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"Enhancing Team Performance in Exploration Missions"

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Abstract

To reduce the risk of crew error stemming from interpersonal stresses during exploration missions, technologies are needed to monitor and evaluate the state of crew cohesion and functioning. Besides being reliable and valid, the tools should be non-intrusive, sensitive to changes in crew cohesion, and provide feedback to the crew. To enable development of these technologies, we first must identify critical features of crew interactions that signify crew cohesion and effective functioning, as well as features that signal crew distress or poor functioning.

The overall objective of the present research was to examine the utility of team communication analysis to monitoring and evaluating crew cohesion. Using the Distributed Team Cognition Laboratory at NASA Ames Research Center, we conducted two studies involving team performance by *ad hoc* teams who worked on six computer-based distributed team search missions over three days. In study 1 we compared interactions of successful and unsuccessful teams to isolate performance-relevant features in team members' interpersonal communication. The objective was to determine whether interactions in successful teams are characterized by features that, according to socio-linguistic work, reflect healthy relationships. Study 2 was designed to validate whether these features are indeed indicators of team cohesion and to expand our analytical method to online coding.

Several features of interpersonal communication proved sensitive to differences in team performance. Successful teams had symmetric and inclusive interactions; that is, team members contributed equally to the discussions and there were no social isolates. Interactions in successful teams also tended to be more positive, and team members were more responsive to each other, frequently building on or expanding the contributions of teammates. These interpersonal communication patterns in successful teams mirrored the characteristics identified by clinicians and socio-linguists as central to healthy relationships. The second study corroborated the findings from the first study; it also found that teams instructed to work cooperatively expressed more positive affect by the end of the study and also were more cohesive as measured by the Group Environment Scale than teams induced to work competitively. The second study took us a step closer to real-time cohesion monitoring through a method that supported coding of features of team communication that signify cohesion while watching video-recordings of interacting team members. Insights into team dynamics gained from these studies may also be diagnostic of behaviors that need to be targeted by countermeasures in order to maintain cohesion and to assure successful crew performance during exploration missions.

Introduction

The success of long-duration space missions will depend on the ability of crew members to collaborate effectively under highly stressful conditions. The well-being of individual crew members and their functioning as a team may be threatened by psychosocial stressors, in addition to ever-present environmental and task stressors. While crew members are highly selected and technically skilled, "the history of space explorations has seen many instances of poor interpersonal relations and faulty decision making" (SSB & NRC, 1998, p. 195). In both U.S. and Russian Space flights, instances of irritation, increased tension and conflict between crew members have been documented that disrupted missions, and even led to premature termination (Ball & Evans, 2001; Harrison, 2001; Kanas & Manzey, 2008; Kanas, Salinitsky & Grund, 2001; Shepanek, 2005; Stuster, Bachelard & Suedfeld, 2000). Approaches to mitigating the likelihood of psychosocial problems during missions have traditionally emphasized preflight measures, such as team building through training, and the selection of compatible individuals (Bishop, 1997; Kass & Kass, 1999). The benefits of these pre-flight 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 missions so that countermeasures can be introduced once mission-significant changes or trends have been detected. One objective of the present research was to identify features in team members' communications that are indicative of interpersonal stress, and that ultimately could be used to provide alerts and feedback to the crew for appropriate interventions to maintain cohesion. A second objective was to develop a coding method that would support real-time assessment of team cohesion.

Need for Cohesion Monitoring Tools

Psychosocial issues have been considered by some researchers to be the limiting factor in long-duration space missions (Gazenko, cited in Oberg & Oberg, 1986; Stuster, 1996). While no serious mishaps have resulted directly from flight crew interaction problems, the stresses on crews may increase in the future due to the greater risks arising from longer-duration lunar missions and the extremes of isolation from family and friends during Mars missions.

Coping with complex unforeseen problems that may arise during exploration missions, e.g., with the habitat, equipment, automated systems, EVA gear, or health of the crew, will require *team* rather than *individual* efforts. Interpersonal stress or poor team cohesion may increase the risk of crew error or failure to perform mission-critical tasks. Errors may result from degraded team coordination or from failures to communicate effectively, collaborate on non-procedural problem solutions, monitor each other's performance, or back up other crewmembers in the case of overload or error. Thus, NASA is concerned with maintaining high levels of crew cohesion, both as a source of crew stress resilience and to support mission goals. In order to prevent escalating crew tensions and deterioration of crew performance, tools and technologies are needed for monitoring and evaluating team psychosocial health to determine whether interpersonal problems are developing. This information can be fed back to the crew as a basis for implementing countermeasures (e.g., Carter's Conflict Management Tool, 2005) before a small problem becomes a large one.

Requirements of Cohesion Monitoring Tools

To be useful and usable, a cohesion monitoring system must be capable of detecting and assessing features that indicate healthy or deteriorating crew cohesion and of providing alerts and feedback to the crew for appropriate interventions. Such a system should meet several requirements:

- Be reliable, valid, and sensitive to changes in levels of cohesion over time and as a function of interventions
- Provide diagnostic information concerning the nature of team interaction problems, not simply changes in level of cohesion
- Be non-intrusive, i.e., not require active input from the crew
- Be automated, i.e., not require judgment or input from an outside observer
- Provide readily understood and actionable feedback to the crew

While a system that meets all these requirements is many years in the future, research that lays the foundation for such a system is being conducted today. Several logically sequenced steps are needed in order to reach the ultimate goal of an automated cohesion monitoring system.

1. A clear definition of cohesion is needed. At present the concept is rather murky, with several diverse measures used to operationally define the concept (Carron & Brawley, 2000; Mudrack, 1989). Convergent validity must be established using a variety of measures and their sensitivity to change must be established.
2. Evaluate cohesion assessment concepts required for Step 1. This will entail research in several stages, from controlled lab experiments to space analogs, to test the soundness of the cohesion features, their validity and sensitivity. Initial approaches will involve the crew in subjective self-report as well as observer ratings of relevant behaviors. This is the present state of the art; non-intrusive automated approaches will be grounded in findings from current techniques.
3. Once validated, sensitive, diagnostic approaches have been established, technologies for automating these techniques will be developed. Research in step 2 will determine *what* needs to be monitored; in step 3 research will establish the validity of the automated system compared to self-report, observer ratings, and objective performance data.
4. Appropriate feedback to the crew based on the product of the monitoring system will be designed and tested with relevant non-astronaut work groups. Feedback development will begin during lab and analog validation work in step 2.
5. The integrated automated monitoring and feedback system will be evaluated in operational NASA environments with astronaut crews in ground-based simulations and ultimately in the ISS.

The research described in this report addresses primarily steps 1 and 2, and lays the foundation for steps 3 and 4. Team communication was analyzed to isolate features indicative of team cohesion. This research is grounded in clinical and socio-linguistic work on healthy versus dysfunctional marital or parent-child interaction patterns.

Definition of Team Cohesion

Festinger (1950) defined group cohesiveness as "the resultant forces, which are acting on the members to stay in a group" (p. 274). Typical components of cohesion that have been studied include work satisfaction, commitment to group goals, interpersonal attraction, and group identification. Cohesion arising from a common response to a task-related challenge has been termed *task cohesion*. Hackman (1987) defined task cohesion as shared commitment to a collective effort. MacCoun (1993) further elaborated task cohesion as "shared commitment among members to achieve a goal that requires the collective efforts of the group. … members are motivated to coordinate their efforts as a team to achieve that goal." (p. 291). A second type of cohesion is *social cohesion*, the extent to which team members "like each other, prefer to spend social time together, enjoy each other's company, and feel emotionally close to one another" (MacCoun, 1993, p. 291). Clearly, both types of cohesion are relevant to exploration missions. While it may be assumed that task cohesion will be high among astronauts and Mission Control teams, it will be equally important for flight crews to be happy living and working together in isolation for extended periods of time.

Benefits of Cohesion: The Relations Between Cohesion, Resilience, and Performance

One of the purported benefits of cohesion is that it serves as a source of resilience to members of a group, helping them to cope with stressful situations. Exactly how that occurs is not well understood, but it has been documented in several critical and highly stressful environments. For example, among submariners exposed to accidents at sea, high ratings of unit cohesion were associated with low levels of PTSD and other stress symptoms and with good reported mental health (Eid & Johnsen, 2002). In clinical medicine, strong perceived family cohesion acted as a protective factor for individuals undergoing major surgical procedures, promoting resilience to the stresses of surgery (Phipps & Mulhern, 1995). Family conflict, on the other hand, served as a direct risk factor that adversely affected adjustment after the procedure.

Despite the positive relationship between cohesion and psychological coping during stress, there is ambiguity concerning the direction of causality. Cohesion could serve as a stress buffer, providing social support for psychological coping. Conversely, those who cope better may reach out and work well with others, thereby fostering cohesion. Also, a third factor could be driving both, such as strong leadership, organizational support, or ideological commitment.

While social cohesion has been related to stress resilience, task cohesion appears to be the main driver of team performance (e.g., Beal, Cohen, Burke, & McLendon, 2003). In addition, several meta-analyses suggest that the team cohesion-performance link is bi-directional. Mullen and Copper (1994) report that team cohesion promotes performance; however, successful performance promotes cohesion even more strongly. In an attempt to determine the causal effects of performance on cohesion and vice-versa, Carron et al. (2002) separated studies on sports teams into those that measured cohesion before performance—and those that measured cohesion after performance. There were high correlations in both directions, and these correlations were not significantly different from each other.

Existing Tools for Assessing Team Cohesion

Given the long history of concern with cohesion in the military and sports domains, several measures have already been developed for assessing team cohesion. They fall into two broad categories: self-report questionnaires or reports and objective behavior-based approaches.

Self-Report Questionnaires

Team cohesion is typically assessed through self-report questionnaires that reflect group members' *perceptions* of cohesion, such as the Group Environment Scale (GES, Moos & Humphrey, 1974) or the Group Environment Questionnaire (GEQ, Carron, Widmeyer, & Brawley, 1985). The GES includes subscales that assess several dimensions of group climate, including Cohesion, Anger and Aggression, Order and Organization, Innovation, Expressiveness, and Independence, dimensions that are expected to relate to team performance. The GEQ was developed to examine cohesion in sports teams. It is a 4-factor model that taps into both social and task cohesion by assessing individual attraction to the group and group integration or unity in the achievement of goals.

A second subjective-report approach is the use of *sociograms*. These are preference rankings of group members on the basis of a specified criterion, such as social relations, influence, communication, or work partners (Dimock, 1993; Moreno, 1960). Frequently represented graphically, sociograms depict reciprocal relationships, isolation, cliques, and leaders.

While self-report techniques are widely used and have been validated on diverse populations, they suffer several limitations. The GES and GEQ both present demand characteristics that may create response biases: respondents may want their group to look good and can manipulate their responses to those ends. For example, data from a recent NEEMO expedition yielded GES cohesion scores uniformly high, near ceiling. In addition, questionnaire data may suffer from a halo effect: if responses are collected following a successful task, positive scales may be inflated. Data from a recent study in our laboratory with ad hoc teams also found extremely high GES cohesion scores with little variability after a successful mission (Orasanu, et al., 2008). Similarly, following a negative experience, judgments may be depressed. These biases can result in distortions that reduce their sensitivity. Also, these instruments do not offer actionable diagnostic feedback to participants.

In contrast to other self-report measures, sociograms are inherently graphic, clearly illustrating the structure of team relationships such as subgrouping and changes in those relationships over time. While they are very good at depicting this structural aspect of team member preferences, they provide no information on the basis for the structure, such as why one member is an isolate, or information about the level of attraction among members.

Behavior-Based Measures of Cohesion

Behavior-based approaches to assessing cohesion rely on interpersonal behavior rating scales and team communication.

Small Group Research. Many researchers studying small group behavior have found that the three most important dimensions of behaviors in groups are

- Positive / negative behaviors
- Task-oriented / expressive behaviors
- Dominant / submissive behaviors

(Isenberg & Ennis, 1981; Parke & Houben, 1985; Schaefer, Droppleman, & Kalverboaer, 1965; Wish, D'Andrade, & Goodnow, 1980). The most commonly used method for coding group interaction has been Interaction Process Analysis, or IPA (Bales, 1950). One of the most important results from this research was the demonstration that both task and socio-emotional/expressive behaviors are important in a group, and that well-functioning groups move through a cycle of task-related behaviors and socio-emotional/expressive behaviors (Bales, 1953).

Bales & Cohen (1979) have suggested that behaviors along two of these dimensions be plotted in a two dimensional space, with the third dimension (dominant/submissive) represented by varying sizes of circles. This approach, called the Group Diagramming Method (GDM) allows *all* the behaviors in a team to be taken into consideration, and hence enables team dynamics to be portrayed and analyzed.

Using a 26-item rating instrument (Parke & Houben, 1985) that captures behaviors on these three dimensions, members rate the frequency with which each of the other members displays the behaviors (i.e., not often, sometimes, often). Numerical scores on these dimensions permit calculation of measures of similarity or diversity among members, clusters of behaviors that characterize more or less cohesive or effective teams, and changes over time (Sandal, 2001).

Team Communication. The vast majority of team communication research has focused on task-related discourse, i.e., how team members' communications support their joint task. Virtually absent is research on relational communication that reflects social relationships between speakers (Keyton, 1999). Various aspects of an individual's speech and communication with others may indicate team cohesion. For instance, voice stress is sensitive to psychosocial stress states, which may eventually be shown to reflect interpersonal conflict (Lieberman, Morey, Hochstadt, Larson, & Mather, 2005). Prosodic mimicking was found to be one of several features that reflect mutual attraction and negotiation success in dyads (Pentland, 2004), and may also prove to be useful for assessing team cohesion. The flow of the communication between team members (i.e., who is talking with whom) has been discussed as a measure of team cognition (Kiekel, Cooke, Foltz, Gorman, & Martin, 2002), but may also be a sensitive measure of the social structure in teams. Research on marital and family dynamics has linked linguistic expressions of interpersonal affect and interactive patterns (e.g., dominating the discourse) with healthy and stable, or unhealthy and unstable, relationships (Carrère & Gottman, 1999). These features may also be useful for characterizing cohesion in teams.

An obvious advantage of using communication as a source of information about cohesion is its ready availability in almost every team situation. Its downside is the laborious and costly process of transcription and hand coding of the data. While automating communication analysis is a promising alternative, available approaches are still limited. Sequential analyses (c.f., Kiekel et al., 2002) rely on highly structured and proceduralized communications in which addressees are clearly identified. Moreover, analyses are content-free; i.e., adjacent contributions by different speakers are assumed to be related based solely on their proximity. In contrast, team tasks that require joint problem solving and decision making typically show less structured communications as several team members interact and build on each other's contributions.

Unlike sequential analysis, Latent Semantic Analysis (LSA) is sensitive to meaning. However, it requires a corpus of domain-relevant text or tagged statements against which input text is compared. While a representative corpus may be readily available for some research questions and domains (e.g., training manuals to identify task-relevant talk in team members' communications), appropriate databases are lacking to be used in an automated assessment of team cohesion. Moreover, LSA in its present form requires that audio recordings be manually transcribed first to text files.

Goals of the Present Study

Two studies were conducted to develop and evaluate linguistic analysis techniques that are suitable for monitoring and measuring team cohesion and that overcome the limitations of self-report measures. Ultimately, cohesion assessment tools must be reliable, valid, and sensitive to changes, provide feedback to the crew, and have potential to be automated. The findings presented here are initial steps along the way.

Linguistic Indicators of Team Cohesion

Prior research on team performance, much of it in aviation and the military, clearly shows the importance of team communication to effective task performance (Cannon-Bowers & Salas, 1998; Orasanu & Fischer, 1992; Prince, Stout, & Salas, 1995). While most team communication research has focused on features that are indicative of how well a team performs on the task, interpersonal issues (that is, how well team members get along as a team) have been largely ignored (Keyton, 1999). However, the social function of communication comes into play even in the context of professional team interactions (Lauche, Ehbets-Müller, & Mbiti, 2001). As team members communicate to achieve their task objectives, they also define (and reaffirm) the nature of their relationships, thus creating a social context that may support or impede their joint task work (Ginnett, 1993).

The interpersonal aspect of human communication has traditionally been studied by social linguists and clinical psychologists interested in describing interactions mostly in dyads. While their primary concern has been to understand how, for example, interactions in happy and unhappy couples differ (Carrère & Gottman, 1999), researchers have identified interpersonal dimensions that may be used to assess cohesion in work teams as well, such as dominance and control, expressed affect, consent, and support.

Dominance and Control

The issue of dominance and control is reflected in the symmetry or complementariness of people's interactions (Watzlawick, Bavelas Beavin, & Jackson, 1967). 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 (Millar & Rogers, 1976; Palmer, 1989). They also tend to be the focal point of interactions as others predominantly respond to them (Kiekel, Gorman, & Cooke, 2004). Symmetric interactions, in contrast, are characterized by equality: individuals contribute equally and take turns in controlling the topics of their conversation. Analyses of the communication flow among team members have indicated that it is a sensitive measure of cognitive team processes (Kiekel, et al., 2002; Sandal, Vaernes, & Ursin, 1995); in addition they may be used to track the leadership structure in teams over time and to determine shifts and breakdowns in a team's control structure.

Team Collaboration

Interactive patterns may also reflect how well team members collaborate with one another and get along. On a relational level, collaboration concerns the extent to which individuals are responsive to one another, take up and extend each other's contributions, and build consensus (Resnick, Salmon, Zeith, Wathen, & Holowchak, 1993; Rogers & Farace, 1975). 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 deemed necessary for team success (Bales, 1976).

Relational Communication

Team members' affective attitudes towards one another may 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 (Carrère & Gottman, 1999). 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 (McLennan, Holgate, Omodei, & Wearing, 2005). 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 is team members' use of personal pronouns, in particular the extent to which they rely on first person singular ('*I*') versus plural ('*we*') pronouns. In studies of marital health, spouses' references to *we* and *us* were found to indicate their degree of shared identity and to predict marital success (Buehlman, Gottman, & Katz, 1992). 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 (2000) based on communication of airline crews, but Gushin and Yusupova (2005) 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 the crew's actions.

The present research involved two studies. Study 1 was conducted to identify interpersonal features in team members' communications that are associated with successful task performance. Study 2 was designed as a validation and methodological extension of these findings.

Study 1: Interpersonal Aspects of Team Communication Associated with Task Success

This study was conducted to identify performance-relevant features in team members' interpersonal communications. The objective was to determine whether interactions in successful teams are characterized by features that, according to socio-linguistic and clinical work, reflect healthy relationships. Given the exploratory nature of this research, we focused on teams at the extremes of the performance spectrum. We compared communication among members in teams that were consistently successful (i.e., high scoring) with communication in teams that were consistently unsuccessful (i.e., low scoring) across six simulated search and rescue missions. We hypothesized that members of successful teams would 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 (that is, whether task success is related to complementary or to symmetric interactions).

Method

Participants

Forty-eight males were recruited as participants via flyers and community online sources. Participants were between 25 and 45 years of age ($M_{age} = 33.5$); 92% were college graduates and 100% were born in the U.S. All participants were paid for their time. 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.

The present analyses are based on the data of 16 participants (or 4 teams). These teams were consistently high or low scoring in all six experimental scenarios. Team performance was operationalized in terms of points earned during each simulated search mission. Team points for the high-scoring teams ranged from 985 to 2585 points ($M = 2025$) and for the low-scoring teams from 365 to 1770 points ($M = 1098.75$).

Experimental Task

Our research involved the Distributed Dynamic Decision-Making (DDD) simulation task environment developed by Aptima, Inc. (Entin, Kerrigan, Serfaty, & Yound, 1998). 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 medical diagnosis). The computer-based task environment presents graphical displays of evolving problem scenarios and engages team members in a low- to mid-level fidelity mission.

The DDD scenarios used in this 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 email and a voice system. Team members' main objectives during a mission were to locate and rescue a crew thought to be lost, to complete the missing crew's repair mission, and to retrieve an important fallen 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 upon completion of each main task. During their search, participants encountered several time-critical emergency tasks designed to introduce task conflict. Team members were penalized by losing points if they ignored these emergency tasks. If they completed them, they gained points; however in so doing, they could be sidetracked from their main tasks or use up valuable resources.

During mission training members of a team were randomly assigned the role of search team member or base station coordinator. They remained in their assigned roles throughout the six missions. While team members' roles were associated with different task functions, no team member was designated as the official leader. Team coordination and communication were not constrained or defined by the experimenters; it was left to the team members to determine the nature of their interactions.

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 played the role of the base station coordinator, called 'Blue,' and 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 downed satellite and missing team were transmitted only to the base station. The base coordinator had to decide which information to disseminate and whether to address the entire team or individual members. As searchers 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, search team members could gain additional information, whose significance was indicated by the point value of the information source, ranging in value from 10 to 80. However, searchers consumed vital resources as they processed these information sources.

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 levels. 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 to replenish fuel and personnel with the assistance of the base station coordinator. Running out of fuel meant that a searcher would no longer be able to help with the search.

Six search and rescue scenarios were developed, representing two levels of task difficulty. Three high difficulty scenarios presented team members with more ambiguous information than the three moderate difficulty scenarios; they also required 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 minutes to accomplish the task objectives. All missions were sufficiently difficult that they could not be completed unless team members worked together to plan effective search and coordination strategies, divide the workload, manage resources, and communicate critical information.

Procedure

The experiment extended over four days. On Day 1 participants were trained to use the experimental software and completed a practice mission. On the following three days teams worked through six experimental missions, one moderate and one difficult scenario per day. Scenario order was counterbalanced across teams. Prior to each mission, participants had 20 minutes to plan for the upcoming mission. 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 and activity during the mission. Each team member's communications were digitally recorded through his headset and routed to a video recorder where video and audio data were synchronized and time-stamped.

Analysis of Team Communication

The present analyses are based on team members' voice communications during the six missions. Communications were recorded, transcribed and analyzed using the Linguistic Inquiry and Word Count (LIWC) software (Pennebaker, Francis, & Booth, 2003). This software counts linguistic features of written text that have been shown to reflect a speaker's (or author's) cognitions, attitudes, and affect (Pennebaker, Mehl, & Niederhoffer, 2003). In addition to the LIWC software, we used a multi-layered coding scheme specifically developed to characterize certain interpersonal aspects of team interactions. Team members' contributions were segmented into units that consisted of a verb and its arguments, or had an elliptical structure. Units with a given social function received an appropriate code (see below for a characterization of coding categories). Units that did not serve any of these social functions (e.g., no interpersonal affect was expressed, or unit referred to a speaker initiation rather than a response) were not assigned a code. The exception were speaker initiations that were left unanswered as our coding noted the absence of a required response.

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 (first person singular pronoun, that is, '*I*') or to the team (first person plural pronoun, '*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.

Table 1. Categories of Interpersonal Affect

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

Hand-coding team members' communications for expressions of specific interpersonal affect complemented these LIWC categories. Our affect codes were modeled after coding schemes psychologists have used to classify speaker affect in marital interaction (Gottman, 1998; Krokoff, Gottman, & Hass, 1989). We coded whether or not speakers verbalized affective reactions towards teammates; when they did, we further noted whether they expressed praise or empathy, showed humor or politeness, tried to appease, or were apologetic, patronizing, criticizing, or defensive (see Table 1 above for a listing of the categories and examples).

Table 2. Interactive Patterns: Responses to Previous Contributions

RESPONSE CATEGORIES	EXAMPLES
Acknowledgments - 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."*
Disagreements - Disagreement/Contradiction	- Blue: "There's an avalanche there, it's no longer passable." *Red: "There was a blockage there, but I cleared it."*
Elaborations - 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?"*
Answers (to Questions)	- Purple: "What's the coordinate Red?" *Red*: *"that's at 7,18."*
Missing Response	- Blue: "Do seismic monitors show up as man-made objects ever?" *<Answer that is required response, is missing.>*

Finally, our coding characterized 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 to their conversational partner's preceding contribution in their own current contribution (Schegloff & Sacks, 1973). While conversational norms dictate that speakers respond to previous utterances, they only loosely constrain how speakers may do so. Several classification systems that vary in purpose and specificity have been proposed in the past to characterize how utterances by conversational partners relate to one another (c.f., Kanki, Lozito, & Foushee, 1989; Resnick et al., 1993). Our coding scheme followed Rogers and Farace (1975) and classified responses as acknowledgements, elaborations, continuations, concessions, challenges, follow-up questions, answers, or missing responses. Table 2 above provides examples of these coding categories and their examples.

Corpus size and coding reliability. The entire corpus consisted of all communications that occurred between team members during the six scenarios, for a total of 30 hours of communication, or 7.5 hours of communication per team. The automated LIWC analyses were based on the full 7.5 hours per team. Our multilayered coding scheme was applied to the team communications that took place during the first and last 15 minutes of each scenario, which represent low- and high-stress task phases. Thus, these analyses are based on three hours of communication per team, or a total of 12 hours of communication.

Three transcripts were randomly selected and independently coded by two raters to establish the reliability 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% for identifying the respondent to a conversational move. All of the remaining transcripts were subsequently coded by one of the coders.

Results

Data screening revealed that some of our variables were not normally distributed but instead showed positively or negatively skewed distributions. We therefore used the Spearman rank correlation for 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

Distribution of talk. For each mission we computed the standard deviation of all team members' word counts 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 (that is, point total) to determine whether team success was related to a particular control structure. A significant negative correlation was found, $r_S(22) = -.44$, $p < .05$, indicating that in unsuccessful teams one or several team members dominated the discourse, while talk and thus control were more equally distributed among team members in successful teams.

Communication flow. 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 each of the other three team members responded to his contributions during a mission and summarized the resulting pattern in a flow diagram. The communication flow typical of unsuccessful teams is represented in the right panel of Figure 1 below. As can be seen, the Blue and Green team members interacted predominantly with one another and formed a sub-group. The remaining members, Red and Purple, seem isolated. While Blue was responsive to both of them (i.e., the thick red line and the medium purple one originating from Blue), they rarely responded to one another, nor to Blue or 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 inclusive, as illustrated in the left panel of Figure 1. Throughout the six scenarios, no member of the successful teams appeared as an isolate; all members participated in the team's discussions.

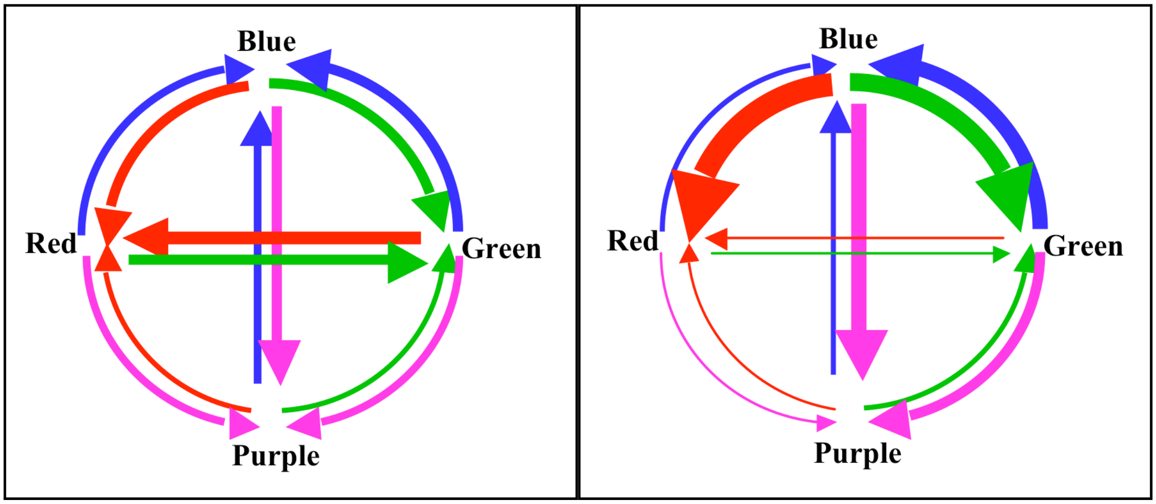

Figure 1. Communication flow in successful (left panel) and unsuccessful (right panel) teams

Note: Color and head of each arrow indicate team member who initiated a communication; base of the arrow indicates team member who responded to that initiation. Thus, all red arrows represent responses to the Red team member's initiations. The width of an arrow reflects the proportion of a team member's initiations that were responded to by the team member at the base of the arrow.

We expressed this observation mathematically by relating a team's performance to the variability 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 Figure 1, Blue initiated 112 contributions; 65 of them were responded to by Green, 27 by Purple, and 20 by Red. Accordingly, the proportions of all responses to Blue's initiating utterances were .58 for Green, .24 for Purple, and .18 for Red.[1] The spread in team members' responsiveness (that is, the difference between the maximum and minimum response ratio) is a measure of a team's balance of responsiveness. In the example provided, the spread in Green's, Purple's, and Red's responsiveness to Blue is .40 (difference between .58 and .18), so the team's interactive relations to Blue vary by .40. In order to describe a team's responsiveness balance during a given mission, we calculated the mean of team members' spread in interactive relations for that mission. Scores could range from 0, indicating no variability in team members' interactive relations and thus a well-integrated team, to 1.0, characterizing a team in which two team members talk with each other to the exclusion of the other two. We correlated teams' mean spread in interactive relations and their performance scores per mission using Spearman rank correlation. A significant negative correlation was

[1] This calculation is independent of the total number of initiating contributions made by each team member; rather, only initiations that received a response were included. Also, one might question whether a team member addressed his initiations disproportionately to one or two of the other three members. However, most initiations were broadcast; hence, anyone could choose to respond.

found, $r_S(22) = -.54$, $p < .01$, indicating that balanced and inclusive relationships were associated with higher team 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, $\chi^2(4, N = 6500) = 178.99$, $p < .0001$. As can be seen in Figure 2, the largest differences concerned elaborations and missing responses. 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.

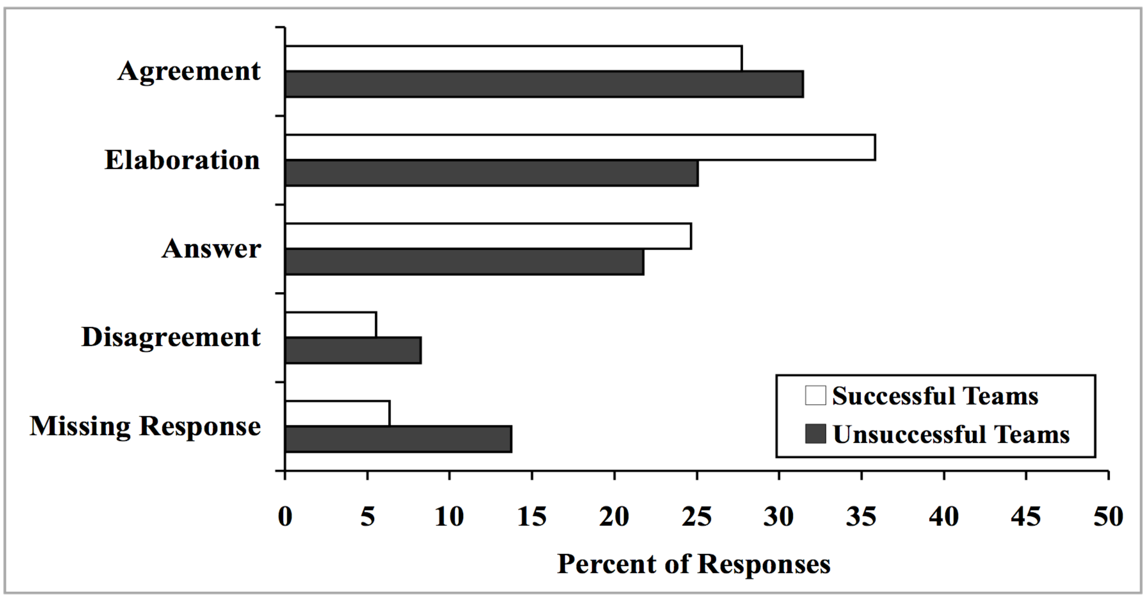

Figure 2. Distribution of response types in successful and unsuccessful teams

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 mission and the LIWC count of emotion words. The frequency of negative emotion words in team members' communications was not significantly related to team performance, $r(22) = .18$. However, a significant positive correlation was obtained between the frequency of positive emotion words and team performance, $r(22) = .47$, $p < .05$. Team performance was also positively correlated with the frequency of assenting responses (i.e., acknowledgments, elaborations, and continuations) relative to expressions of dissent, $r(22) = .46$, $p <. 05$. Both of these findings suggest the presence of a more positive social climate in successful as compared to unsuccessful teams. This interpretation is consistent with the observation that teams differed in their expression of interpersonal affect, $\chi^2(2, N = 669) = 42.59$, $p < .0001$ (see Figure 3). Specifically, members in successful teams showed more humor (23.8% versus 15.5% of affective expressions in unsuccessful teams), praise (21.2% versus 11.6%), and empathy (3.9% versus 1.1%), while their unsuccessful colleagues displayed more negative behavior, in particular, insults (8.3% versus 1.3% of expressed affect in successful teams) and defensiveness (6.6% versus 2.0%).

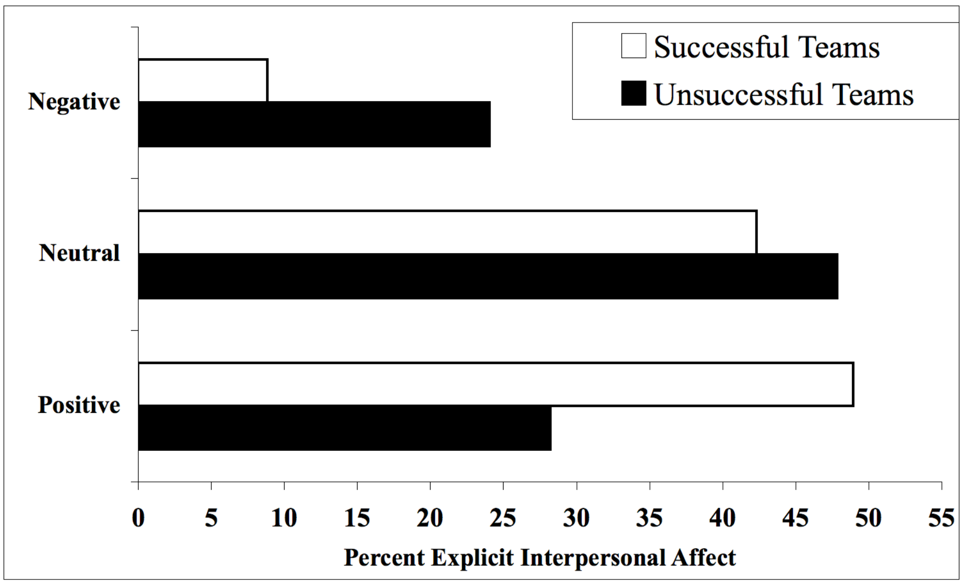

Figure 3. Frequency of positive, negative or neutral interpersonal affect in communications of successful and unsuccessful teams

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.

Group Identification

The frequency with which team members used 1st person singular or plural pronouns (that is, made reference to self ('I') or to the team ('we') was not significantly related to team performance, $r_S(22) = .01$ and $r_S(22) = .009$, for references to self and to team, respectively, nor was the ratio of self to team references, $r(22) = .07$.

Discussion

The objective of this study was to determine whether successful and unsuccessful teams differ in terms of their interpersonal communications, and more specifically, whether successful teams show communication patterns that socio-linguistic and clinical research associates with healthy relationships. As the prior body of work had focused on dyads, predominantly on interactions between spouses or between parent and child, it was not at all clear whether its conceptual distinctions would generalize to a team context. Several aspects of interpersonal communication proved sensitive to differences in team performance. 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 (Palmer, 1989), 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 their communications, that members of unsuccessful teams split into subgroups. Most of the conversation in unsuccessful teams occurred in 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 and his collaborators (2001; 2002) 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, no-responses violate the cooperation principle presumed basic to any communication (Clark & Schaefer, 1989; Grice, 1975). Moreover, since they are ambiguous—possibly indicating an addressee's preoccupation, stress, disagreement, or withdrawal—they introduce uncertainty, increase team members' 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.

This study thus equipped us with discourse features and analytic tools for assessing team cohesion. However, since the analyses were based on transcribed discourse, their practical application for monitoring team cohesion was limited. Our subsequent research was conducted to overcome some of these limitations by adapting our method for online coding.

Study 2: Adaptation of Communication Coding Techniques to On-line Coding

This study had two objectives. On the one hand, we wanted to validate that the linguistic features identified in Study 1 are indeed indicators of team cohesion. To do so, we examined whether these features could discriminate between teams in which the team climate had been manipulated (interpersonal competition vs. cooperation). The second objective was methodological: to develop a coding method that could be used to assess team cohesion directly from video recordings of team member interactions without the need for time-consuming dialogue transcription. Building on our previous study, the new coding targeted those relational aspects of team communication that had been identified as significant indicators of high levels of team functioning, that is, *inclusive and symmetric interactions*, *shared conversational control*, and *positive affect*. The challenge, however, was to adapt the coding categories used in Study 1 for online coding. We had to find a level of analysis that was not too fine-grained so that coding could be done reliably online; at the same time it had to be sufficiently specific to capture those critical aspects of team members' interactions.

Method

Participants

Ninety-six participants (50% female) were recruited via flyers and community online sources for this study. Participants were between 22 and 50 years of age (M_{age} = 32.7); 95% were college graduates and 98% were born in the U.S. All participants were paid for their time. Participants were randomly assigned to either single- or mixed-gender four-person teams resulting in eight all-male, eight all-female, and eight gender-mixed (2 males, 2 females) teams.

Individuals in a team were trained together on the experimental task and remained in the same team for the duration of the experiment. Half of the teams (equally distributed across gender composition) were instructed to work together as a team to accomplish the search goals and to earn as many points as possible (cooperative condition; i.e., instructions sought to induce team task cohesion, c.f., Zaccaro, Gualtieri, & Minionis, 1995). Members in the remaining teams were instructed to compete with each other to achieve the search goals and earn points on their own (competitive interpersonal stress condition).

The present analysis is based on a subset of twelve teams. Four all-male, four all-female, and four gender-mixed teams were randomly selected for analysis. Six of these teams (two per gender composition) worked under cooperative instructions, six under competitive instructions.

Experimental Task and Procedure

The study was conducted in the Distributed Team Performance Laboratory at NASA Ames Research Center and involved the same procedure as during our Phase 1 work. As before, participants completed six 75-minute missions. Missions were of two levels of difficulty (moderate versus high) and simulated geological search tasks in Antarctica.

Measures

Cohesion Measures

GES. The Group Environment Scale (GES; Moos & Humphrey, 1974) is a self-report measure of perceived social climate. The version used here consists of 6 subscales: cohesion (tightness of the group), expressivity (tendency to share thoughts and express emotions in a group), independence (members can depend on themselves), innovation (members are encouraged to be creative), anger and aggression (expressed hostility in a group), and order and organization (a group is organized versus disorganized). Our adapted version used 48 of the original 90 items. Subscales and items that were not relevant for the lunar search task were removed, resulting in a 4-minute test. It was administered once, following completion of the last search mission.

Group Communication Efficacy Questions. After their last search mission participants were asked to rate their "group's ability to communicate very effectively with each other," as well as the extent to which team members "were able to explain clearly to each other what they thought." Ratings could range from 1 to 7, and were averaged across items.

Analysis of Team Communication

Structure of Team Members' Interactions. While the transcript-based analyses of our previous study characterized the structure of team members' interactions in terms of adjacency pairs, this level of analysis could not be performed reliably in real-time. Instead of coding team interactions on the level of individual turns and their functional relationships (e.g., question-answer, or statement-elaboration), we found that we could reliably describe the structure of team members' interactions on the level of exchanges. Table 3 below provides examples of this type of coding.

An exchange was defined as a sequence of turns by two, three, or all four team members. Turns were considered part of an exchange if they occurred in relative succession to one another (i.e., not separated by prolonged pauses) and were thematically related. In addition to pauses and falling intonations, the end of one exchange and the beginning of a new one could also be signaled by shifts in participants and topics: A new exchange was initiated when the participant of an ongoing exchange introduced a new topic and with the change in topic shifted conversational partners, either to a subset of his or her current partners or to a team member who had not been part of the ongoing exchange. In addition to being terminated from the inside, an ongoing exchange could be terminated from the outside (i.e., a team member who was not part of an ongoing exchange stepped into the exchange, but instead of joining it, introduced a new topic and pulled one or several of the original participants into a new exchange). For each exchange we noted its starting time and who participated in it; exchanges that were initiated by one team member but did not receive a response were coded as unreciprocated.

Table 3. Examples Illustrating the Coding of Team Member Exchanges

		ANNOTATION:
Blue	Can someone summarize for me what's left for us? We have one stone but not the other?	*This example illustrates how team members can be brought in or join ongoing conversation between others. In the* example *Green answers Blue's question and by referring to Red, he draws him into the conversation. Purple subsequently joins the ongoing conversation. (Note: Links between different speakers are highlighted by the same color.)*
Green	We have Omega still outstanding and Red is about to process an emergency.	
Red	I think we are missing an emergency. I really do.	
Blue	Well the other stone could be right off the path	
Purple	I'm heading right up, I'm right on the horizontal, between 9 and 13. I might have missed it there.	
	(Short pause)	
Red	Where are you?	*Here, Red pulls Purple out of the conversation by changing the topic from potential location of missing stone to current location of Purple. An exchange between these two team members ensues in which Purple tries to clarify her location.*
Purple	Between, ah, on the y between 9 and 13.	
Red	On the y?	
Purple	Between 9 and 13 on your y column, the horizontal. With me?	
Red	No. I've completely lost you.	
Purple	19, 11 are my coordinates.	
Red	Gotcha. Now I know where you are. OK.	
Blue	Red, when you're done where are you headed?	*This example typifies an exchange that is set off from previous discourse by a pause; its end is marked by turn-ending signal (yeah, yeah and falling intonation), and subsequent pause.*
Red	I'm gonna head up to the left margin	
Blue	OK. So	
Red	into that lovely storm. Could you, did you restock me as well?	
Blue	Did I restock you?	
Red	Can you, can you restock me again? I might as well stock up.	
Blue	Yeah, yeah	

Expressions of Positive Affect. Three broad categories of positive affect were distinguished. Examples and definitions are provided in Table 4 below. In addition to coding the type of positive affect, we noted its time of occurrence, who initiated the positive interaction, and to whom it was directed.

Corpus Size and Coding Reliability

Data included in the present analyses were the voice communications between team members that occurred during the missions on the first and the last day (two missions per day). That is, analyses are based on 60 hours of communication, or 5 hours of communication per team.

To establish the objectivity and feasibility of the exchange coding, two raters independently coded two missions, randomly selected for this purpose. To assess the reliability of the positive affect coding, four different missions were randomly selected. Inter-rater reliability as measured in terms of Cohen's Kappa was .71 and .81 for the exchange and positive affect coding, respectively.

Table 4. Categories of Positive Affect

CATEGORIES OF POSITIVE AFECT	EXAMPLES
Compliment - Expression of appreciation of teammate's performance or actions (code only if compliment concerns other player but NOT if it is a comment on the value of information received, e. g., from a seismic monitor) - Cheering - Encouragement • Comments aiming to build teammate's confidence or confidence in team - Expressions of joy	"Good idea!" "Excellent" "that's alright. You're coming." "This is awesome" (= reference to progression of session; team success)
Endearment - Forms of address such as 'honey" or 'pal"	"Oh, I am sorry, honey."
Humor - Task-related Jokes • Reference to features, quirks of the game, or events in the game - Cultural Jokes • Word play • Reference to culturally based knowledge, such as pop culture, politics, etc. - Playfulness • Bantering • Role-playing • Exaggeration - Teasing • Poking fun at other in friendly way	"just got a message advising everyone to monitor their fuel. – Funny, NOW they tell us." "Catch you on the flip side as they say" 'Hi there!" "Nice to see you" "Red, you were right, except it was not alpha but omega"

Results

Inclusiveness of Team Members' Interactions

Study 1 indicated that one measure of team cohesion is the inclusiveness of team members' interactions. In the present analysis we operationalized this aspect in terms of the size and the symmetry of team members' exchanges.

Figure 4 below indicates that while dyadic interactions were most prevalent overall, interactions involving three team members occurred more often in teams working under cooperative instructions than in teams in which conflict had been induced. A 2 (Condition) x 2 (Day) x 2 (Task Difficulty) Analysis of Variance with Day and Task Difficulty as repeated variables revealed that cooperative teams had a significantly higher proportion of triadic interactions than competitive teams, $F(1,10) = 5.26$, $p = .045$, $\eta^2 = .35$. In a separate Analysis of Variance, the difference between competitive and cooperative teams concerning the proportion of dyadic interactions was also significant,[2] $F(1,10) = 3.32$, $p = .098$, $\eta^2 = .249$.

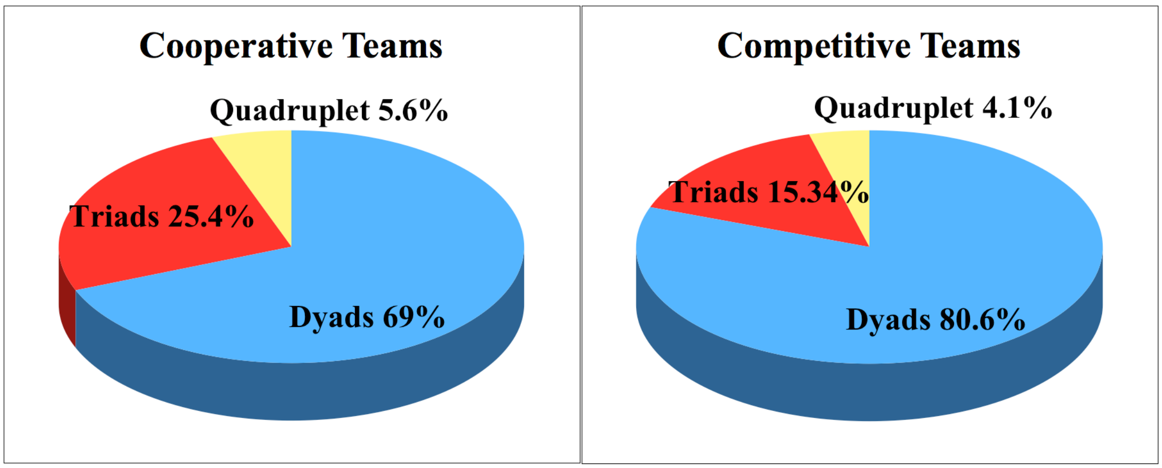

Figure 4. Number of team members participating in exchanges in cooperative and competitive teams

To assess the symmetry of team members' interactions we examined whether the six possible dyadic interactions in a team were equally distributed across team members, or whether dyads involving specific team members dominated the discourse. Mathematically we expressed this concept by calculating how much the proportion of each team member pairing differed from 1/6, the mean proportion given the assumption that all pairings occur equally often, that is, interactions are symmetric. The absolute values of these differences were summed to indicate the degree of variability in team members' dyadic interactions. Values could range from 0 (indicating perfect symmetry in team members' dyadic interactions) to 1.667 (indicating that the discourse is monopolized by one dyad to the exclusion of all others). A 2 (Condition) x 2 (Day) x 2 (Task Difficulty) Analysis of Variance revealed that while there was no significant main effect of condition on the spread of team members' dyadic interactions, $F(1,10) = 1.08$, *ns*, the condition by day interaction was significant, $F(1,10) = 4.85$, $p = .052$, $\eta^2 = .33$. Dyadic interactions in cooperative teams were found to be more balanced ($M_{SpreadCoop} = .42$, $SD = .14$) than interactions in competitive teams ($M_{SpreadComp} = .63$, $SD = .26$) during missions on the first day, but converged for missions on the last day ($M_{SpreadCoop} = .50$, $SD = .19$, and $M_{SpreadComp} = .51$, $SD = .23$). This finding may indicate that some competitive teams started to cooperate as days

[2] For analyses involving comparison between the two team stress conditions, we adopted an alpha level of .10 because there were only six teams per condition.

progressed, a plan that was explicitly stated by one the six competitive teams.

Dominance and Control

In the present analysis dominance and control concerned the issue of equal participation in a team's exchanges. That is, we examined whether all four team members participated equally in their team's interactions, or whether one or several team members were dominant.

For each of the four team members we calculated the proportion of exchanges in which he or she took part. The basis was all exchanges in a team involving two, three or four team members. We then computed the deviation of each proportion from the mean (.25 under the assumption of equal participation), and summed the absolute values of these deviations to quantify the variability in team members' participation. Values could range from 0 to 1.5. A 2 (Condition) x 2 (Day) x 2 (Task Difficulty) Analysis of Variance found no significant main effect of condition, $F(1, 10) = 1.02$, *ns*, but a significant condition by day interaction, $F(1, 10) = 3.72$, $p = .08$, $\eta^2 = .27$. Member participation was more equal in cooperative ($M_{\text{SpreadCoop}} = .16$, $SD = .07$) than in competitive teams during missions on the first day ($M_{\text{SpreadComp}} = .27$, $SD = .14$), but not during missions on the last day ($M_{\text{SpreadCoop}} = .20$, $SD = .11$, and $M_{\text{SpreadComp}} = .21$, $SD = .13$). This finding may reflect a strategy shift by competitive teams towards cooperation, and is consistent with our explanation of the results pertaining to the symmetry of team member interactions.

Positive Affect

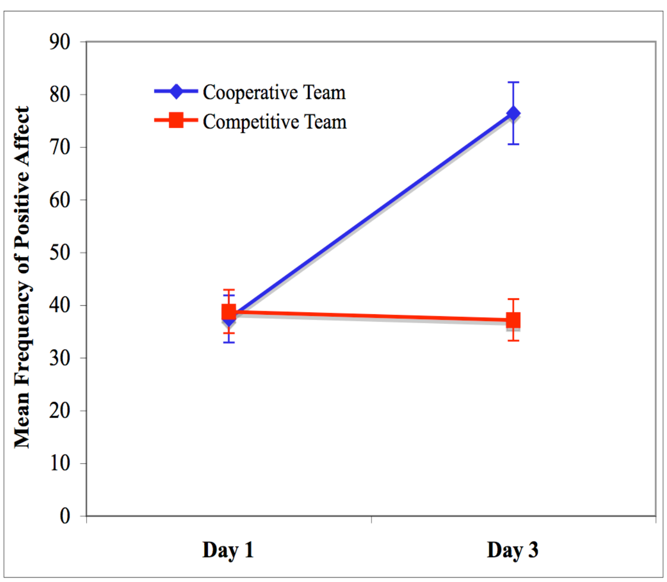

Figure 5. Mean frequency of positive affect expressed in team members' communications

A 2 (Condition) x 2 (Day) Analysis of Variance on frequency of positive affect revealed a significant main effect of day, $F(1, 10) = 5.10$, $p = .047$, $\eta^2 = .338$, and more importantly a significant condition by day interaction, $F(1, 10) = 6.01$, $p = .034$, $\eta^2 = .375$. As can be seen in

Figure 5 above, cooperative teams showed significantly more instances of positive affect than competitive teams on the last day, while no differences between the groups were observed during their first missions.

Team Communication and Team Members' Perceptions of Their Team's Communication Efficacy and Cohesion

Two rating scales were used to assess how team members perceived their team's cohesion and communication efficacy. Cohesion was measured with the cohesion subscale of the Group Environment Scale (GES). Ratings were converted to Standard Moos Scores (ranging from 20 to 61), and ratings by members of the same team were averaged to reflect their team's cohesion score. Analogously, a team's communication efficacy score was obtained by calculating the mean of individual team members' ratings (scores could range from 1 to 7). Team cohesion scores were consistent with the team climate manipulation ($F(1,10) = 5.595$, $p = .04$, $\eta^2 = .359$), with the cooperative teams having higher scores ($M = 52.54$, $SD = 3.96$) than the competitive teams ($M = 43.92$, $SD = 8.01$). In contrast, cooperative and competitive teams did not differ significantly in perceived communication efficacy ($F(1,10) = 2.71$, *ns*.; $M_{Coop} = 4.08$, $SD = .35$; $M_{Comp} = 3.5$, $SD = .79$).

Correlations between team communication measures and team cohesion scores and team communication efficacy ratings are provided in Table 5 below. For communication measures that were not normally distributed, we used the Spearman rank correlation r_S; otherwise the Pearson Product Moment (r) correlation was applied.

As can be seen, communication features indicating symmetric and inclusive interactions as well as shared conversational control were significantly correlated with team members' perceptions of their team's cohesion and communication efficacy. Specifically, low team cohesion scores and communication efficacy ratings were associated with larger variability in member participation and an imbalance in dyadic interactions, as well as a high rate of dyadic interactions. In contrast, the higher the rate of interactions involving three team members, the more positive team members were concerning the cohesiveness of their team and its communication efficacy. Interestingly, team members' perceptions correlated more strongly and more consistently with team communication patterns present on Day 1 than those on Day 3. This observation is consistent with the communication analyses above suggesting that differences between cooperative and competitive teams diminished from day 1 to day 3. This finding also implies that team members' ratings were not simply a reaction to their teamwork during the immediately preceding missions—recall that cohesion and efficacy ratings were collected on the last day after the last mission—but apparently reflected team members' overall assessment of team processes.

Table 5. Correlations Between Team Communication Measures and Team Members' Perceptions of Team Cohesion

	COHESION RATINGS	
	Communication Efficacy of Group *(EfgComm)*	Group Environment Scale Cohesion *(GESCohst)*
COMMUNICATION MEASURES OF DAY 1		
Prop of Dyadic Interaction	$-.702^{*}$	$-.805^{**}$
Prop of Triadic Interaction	$.712^{**}$	$.814^{**}$
Variability in Participation	$-.765^{**}$	$-.743^{**}$
Variability in Dyadic Interactions	$-.728^{**}$	$-.730^{**}$
Positive Affect	.045	.026
COMMUNICATION MEASURES OF DAY 3		
Prop of Dyadic Interaction (*Spearman's rho* r_S)	-.382	-.382
Prop of Triadic Interaction (*Spearman's rho* r_S)	$.527^{\dagger}$	$.519^{\dagger}$
Variability in Participation (*Spearman's rho* r_S)	$-.512^{\dagger}$	$-.608^{*}$
Variability in Dyadic Interactions	-.379	-.437
Positive Affect	.399	.454

Note: df = 10; † $p \leq .10$; * $p \leq .05$; ** $p \leq .01$

Discussion

Research during the first phase of this project revealed that interpersonal communication in successful teams had characteristics that clinical and socio-linguistic research has linked to healthy relationships. Features of team members' communications related to team effectiveness were *inclusive and symmetric interactions*, *shared conversational control*, and *positive affect*. Research during phase 2 demonstrated that these features were also prevalent in teams working under cooperative instructions in contrast to teams in which interpersonal stress had been induced through competitive instructions. Exchanges in the cooperative teams we studied, involved more team members, indicating that these teams had a tighter team structure than competitive teams. Similarly, cooperation tended to be associated with more balanced and positive interactions and equal participation. Members of cooperative teams showed less variability in their dyadic interactions as well as in their overall contributions to their team's discourse, and expressed more positive affect than members of competitive teams. This pattern of findings suggests that relationships in cooperative teams were characterized by equality while members of competitive teams tended to favor one or two teammates over the team as a whole. This interpretation is consistent with the teams' self-reported cohesion based on the Group Environment Scale (Moos & Humphrey, 1974). The higher team members rated their team's cohesion at the end of their three-day mission, the more they had engaged in interactions characterized by symmetry, inclusiveness, and shared control.

In addition to validating the critical linguistic features identified in study 1, the second study took us a step closer to monitoring team cohesion in real time. A coding method was developed that allowed us to assess features of team cohesion while watching video-recordings of team interactions. In future work we propose to implement our online coding method in a coding tool that supports real-time coding and might ultimately feed into an automated assessment tool.

General Discussion

The goals of this project were to evaluate the reliability, validity, and sensitivity of team communication analysis to monitoring and assessing team cohesion. Of additional concern were the feasibility of this approach, its potential for automation and for providing astronauts with diagnostic feedback about their crew functioning.

Reliability

At present the linguistic analysis of team communication relies heavily on coder judgments, which means coders must be highly trained prior to coding. Inter-rater reliability checks of coding both from transcripts and on-line from video showed that good reliability can be obtained. High reliability is essential not only to ensure the objectivity of the measure but also to detect changes in team communication behavior over time or differences between groups. Linguistic analysis conducted in Study 1 identified differences in the relational communication of successful and unsuccessful teams. Differences concerned the symmetry, inclusiveness, and control structure of team interactions as well as the presence of positive affect. In addition to confirming these findings, analyses in Study 2 revealed increases in expressed positive affect in the cooperative groups from the first to the third day of working together, while the competitive groups showed no such increase.

Validity

Using linguistic analysis to assess team cohesion is grounded in theory and prior research findings from clinical psychology, discourse theory, and sociolinguistic theory. Concurrent validity of the linguistic features was documented by positive significant correlations with established methods for assessing team cohesion. Specifically, findings of the linguistic analysis were congruent with ratings on the Group Environment Scale and with manipulated team stress (cooperative vs. competitive goal instructions).

Feasibility of Techniques for Use in Space

The possibility of using linguistic analysis with flight crews and ground controllers during exploration missions depends on the feasibility of collecting the raw data. Obviously, communication data are easy to obtain, providing that crewmembers talk with each other and with ground control. It can either be recorded for subsequent analysis or (ultimately) analyzed on-line in real time.

Other cohesion techniques used in this study could be used in space, providing a computer is available for data collection. These include the sociometric ratings of task and social cohesion for each crew member (ratings on two items per other crew member), a task taking less than one minute. The 48-item GES involving six scales (reduced from the 90-item 10-scale version) takes approximately four minutes and has been used extensively by Kanas and others in space research (Kanas, 2005; Kanas & Manzey, 2008). While the GES is widely used and well validated, it does not yield specific diagnostic information about individual team member behaviors; it also is subject to social bias, which may lead to ceiling effects. Group social and task efficacy ratings are brief (a 9-item scale) but their sensitivity to change has not been validated. However, all of the scales mentioned involve ratings on Likert scales, which make their data easy to analyze with simple programs.

Automating Cohesion Monitoring and Assessment

Certain features of crew communication seem easily amenable to automated analysis. These are predominantly non-content aspects of speech such as voice stress (Brenner & Brazy, 2003; Johannes, Salnitski, Gunga, & Kirsch, 2000; Lieberman et al., 2005) or rate, rhythm and prosody (Madan, Caneel, & Pentland, 2004; Pentland, 2004). Voice stress has been used primarily to detect psychological or cognitive stress within a single individual, not in dyads or larger groups, but the possibility exists of such extension. Likewise, Pentland’s approach to analyzing mutual attraction has been applied in dyads, but not in larger groups.

Participation and interaction rates among members of a group can be analyzed automatically, providing that the data include “press-to-talk” targeted initiations and responses of audio communication (Kiekel et al., 2002; Kiekel et al., 2004). Initial forays using natural language processing technology to assess Latent Semantic Analysis have only reached a modest reliability level (Gorman, Foltz, Kiekel, & Martin, 2003), which means they have a way to go before being usable. However, active research in this area is sure to move the technology forward quickly.

An alternative content-based approach is to target specific words or phrases using natural language processing tools. Our analyses and those of other researchers are identifying and validating critical targets that represent positive and negative relational communication, or specific task-oriented communication. Obviously, a critical intermediate step is identifying those linguistic targets and developing an efficient device for on-line coding of those targets in order to establish their validity in natural discourse.

Building on our method for coding relational aspects of team members' communications directly from video recordings, we are currently developing a tablet-based coding tool to support real-time coding of video-recorded or live team interactions (Fischer, 2009). The tool is designed with two objectives: to advance communication research and to provide team leaders and teams with an easy-to-use tool for self-assessment. We envision that the tool will be extremely versatile as users will be able to define coding categories. However, our current efforts focus on communication coding categories and design requirements (such as common codes across team members) relevant to the assessment of team cohesion.

Our work could ultimately feed into automated communication analyses. For instance, our corpus of coded team communications could serve as the training corpus for Latent Semantic Analysis, or provide automated speech recognition systems with relevant key words or phrases.

Providing Feedback to Crews

For any cohesion monitoring and assessment tool to be useful, it must be capable of providing feedback to the crews that is easily understood and diagnostic with respect to what intervention might be appropriate. For example, if one crewmember is not participating in conversations, that would be apparent from the linguistic analysis. Or if the ratio of negative to positive relational communication is too high, an adjustment might be in order. What form this feedback should take has not yet been established.

Our team interaction coding tool will have a result screen that will provide users with graphic data summaries and basic statistics for immediate feedback (e.g., a pie chart depicting the frequency distribution of communication codes). Stored summaries of previous analyses of a team can be called up for comparison with the current analysis. This feature should be useful for observers and teams alike to detect mission-relevant changes in their interactions over time (e.g., an increase in negative affect). In addition, validation of the tool in the lab and various space-analogs will identify communication patterns that characterize cohesive teams. A team's interactions could thus be compared to these profiles to determine the extent to which they match (or deviate from) the ideal. Future tests will need to be conducted to determine how useful and acceptable these kinds of feedback are to flight and ground crews.

Remaining Issues

While we learned much from the studies reported here, they represent only a step toward practical team cohesion monitoring tools. The following tasks remain and will be addressed in future work:

- The ability of linguistic features to determine stability of interaction patterns over time, as well as their sensitivity to changes brought about by introduction of training, interpersonal conflicts, or environmental events must be established.

- The generality of our findings must be tested with existing teams in real work environments. At present all of our work has examined *ad hoc* groups in the laboratory.
- Cohesion data collection feasibility must be explored in space analog environments (e.g., NEEMO, Haughton-Mars).

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