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STATEMENTS

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The views expressed in this report are those of the author and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government.

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The study protocol was reviewed by the Wright-Patterson Air Force Base Institutional Review Board in compliance with all applicable federal regulations governing the protection of human subjects.

Factors Affecting Communication and Performance among Critical Care Air Transport Team (CCATT) Personnel

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Contents

Abstract

Critical Care Air Transport Team (CCATT) members must coordinate effectively to care for their patients, but such coordination is not explicitly trained. CCATTs are assembled ad-hoc for each deployment. Each team must develop coordination practices in real-time, and patient care could suffer if a team adopts ineffective coordination patterns. This study examined 91 recordings of simulated patient care scenarios in order to characterize CCATT coordination patterns and examine their relationship to individual team member communication behaviors and team performance. We identified Authoritarian and Egalitarian teams based on the distribution of utterances across team members. We examined the link between Authoritarian/Egalitarian status and team performance, as well as differences in communication content across roles. We found considerable variability between teams in the distribution of utterances across team members and a significant interaction between Authoritarian/Egalitarian team type and team role in predicting communication content. Authoritarian/Egalitarian team type did not predict team performance. CCATT coordination patterns appear to be an emergent property of the interactions between members of a particular team. Individuals in our sample were able to adjust their communications to interact adaptively with unfamiliar teammates. Given the flexibility of CCATT personnel in adapting communication styles and the lack of a link between team coordination style and performance, the current practice of assembling ad-hoc CCATTs is unlikely to impact patient care negatively.

Introduction

Critical care patients require a team of trained, skilled individuals working together as a unit towards a common goal (Lairet, King, Vojta, & Beninati, 2013). Teams must work together particularly well in the Critical Care Air Transport Team (CCATT) environment, where the care team is isolated aboard an aircraft and must function independently (Lairet et al., 2013). CCATT aircrew care for critically ill or injured patients during long-duration flights from lower-tier treatment facilities to definitive care centers, often in Germany or the United States. CCATTs are typically composed of three members: a critical care-trained physician, a critical care/emergency department nurse, and a respiratory therapist (United States Air Force, 2017). Coordination among these providers is critical for delivering high-quality medical care, but the unique nature of the flight environment can potentially make communication difficult. Unfortunately, the current training curriculum emphasizes the skills of individual providers; team-level performance is addressed more informally via practice in simulated scenarios or debriefing sessions. A better understanding of team-level performance and the teamwork processes, such as communication, that contribute to performance could have implications for readiness evaluations and future teamwork training modules. Ultimately, the main findings of this study can potentially identify characteristics of good coordination, which could inspire new training interventions designed to help maximize the effectiveness of CCATT aircrew via improved coordination.

Towards this end, this study examined coordination among CCATT members during simulated care scenarios to both characterize distinct coordination patterns between teams, and identify which patterns predict good team performance. Methods and techniques to distinguish team coordination quality is an active area of research (Gorman, Cooke, Amazeen, & Fouse, 2012; Rothwell, Shalin, & Romigh, 2021). Many published techniques for measuring coordination have been developed and validated on laboratory tasks that relatively naïve participants can perform without extensive training. Therefore, these techniques may not generalize to high-fidelity simulation or real-world tasks that involve highly trained participants where many more factors may contribute to performance (e.g., knowledge, skills, abilities, motivation, and group- and organizational-level factors). The secondary findings of this study explore the use of many coordination measures in a high-fidelity simulation to identify which are effective measures to use for capturing and evaluating teamwork processes.

The Importance of Effective Coordination

Communication is a major component of team functioning, which in turn determines the quality of patient care (McMullan, Parush, & Momtahan, 2015). Cooke's (2015) theory of interactive team cognition posits that team cognition is not found in the minds of individual team members. Instead, team cognition is found in the communication and coordination *between* team members. According to this theory, communication among team members *is* team cognition. In other words, teams think via the interactions between team members. Team coordination processes are one of the best predictors of team performance. In fact, team coordination predicts team-level performance better than the aggregate knowledge or skill of individual team members (Cooke, Gorman, Myers, & Duran, 2013); coordination allows teams to become more than the sum of their individual members.

Team coordination is particularly important in the medical domain, as communication errors are a leading cause of preventable medical harm (Brewer & Ryan-Wegner, 2009). Adaptive coordination improves team performance during nonroutine anesthesia events (Burtscher, Wacker, Grote, & Manser, 2010), whereas poor communication can increase the risk of surgical complications and death (Mozzoco et al., 2009). Accordingly, CCATT nurses believe that team communication is a key component of CCATT care as part of a broader process of group identification and integration (Davis et al., 2014). Patient outcomes will suffer if CCATT providers struggle to communicate effectively.

The medical community has long acknowledged the need for good coordination. For example, the TeamSTEPPS approach (Agency for Healthcare Research and Quality, 2013) describes best practices for improving coordination and optimizing team performance at multiple healthcare system levels. However, such approaches can only provide a framework to guide action. Individual providers and care teams may implement various recommendations in different ways, or emphasize different aspects. Individual and situational factors will likely influence the specific manner in which individual teams and providers implement frameworks. Such idiosyncratic adaptations to context, the factors that influence them, and their link to performance are the topic of study here.

Medical errors are attributable to the interaction of various components of a system rather than the actions of any one individual (Institute of Medicine, 2000). In the medical domain, the system can include personnel, standardized procedures, equipment, and the physical design of the workspace (Lewin & Baxter, 2007). Systems may be as large as a patient care network or as small as an operating suite (Institute of Medicine, 2000). For the purposes of this study, we have defined the aircraft as a system in order to examine the communication of the CCATTs working within it. Studies of team coordination in a traditional clinical setting are unlikely to adequately capture the challenges faced by CCATT personnel in the aircraft as they try to communicate effectively with patients and each other. It is therefore important to identify the specific communication patterns found in the CCATT domain. Each CCATT member contributes unique knowledge and skills, requiring effective team communication to achieve efficient and effective patient care (McNeill, 2018).

Differences between the ICU and CCATT Environment

Team cognition is tied to context, including other team members and the work setting (Cooke et al., 2013). The physical environment is a major determinant of behavior (Hutchins, 1995). The tools, resources, and sociocultural systems in which people operate all influence how they accomplish tasks (Feufel, Robinson, & Shalin, 2011; Robinson et al., 2020). Teams likely adapt their coordination to accommodate differences between the CCATT environment and a traditional clinical setting. The CCATT domain is very different from a typical care setting, adding challenges to communication and potentially increasing the risk for error if teams are not sufficiently prepared to work together in such an environment.

Many factors within the flight environment can make delivering care more difficult than in a standard clinical setting, potentially impacting communication by increasing workload and disrupting habits adapted for a more typical care environment. For example, long flights across multiple time zones can contribute to fatigue among caregivers (Bridges, 2018). Patients frequently have injuries with which providers have little opportunity for practice in their non-deployed duties (e.g., blast injuries), and aspects of flight such as reduced ambient pressure can affect patient physiology (Bridges, 2018). CCATT personnel may also be required to care for a higher number of more complex critically ill patients during combat operations than during peacetime, as well as operate and troubleshoot the ventilators, monitors, and infusion pumps that accompany these patients (Brewer & Ryan-Wenger, 2009; Davis et al., 2014; McNeill, 2018). Whereas personnel in a hospital intensive care unit (ICU) may be responsible for two patients at any given time, CCATT personnel may be responsible for up to six patients at once (United

States Air Force, 2017). Each of these changes from the traditional care environment may increase workload or force providers to deviate from their habitual behaviors tailored to their typical work setting. In effect, providers may have to work harder as a team to maintain cohesive patient care.

In addition to high workload and a unique patient population, the physical environment in which CCATT providers work is vastly different from the standard clinical environment of a more traditional ICU. The hospital ICU environment is typically well-lit, has tolerable noise levels, and has ample space for medications, monitors, ventilators, and other equipment. Most often, additional resources and materials are easily available to a provider if needed; ICUs are staffed with personnel available to assist a provider if needed, and providers typically have access to a separate laboratory or radiology department for patient monitoring or diagnostic assistance. In contrast, the flight environment is much more limited. Lighting may be dim for operational reasons, making it challenging to locate supplies or identify blood vessels. The aircraft also produces high ambient noise, making communication between providers and patients more difficult by increasing the likelihood of words being lost or misheard, likely increasing requests for clarification, and necessitating greater effort to speak loudly. Space is limited, so equipment and medications must be secured directly on and around the patient's litter, and there is little room to maneuver around the patient to provide care. The team is physically isolated, although aeromedical evacuation teams may provide additional personnel as backup and clinical or operational advice may be obtained via satellite communication (United States Air Force, 2019). In addition, the only resources available are those packed on the aircraft before takeoff.

Tight physical spaces that restrict movement, caregiver fatigue, high workload, poor lighting, and high ambient noise may all affect communication both within the care team and between providers and patients (Brewer & Ryan-Wenger, 2009). Davis et al. (2014) found that task saturation was specifically associated with impairments on teamwork and communication measures in simulated CCATT patient care scenarios. This increase in workload compared to a standard clinical setting, in combination with the challenges induced by the physical environment of the aircraft, may impair communication and therefore degrade the quality of care.

Current CCATT Training on Team Coordination is Limited

Despite the importance of communication to healthcare delivery and the particular challenges of working in the CCATT environment, current CCATT training does not emphasize team communication as much as other aspects of care. CCATT personnel deploy as individuals rather than as stable teams; accordingly, current training emphasizes individual knowledge and skills such as the physiological factors of flight and their potential impacts on patients and providers (McNeill, 2018). Classes review closed-loop communication, but other team-level processes are mainly addressed informally via unstructured debriefing sessions or via implicit practice while completing the team scenarios. Likewise, training evaluations assess individual team members instead of the team as a whole.

Individual skills are undoubtedly critical to optimal team performance, and each member must have the capacity to fulfill the unique responsibilities of their role. However, an overemphasis on individual skill neglects an important aspect of overall care delivery. Even when communication is assessed, the current evaluation system used during CCATT training considers communication as part of performance on various subtasks, rather than as a core skill that contributes to general performance in its own right. Evidence suggests that communication volume and content varies depending on one's role within a team (Tiferes & Bisantz, 2018). A better understanding of how each member contributes to the overall team will help tailor training to improve coordination between various team roles. In addition, the evaluation of communication at the individual level neglects emergent team-level processes that could likely benefit from explicit feedback and attention during training.

Experience and Familiarity may affect Communication

Despite the challenges of the flight environment and the lack of explicit training in team communication, CCATT personnel are a successful and vital contributor to the United States military's combat casualty care system. Based on this fact and data from other domains described below, we believe CCATT personnel likely learn to adapt and communicate with one another as they gain experience in the aircraft environment. Generally, teams comprised of members with domain-relevant experience tend to perform better than teams without such experience (Cooke, Gorman, Duran, & Taylor, 2007).

In addition to domain-related experience, interpersonal familiarity may also affect team performance. Familiarity can increase the likelihood that team members will request and accept backup from one another (Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas, 2009) and improve overall task performance (Espevic, Johnsen, Eid, & Thayer, 2006). Experience and long-term familiarity can improve performance, particularly with strong leadership (Sieweke & Zhao, 2015). Familiarity can also reduce variation and make health outcomes more predictable (Stucky & De Jong, 2021). However, such stability is lacking in the CCATT domain. As mentioned before, CCATT personnel deploy individually, not as teams. CCATTs are therefore ad-hoc groups of providers that can change across deployments and from mission to mission. Shifting team makeup is not necessarily undesirable, however. Unstable team membership can improve team processes and performance compared to teams with stable membership; shifting team membership promotes adaptive and flexible coordination patterns, as teams must learn to adjust to the behaviors of new members (Gorman, Amazeen, & Cooke, 2010; Gorman & Cooke, 2011).

The effects of experience and team member familiarity are relatively understudied overall, and more research is needed (Tiferes & Bisantz, 2018). We anticipate that CCATT providers develop communication practices as they gain experience, both within the aircraft environment generally and also working across various teams. As teams form and disperse, emergent communication patterns within each team likely develop based on these individual practices.

The Present Study

One possible explanation for the reduced emphasis on communication training is that team communication in the flight environment is understudied. An implicit assumption appears to be made that teams will function the same way in the aircraft as in a hospital, and additional focus on communication is therefore unnecessary. However, teams are unlikely to function in a loud, cramped, dark aircraft as they would function in a quieter, spacious, well-lit hospital (or in a similarly controlled classroom environment). Further, CCATTs are smaller than critical care teams in the standard clinical environment, necessitating CCATT members to assume different responsibilities and workloads. We believe that different CCATTs are likely to adopt unique communication patterns to adapt to the flight environment, but these varied communication patterns are unlikely to be equally effective.

This study used audio and video from CCATT training simulations to 1) characterize the various patterns in communication utilized by CCATTs, 2) identify changes in communication patterns among care providers as a function of prior deployment experience of team members, and 3) link patterns of communication to team performance, assessed based on patient parameters. This study will inform training interventions to speed the acquisition of team coordination skills and promote adaptive coordination patterns, as well as CCATT deployment planning decisions, thereby enhancing patient care outcomes by improving CCATT aircrew communication in the flight environment.

Method

CCATT Advanced Course

This study relied on archival videos of recorded training exercises from the CCATT Advanced course at the Center for Sustainment of Trauma and Readiness Skills (CSTARS), University of Cincinnati Medical Center. The CCATT Advanced course serves as the final stage of training to certify new CCATT providers as ready to deploy, and as periodic refresher training for current CCATT aircrew. Class members are therefore a mix of new CCATT personnel and those who have had prior deployment experience. However, all trainees are qualified medical practitioners in their respective specialties.

The CCATT Advanced course is a two-week course designed to train students on the unique factors of working within the CCATT domain. The first week of the course is primarily lecture-based to convey the unique aspects of providing critical care in the flight environment (for example, the effects of reduced barometric pressure on patients with head trauma). The second week of the course consists of a series of simulated patient care scenarios, including four "validation scenarios" that trainees must pass to be considered eligible for deployment.

Simulations were conducted in a room set up to mimic the dimensions of a C-130 transport aircraft, complete with darkened lighting and aircraft noise generated from speakers mounted in the room. Each simulation lasted between 30-45 minutes and required the team to care for two patients, "Chuck" and "Dave", represented by two high-fidelity patient simulation manikins. The manikins were controlled by CSTARS training staff from a control station in a separate room and could simulate breathing, urination, and other biological functions. Physiological responses to medication or other interventions could be simulated based on training staff inputs from the control station. The manikins could also be connected to standard monitoring equipment and could “talk” with the trainees via a speaker and microphone system controlled by the training staff.

Each individual validation scenario required the teams to demonstrate different capabilities, such as managing patients with cardiac issues, airway issues, amputations, or head trauma[1]. Teams had an opportunity to meet prior to the simulation to discuss their plan and concerns for that particular scenario, and determine what medications or supplies would be required. CSTARS instructors provided medications, bandages, monitors, and other supplies as they would be on a real-world mission, depending on what the team requested prior to the start of the simulation. Each scenario began the same way for each team and followed a basic outline to ensure the targeted skills were assessed. However, the exact details of the scenario varied across teams because the simulated patients responded to the specific actions and interventions of each team. Each scenario lasted approximately 30-45 minutes from the start of patient care to the end of the scenario. Team members were shuffled across scenarios, so that team composition changed every time.

Team members communicated with one another via standard headsets as would be used in the aircraft. Simulations were monitored via multiple cameras to allow instructors in the control room to observe provider behavior and zoom in on patient monitors or other features of interest. Audio and video data were recorded as part of a single data stream. In addition, Chuck and Dave each had separate files that recorded their vital signs, interventions completed by the trainees, and any inputs from the operator at the control station.

[1] We have omitted detailed descriptions of the scenarios at the request of CSTARS personnel to prevent future trainees from potentially having advance knowledge of the scenarios. Those interested in learning more about the scenarios are invited to contact Dr. Robinson directly at frank.robinson.5@us.af.mil.

The Present Data Set

We retrieved 217 data files from CSTARS in June of 2019. Teams in the data set spanned courses from 2016-2018. We eliminated redundant files and files for which we could not locate a full set of data (i.e., audio/video and data from Chuck and Dave manikins), as well as teams from a period in 2018 that used a modified set of training simulations. We were therefore left with a final sample of 91 teams spanning 2016-2017. Thirty-one teams were from Validation Scenario 1, 18 teams were from Validation Scenario 2, 29 teams were from Validation Scenario 3, and 13 teams were from Validation Scenario 4.

Analysis

We used qualitative and quantitative methods based on transcripts of each team's simulation. We generated audio files of each team from the recorded video using Movavi video conversion software. A medical transcription company then transcribed the audio files (MedLinks Transcription, Inc., Maryville, TN). Transcripts received from the transcriptionist included the unique speaker (identified as Speaker 1, Speaker 2, etc.), the timestamp corresponding to the beginning of the utterance, and the utterance itself. Transcripts were spot-checked for accuracy by members of the research team, and speakers were identified as the doctor, nurse, or RT by members of the research team with CCATT expertise.

Qualitative Predictors

Developing the Coding Scheme

We generated a coding scheme to characterize the content of team communications. We developed an initial coding scheme using behaviors of interest identified a priori based on our expectations of behaviors that may differentiate teams (e.g., whether an update was offered proactively or requested) as well as via a literature review of team communication measures, with particular emphasis on communication in the military and/or medical domain (e.g., Achille, Schulze, & Schmidt-Nielsen, 1995; Hargestam et al., 2013; Parush et al., 2014; Tiferes, Bisantz, & Guru, 2015). We also examined a sample of several transcripts to identify any additional behaviors that may be of interest. Our coding scheme included behaviors broadly related to communication patterns, sharing information (further broken down into status information, information related to the intent of a specific message, and clarifying information to maintain communication more broadly), action-oriented behavior, and a catch-all "other" category.

Once a preliminary coding scheme had been developed, we refined it based on an iterative process of applying it to our sample transcripts and modifying as needed to reduce overlap and ambiguity among coding categories and eliminate rare or superfluous categories until we felt the coding scheme captured relevant behaviors and could be implemented by the team reliably. Our first iteration included 34 variables and our final coding scheme included 17 variables, described below. The coding scheme was then instantiated in a manual (Appendix A) with descriptions of the categories and examples of utterances within each category or decision rules to help utilize the coding scheme consistently. Unless otherwise noted in the analysis section of the report, each individual category served as its own predictor variable in the analysis. The final coding scheme contained the following categories:

Communication patterns:

- *Speaker target*. The intended target of the utterance. This category could be scored as Doctor, Nurse, RT, entire team, or unsure.

Sharing information (status):

- *Request update*. Requests for information, such as asking what a patient's vital signs were or the status of a task.

- *Provide update.* Utterances that conveyed information about the patient's status or progress on a task. This category was scored as *prompted* if the information was provided in response to a request, and as *unprompted* if the information was provided proactively.

Sharing information (message intent):

- *Request clarification.* Requests to clarify the intent of a statement, repeat something, or confirm a dose or procedure.
- *Provide clarification.* Providing additional details about intent or repeating a statement, This category was scored as *prompted* if the speaker was responding to a request for clarification, or as *unprompted* otherwise (typically correcting a misstatement – e.g., "Chuck's heart rate is 73. I mean Dave's heart rate, sorry").

Sharing information (clarity of communication):

- *Closing the loop.* Statements confirming that another person's statement or request was understood or agreed to.
- *Getting attention.* Trying to get someone's attention or direct a message to someone specific.
- *Communication quality.* Statements related to making sure messages were received and understood, typically by the speaker of the message. This category also applied to troubleshooting issues such as a bad headset.

Action-oriented behavior:

- *Stating a goal.* Statements that conveyed a desirable end state, whether for the patient or for the team.
- *Activity coordination.* Statements related to determining what should be done, who should perform the action, and how tasks should be accomplished.

Other:

- *Crosstalk.* Periods of time where multiple team members attempted to talk over one another resulting in unintelligible communications. These were explicitly noted in the transcripts.
- *Uncodable/ambiguous.* Statements that were unclear or were cutoff prior to the meaning of the sentence becoming apparent. This category was not analyzed.
- *MCD.* This category was used to note when team members communicated with the Medical Crew Director (MCD), an aircrew member associated with the aircraft who can offer assistance such as communicating with the pilot or acting as an additional set of hands for simple tasks. The role of the MCD was played by one of the course instructors and we did not analyze these communications.
- *Patient interaction.* This category was used to note when team members spoke to the patient, played by one of the simulator operators speaking through the manikin from the control room. We did not analyze these communications.
- *Miscellaneous.* Any utterance that did not fit into a predetermined coding category was counted as "miscellaneous". We did not analyze this category.

Coding the Data

Team members were trained on the coding scheme by coding a sample of otherwise unusable transcripts that could not be analyzed (e.g., due to missing simulator data files). Team members coded these transcripts either collaboratively as a group or individually with feedback from other team members, allowing opportunities for discussion and consensus regarding how to apply each coding category of the coding scheme. When the team felt confident that a shared understanding had been established about how each category should be implemented, the sample of 91 transcripts was coded.

Each transcript was coded by a single rater who tallied the total number of instances of each coding category in each utterance. Utterances were transcribed as complete conversational turns by the speaker – a single utterance could be a very brief statement or several sentences long. We therefore coded individual pieces of information within each utterance, defined as something that could stand alone as its own sentence. For example, the utterance “Chuck’s temperature is 102 and his heart rate is 87” would count as two pieces of information because the message can be divided into two sentences – “Chuck’s temperature is 102” and “Chuck’s heart rate is 87”. A single coding category was assigned to each individual piece of information in the utterance; the preceding example would be scored as two instances of *providing an update* (either prompted or unprompted as appropriate). If the rater was uncertain about how to code a particular utterance, the uncertainty was resolved by discussion with other team members. Qualitative coding categories were quantified and used as predictors in our analysis.

Quantitative Predictors

In addition to the quantified coding categories, we used several other variables derived from the transcripts to predict team performance:

Coding Categories

We utilized the frequency of each coded behavior as an individual predictor. Frequency of each individual category was normalized as a percentage of total coded behaviors at both the team and individual level, calculated by summing the individually-tallied instances of each code and dividing by the total number of coded behaviors. Normalizing the data allowed us to compare the relative use of each category across teams without concern for inter-team or individual differences in total volume of communication.

Proactive Communication

The anticipation ratio (Entin & Serfaty, 1999) is calculated by dividing the number of information transfers made to a person by the number of information requests made by that person. Ratios greater than one indicate that information is being offered proactively. This measure has been shown to respond to training designed to improve recognition of changes to situational stress levels (Entin & Serfaty, 1999). We derived a similar metric by calculating the sum of all unprompted updates within each team, and dividing by the total number of updates provided to generate the percentage of all updates that were unprompted.

Experience

We expected that more experienced CCATT personnel may have developed communication techniques to facilitate working in the CCATT domain, which would likely affect team coordination as a whole. We therefore utilized experience as a binary predictor variable. We derived deployment data for each of the 91 teams by matching course rosters with the trainees in each of the recorded files. We defined individuals as "experienced" if they had deployed as a CCATT crew member at least once. We considered a team to be "experienced" if at least one team member had prior CCATT deployment experience. Fifty-one teams had no experienced members and 13 teams had at least one experienced member. The remaining teams had incomplete data, preventing a conclusive determination.

Validation Status

We identified whether each trainee "validated" (i.e., passed the course and was considered deployable) or not. We considered a team to have been "validated" if all members had passed the course. We identified one individual nurse and five individual RTs who did not validate. Similar to the experience variable, we could not determine the validation status for all teams. We verified validation status for 61 teams, 11 of which had at least one member who did not validate.

Word Count

We examined the cumulative word count of each individual team member as well as the collective team. Cumulative word count was measured by taking the sum of all words spoken by the physician, nurse, and RT in each transcript. We utilized a Matlab script to identify and exclude fillers such as uhh and umm, as well as utterances from the patient or CSTARS staff members. Repeated words (such as "I think he… he… he") were all counted.

Recurrence Analysis

We applied recurrence quantification analysis (RQA), a recently developed technique for measuring linguistic coordination in teams. RQA is a non-linear time series analysis from the field of dynamic systems and provides metrics for characterizing the relationship between speakers' utterances, including the nature of the adaptations. We characterized the sequence of words from all the speakers during a simulation event as a single time series, then we used RQA to measure the recurrence within that one time series (analogous to autocorrelation). These methods were developed for continuous data, but have been adapted for categorical data in psychology, including for lexical analysis (Fusaroli & Tylén, 2016; Rothwell, Shalin & Romigh, 2021). Recurrence metrics can quantify: *Recurrence Rate* (RR) how much recurrence happens, *Determinism (DET)* the proportion of recurrence appearing in longer sequences, *Average Line Length (L)* the average length of recurrence sequences, and *Entropy (ENTR)* the variety in recurrence lengths. Individual recurrence metrics of RR, DET, L, and ENTR were calculated from recurrence plots created from each dialogue in the corpus.

For each dialogue, two distinct recurrence plots are created. One recurrence plot is a baseline that is constructed by identifying the speaker with the most self-repetition. This baseline plot represents a speaker's self-consistency, or lack of adaptation to the other speakers. The second recurrence plot uses the whole dialogue with contributions from all speakers, which is a test of the coordination between speakers. To assess the relationship of each recurrence model to task performance, metrics from each recurrence model were used in separate regression models (not to be confused with adding/removing predictors from a single regression model). Linear models were evaluated by examining R^2 values.

Prior to conducting the analysis, a standard practice in recurrence quantification is testing if the structure of recurrence measured in the recurrence plot was greater than what would be expected by chance. Paired t-tests were used to compare each recurrence metric to a 'shuffled' metric for each type of analysis (i.e., baseline and coordination). In other words, the time series for the whole dialogue was randomly permuted then the RQA was performed as described above. This process results in 4 sets of recurrence metrics: a set of baseline metrics, a set of shuffled baseline metrics, a set of coordination metrics and a set of shuffled coordination metrics.

All recurrence analyses were conducted in R (R Core Team, 2017) and the crqa package (Coco & Dale, 2014).

Communication Pathways

We calculated the percentage of total utterances that traveled along each possible communication pathway (e.g., from the doctor to the nurse or from the RT to the team).

Egalitarianism

We calculated a rough metric of how egalitarian/authoritarian a team appeared to be based on how evenly distributed communication was across the team members. We determined the percentage of communication (based on word count) accounted for by each team member, then averaged the difference in those percentages across each pair of speakers. For example, if the doctor contributed 50% of the communication, the nurse contributed 30%, and the RT contributed 20%, the difference between the doctor and nurse would be 20%, between the doctor and RT would be 30%, and between the nurse and RT would be 10%, for an average difference of 20%. Higher averages implied more authoritarian tendencies such that a single team member tended to dominate communication, with a maximum possible value of 66.67 (one person generated 100% of utterances) and a minimum possible value of zero (all team members speak equally).

Outcome Measure

The CCATT Advanced course is meant to validate individual caregivers as ready to deploy; all evaluations and performance measures are oriented to individuals rather than the team as a whole. We therefore developed a team-level performance measure to evaluate effects of communication patterns on team performance.

We derived an objective measure for each team in each simulation scenario based on time. For each scenario[2], members of the research team with CCATT experience identified the most relevant physiological parameters and defined thresholds based on clinical guidelines (for example, target blood oxygen saturation) or identified useful clinical endpoints such as the return

[2] Due to operational considerations from the CSTARS training staff, we once again omit specific details of which parameters were considered most relevant in each scenario. Please contact Dr. Robinson at frank.robinson.5@us.af.mil for more details if desired.

of spontaneous circulation in the case of a cardiac arrest. We then utilized the simulation data from Chuck and Dave to calculate time spent outside of target parameters and/or time between the onset of a critical event and its endpoint. We summed the total time for each criterion across Chuck and Date within each scenario to calculate a team's total time. Longer times indicated more time spent outside of prescribed physiological states or longer time to resolve critical events; longer times therefore indicate worse team performance.

Because each scenario had different relevant criteria, we converted each team's time to a Z score relative to the other teams within each scenario. This allowed us to compare each team's relative performance across scenarios. These Z scores served as our outcome measure for all subsequent analyses predicting team performance, reverse scaled so that larger Z scores indicated good performance relative to other teams. Z scores ranged from -2.45 to 2.08.

Analysis Outline

We first established the reliability of our coding scheme. Our other analyses followed two main tracks: 1) predicting team performance and 2) characterizing coordination within teams. After verifying that our outcome measure was appropriate for parametric analyses, we first attempted to predict team performance based on team-level traits (i.e., experience and word count). Next, we predicted performance using metrics related to overall patterns of team coordination such as communication pathways, egalitarianism, proactive information sharing, and recurrence analysis. Finally, we predicted team performance based on communication content using the coded communication categories.

We next characterized coordination between team members based on team role (doctor, nurse, or RT) and whether a team was egalitarian or authoritarian. We then examined potential predictors of team coordination behaviors such as experience and validation status. Finally, we explored whether team communication behaviors were due to internal (i.e., individual) characteristics or due to external (i.e, environmental or scenario-specific) factors.

Results

Interrater Reliability

Three researchers independently coded the same set of six transcripts; we evaluated interrater reliability using a weighted Cohen's Kappa. Because Kappa cannot accommodate more than two raters at a time, we used one rater (the lead investigator, who developed the initial coding scheme) as a "gold standard" against which each of the other two raters were compared. Cohen originally described a kappa value of 0.4 as the threshold for "moderate" agreement, but others advocate for a more stringent standard of 0.6 (McHugh, 2012). We adopted a threshold of 0.5 for a category to be considered reliable; this threshold was more stringent than the original threshold of 0.4, but provided flexibility to account for the semi-exploratory nature of the study and the fact that the most difficult utterances were coded via consensus. We evaluated reliability for each coding category individually. Kappa had to be greater than 0.5 for both pairs of raters (i.e., the lead investigator with rater 1 and with rater 2) for the category to be considered reliable. Unreliable categories were removed from further analysis. Table 1 lists the Kappa values for each category and pair of raters. Ten categories were deemed reliable and retained for further analysis. Note that several of these categories exceeded even the more stringent 0.6 cutoff suggested by McHugh (2012).

Table 1. Kappa values for each category and pair of raters.

Category	PI/Rater 1	PI/Rater 2
Speaker Target*	0.74	0.69
Request Update*	0.73	0.69
Provide Update (prompted)*	0.60	0.55
Provide Update (unprompted)*	0.75	0.71
Request Clarification*	0.68	0.50
Provide Clarification (prompted)	0.65	0.47
Provide Clarification (unprompted)	0.44	0.33
Closing the Loop*	0.77	0.74
Getting Attention*	0.74	0.73
Communication Quality	0.44	0.26
Stating a Goal*	0.58	0.67
Activity Coordination*	0.81	0.69
Crosstalk*	0.90	0.88

Note. Categories with an * were judged to be reliable. Unreliable categories were excluded from further analyses.

Examining Team Performance

Outcome Measure Evaluation

We first evaluated whether our outcome measure was normally distributed and met the assumptions of parametric statistical tests. A histogram of the team performance score indicated the distribution of performance scores was slightly negatively skewed, but descriptive statistics indicated that the distribution was normal enough to proceed (Skewness = -0.51, Std Error = 0.25; Kurtosis = -0.27, Std Error = 0.50). Due to the nested nature of the training course (four unique scenarios with different teams completing each), we next confirmed that the outcome score did not vary based on the simulation scenario completed. An ANOVA with Welch's test did not reveal any differences in the outcome measure across scenarios ($F(3, 38.82) < 0.01$; $p = 1.0$). As expected, normalizing the outcome measure using Z scores eliminated any differences between scenarios. We therefore completed the remaining analyses with the data pooled across scenarios into a single sample, ignoring any cross-scenario differences unless otherwise noted.

Team-level Predictors

Experience. We attempted to identify any experience-based differences in team performance. We used a Welch's t-test to compare the performance scores of the 51 teams with no members with deployment experience to the performance of the 13 teams with at least one member with deployment experience. Although experienced teams had slightly higher average performance scores than inexperienced teams (Means = 0.18 and -0.11, respectively), the experienced teams were not significantly different from the inexperienced teams ($t(1, 34.72) = 1.56$; $p = 0.22$).

Word Count. We next examined whether a team's total volume of communication predicted performance. We used linear regression to examine whether a team's raw total word count predicted performance scores. We found a significant negative relationship between total word count and team performance ($\beta = -0.26$, $t(89) = -2.53$, $p = 0.01$). Raw word count explained a small, but statistically significant proportion of the variance in team performance, $R^2 = 0.07$, $F(1, 89) = 6.41$, $p = 0.01$. Teams with a higher total volume of communication appeared to perform worse than teams with lower total volumes of communication.

Communication Patterns and Performance

Communication Pathways. We expected that teams would develop unique patterns of information sharing that would in turn affect their performance. We therefore examined whether team performance varied as a function of information flow between team members. We calculated the percentage of communication (word count) that traveled along each possible communication channel (e.g., doctor to nurse, nurse to doctor, doctor to team, etc.). The values for all possible communication channels were entered as predictors into a single regression model predicting team performance. The model failed to predict team performance ($R^2 = 0.03$,

$F(8, 82) = 0.29$, $p = 0.97$), but significant multicollinearity was noted among the predictors. Further examination indicated many individual coordination channels were correlated. Though this does not necessarily affect the accuracy of the overall model (Lieberman & Morris, 2014), it reduces our ability to draw conclusions about the effects of any individual predictor. We therefore attempted to reduce multicollinearity and perform a new analysis.

To reduce correlations among our predictors, we calculated new variables based on the proportion of the time that a given channel was utilized, regardless of the direction of information flow (e.g., communication from doctor to nurse was combined with communication from the nurse to the doctor into a single doctor-nurse channel). These new variables (Doctor-Nurse, Nurse-RT, Doctor-RT, and communication from any member to the entire team) were entered into a single regression model predicting team performance. As before, the model was not significant ($R^2 = 0.01$, $F(3, 87) = 0.31$, $p = 0.82$). The overall pattern of communication (i.e., who talks to whom and how often) does not appear related to team performance.

Egalitarianism and Performance. We next examined whether a team's egalitarianism rating was related to performance. We used linear regression to predict team performance scores using each team's egalitarian rating. The model failed to predict any variance in performance scores ($R^2 < 0.01$, $F(1, 89) = 0.02$, $p = 0.89$). Whether a team adopts an egalitarian or authoritarian pattern of communication does not appear to be related to performance in the CCATT domain.

Proactive Information Sharing and Performance. We examined whether the prevalence of proactive information sharing among team members predicted performance. We generated a regression model using the proportion of Provide Update (unprompted) relative to the total number of instances of Provide Update to predict team performance. The model failed to predict variance in team performance ($R^2 < 0.01$, $F(1, 89) = 0.12$, $p = 0.73$), indicating that proactive or reactive information sharing did not affect team performance.

Recurrence Analysis. Finally, we conducted a recurrence analysis to examine whether we could identify any discernable patterns in the content of team members' interactions and if any such patterns were related to team performance. A preliminary test detected if the measured recurrence was greater than what would be expected due to chance. We conducted paired samples t-tests comparing shuffled and unshuffled RR, DET, L, and ENTR within both baseline and coordination. All comparisons for the DET, L, and ENTR variables were significant; comparisons for RR were not (Table 2).

Table 2. Recurrence metrics and t-test results.

Variable	Mean (shuffled)	Mean (unshuffled)	*t*(90)	*p*
Coordination				
RR	0.87	0.88	-1.28	0.20
DET	4.90	17.73	-43.12	< 0.01
L	6.07	2.70	27.69	< 0.01
ENTR	0.06	0.51	-40.08	< 0.01
Baseline				
RR	1.10	1.12	-1.27	0.21
DET	12.57	26.74	-32.15	< 0.01
L	16.86	3.86	7.45	< 0.01
ENTR	0.14	0.60	-23.81	< 0.01

Next, the significantly different Coordination and Baseline recurrence measures were used in separate linear regression models predicting team performance. The Coordination model demonstrated a trend toward significance ($R^2 = 0.07$, $F(3,87) = 2.25$, $p = 0.09$), but the Baseline model did not account for significant variance in performance ($R^2 = 0.01$, $F(3,87) = 0.20$, $p = 0.90$). However, we noted that the coordination values for DET, L, and ENTR were correlated, reducing our ability to draw conclusions about the combined associations of DET, L, and ENTR with performance.

We therefore examined Pearson coefficients of the individual predictors and found that coordination DET was significantly correlated with team performance ($r = 0.21$, $p = 0.02$). Determinism can potentially increase as an artifact of time on task; we therefore investigated simulator completion time as an explanation for this finding by exploring whether completion time mediated the relationship between DET and team performance. Our analysis indicated that DET predicted completion time (B = -55.78, SE = 13.60, 95%CI[-82.81, -28.76], $\beta = -0.40$, $p < 0.001$), and completion time predicted performance (B = -0.001, SE = 0.0003, 95%CI[-0.0013, -0.0002], $\beta = -0.32$, $p = 0.004$). DET did not significantly predict performance after controlling for completion time (B = 0.03, SE = 0.04, 95%CI[-0.04, 0.10], $\beta = 0.08$, $p = 0.46$), consistent with full mediation. Our predictors accounted for approximately 13% of the variance in team performance ($R^2 = 0.13$). The indirect effect was tested using the PROCESS macro Version 4 (Hayes, 2013). The indirect coefficient was significant (B = 0.04, SE = 0.02, 95%CI[0.01, 0.09], $\beta = 0.13$). DET had little to no direct effect on team performance after accounting for the effects of completion time on performance.

Predicting Performance with Communication Content

Overall communication patterns did not appear related to team performance; we next investigated whether communication content explained any variance in team performance. Each of the coded categories of communication was entered into a single regression model predicting team performance score. The overall model was not significant ($R^2 = 0.08$, $F(9, 81) = 0.80$, $p = 0.62$). However, we again noted pronounced multicollinearity among the predictors.

We first attempted to resolve the multicollinearity using a Principal Components Analysis (PCA) to group the predictors into related categories for analysis. However, the value for the Kaiser-Meyer-Olkin (KMO) test was only 0.229, indicating our sample size was not adequate to perform a reliable PCA. We therefore examined the correlations among our qualitative coding categories and removed predictors based on redundancy with other categories. The variables removed from the model are described below, along with a brief rationale:

- Getting Attention was correlated with activity coordination and both prompted and unprompted updates. Getting attention was judged as likely to be less relevant to team performance than these other categories, particularly in a small group setting.
- Request Update was correlated with Providing Updates (prompted); both were also related to closing the loop and activity coordination. Requesting Updates was more strongly correlated with these variables than Providing Updates (prompted), and we wanted to preserve the comparison between prompted and unprompted updates.
- Activity Coordination was correlated with both prompted and unprompted instances of Providing Updates; we felt both types of updates were critical for overall team situation awareness, so we elected to remove activity coordination.

We generated a new regression model to predict team performance using only the variables Provide Update (both prompted and unprompted), Request Clarification, Closing the Loop, Stating a Goal, and Crosstalk. Multicollinearity was greatly reduced, but the model again failed to predict variance in team performance ($R^2 = 0.06$, $F(6, 84) = 0.82$, $p = 0.56$).

Characterizing Coordination Content

Between-role Differences in Communication

We next sought to characterize differences in individual coordination behaviors based on the role of each team member. We examined differences in the use of each qualitative coding category by each team member using a MANOVA[3] to determine whether speaker (doctor, nurse, or RT) predicted the proportion of each speaker's utterances associated with a given coding category (for example, the proportion of RT utterances that were unprompted updates). The omnibus test indicated significant differences between the team roles in how frequently they used several of our coded categories (Table 3).

Table 3. MANOVA results examining the effect of team role on coded category use.

Source	Coded Category	SS	df	MS	F	p	η_p^2
Speaker	Request Update	280.74	2	140.37	9.55	< 0.01	0.07
	Prompted Update	2437.01	2	1218.51	45.48	< 0.01	0.25
	Unprompted Update	1810.27	2	905.13	16.70	< 0.01	0.11
	Request Clarification	89.50	2	44.75	7.71	< 0.01	0.05
	Close the Loop	71.06	2	35.53	1.29	0.28	0.01
	Get Attention	2.08	2	1.04	0.13	0.88	< 0.01
	State a Goal	34.84	2	17.42	21.81	< 0.01	0.14
	Activity Coordination	5081.29	2	2540.65	67.92	< 0.01	0.34
Error	Request Update	3966.85	270	14.69			
	Prompted Update	7233.35	270	26.79			
	Unprompted Update	14636.01	270	54.21			
	Request Clarification	1567.11	270	5.80			
	Close the Loop	7440.24	270	27.56			
	Get Attention	2243.32	270	8.31			
	State a Goal	215.64	270	0.80			
	Activity Coordination	10099.67	270	37.41			

[3] We note that the assumption of independent observations is likely violated due to shared participants across teams. However, we do not have a ready remedy for that issue due to the nature of the CCATT Advanced Course. Further, we believe each team can be considered unique due to emergent properties of the interactions between team members.

Post-hoc Tukey tests indicated that doctors requested updates more than both the nurses and the RTs ($p = 0.01$ and < 0.01, respectively). Nurses and RTs were more likely to provide prompted and unprompted updates than the doctors ($p < 0.01$ for all comparisons). Nurses were more likely than the doctor and RT to request clarification ($p < 0.01$ for both). Doctors were more likely to state a goal than both nurses and RTs ($p < 0.01$ for both), but RTs were also more likely to state a goal than nurses ($p = 0.05$). Finally, doctors were more likely to utilize activity coordination than nurses and RTs ($p < 0.01$ for both).

Egalitarian/Authoritarian Effects on Team Member Behavior

We next examined whether the types of communication used by each team member may vary based on whether their team was egalitarian or authoritarian. Egalitarian scores were normally distributed, so we took a subsample of 44 teams (the highest and lowest 22 teams; roughly quartiles) on this measure and conducted another MANOVA similar to the one described above, this time with egalitarian status (high vs. low) included as an additional predictor. We again found a main effect of speaker, indicating that different roles on the team used the coding categories differently. However, we also noted an interaction for several coding categories such that membership in an egalitarian/authoritarian team affected how each role used the coding categories (Table 4).

Table 4. MANOVA results with egalitarianism as a second predictor.

Source	Coded Category	SS	df	MS	*F*	*p*	η_p^2
Speaker	Request Update	96.83	2	48.41	4.34	0.02	0.06
	Prompted Update	826.55	2	413.28	18.00	< 0.01	0.22
	Unprompted Update	1331.22	2	665.61	13.18	< 0.01	0.17
	Request Clarification	26.11	2	13.06	3.20	0.04	0.05
	Close the Loop	57.02	2	28.51	0.98	0.38	0.02
	Get Attention	10.44	2	5.22	0.52	0.60	0.01
	State a Goal	28.18	2	14.09	15.94	< 0.01	0.20
	Activity Coordination	2533.21	2	1266.60	33.33	< 0.01	0.35
Egalitarian	Request Update	40.08	1	40.08	3.60	0.06	0.03
	Prompted Update	7.33	1	7.33	0.32	0.57	< 0.01
	Unprompted Update	19.63	1	19.63	0.39	0.53	< 0.01
	Request Clarification	0.04	1	0.04	0.01	0.92	< 0.01
	Close the Loop	7.33	1	7.33	0.25	0.62	< 0.01
	Get Attention	0.07	1	0.07	0.01	0.94	< 0.01
	State a Goal	1.10	1	1.10	1.24	0.27	0.01
	Activity Coordination	11.42	1	11.42	0.30	0.58	< 0.01
Speaker x Egalitarian	Request Update	36.95	2	18.48	1.66	0.20	0.03
	Prompted Update	382.20	2	191.10	8.32	< 0.01	0.12
	Unprompted Update	165.21	2	82.61	1.64	0.20	0.03
	Request Clarification	39.50	2	19.75	4.84	0.01	0.07
	Close the Loop	184.57	2	92.29	3.18	0.05	0.05
	Get Attention	47.05	2	23.52	2.32	0.10	0.04
	State a Goal	9.31	2	4.66	5.27	0.01	0.08
	Activity Coordination	164.11	2	82.05	2.16	0.12	0.03
Error	Request Update	1404.75	126	11.15			
	Prompted Update	2893.50	126	22.96			
	Unprompted Update	6363.37	126	50.50			
	Request Clarification	514.48	126	4.08			
	Close the Loop	3652.16	126	28.99			
	Get Attention	1276.62	126	10.13			
	State a Goal	111.36	126	0.88			
	Activity Coordination	4788.39	126	38.00			

Though effect sizes are relatively small, our analyses indicated significant interactions between team type and role for prompted updates, requesting clarification, closing the loop, and stating a goal. The proportion of communication accounted for by prompted updates within each role steadily increased from the doctor, to the nurse, to the RT on authoritarian teams. Prompted updates were used more equally across the team members on egalitarian teams (Figure 1). Nurses on authoritarian teams were far more likely to request clarification compared to their teammates, whereas each team member's use of this category was relatively equal on egalitarian teams (Figure 2). Doctors on authoritarian teams were slightly less likely to close the loop compared to doctors on egalitarian teams, but nurses showed the opposite pattern (Figure 3). Doctors were more likely to state a goal on authoritarian teams compared to doctors on egalitarian teams (Figure 4). Whether a team is egalitarian or authoritarian seems to be associated with small, but noticeable, differences in the ways that individual team members communicate.

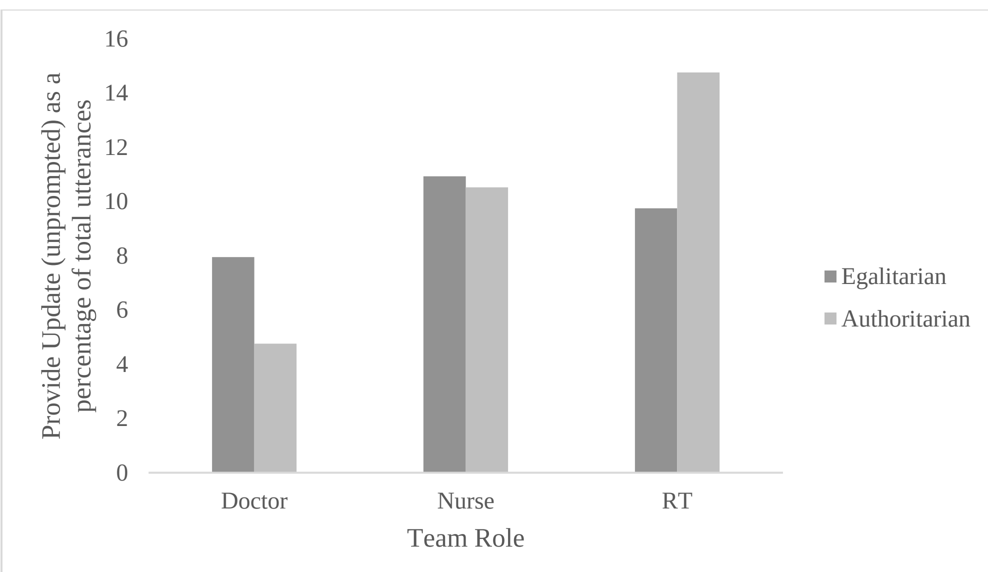

Figure 1. Interaction between team role and egalitarian/authoritarian team type on Provide Update (unprompted).

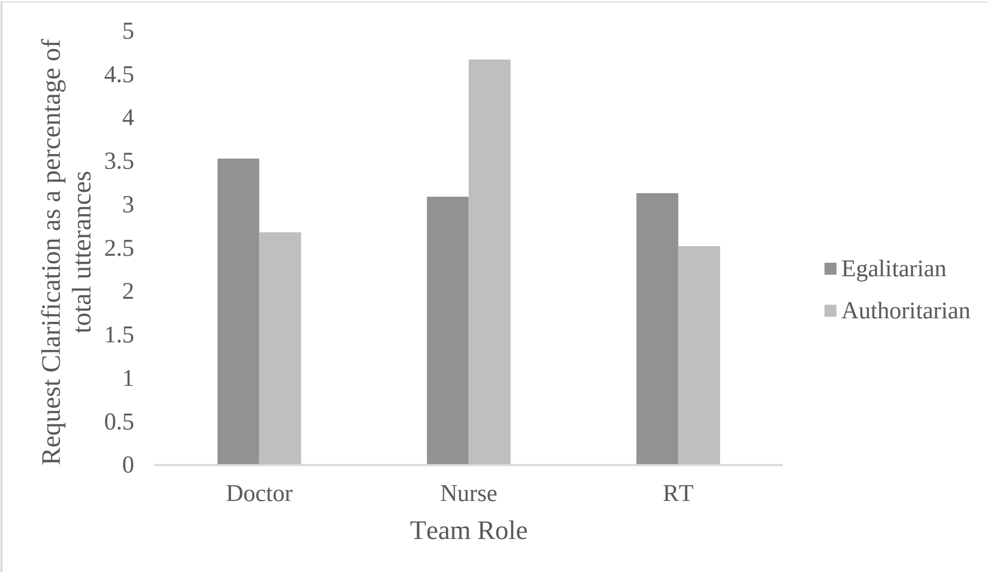

Figure 2. Interaction between team role and egalitarian/authoritarian team type on Request Clarification.

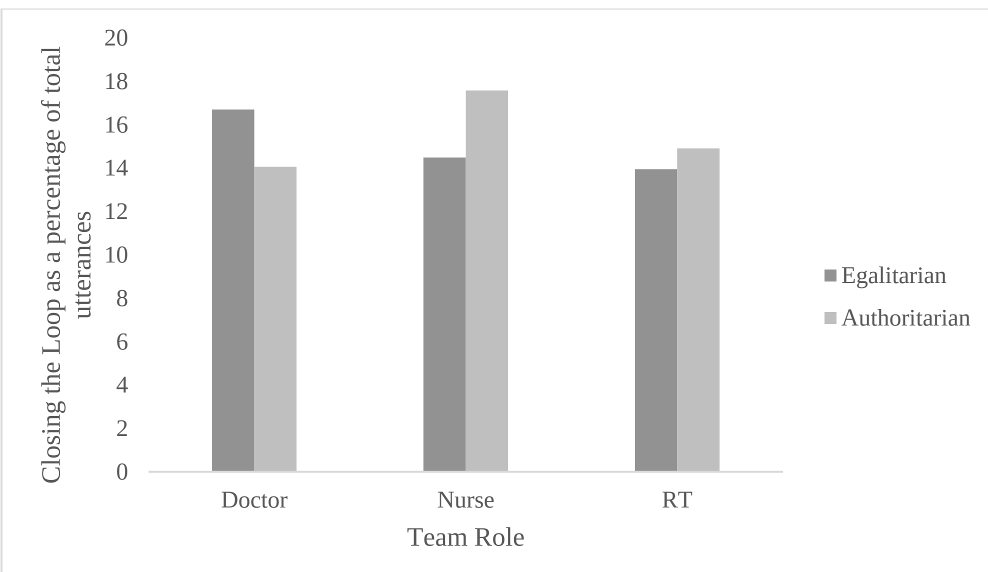

Figure 3. Interaction between team role and egalitarian/authoritarian team type on Closing the Loop.

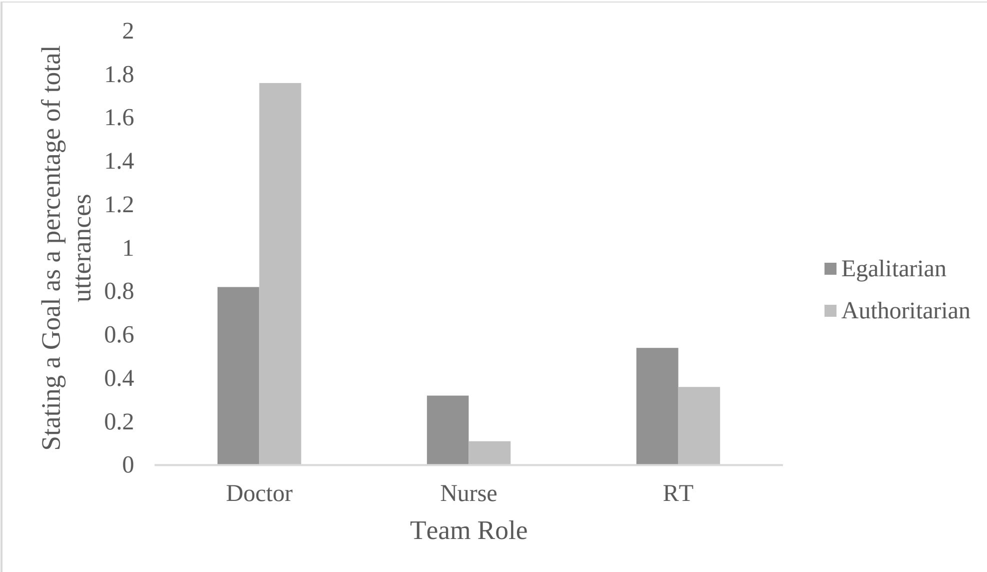

Figure 4. Interaction between team role and egalitarian/authoritarian team type on Stating a Goal.

Predictors of Team Coordination Behaviors

Experience. We hypothesized that experience would affect how team members communicated with one another. We therefore conducted a Welch's test to determine whether experience predicted egalitarian scores. The difference was not significant ($t(25.40) = 0.71$, $p = 0.41$), indicating that experienced teams were no more or less egalitarian than inexperienced teams. We further hypothesized that more experienced team members would better anticipate other team members' needs; we therefore also evaluated whether experience predicted the proportion of Provide Update (unprompted) at the team level. A Welch's t test indicated that experience did not predict how much teams used Provide Update (unprompted) ($t(15.45) = 1.96$, $p = 0.18$).

Validation Status. We examined whether having a team member who did not validate affected team performance, and whether validation status predicted individuals' communication behaviors. A Welch's t test found no link between validation status of team members and the performance of the team (t(13.56) = 0.12, p = 0.74). Because all but one of the trainees who did not validate were RTs, we next examined whether RT validation status predicted RT coordination behaviors. However, RT validation status was not correlated with any of the coded coordination categories (all $p > 0.13$).

Exploring Influences on Team Dynamics

The effect of egalitarianism on how individual team members utilized different types of communication prompted us to explore how individuals behaved across teams. We wanted to determine how stable individual behavior was across membership in multiple teams. We identified individuals who had completed multiple scenarios (i.e., been a member of multiple teams) and calculated the proportion of total word count they contributed to each team's communication. We then used a series of matched sample t tests to compare their highest and lowest contributions within each role. Doctors ($t(18) = -8.92$, $p < 0.01$), nurses ($t(17) = -5.68$, $p < 0.01$), and RTs ($t(19) = -5.52$, $p < 0.01$) all demonstrated significant differences between their largest and smallest contributions, indicating that they changed their behaviors across teams.

However, participation across multiple teams was also typically confounded with completing a new scenario; in order to ensure that the observed differences were not due to different demands on each role across scenario, we also evaluated whether egalitarianism varied across scenarios. An ANOVA revealed that scenario did not affect team egalitarianism ($F(3, 87) = 0.38$, $p = 0.77$). We next performed a MANOVA using scenario to predict the use of individual coding categories (Table 5).

Table 5. MANOVA results examining cross-scenario differences in coding categories.

Source	Coded Category	SS	df	MS	*F*	*p*	η_p^2
Scenario	Request Update	7.87	3	2.62	0.44	0.73	0.02
	Prompted Update	47.00	3	15.67	2.21	0.09	0.07
	Unprompted Update	107.91	3	35.97	1.44	0.24	0.05
	Request Clarification	9.45	3	3.15	1.28	0.29	0.04
	Close the Loop	179.40	3	59.80	5.99	< 0.01	0.17
	Get Attention	21.88	3	7.29	2.48	0.07	0.08
	State a Goal	3.40	3	1.13	2.32	0.08	0.07
	Activity Coordination	165.48	3	55.16	2.28	0.08	0.07
	Crosstalk	42.91	3	14.30	1.57	0.20	0.05
Error	Request Update	524.53	87	6.03			
	Prompted Update	617.92	87	7.10			
	Unprompted Update	2180.88	87	25.07			
	Request Clarification	214.74	87	2.47			
	Close the Loop	868.30	87	9.98			
	Get Attention	255.95	87	2.94			
	State a Goal	42.52	87	0.49			
	Activity Coordination	2109.51	87	24.25			
	Crosstalk	791.74	87	9.10			

We observed scenario-specific differences across teams in closing the loop and non-significant trends toward differences in several other categories. Overall, though, scenario had a relatively small impact on how teams used the various coding categories. Changes in individual and team communication patterns therefore appear to be driven by changes in team composition rather than by changes in scenario-specific demands.

Discussion

This study attempted to identify unique patterns of team coordination in the CCATT domain and link those patterns of coordination to experience and performance. We were partially successful in our efforts, but not entirely. We were able to characterize team coordination behaviors, explore potential influences on the behavior of individuals within a team, and identify differences in communication patterns across teams based on how egalitarian or authoritarian they appeared to be. We also identified a recurrence measure associated with team performance, but believe this relationship is an artifact of completion time. We could not link any of our predictors to prior deployment experience, and many of our measures did not predict performance. Despite this, we believe our findings have value for the CCATT community via improved understanding of team dynamics within the CCATT domain and reassurance that assigning team members in an ad-hoc fashion appears unlikely to negatively impact team effectiveness.

Characterizing CCATT Coordination

CCATTs are expected to follow a hierarchy based on team role, with doctors guiding and directing action, nurses acting in a support role, and RTs playing a smaller, more specialized role. The teams in our sample followed this expected pattern (consistent with the studies reviewed in Tiferes and Bisantz, 2018), with a clear tendency for doctors to lead the team (evidenced by greater numbers of behaviors related to requesting updates, stating goals, and activity coordination). In contrast, nurses and RTs were more likely to provide updates, implying they were answering to the doctor. Further, nurses were more likely than either team member to request clarification, indicating they played a more active role in assisting than the RT. However, we also found significant variability in these behaviors; some teams demonstrated relatively equal communication between team members whereas others were dominated by a single person.

These differences between teams were associated with changes in the content of communication between the different team roles. The overall lack of a main effect of egalitarianism on the various coding categories indicated that the two types of teams did not differ in the overall amount of each type of communication behavior; rather, the interaction between team role and team type indicates that egalitarian and authoritarian teams allocated those behaviors differently among the team roles. Indeed, nurses and RTs on egalitarian teams appear to have more autonomy and active participation in the task at hand than their counterparts on authoritarian teams. For example, RTs on egalitarian teams were less likely to provide prompted updates, whereas doctors on egalitarian teams were more likely to use prompted updates. This shift may indicate that the RT is not being solely “talked at” and is instead a more active participant. Similarly, doctors on egalitarian teams appear to receive and respond to teammate requests more often.

Communication Style Appears to be an Emergent Property of Team Makeup

Whether a team adopts an egalitarian or authoritarian pattern of communication appears to be an emergent property of the interactions among team members. We found that individuals demonstrated significant changes in their relative contribution to the overall volume of communication from one team to the next, but did not find any link between scenario and either team egalitarianism or use of different types of communication. These findings imply that individuals adapt how much they communicate based on their team members rather than the unique task demands of any particular scenario.

Implications for CCATT Performance

In addition to variability in team coordination styles, we were able to identify two links between team coordination behaviors and team performance. We noted that coordination DET was positively associated with team performance, indicating that teams who demonstrated more structured communication content tended to perform better. This finding makes sense, as increased structure is likely associated with more efficient communication and more predictable team behavior. However, further analysis indicated that the link was likely an artifact of completion time rather than a true effect of DET on performance. The overall evidence for an effect of DET on performance in this study is therefore weak. The ability to link RQA measures with performance in an open, dynamic team setting would open the possibility for new team training and performance assessment tools, but at this time further research is necessary to establish such a link when completion time can be better accounted for.

We also found a negative correlation between word count and performance, but we are uncertain how to interpret this finding in the absence of other significant effects. The correlation could be a product of lower-performing teams taking longer to complete the scenario and thus speaking more in terms of absolute word count. Alternatively, word count may be linked to communication efficiency due to the presence or absence of a shared mental model of the situation (Maynard & Gilson, 2014). Teams with a better common understanding of the task may have been able to coordinate more effectively, increasing performance and reducing word count.

Our qualitative behavioral categories and quantitative predictors such as anticipation ratio and an analysis of communication pathways failed to explain significant variance in performance. The lack of performance effect on these measures may be explained by several factors. First, our performance measure may not have been sensitive or otherwise lacked validity to detect performance effects. The fact that team validation status did not correlate with team performance certainly indicates a potential lack of validity, but this is difficult to evaluate given that all but one non-validating trainees were RTs, who have a smaller role on the team compared to doctors and nurses. Further, the measure was derived from current clinical guidelines based on parameters that should have been relevant for any given scenario. We also observed good variability in scores (indicating range restriction was not an issue), and we were able to detect significant differences in other analyses. Overall we are confident in the utility of our performance measure, despite the lack of independent validation.

A second possible explanation is related to the biased nature of the sample population. All participants in the CCATT Advanced course are already qualified and experienced care providers, likely leading to relatively consistent skill levels across the sample. It is possible that a ceiling effect prevented us from observing significant performance differences (i.e., all teams were fairly proficient, limiting observable differences between them). The high validation rates of individual trainees (particularly doctors and nurses) further supports that hypothesis.

These findings are encouraging from an operational perspective. It appears that CCATT providers adapt their behaviors to their teammates, but that these adaptations do not reduce team performance. Further, the presence of a team member with prior deployment experience likewise did not affect team performance. Our findings imply that the current practice of ad-hoc team deployments may have less impact on team performance than we hypothesized.

Limitations

This study has several limitations related to the unique traits of our data set and our outcome measure. Our data were originally collected and maintained in a very specialized environment for non-research purposes and teams were not assembled in the way that they would be for a prospective study. Recordkeeping was sometimes incomplete, making it difficult or impossible to determine which students participated in a given scenario or whether an individual had any prior deployment experience. Simulator data files were also generated and stored separately from the videos of the simulations, and we could not always ascertain which video matched a given set of simulation data.

Incomplete data about the students in each scenario coupled with CSTARS training practices led to the inclusion of some teams in which members were familiar with the scenario due to prior exposure or were more familiar with one another than members of other teams. Class composition did not always include an equal number of doctors, nurses, and RTs. As a result, class members of underrepresented specialties sometimes had to repeat scenarios to provide a complete team for the other specialties. Prior exposure by a team member to a nominally unfamiliar scenario may have altered the behavior of some team members due to learning effects. In addition, team makeup was shuffled such that trainees did not work with the same teammates for each validation scenario. However, some teammates may have worked together more than others.

We would typically attempt to avoid these confounds in a prospective study by controlling team composition and ensuring an equal number of doctors, nurses, and RTs, but that was not possible in the current study. Alternatively, we considered filtering out data from teams in which anyone had prior experience with a scenario. However, this option was not satisfactory either because in the absence of complete records of who participated in each simulation we could not ensure we filtered out all examples of duplicate participation. We therefore elected to keep all teams in the data set and maximize sample size, rather than risk an incomplete (and therefore ultimately ineffective) filter.

Similarly, we did not have any information regarding trainees who had taken the course previously but had not deployed (either due to not validating or other unforeseen reasons). We expect the influence of this group on our results to be minimal, however, due to the presumably small number of trainees falling into this category. Further, an analysis by CSTARS personnel indicates that prior course experience (without deployment) is not a significant predictor of future validation (Brown et al., in preparation). This indicates that prior course exposure alone does not cause large changes in performance, although we have no data available about possible effects on communication behaviors.

Despite our decision to maximize sample size by including all teams, our sample size was still reduced due to incomplete data. We removed transcripts from the sample if we could not confidently match them with accompanying simulator data files used to generate team performance scores, reducing our total sample size. Our analysis of experience was even more limited. We were only able to determine deployment status for 64 out of 91 teams, and only 13 of those qualified as “experienced”. Our analysis of experience should therefore be interpreted with caution due to the small sample of experienced teams, and the discrepancy in sample size for comparisons between experienced and inexperienced teams. Our limited sample of experienced teams also prevented us from exploring role-specific experience effects on individual behavior and team performance. Given the differences in behaviors across doctors, nurses, and RTs, we would potentially expect experience to have different impacts on the team depending on which member had deployed. Role-specific experience effects may have been obscured by our aggregated experience measure.

Finally, we note that our outcome and qualitative measures were developed specifically for this study and have not been validated against any other measure. Our outcome score was developed based on current clinical guidelines in consultation with CCATT practitioners. Although we are therefore confident in the clinical relevance of our outcome measures, they were very scenario-specific. We could not make straightforward comparisons across the individual scenarios or generalizations to other domains. Similarly, the categories used in our subjective coding scheme may have been incomplete. We developed our coding scheme based partly on studies of medical team coordination and on our own sample of transcripts. However, the CCATT domain is unique and we may have missed certain elements that are important to coordination in such a setting.

Future Directions

The findings and methods developed from this study will serve as the basis for multiple future efforts to better understand and promote team performance in the CCATT domain. First, we would like to explore some of the questions raised in this study using a more controlled sample. We found indications that ad-hoc team membership and teams with experienced providers do not impact performance, but we lacked a comparison group of teams with stable membership and our sample of experienced teams was very limited. Exploring these questions with better control over team membership and a larger sample of providers with deployment experience would allow us to draw much more definitive conclusions. Further, our measures were aggregated across entire scenarios, but the scenarios themselves changed dynamically. More nuanced analyses that account for coordination during key situational changes in the scenario (e.g., coordination during the onset of a cardiac arrest) may reveal patterns that we could not observe with our current analyses. We intend to conduct these analyses, particularly with our recurrence measures.

We also plan to conduct additional analyses to explore potential links between DET and performance by better controlling for completion time. If those analyses reveal stronger evidence of a relationship between DET and performance, we would potentially examine the effect of line length on the correlation between DET and our outcome measure, and identify the content of those phrases to determine what functional role such utterances fulfil for the team. A content-based recurrence analysis could also potentially be automated and conducted in near-real time. We would like to explore this further, and work towards development of an automated system that would be able to capture, transcribe, and analyze communication in order to provide feedback to instructors and students during training exercises, or potentially help monitor teams in safety-critical domains to provide an early warning when coordination dynamics begin to change over time. Similarly, we would like to investigate the link between word count and performance, perhaps by performing a more detailed qualitative analysis of high-word-count teams to better understand how word count was linked to performance. Word count would be a readily accessible measure that could also potentially be used to aid in team performance monitoring.

We would also like to explore how teams are affected by the physical environment. CCATTs operate in multiple platforms such as the C-130 or C-17 aircraft, each with unique features and options for loading patients and equipment. We would like to identify how aspects of the environment such as space limitations, ambient noise, or ambient lighting affect team coordination, or if different patient configurations affect workflow. If team behavior changes based on the aircraft or patient configuration, CCATT providers would benefit from the ability to incorporate that knowledge in their mission planning to work most effectively in a given space.

Similarly, we would like to examine the physical fidelity necessary to induce the types of team coordination behaviors identified here in a simulator. The simulators at CSTARS are quite complex, with associated cost, personnel, and maintenance requirements. If realistic team behaviors can be induced using a more austere training environment, perhaps some team-based training could be accomplished in a less expensive setting.

Finally, we do not want to give the impression that we dismiss the value of explicit communication training. Teams in this study seemed to perform fairly well despite the lack of explicit instruction on team coordination in the CCATT environment, but that does not preclude the possibility that performance could be improved with more targeted interventions. In addition, we could not assess whether any CCATT Advanced trainees had prior training on crew resource management or other more medically-oriented team communication techniques. Future work will assess the value of additional coordination interventions on team performance in the CCATT domain.

Conclusions

CCATT personnel often work with unfamiliar teammates in an extremely challenging environment, requiring them to adapt their behaviors compared to a traditional clinical setting. The main finding of the study is that we have identified unique coordination styles among CCATTs, with associated differences in the communication behaviors of each team member. Team coordination style appears to be an emergent feature driven by the interactions of individual team members, implying that individuals can be quite flexible in how they work with others depending on the demands of the situation.

A secondary finding is that we were partially able to predict team performance in a complex, realistic task based on RQA. However, this effect appeared to be an artifact of completion time. We were therefore unable to definitively extend RQA measures from laboratory-oriented tasks to more dynamic simulations, but we have raised questions for further study. Successfully predicting team performance with RQA methods in real-world scenarios would be an important and useful pursuit to improve team training and performance in the future via automated or real-time feedback. Operationally, the lack of a relationship between factors such as experience and team performance implies that current ad-hoc deployment and team assembly practices are likely not detrimental to team performance, but more work needs to be done with a more definitive sample of providers.

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Appendix A. Coding manual for qualitative coding scheme.

Function	Subcategory	Variable	Definition	Examples
Comm patterns	-	Target	Who a speaker is trying to talk to. This will be broken down into doc, nurse, RT, team (everyone), or unsure. If the speaker doesn't specify anyone, code it as "team". If they specify someone or are obviously talking to a specific person but you can't tell who code it as "unsure".	-
Sharing information	Status	Request Update	Asking a teammate for information about the status of something. This applies to patient status (vital signs, awake/asleep, etc.), task completion, equipment status or supply, or status of a team member. This combines everything in the old categories of patient, task, team, and equipment updates.	"What are the patient's vital signs?" "Did you hook up the vent yet?" "Where is the tubing?" "How are things going over there?"
		Provide update (prompted)	Provide information about the patient, equipment, or self AFTER someone else asks for it. This combines everything in the old categories of patient, task, team, and equipment updates.	"Chuck's blood pressure is 120/72." "Dave had 2 doses of Ketamine." "The monitor isn't hooked up yet." "I'll be over there in a minute."
		Provide update (unprompted)	Provide information about the patient, equipment, or self WITHOUT someone else asking. This combines everything in the old categories of patient, task, team, and equipment updates.	"I'm not getting a waveform on the monitor." "There's an alarm going off." "Dave is awake." "Coming behind you real quick." "We'll be landing in 10 minutes."
	Intent	Request clarificaton	Asking a teammate to clarify the intent of their statement, repeat values, or confirm a dose/procedure	"Is is mics per kg per hour, or do you guys like minute?"; "You said his heart rate was 120?"; "Are you going to tighten it down or are you putting it there just in case?"; "what dose do you want?"
		Provide clarification (prompted)	Providing clarification to someone who asked for it	"Yeah I meant tighten it down." "The dose is in mics per kg." "I said 90 beats per minute."
		Provide clarification (unprompted)	Providing clarification or information to someone without someone asking; usually correcting a wrong statement or a speaker repeating themselves	"His heart rate is 77 - sorry 87." "I have a low O2 alarm on Dave - low O2."
	Clarity	Closing the loop	Confirming that a statement or request/direction was understood and agreed to	"Got it." "OK." "Roger that." "Thanks." "Will do."
		Getting attention	Trying to get someone's attention or direct a message to someone specific	"Hey." "Excuse me." "Doc, I..."
		Communication quality	Making sure that a team member heard or understood what was said. This will usually be done by the speaker of the message. Helping to make sure that everyone can be heard, etc.	"Did you get that?"; "Can everyone hear me?"; "Can you speak louder? I'm having a hard time hearing you", "put the microphone closer to your mouth"
Action		Stating a goal	Stating what an ideal end state or target is. This applies to patient goals and team goals.	We need to keep his sats between 85-90; his temperature should be below 99; let's finish that in the next 10 minutes; we need to warm him up
		Activity coordination	Establishing what tasks need to be done, or who is responsible for a task. Choosing an action from different options. Also includes planning for the future. This is about deciding what needs to be done, when it needs to be done, who will do it, and how it should be done (the actual status of a task or progress on completion would fall under updates). This category combines the old categories of claim a task, assign a task, suggest a task, unassigned task, request a task, task rejection, prospective planning, prioritizing/sequencing events, action selection, and instruct.	"Let's give him 10mg of ketamine." "I need you to go get the ACLS bag." "I'll get the monitor set up." "Let's boost his oxygen a little bit" "We'll need to keep an eye on that." "hold that there, open the roller clamp" "we'll give him more fluid after I set up the vent." "Good idea."
Other		Crosstalk	Multiple speakers talking over one another to the point where the content can't be determined	(this will be transcribed as crosstalk)
		Uncodable/ambiguous	This code is for statements that have ambiguous meaning so the correct code is unclear. The main difference between this and miscellaneous is whether the statement would be codeable with more context. If it wouldn't fit anywhere, it would be miscellaneous instead.	"<inaudible> Chuck's cuff pressure"
		MCD	If the speaker is talking to the MCD, or the MCD says something to a team member, code it as normal, but also mark the MCD category so we can filter it out later if we want	
		Patient interaction	Talking to the patient instead of a team member	
		Miscellaneous	This code is for statements that don't fit into any other category	