

# Linguistic Correlates of Team Performance: Toward A Tool for Monitoring Team Functioning During Space Missions

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**Introduction:** Approaches to mitigating the likelihood of psychosocial problems during space missions emphasize preflight measures such as team training and team composition. Additionally, it may be necessary to monitor team interactions during missions for signs of interpersonal stress. The present research was conducted to identify features in team members' communications indicative of team functioning. **Methods:** Team interactions were studied in the context of six computer-simulated search and rescue missions. There were 12 teams of 4 U.S. men who participated; however, the present analyses contrast the top two teams with the two least successful teams. Communications between team members were analyzed using linguistic analysis software and a coding scheme developed to characterize task-related and social dimensions of team interactions. Coding reliability was established by having two raters independently code three transcripts. Between-rater agreement ranged from 78.1 to 97.9%. **Results:** Team performance was significantly associated with team members' task-related communications, specifically with the extent to which task-critical information was shared. Successful and unsuccessful teams also showed different interactive patterns, in particular concerning the frequencies of elaborations and no-responses. Moreover, task success was negatively correlated with variability in team members' word count, and positively correlated with the number of positive emotion words and the frequency of assenting relative to dissenting responses. **Conclusions:** Analyses isolated certain task-related and social features of team communication related to team functioning. Team success was associated with the extent to which team members shared task-critical information, equally participated and built on each other's contributions, showed agreement, and positive affect.

**Keywords:** team work, team processes, task-related and social aspects of team communication.

THE SUCCESS OF long-duration space missions will depend on the ability of crewmembers to collaborate effectively under highly stressful conditions. External stressors stemming from the environment and task characteristics as well as psychosocial stressors may threaten the well-being of individual crewmembers and their functioning as a team. While crewmembers are highly selected and technically skilled, "the history of space explorations has seen many instances of poor interpersonal relations and faulty decision making" (49, p. 195). In both U.S. and Russian spaceflights, instances of irritation, increased tension, and conflict between crewmembers have been documented that disrupted missions, and even led to premature termination (2,20,50). Similarly, research on crewmembers in isola-

tion chambers revealed significant decreases in reported group cohesion, leader control, and support (21).

In summarizing the risks posed to long-duration missions, both the Institute of Medicine and the National Academy of Sciences highlight failures in psychosocial adjustment and rank this problem second to radiation damage (2). The same assessment is included in the Bioastronautics Critical Roadmap, which gives the highest risk rating to "human performance failures due to poor psychosocial adjustment" and states that "problems of group cohesiveness have a high likelihood of occurrence in prolonged spaceflight and if not mitigated . . . will pose grave risks to the mission" (33). Approaches to mitigating the likelihood of psychosocial problems during space missions have traditionally emphasized preflight measures, such as team building through training, and the selection of compatible individuals (3,23). The benefits of these preflight measures notwithstanding, they may not be sufficient to ensure healthy team interactions during missions, as evidenced by past incidents of interpersonal tension. Rather, tools are needed that facilitate the assessment of team functioning during space missions so that countermeasures can be introduced once mission-significant changes or trends have been detected. The research reported in the present paper was conducted to support development of one such tool: the linguistic analysis of team members' communications as a means of monitoring team functioning for signs of interpersonal stress.

Prior research on team performance, much of it in aviation and the military, clearly shows the importance of team communication to effective task performance

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(6). While this body of research has predominantly focused on developing guidelines for team training, their findings could also be incorporated into a tool for monitoring team performance.

The overarching goal of team communication research has been to identify aspects in team members' interactions that are supportive of effective task performance. Consequently, researchers examined how members of high-performing teams talked about their joint task and how their communications differed from poorly performing teams. Teams that worked effectively were found to share more task-critical information than less effective teams, especially concerning the problem at hand, task goals, and team strategies (4,35,48), and presumably were thus able to build shared situation models that supported their joint problem solving efforts (34). Moreover, members of effective teams tended to anticipate each other's needs and volunteered information and their assistance (35,47). Team efficiency also was associated with closed-loop communication in which team members responded immediately to each other's initiations (e.g., questions were answered, observations were acknowledged), thus keeping their communications tight and reducing the cognitive load under stressful, heavy workload conditions (22). Analyses of aviation accidents isolated further problematic aspects in crew communication, especially indirect and ambiguous references, that may have resulted in critical misunderstandings and a breakdown in crew coordination (11,13).

While team communication research has identified linguistic markers of team cognition, it has largely ignored the social dimension of team interactions (24). Traditionally, interpersonal matters have been considered as an issue of team composition. The prevalent conviction has been that by selecting individuals who are compatible in terms of their personality, one ensures that team members will get along (3,38,44). This view, however, underestimates the team-building function of team members' communications. The importance of crew selection notwithstanding, compatible personalities alone do not bind individuals together as a team; rather their communication does. As linguists and social scientists have pointed out, human communication serves two essential functions: it transfers information and it carries relational meaning (1,51). The social function of communication comes into play even in the context of professional team interactions (29). As team members communicate to achieve their task objectives, they also define (and re-affirm) the nature of their relationship, thus creating a social context that may support—or impede—their joint task work (24).

Team communication research, however, is all but silent on the issue of which linguistic features are most indicative of a team's social climate or health. Instead, the relational aspect of communication has been studied by social scientists and clinicians interested in describing interactions mostly in dyads (especially between spouses, or between parent and child). While their primary concern has been to understand how, for example, marital dysfunction is manifest in the interactions of spouses, researchers have identified interper-

sonal dimensions that may be relevant to work teams as well, such as dominance and control, expressed affect, empathy, closeness, openness, and support.

The issue of dominance and control is reflected in the symmetry or complementarity of people's interactions (51). In complementary interactions one person is in charge and dominates the interactions while others take on supportive roles. Dominant individuals typically talk more than others, are more assertive, and determine the topic of the conversation (31,39). They also tend to be the focal point of interactions as others predominantly respond to them (27). Symmetric interactions, in contrast, are characterized by equality: individuals contribute equally and take turns in controlling the topics of their conversation. Communication features associated with dominance and control could be used to track the leadership structure in teams over time and to determine shifts and breakdowns in a team's control structure. Analyses of the communication flow among team members have indicated that it is a sensitive measure of team stability, reflecting cognitive as well as interpersonal team processes (25,26,45).

Interactive patterns also reflect how well team members collaborate with one another and get along (42,43). On a relational level, collaboration concerns the extent to which team members are responsive to one another, take up and extend each other's contributions, and build consensus. Moreover, the frequency of team members' agreement relative to their disagreement carries affective meaning insofar as agreements are considered to be positive conversational moves while disagreements are judged to be negative. Consequently, a preponderance of agreement is believed to indicate a positive team climate, which, in turn, is assumed necessary for team success (1).

Team members' affective attitudes toward one another may also be expressed verbally (e.g., as praise or accusation, sympathy, disdain, or hostility). Research examining communication among spouses during a conflict discussion found that expressed affect predicted marital success. Couples who showed positive affect, such as humor and concern for the other's feelings, were more likely to remain together than couples in which negative affect prevailed (7). Observations of wildfire incident management teams during training simulations identified negative stereotyping of other group members as one factor that may have contributed to a team's poor performance (30). While denigrating remarks about other team members present a rather unequivocal—but also infrequent—sign that team functioning is at risk, research has identified more subtle linguistic devices that indicate the social climate of a team. One such device may be team members' use of personal pronouns, in particular the extent to which they rely on first person singular ("I") vs. plural ("we") pronouns. In studies on marital health, spouses' references to "we" and "us" was found to indicate the degree of their shared identity and to predict marital success (5). In a similar vein, a prevalence of plural pronouns in team members' communications may characterize cohesive teams in which individual members strongly identify themselves with the team. Findings

consistent with this hypothesis are reported by Sexton and Helmreich (48), whereas Gushin and Yusupova (17) did not observe a preference for plural pronouns in the communications of ISS commanders to mission control. Commanders instead used “I/Me” more often than “We/Us,” apparently emphasizing their personal responsibility for their crew’s actions.

### *Predictions*

The present research was conducted to identify features in team members’ communications that reflect how well the team functions during a complex problem solving task. Unlike previous studies that focused primarily on task-related aspects of team communication, the present analyses also examined social aspects and their relation to task performance. We compared the communication between members in teams that were consistently successful (i.e., high scoring) with the communication in teams that were consistently unsuccessful (i.e., low scoring) across six scenarios. Members of successful teams were expected to share more task-relevant information than members of unsuccessful teams, especially concerning their goals, plans, and strategies. Moreover, we hypothesized that they will also show a higher degree of collaboration and identification with the team, and express more agreement and positive affect. We had no specific hypotheses concerning the control structure in team members’ interactions. Instead the present analyses were conducted to determine whether successful and unsuccessful teams adopt different control structures; i.e., whether task success is related to complementary or to symmetric interactions.

## METHODS

### *Participants*

There were 48 U.S.-born men\* who were recruited as participants via an ad posted on the Bay Area’s craigslist, a web-based resource that provides local classifieds. Participants were randomly assigned to teams of four. Individuals in a team were trained together on the experimental task and remained in the same team for the duration of the experiment. Participants were paid for completing the 4-d experiment.

The present analyses are based on the data of 16 participants. The data of these individuals were included in the present analyses because their teams were consistently high or low scoring in all six experimental scenarios. Team performance was operationalized in terms of points gained during a scenario. Team points for the high-scoring teams ranged from 985 to 2585 ( $M = 2025$ ); for the low-scoring teams from 365 points to 1770 ( $M = 1098.75$ ). Members of low and high scoring teams were similar in age (Low: Mean = 32.25 yr,  $SD = 6.36$ ; High: Mean = 30.88 yr,  $SD = 5.64$ ;  $t(14) =$

$-0.46$ , n.s.), and all had university degrees. Of the participants, 12 (all 8 team members of the low scoring and 4 of the high scoring teams) had a bachelor degree; 4 members of the high scoring teams—3 of whom were in the same team—had, in addition, a masters degree. All but two participants were employed at the time of the study. Participants provided written informed consent prior to the study. The consent form, experimental task, and procedure were approved in advance by the Institutional Review Boards at both NASA Ames Research Center and the Georgia Institute of Technology.

### *Experimental Task*

Our research involved the Distributed Dynamic Decision-Making (DDD) task environment developed by Aptima, Inc. (12). The DDD provides an ideal environment for studying team interaction and problem solving because its underlying cognitive demands reflect those of many real-world team tasks. It has been used to simulate military decision-making environments (e.g., Joint Task Force, AWACS), industrial environments (e.g., manufacturing systems, civilian search and rescue), and health care applications (e.g., distributed diagnosis). The computer-based task environment presents graphical displays of evolving problem scenarios and engages team members in a low- to mid-level fidelity degree of realism.

The DDD scenarios used in our study simulated search and rescue missions in Antarctica. Study participants worked in teams of four on individual but linked computer terminals. Communication between team members was supported by e-mail, and an intercom system. Team members’ main objectives during a mission were to rescue a crew considered to be lost, complete its repair mission, and retrieve an important satellite. In order to succeed in these tasks, team members had to develop a search strategy (e.g., divide the space into sectors to be searched by different team members), set priorities (e.g., how to balance main objectives and emergency tasks), assign and coordinate tasks (e.g., who keeps track of team progress), manage resources (e.g., be mindful of supply requirements), and share task-critical information.

Team members received 300 points on completion of each main task. During their search, participants encountered several time-critical emergency tasks designed to introduce task conflict. Team members were penalized (= lost points) if they ignored these emergency tasks. If they completed them, they gained points; however, in so doing, they could be side-tracked from their main tasks or use up valuable resources.

During task training members of a team were randomly assigned to the role of search team member or base station coordinator. They remained in their assigned roles throughout the experimental scenarios. While team members’ roles were associated with different task functions, they were not identified with status differences such that one team member was the designated leader. That is, team coordination and communication was not constrained or defined by the experimenters, but instead it was left to the individual team members to shape the nature of their interactions.

\* This study was the first of a series of studies examining the relation of team composition (homogenous in terms of gender and culture versus heterogeneous concerning these characteristics) and team processes and performance. At the time of the present analyses, the studies involving all-female and gender- and culturally mixed teams had not been completed.

Within each team, there were three search team members, called 'Red,' 'Green,' and 'Purple,' who engaged in the search by controlling virtual snowcats. A fourth team member, called 'Blue,' remained at the base station. He assisted search team members with refueling and re-supplying of their search vehicles. Moreover, satellite messages concerning environmental hazards, weather systems, and the detection of objects possibly relevant to locating the main tasks were transmitted only to the base station. It was 'Blue's' task to decide which information to disseminate and whether to address the whole team or individual members. As search team members moved through the environment, they encountered clues and seismic monitors that provided potentially valuable information on the movement of the lost party. By processing seismic monitors correctly, team members could gain additional points, ranging in value from 10 to 80 depending on the significance of the information provided. However, in so doing, they used up resources that were vital to their main tasks.

Time and resources available for the search were severely constrained. Each snowcat carried a limited amount of fuel and had a limited number of (simulated) "support personnel" on board, each possessing a different set of skills (medical, technical, mechanical, or scouting) and expertise level. As the search progressed, snowcats used up fuel and personnel resources. To save resources, search team members could pool their personnel and collaborate on tasks. Alternatively, they could return to base or go to field camps and coordinate with the base station player to replenish fuel and personnel. If the snowcat of a team member ran out of fuel, he could retain his personnel resources by removing them from the search vehicle. Failure to do so would deprive him of any resources and he would no longer be able to help with the search.

Six search and rescue scenarios were developed, representing two levels of task difficulty. The three high difficult scenarios presented team members with more ambiguous information than the moderately difficult scenarios, required the completion of more emergency tasks in addition to the rescue and repair mission, and thus placed team members under more time pressure. Team members had 75 min to accomplish the task objectives and to gather as many points as possible.

#### *Procedure*

The experiment extended through 4 d. On Day 1 participants were trained to use the experimental software and completed a practice scenario. The following 3 d, teams worked through six experimental scenarios, one moderate and one difficult scenario per day. The order was counterbalanced across and within days. Prior to each scenario, participants had 20 min to plan for the upcoming task. Both individual and team performance measures were recorded and time-stamped by the DDD software. Cameras mounted on top of team members' computer monitors recorded their facial expressions during a scenario. Each team member's communications were digitally recorded through his headset and routed to his video recorder, where video and audio data were synchronized and time-stamped. In

addition to performance and communication data, several physiological measures (heart rate, pulse, muscle tension, skin conductance, and respiration) were taken to obtain physiological indices of stress. Throughout the experiment, participants were also asked to respond to a number of psychometric measures, such as the NEO-FFI (10) and the NASA-TLX (18), and to provide performance feedback. These measures were collected to model the impact of individual variables on team performance. Results of these analyses are summarized elsewhere (36,37) and will not be discussed in this article.

#### *Analysis of Team Communication*

The present analyses are based on team members' voice communications during the six scenarios. Communications were recorded, transcribed, and analyzed using the Linguistic Inquiry and Word Count (LIWC) software (40). This software counts linguistic features of a text that have been shown to reflect a speaker's (or author's) cognitions, attitudes, and affect (41). In addition to the LIWC software, we used a multi-layered coding scheme specifically developed to characterize team interactions in terms of their task-related and social components.

*Coding of task-related aspects:* Team members' contributions were segmented into conversational moves corresponding to Hirokawa's (19) definition of a functional utterance. That is, a unit was an uninterrupted utterance by a team member that had a discrete problem-solving function. As such, a unit could correspond to a grammatical sentence, to an independent clause, or to several sentences. For each unit we noted its grammatical form (declarative, interrogative, imperative, or ellipsis) and speaker. The task-related (i.e., problem-solving) function of a unit was classified using the coding scheme developed by Orasanu and Fischer (35). Main and sub-categories plus examples are provided in **Table I**.

*Coding of social aspects:* Our analyses focused on the control structure and interactive patterns in teams, as well as on team members' identification with and affective responses to the group. Several LIWC categories were exploited for our purposes. The word count category was applied to assess how much each team member talked and whether an individual or individuals talked more than others, thus dominating the team's discourse. In addition, we used the LIWC to count how often team members referred to themselves (frequency of first-person singular pronouns, e.g., "I") or to the team (frequency of first-person plural pronouns, e.g., "we") and how often positive or negative emotion words occurred in their communications. The former categories were expected to tap team members' identification with the group; the latter to gauge the social climate in a team.

These LIWC categories were complemented by hand-coding team members' communications for expressions of specific interpersonal affect. Our affect codes were modeled after coding schemes psychologists have used to classify speaker affect in marital interaction (14,28). We coded whether or not speakers verbalized affective

TABLE I. CATEGORIES OF TASK-RELATED COMMUNICATIONS.

Function	Examples
<i>Information Sharing</i> Info about task, logistics Info about location and movement of self and other	"The emergency task requires 3 medics." "One needs to be inside the ring [before processing]." "What was that coordinate?" "I am at 14,30, heading S."
<i>Problem Solving</i> Setting goals Forming hypotheses, predictions Making plans	"Need to find antenna next." "Maybe they went through there." "We'll cover everything below row 22, then we'll rejoin in rows 20 and 21."
<i>Meta-Cognition</i> Monitoring team progress Assessing team performance Reporting on own progress, past actions	"Seismic monitor is done." "Purple, you serviced the emergency?" "We've got all waypoints." "What's our score?" "I can't see anything yet."
<i>Team Coordination</i> Coordinating with others on on-going task Directing the actions of others Stating one's intentions	"I could go north, you could go south" "Should I wait for everyone?" "Keep looping around" "Why don't you pick that one up?" "I'm gonna zoom in"
<i>Non-task Related</i>	"I thought Kobe was goin' to shoot that and Boiong was gonna foul 'im. Did you see that play?"

reactions to teammates, and when they did we further noted whether they expressed praise and empathy, showed humor or politeness, or tried to appease, or were apologetic, patronizing, criticizing, or defensive (see **Table II** for a listing of the categories and examples).

Finally, our coding sought to characterize the interactive patterns present in team members' communications. This type of coding was based on the notion of adjacency pairs, which implies that speakers are expected to refer in their current contribution to the preceding contribution by their conversational partner (46). While conversational norms dictate that speakers do respond to previous utterances, they only loosely constrain how speakers can do so. Several classifications systems that vary in purpose and specificity have been proposed in the past to characterize how utterances by conversational partners relate to one another (cf., 22, 42). Our coding scheme followed Rogers and Farace (43) and classified responses as acknowledgments, elaborations, continuations, concessions, chal-

lenges, follow-up questions, answers, or missing responses. **Table III** provides examples for these coding categories and their examples.

*Corpus size and coding reliability:* The LIWC analyses were performed on all communications that occurred between team members during the six scenarios. Thus, the analyses are based on a total of 30 h of communication, or 7.5 h of communication per team. Our multilayered coding scheme was applied to the team communications that took place during the first and last 15 min of each scenario, which represent low- and high-stress task phases. Thus, these analyses are based on 3 h of communication per team, or a total of 12 h of communication.

Three transcripts were randomly selected and independently coded by two raters to establish the objectivity and feasibility of the coding categories. Inter-rater reliability was 85.5% for the task-related codes, 97.9% for the interpersonal affect codes, 78.1% for classifying interactive patterns, and 86.6% in identifying the respondent to a conversational move. The remaining

TABLE II. CATEGORIES OF INTERPERSONAL AFFECT.

Expressed Affect	Valence	Example
Humor/Joking/Teasing Praise/Pos. Reinforcement Empathy/Concern for Other	Positive	"I'm gonna [be] stuck already." "Flat tire." "Yes, this is good that you . . . give coordinates." "How are you with having this expanded area?"
Politeness Mediation/Appeasement	Neutral	"OK. Thank you." "That's - you know - I'm not scolding you. Trying to figure out how we can get more points." "Well, . . . I mean I apologize for that."
Apology Irony/Patronizing Blame/Critique Insult/Attack Defensiveness	Negative	"I've told you so." "You had the men, if you didn't process anything else on the way." "{loudly} AT LEAST I HAVEN'T RUN OUT OF GAS YET, OK" "I . . . you know, I . . . I don't have the men."

TABLE III. INTERACTIVE PATTERNS: RESPONSES TO PREVIOUS CONTRIBUTIONS.

Response Categories	Examples
<i>Acknowledgments</i> Acknowledgement/Agreement Concession	Blue: "Purple, you can sweep up that double row.." Purple: "Sure, I can." Red: "I'll go up this little one right here." Purple: "OK." (Blue in response to disagreement voiced by Red below) "Oh, OK."
<i>Disagreements</i> Disagreement/Contradiction	Blue: "There's an avalanche there, it's no longer passable." Red: "There was a blockage there, but I cleared it."
<i>Elaborations</i> Elaboration Completion Follow-up Question	Green: "I got waypoint 3." Purple: "So we need 4a and b." Purple: "Oh, so maybe when the first waypoint is found, we should focus" Green: "on that." Blue: "So you'll need to blow that out to get through there, Purple." Purple: "At where again?"
<i>Answers (to Questions)</i>	Purple: "What's the coordinate Red?" Red: "that's at 7, 18."
<i>Missing Response</i>	Blue: "Do seismic monitors show up as man-made objects ever?" (Answer, i.e., required response, is missing.)

transcripts were subsequently coded by one of the coders.

**RESULTS**

*Task-Related Aspects of Team Communication*

A Chi-square test revealed differences in the communications of successful and unsuccessful teams across scenarios regarding the frequencies with which team members mentioned the task-related functions defined in Table I [ $\chi^2$  (4, n = 8855) = 33.31;  $p < 0.0000$ ]. The largest difference was observed in the information-sharing category: 41% of the communications between team members of successful teams concerned information, such as weather and terrain updates, that was necessary to accomplish the mission; in unsuccessful teams this type of communication occurred 36% of the time (Fig. 1).

*Social Aspects of Team Communication*

Data screening revealed that some of our variables tapping the social dimension of team communication were not normally distributed, but instead showed positively or negatively skewed distributions. We, there-

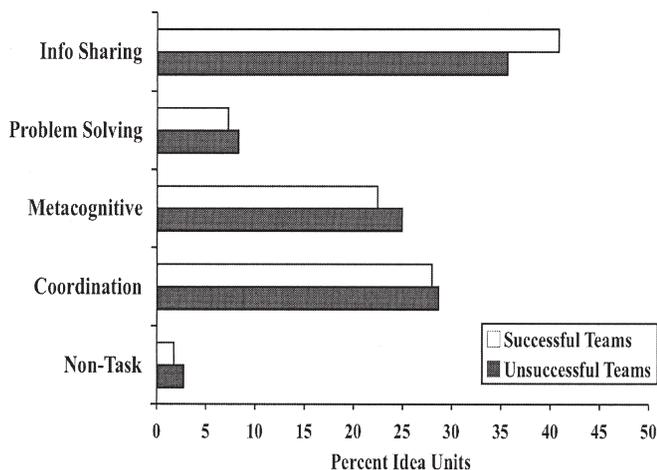
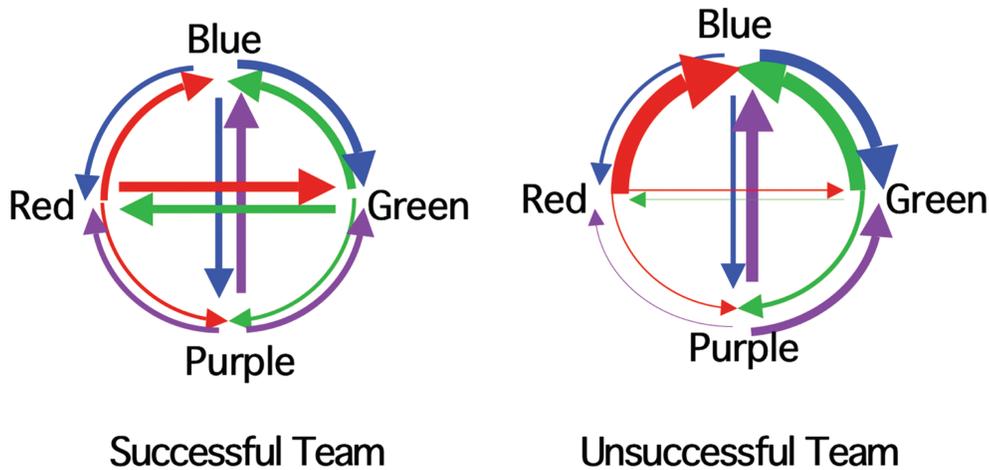


Fig. 1. Distribution of task-related communications in successful and unsuccessful teams.

fore, used the Spearman rank correlation in analyses involving these variables. Results from these analyses will be indicated by the correlation coefficient  $r_s$ . In analyses involving normally distributed variables we used the Pearson Product Moment correlation; the correlation coefficient for these analyses will be given as  $r$ .

*Dominance and control:* For each scenario we computed the standard deviation of team members' word count as a measure of variability in team members' amount of talk and thus as an indication of their differential influence on their team's interaction. We then correlated this measurement with the team's corresponding performance score (i.e., point total) to determine whether team success was related to a particular control structure. A significant negative correlation was found [ $r_s$  (24) = -0.44;  $p < 0.05$ ], suggesting that in unsuccessful teams one or several team members dominated the discourse, while talk and, thus, control were more equally distributed among team members of successful teams.

Analyses of the communication flow between team members in successful and unsuccessful teams lend further support to this interpretation. For each team member, we noted how often the other three team members responded to his contributions during a scenario, and summarized the resulting pattern in a flow diagram. We focused on team members' responses rather than on their initiations to characterize their interactive behavior because team members tended to broadcast their communications for everybody to hear, frequently without identifying a specific addressee. The communication flow typical of unsuccessful teams is represented in the right portion of Fig. 2. As can be seen, the team members called 'Blue' and 'Green' interacted predominantly with one another and formed a subgroup. The remaining members, 'Red' and 'Purple,' seem isolated. While 'Blue' was responsive to both of them, they rarely responded to one another, nor to 'Blue' and 'Green.' Both unsuccessful teams showed this type of pattern in all six scenarios: two or three team members had reciprocal interactions to the exclusion of the other team member or members. In the two successful teams, interactions were more balanced and



**Fig. 2.** Communication flow in successful and unsuccessful teams. Note: Team member at base of arrow indicates speaker, head of arrow indicates team member who responded to speaker. The width of an arrow reflects the proportion of the speaker's contributions responded to by team member to whom the arrow points.

inclusive, as illustrated in the left panel of Fig. 2. Throughout the six scenarios, there was never an outsider; rather, all members participated in the team's discussion.

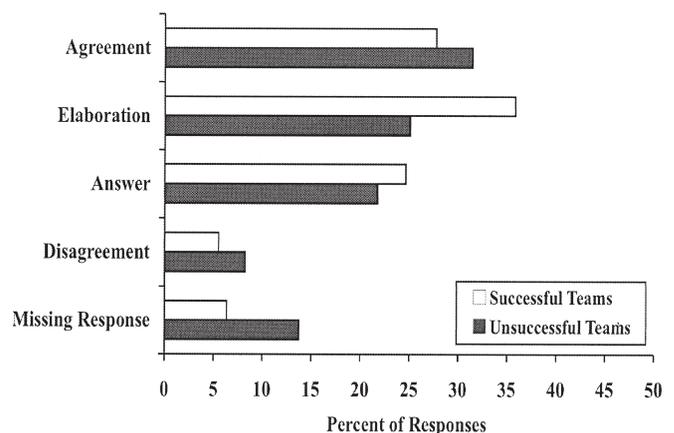
Mathematically we expressed this observation by relating a team's performance to the variance in team members' interactive relations. In order to do so, we calculated the proportion of a team member's contributions that were responded to by each of the other three team members. For instance, in the unsuccessful team depicted in Fig. 2, 'Blue' had 112 contributions; 65 of them were responded to by 'Green,' 'Purple' responded to 27, and 'Red' to 20. Accordingly, the ratio of 'Green's' responses to 'Blue's' utterances was 0.58, for 'Purple' it was 0.24, and for 'Red' 0.18. If 'Green,' 'Purple,' and 'Red' had been equally responsive to 'Blue,' each of these ratios should have been one-third. That is, the spread in team members' responsiveness (i.e., the difference between the maximum and minimum response ratio) is a measure of a team's synergy. In the example provided, the spread in 'Green's,' 'Purple's,' and 'Red's' responsiveness to 'Blue' is 0.40 (difference of 0.58 and 0.18), so 'Blue's' interactive relations to his teammates vary by 0.40. In order to describe a team's synergy during a given scenario, we calculated the mean variance in team members' interactive relations for this scenario. Scores could range from 0, indicating no variance in team members' interactive relations and, thus, a well integrated team, to 1, characterizing a team in which two team members talk with each other to the exclusion of the other two. Teams' mean spread in interactive relations and their performance scores were correlated using Spearman rank correlation. A significant negative correlation was found [ $r_s(24) = -0.54$ ;  $p < 0.01$ ], indicating that balanced and inclusive relationships were associated with higher performance.

**Interactive patterns:** Successful and unsuccessful teams differed not only in the extent to which team members responded to one another, but also in how their contributions related to one another [ $\chi^2(4, n = 6500) = 178.99$ ;  $p < 0.0000$ ]. The largest differences concerned elaborations and missing responses (Fig. 3). Members of successful teams built on and extended the contributions of other team members thus advancing their joint problem solving 36% of the time, while they failed to

provide a required response in 6% of the cases. In unsuccessful teams, elaborations occurred only 25% of the time, while 19% of the communications that required a response lacked one. These patterns indicate that members of successful teams were both more responsive and more collaborative in their interactions than members of unsuccessful teams.

**Group identification:** The frequency with which team members used first-person singular or plural pronouns (i.e., made reference to self or to the team) was not significantly related to team performance [ $r_s(24) = 0.01$  and  $r_s(24) = 0.009$  for references to self and to team, respectively], nor was the ratio of self to team references [ $r(24) = 0.07$ ].

**Interpersonal affect:** We further investigated whether team performance was related to the expression of positive as well as negative affect. Pearson correlation coefficients were calculated between a team's score in a given scenario and the LIWC count of emotion words. The frequency of negative emotion words in team members' communications was not significantly related to team performance [ $r(24) = 0.18$ ]; however, a significant positive correlation was obtained concerning the frequency of positive emotion words [ $r(24) = 0.47$ ;  $p < 0.05$ ]. Team performance was also positively correlated with the frequency of assenting responses (i.e., acknowledgments, elaborations, and continuations) rela-



**Fig. 3.** Distribution of response types in successful and unsuccessful teams.

tive to expressions of dissent [ $r(24) = 0.46; p < 0.05$ ]. Both of these findings suggest the presence of a more positive social climate in successful as compared with unsuccessful teams. This interpretation is consistent with the observation that teams differed in their expression of interpersonal affect [ $\chi^2(2, n = 669) = 42.59; p < 0.0000$ ; Fig. 4]. Specifically, members in successful teams showed more humor (23.8% vs. 15.5% of affective expressions in unsuccessful teams), praise (21.2% vs. 11.6%), and empathy (3.9% vs. 1.1%), while their unsuccessful colleagues displayed more negative behavior, in particular insults (8.3% vs. 1.3% of expressed affect in successful teams) and defensiveness (6.6% vs. 2.0%).

**DISCUSSION**

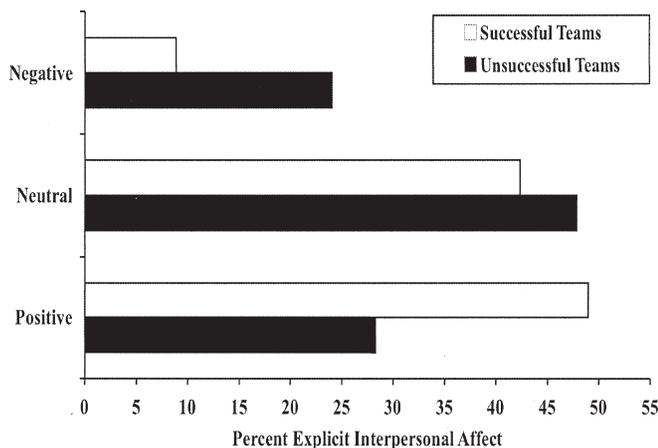
The objective of the present study was to identify features in the communications of team members that reflect team functioning. In order to achieve this goal we needed an analytical tool that enabled us to infer from team members' communications how well the team was performing both on its task and as a team. We, therefore, developed a coding system that focused not only on task-related aspects of team communication, but also on its social dimension. This coding system proved sensitive to differences in team functioning, as we were able to isolate features in team members' communications that were related to team performance.

Consistent with past research on the role of communication in team problem solving, we found that task performance was associated with the extent to which team members shared task-critical information. Unlike past research, however, we did not observe that successful teams talked more about their goals and plans, or showed more progress in monitoring and performance assessments. This finding suggests that differences between successful and unsuccessful teams in our task may have been more related to the quality of their problem solving and meta-cognitions rather than to the

frequency with which they covered these aspects in their communications. Indeed, a qualitative analysis of the teams' task planning revealed that successful teams had more comprehensive plans and better resource management strategies than unsuccessful teams (Tada Y, Orasanu J, Beckum L, et al. Unpublished report. 2006).

Task success of the teams was also connected with certain social aspects of their communications. First, symmetric relationships between team members apparently helped their joint performance. Teams in which individual members equally contributed to the discussion were more successful than teams in which some member(s) talked more than others. In light of past research indicating a relation between amount of talk and interpersonal dominance (39), our finding suggests that control was shared in successful teams, while in unsuccessful teams, one or several team members dominated the conversation and thus the team's actions. Consistent with this interpretation is the observation, as inferred from the flow of their communications, that members of unsuccessful teams split into subgroups. Most of the conversation in unsuccessful teams occurred in the subgroups while the rest of the team was excluded or chose not to participate. Interactions in successful teams, in contrast, were inclusive. Everybody usually contributed to the team discussion, and team members talked with one another. This is an interactive structure suggestive of equality and a distribution of power. While symmetric relationships among team members apparently supported team performance in our task context, different team structures may be beneficial in different tasks, as long as they are inclusive. For instance, Kiekel et al. (25,26) observed in the context of a UAV navigation task that communication in well-performing teams centered around one team member, who, as the "hub" of the team, had an integrating function (i.e., the "hub" received information from team members and disseminated information to the team).

The teams who were successful in our task also differed from unsuccessful teams in terms of their interactive patterns; specifically, in terms of how team members responded to one another. Members of successful teams were more collaborative in their interactions than members of unsuccessful teams insofar as they frequently built on or expanded the contributions of their team mates. In so doing, they not only provided strong evidence of their understanding but also advanced their joint task efforts. Their communication thus reflected and supported their collaborative effort. Members of unsuccessful teams, in contrast, appeared less collaborative. They not only made fewer elaborations, but also often failed to give a response where, according to conversational norms, they were required to do so. Missing responses are likely to disrupt a team's functioning. By breaking with conversational norms, non-responses violate the cooperation principle presumed basic to any communication (8,16). Moreover, since they are ambiguous—possibly indicating an addressee's preoccupation, stress, disagreement, or withdrawal—they introduce uncertainty, increase team members'



**Fig. 4.** Frequency of positive, negative, or neutral interpersonal affect in communications of successful and unsuccessful teams. Note: Positive affect refers to expressions of humor, praise, and empathy. Negative affect includes verbal attacks/insults, attributions of blame, patronizing, and defensiveness. Neutral affect concerns expressions of politeness, attempts to mediate and appease, and apologies.

workload, and may lead to misunderstandings and tension between them.

Differences between successful and unsuccessful teams were also apparent pertaining to their affective communication. Our analyses indicated that members of successful teams were more positive and supportive in their interactions than members of unsuccessful teams. They rarely disagreed with one another, but instead tended to voice agreement and support, and to express positive rather than negative affect, in particular humor, empathy, or praise.

Positive social climate, cooperation, integration, and equality could be either the result of task success, or one of the prerequisites for successful performance. While our dataset is too small to permit causal analyses, evidence in support of both positions can be found in the research literature. Mullen and Copper (32) conducted a meta-analysis of research studies on the relationship between team cohesion and performance, and found a positive but small effect linking cohesion to performance (i.e., cohesive teams tended to perform better than less cohesive teams). However, when the temporal pattern of this association was analyzed, an even stronger effect was obtained relating team performance at time T to cohesion at time T+1. In light of Mullen and Copper's findings we may speculate that the positive social climate we observed in our successful teams may have been the result of their successful task performance, while poor performance may have led to negative exchanges between team members. That is, as teams succeeded on the task, they presumably had more opportunities for positive interactions than failing teams. According to this line of reasoning it was the team's task success that gave rise to praise and promoted a jocular mood in team members.

Positive interactions need not be confined to success; they are possible responses to failure and may, in fact, be constructive coping strategies. Providing encouragement to team mates or interjecting some humor in the face of failure may boost the team's morale and diffuse frustration and tension. Several studies on the role of humor have identified a person's sense of humor as an effective means to mitigate task and interpersonal stress and to facilitate the development of social relationships (9,15).

The notion that team members' relationships may promote or impede their joint performance is implicit in current theories of human communication. A central tenet of these theories is that any communication carries a relational message. Thus, the social component of team members' communications is believed to set the tone and to provide the context for their subsequent team work (24). According to this view the success of our high performing teams would have to be attributed—at least in part—to their positive social climate. Specifically, positive affect and support between the team members as well as inclusive and symmetric interactions may have promoted their collaboration and information sharing, ultimately leading to superior team performance. Conversely, the fact that poorly performing teams were negative, exclusive, and less collaborative in their interactions may have contributed to

their failing. This interpretation is consistent with a path analysis by Orasanu et al. (36) that used data of all 48 participants in the study and related their assessments of their group climate to team performance. This analysis revealed that team members' perception of their team's cohesion predicted their collaboration. Team members' collaboration, in turn, mediated team performance.

Further analyses involving the communication data from all 12 teams will have to be conducted not only to strengthen our present analyses, but also in order to examine the social climate-performance effect in our task environment. In particular, temporal analyses are needed to determine the nature and strength of the relationship between team members' communication behavior and their performance. Our present analyses were the first step in this direction, insofar as they identified performance-relevant features in the communication of teams that, in turn, can be used as the basis for a tool to monitor team functioning.

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