Understanding Teamwork in High-Risk Domains Through Analysis of Errors

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Abstract
Trauma care is an example of dynamic, complex, and safety-critical teamwork. The staff in trauma centers works under time pressure and lacks effective information technologies to support teamwork and reduce errors. This work presents a qualitative study that looked at the teamwork errors and their causes to better understand the challenges in providing computerized support for this user group.

Keywords
Teamwork, human errors, healthcare, trauma

ACM Classification Keywords
H.5.3 [Group and Organization Interfaces]: Computer-supported cooperative work.

Introduction
Trauma resuscitation is a high-risk medical domain in which teams of physicians, nurses, and technicians must coordinate action, observation, and expertise to make effective decisions. The trauma team must stabilize the patient, determine the extent of the injury, and develop a plan for subsequent patient care. This highly dynamic process follows a standard protocol called Advanced Trauma Life Support (ATLS) that has been adopted by trauma centers worldwide [1]. The first phase of ATLS is a rapid evaluation of major physiological systems such as airway, breathing, and

circulation to identify life-threatening injuries (called ABCD). This primary survey is then followed by a detailed evaluation of other injuries. Because early care after a traumatic injury (the "golden hour") has an important impact on patient outcome, trauma resuscitation should be efficient and error-free.

Trauma teams face many challenges when performing the multi-step evaluation and treatment procedures of ATLS. Due to the minimal use of information technology and external memory aids during trauma resuscitation, trauma teams have difficulty with longitudinal tracking and integration of information. This problem occurs not only with time-series data, such as periodical blood pressure measurements, but also with individual observations. Trauma teams rarely consider the facts found earlier in the process and defer judgments until a strong evidential cue becomes available. Prior research in decision-making has shown that such suboptimal team functioning often leads to significant errors and delays [5]. This paper aims to identify errors unique to teamwork and explain why they happen in trauma resuscitation. Identifying errors and their causes in a highly team-dependent work such as trauma resuscitation can inform the design of technologies for supporting teamwork in other dynamic, safety- and time-critical work settings.

I begin with discussion of prior work on human error and error analysis in trauma resuscitation. This is followed by an overview of study methodology. I then present the hypotheses about teamwork errors that emerged from the qualitative analysis of 18 trauma resuscitations. Finally, I discuss challenges in designing technology to support teamwork in this collaborative, high-risk environment.

Related Work

Human Error

Most theoretical studies of human errors were based on Rasmussen's model of human cognitive information processing called the "skills-rules-knowledge" (SRK) framework [7]. Skills- and rules-based behaviors operate quickly and effortlessly, while knowledge-based processing is slow and requires significant cognitive effort. Reason [8] attributed individual errors to cognitive under-specification, such as incomplete or ambiguous input information, fragmentary cues for memory retrieval, and incomplete or inaccurate knowledge. In contrast to individual worker's errors, little is known about errors that are unique to teamwork. A few studies offer a preliminary theoretical framework for understanding team errors [9],[10], but do not examine technology requirements needed to achieve practical system designs [6].

Errors in Trauma Resuscitation

The existing classifications of errors in trauma resuscitation [3],[4] are "problem-centric" and focus on errors related to medical tasks and their effect on the patient. Clarke et al. [3] classified errors during trauma resuscitation as: error of commission (wrong goal pursued), error of omission (required goal overlooked), and error of selection (goals addressed out of order). This taxonomy is static and does not consider errors as part of the process. Gruen et al. [4] developed a framework that considered where in the process errors happen and classified them by cause as: input errors (incorrect action based on incorrect input data), intention errors (incorrect action based on incorrect intention), and execution errors (correct intention but incorrect action). Gruen et al. [4] judged errors as they related to the patient evaluation process, but viewed the team as an undivided system, rather than as a group of communicating individuals. While both taxonomies are useful for tracking the impact of errors, neither provides a view of why errors occur and how information technology might prevent or correct them.

Methodology

Critical care units such as trauma resuscitation bay present some unique challenges for conducting research. To gain the requisite knowledge and understanding of trauma teamwork, I employed several techniques for studying the domain.

I conducted an observational study in a regional, Level 1 (highest) trauma center over the past 2 years. As video recording has been commonly used for collecting behavioral data for detailed analysis, I selected this method as a primary means for data gathering. However, obtaining the permission to videotape actual trauma resuscitations turned out to be challenging. To circumvent the risks involved in videotaping live resuscitations, such as patient privacy and medico-legal concerns, I ensured that any written records produced during the study excluded resuscitation dates, times, and any personal or other information that could permit identification of a patient, specific resuscitation, or a team member. As a result, Institutional Review Board (IRB) approval was secured, but it required that I erase video recordings within 96 hours. Trauma resuscitations were recorded using strategically positioned, ceiling-mounted cameras and microphones, two of each. Written consents were obtained from a pool of health care professionals before the study began.

The 96 hours limit has led me to develop a method for formally representing and analyzing trauma teamwork without relying on actual video recordings. To preserve the richness of the video record after it was deleted, I generated detailed transcripts that included every utterance and action that took place during the events. Transcribing the videos was a difficult and tedious process. Although resuscitation events lasted between 20 to 30 minutes, they were extremely fast-paced and information-laden. At times, there were several conversations happening simultaneously, with trauma team members performing many parallel tasks. On average, it took about 20 hours to transcribe one event. To acquire the skills needed to critically analyze the conduct of trauma resuscitation, I attended a one-day didactic course modified from the ATLS. A trauma surgeon and a nurse verified the accuracy of transcripts and marked the medical errors.

In addition to video recording, I observed resuscitation events whenever possible. I logged a total of 60 days at the trauma center, with many hours passing without trauma patients coming in. I used idle hours to conduct informal interviews with trauma team members. Interviewing trauma team members immediately after the events was almost impossible since physicians and nurses followed the patient to the next hospital unit.

Transcripts were analyzed using data driven approach. Critical situations that resulted in similar inefficiencies and near-miss errors were grouped together. With each pass through the data, these groups were refined until a distinct set of hypotheses (or themes) about teamwork errors emerged.

I now present the findings grouped by thematic clusters that emerged through the analysis of transcripts and observational data from 18 trauma resuscitations.

Findings

Asynchronous Gathering of Information Leads to Poor Data Integration and Impairs Decision Making

To reach a diagnosis, a trauma team must first observe signs of the injury. Observations are primarily done by the team leader, who makes major decisions and supervises patient care. However, as in most other team-dependent, high-reliability work settings, trauma teamwork is characterized by both cognitive and physical division of labor. This means that other team members, such as orthopedic surgeon, junior residents, nurses, or technicians take active role in information gathering. To successfully link symptoms with diagnoses, the team must know and memorize the list of symptoms to observe, the order of observations (which is prescribed by the ATLS protocol), and the outcomes of all observations. A team with labor division needs to gather all or partial observations for one individual to interpret the findings. As various trauma team members observe signs of the injury, they verbally convey information to the team leader, who then mentally integrates the data and makes a decision. This, however, makes evidence gathering sporadic, time-consuming, and cognitively demanding. The observations needed for diagnosis are completed at different times, sometimes with many minutes between individual observations. As an example, in one critical event, the findings necessary to diagnose internal bleeding due to a severe pelvic fracture became available as follows: pre-hospital blood pressure drop; rectal exam results reported by junior resident at 7′ 44″ into the event; pelvic rock exam performed by orthopedic resident at 8′ 30″ into the event; and a life-threatening blood pressure drop at about 15 minutes. The team confirmed, localized and treated internal bleeding only after reviewing the x-rays that became available 20 minutes after the evaluation had started. This temporal accumulation of data makes it difficult for a single decision maker to collect evidential information and make timely and effective decisions. The team leader relies on other roles to acquire, retain, and validate information needed for decision making. Observations have to be memorized and recalled. As trauma teams primarily rely on collective memory, observations are recalled through questions and responses. This process leads to poor data integration, with most findings being considered in isolation.

Information Loss Leads to Incomplete Situational Awareness and Negatively Impacts Decision Making

Trauma bay is a noisy place. Information about patient status is conveyed and team activities are coordinated mostly by speech. Team members often raise their voices to be able to transfer information. Many kinds of equipment generate background noises. Sometimes, even the patient creates noise because of pain. Noise however is not the only cause of information loss. Information can also be lost if not reported. Team members often fail to propagate critical patient information. Several reasons may account for this inefficiency. Firstly, team members simply forget to either obtain or report information. Common example is failure to report vital signs, an error observed in all events. The technician and primary nurse are assigned to call out the patient’s vital signs periodically for everyone, but often forget to check the monitor. Even when the vital signs are called out, most often not all parameters are reported. Secondly, given the large amount of information gathered during resuscitation, individuals who obtain information ignore less important items, e.g., weak cues. A commonly observed error is failure to report positive or uncertain examination findings. In two events, the orthopedic and junior residents failed to report findings from their assessments that turned out to be critical later in the event. Because they found everything normal, they might have decided, consciously or unconsciously, that reporting these findings would contribute no new information and would only add to the ambient noise. However, propagating information makes it part of collective memory and facilitates team's situational awareness. Failure to report critical patient information, even when positive, negatively affects decision making and can lead to adverse patient outcome. Each team member may be doing their work correctly, but because of failure to propagate information, they are failing at the team level.

Concurrent Task Execution Over Shared Resources Potentially Leads to Adverse Patient Outcomes
The work done by the trauma team involves a great deal of parallelism. The primary nurse can start setting up the intravenous access immediately upon patient arrival (part of step C of the ATLS), without a specific direction from the team leader. At the same time, the team leader may start with the chest examination (part of step B), and the orthopedic surgeon may start his assessment for fractures (part of secondary survey). These variations in the order of tasks prescribed by the ATLS rarely contribute to adverse patient outcomes. Problems, however, occur when team members perform their tasks simultaneously over the same body part, i.e., a "shared resource." For example, in one event, the orthopedic resident repeatedly lifted the patient's arm while the team leader was working on chest tube insertion on the same side. This interference prompted the attending physician to step in and ask the orthopedic to defer his examination to a later time. In another event, the primary nurse started drawing blood samples while the team leader wanted to take x-rays. He decided to hold until the primary nurse completed the blood draw. This decision resulted in delaying the x-rays results.

Tracking the Progress of Multi-Step Procedures is Challenging When Multiple People are Involved
Diagnostic and treatment tasks in trauma resuscitation, such as administration of medications and fluid, require multiple steps. For example, administering a medication involves six steps: it is ordered by a physician, prepared by a pharmacist, and given to a nurse who checks it for correctness, administers it, and reports that the medication has been administered. When a person is executing a multi-step procedure alone, it is relatively easy to keep track of the current step. However, when multiple people are involved, tracking the progress and being aware of the current step is hard. Difficulties in tracking which steps had already occurred and whether medications had been administered were commonly observed throughout the events. For example, in one event, an anesthesiologist inquired 8 times over a period of 3 minutes if a paralytic medication had been prepared.

Challenges in Supporting Trauma Teamwork
Trauma teams face significant challenges when treating severely injured patients. The sporadic occurrence of cues increases difficulties in data integration and decision making. Large amounts of situational information need to be memorized and large amounts of domain knowledge need to be recalled at the time a diagnosis is attempted. Critical patient information is not always available to the whole team due to communication failures and loss of information. The

urgency to evaluate the patient forces team members into colliding over shared resources. Finally, the difficulty in tracking the progress of multi-step procedures raises uncertainty about administration of emergency medications or fluid, and often results in delayed treatments.

Computer technology may have potential to improve current situation in trauma teamwork. Some progress has been made already in supporting team's awareness in other medical settings via shared and interactive displays, e.g., [2]. The biggest challenge, however, in supporting complex teamwork, such as trauma resuscitation, is the ability to track context. As seen from the above descriptions of teamwork errors, observed problems are mostly context-dependent. In order for a system to provide meaningful support, it has to be aware of context. Displaying information will require knowing what information is relevant to current work, who needs it, and when it needs to be displayed.

The present study is only a first step towards understanding the needs for a computerized support of trauma teams. It proposed an explanation for the causes of team errors in trauma resuscitation and major challenges in supporting complex teamwork. Further work is needed in testing these hypotheses on a larger number of trauma resuscitations and identifying the contextual information needed for computerized support.

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