.

Chidester, T. R., Kanki, B. G., Foushee, H. C., Dickinson, C. L., & Bowles, S. V. 1990. Personality factors in flight operations: Volume I. Leadership characteristics and crew performance in a full-mission air transport simulation. Technical Memo, 259, NASA Ames Research Center.

Flavell, J. H. 1981. Cognitive monitoring. In W. P. Dickson ed., *Children's oral communication skills.* New York, NY: Academic Press.

Foushee, H.C., Lauber, J.K., Baetge, M.M., & Acomb, D.B. 1986. Crew factors in flight operations: III. The operational significance of exposure to short-haul air transport operations. Technical Memo, 88322, NASA-Ames Research Center.

Garrod, S., & Anderson A. 1987. Saying what you mean in dialogue: A study in conceptual and semantic co-ordination. *Cognition*(27):181-218.

Goguen, J., Linde, C., & Murphy, M. 1986. Crew communication as a factor in aviation accidents. Technical Memo, 88254, NASA Ames Research Center.

Grice, H. P. 1957. Meaning. *Philosophical Review*, 67.

Hutchins, E., & Klausen, T. 1991. Distributed cognition in an airline cockpit. Unpublished manuscript. University of California, San Diego, CA.

Ilgen, D. R., Major, D. A., Hollenbeck, J. R., & Sego, D. J. 1991. Decision making in teams: Raising an individual decision making model to the team level. Technical Report, 91-2. Industrial/Organizational Psychology and Organizational Behavior, Michigan State University, East Lansing.

McGrath, J. E. 1984. *Groups: Interaction and performance.* Englewood Cliffs, NJ: Prentice Hall.

Orasanu, J. (1990). Shared mental models and crew performance. Technical Report, 46. Cognitive Science Laboratory, Princeton University.

Orasanu, J., & Salas, E. (in press). Team decision making in complex environments. In G. Klein, J. Orasanu, R. Calderwood, & C. Zsambok eds., *Decision making in action: Models and methods.* Norwood, NJ: Ablex Publishers.

Resnick, J. Levine, & S. Behrend eds. 1991, *Shared Cognition: Thinking as social practice.* Washington, D.C.: American Psychological Association.

Searle, J. 1969 *Speech Acts.* London: Cambridge University Press.

Steiner, I. 1972. *Group process and productivity.* New York: Academic Press.

Torrance, E. P. 1954. Some consequences of power differences on decision making in permanent and temporary 3-man groups. *Research Studies, State College of Washington* 22:130-140.