Constructing Awareness through Speech, Gesture, Gaze and Movement during a Time-Critical Medical Task

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Abstract. We conducted a video-based study to examine how medical teams construct and maintain awareness of what is going on in the environment during a time-critical, collaborative task—endotracheal intubation. Drawing on a theme that characterizes work practices in collaborative work settings—*reading a scene*—we examine both vocal and non-vocal actions (e.g., speech, body movement, gesture, gaze) of team members participating in this task to understand how these actions are used to display status of one's work or to acquire information about the work status of others. While each action modality was helpful in constructing awareness to some extent, it posed different challenges, requiring team members to combine both vocal and non-vocal actions to achieve awareness about each other's activities and their temporal order. We conclude by discussing different types of non-vocal actions, their purpose, and the need for computational support in this dynamic work setting.

Introduction

Despite its importance and influence on both social and technical research in CSCW, the concept of awareness remains difficult to grasp (Gross, 2013). A number of workplace studies have served to define awareness in cooperative work, showing how actors align and integrate their distributed but interdependent activities by tacitly monitoring the work of others (e.g., Heath and Luff, 1992; Hutchins, 1995; Berndtsson and Normark, 1999). Yet many questions about awareness in cooperative work remain unanswered (Schmidt, 2002), calling for further research (Gross, 2013). Questions such as what actors monitor for and what they ignore, what features of work are displayed and what features remain hidden, what the actors are able to perceive about the actions of others, and which indicators play a key role in determining the current state of affairs, become increasingly important as we consider the design of meaningful computation environments to support awareness (Schmidt, 2002).

Awareness is especially critical in medical work. Many CSCW studies have paid attention to this concept (e.g., Bossen, 2002; Reddy et al., 2006; Svensson et al., 2007) and many systems have been developed to support it (e.g., Bardram et al., 2006). Yet, as found out by a recent review of CSCW research in healthcare, most studies focus on understanding how work is collaboratively carried out in everyday practice (Fitzpatrick & Ellingsen, 2013). Few studies have examined how workers achieve or sustain awareness through moment-to-moment analysis of interactions among clinicians. Those that looked into embodiment in medical teamwork focused on smaller groups and isolated events (e.g., Hindmarsh and Pilnick, 2007), or on the collaborative use of artifacts (Svensson et al., 2007).

Our goal is to design a computational environment to support awareness and work coordination during complex and high-risk medical activities such as emergency medical and trauma resuscitation. Although emergency medical teamwork has been studied extensively, little is known about how members of trauma or emergency medical teams achieve and sustain awareness during critical resuscitation moments. For the purposes of this research, we define awareness as an ongoing, dynamic process that is being shaped by emerging information and events, and is observable through coordinative actions in the environment.

In this paper, we describe a video-based study of 11 simulated trauma resuscitations conducted to understand how resuscitation team members coordinate work during a highly collaborative, life-critical medical task—endotracheal intubation, or insertion of a tube into the patient's trachea to secure an unobstructed airway. We examine how vocal and non-vocal actions (e.g., speech, body movement, gesture, gaze) constitute work practices that are then used to achieve and maintain awareness. To corroborate findings from video analysis, we draw from materials collected over five years of fieldwork, including observations, video review of resuscitations, and interviews with team members.

To interpret our findings, we draw on Suchman's (1997) work on centers of coordination and on one theme in particular that characterizes work practices in these workplaces—*reading a scene*. As Suchman described it, reading a scene involves assembling the knowledge about past, present and future events 'through juxtaposition and interpretation of verbal reports, visual images, and various forms of text in real time' (1997, pp. 49). Although rarely called a center of coordination, trauma resuscitation shares many characteristics of such a center: (a) strict division of labor, (b) collocated team members, (c) team-dependent task coordination, and (d) diverse sources of information. Where it differs from centers of coordination is in the lack of tools and technologies to facilitate work coordination. Resuscitation bay instruments, such as vital signs monitors and sensors, provide data about the patient's physiological status. This sensor-based data, however, provides limited contextual information about team activities. Awareness of who is around or what others are doing is achieved through verbal communication, with dedicated roles calling out and reporting different types of information. The means by which resuscitation teams coordinate and communicate are therefore radically affected. Exploration of these mechanisms through the lens of the *reading a scene* theme allows for new insights as well as for the re-examination of challenges in designing computational environments to support awareness in high-risk cooperative work.

We contribute to CSCW in three ways. First, we are adding knowledge to the growing body of CSCW research concerned with the interplay of embodied action and speech in co-present, ephemeral and time-critical settings. Second, by drawing on a Suchman's theme characterizing the centers of coordination, we show how different types of 'immaterial mechanisms' (Bossen, 2002) are used in coordinating tasks and constructing two critical types of awareness in trauma resuscitation—activity and temporal awareness. Finally, we discuss implications for computational environments in supporting awareness in this work setting.

Related Work on Awareness and Embodied Action

The literature on awareness within CSCW is vast, spanning different foci and areas of research. Below we review key studies of awareness in centers of coordination and critical care settings, as well as those that focused on the interplay between speech, embodied action, and object manipulation as mechanisms for achieving awareness.

Awareness in Centers of Coordination and Critical Care Settings

Seminal studies of collaborative work in centers of coordination such as London Underground line control rooms (Heath and Luff, 1992), air traffic control (Berndtsson and Normark, 1999; Hughes et al., 1992), airport operations rooms (Goodwin and Goodwin, 1996) and ship navigation (Hutchins, 1995) have shown that collaborators tacitly monitor each other to maintain representations of their work, and to plan and organize their own conduct. Specifically, these studies examined the ability of actors to see and analyze events using a range of artifacts and systems, while aligning their activities in an unobtrusive and seamless fashion. Similarly, CSCW studies of awareness in critical care settings have found that clinicians use a variety of mechanisms, processes and artifacts to coordinate work and achieve awareness. For example, Reddy and colleagues

(Reddy and Dourish, 2002; Reddy et al., 2006) showed the importance of temporal rhythms and patterns in orienting clinicians in an intensive care unit (ICU) toward future activities. Bardram et al. (2006) and Bardram and Hansen (2010) studied the processes of planning and scheduling activities in the operating suites with a focus on technology design to promote spatial, temporal and social awareness for improved coordination and communication in this environment.

This body of work has produced rich accounts of how activities are carried out and how awareness is achieved in high-stakes work settings through the collaborative use of coordination mechanisms, such as various artifacts and technologies (Schmidt and Simone, 1996). Our paper extends this line of research, but focuses on the use of immaterial coordination mechanisms, like speech and embodied action. In doing so, we perform moment-to-moment, fine-grained analysis of both vocal and non-vocal actions to identify the mechanisms by which multidisciplinary medical teams construct and maintain awareness during a highly collaborative, time-critical medical task.

Awareness and Embodied Action

The team-driven nature of medical work has provided an opportunity for studying the use of different media and embodied resources for achieving awareness in a range of clinical environments. For example, Koschmann et al. (2011) found that surgeons establish common references to particular locations of the surgical field by coordinating their talk and gestures with their hands and instruments. Svensson et al. (2007) analyzed passing of instruments among clinical staff during surgery, and found that the arrangement, configuration and passing of an instrument relied upon the participants' abilities to see and prospectively anticipate actions of others. Mentis and Taylor (2013) observed the use of new intraoperative imaging technologies during neurosurgery, showing how medical images are constructed and embodied with the actions by which surgeons manipulate the body.

Examined together, these studies are concerned with the use of instruments, tools and artifacts as coordinative mechanisms. In addition, most of them involved an analysis of new technologies or digital interventions, which to some extent either transformed or changed the ways in which workers interacted with each other. There are, however, important works that focused on bodily conduct alone in complex interactional and organizational contexts, such as studies by Hindmarsh and Pilnick (2002; 2007) and Goodwin et al. (2005). In particular, Hindmarsh and Pilnick (2002) examined the patient's social and interactional impact on the organization of work and communication among members of the anesthetic team, identifying several key practices and skills associated with *in situ* teamwork. For example, they found that members of anesthetic teams conduct certain tasks in tandem and mutually monitor each other's work by seeing or overhearing conversations, which allows them to efficiently orient to the trajectories of colleagues' actions. In their follow-up study on embodiment and ephemeral teamwork in preoperative anesthesia, Hindmarsh and Pilnick (2007) used the endotracheal intubation task to examine the bodily conduct of medical personnel as a coordinative resource. Their observations showed how participants successfully anticipate the future activities of colleagues based on their intimate understanding of the trajectories of actions and by making sense of emerging conduct of colleagues. The authors highlighted the importance of placing the body at the heart of the analysis of work and organization, calling for future studies of social interaction and work practices to follow their suit.

Although we examine the collaborative practices of medical professionals using a similar context—the work of anesthesia and the endotracheal intubation task, our study differs from this previous work in two significant ways. First, prior studies examined intubation during preoperative anesthesia as an isolated event with only two roles participating in the task, the anesthesiologist and his or her assistant. In contrast, we examine how this task is performed in the larger context of trauma resuscitation and with more players, making the "scene" much larger and more complex than that of preoperative anesthesia. Second, the anesthesiologists and their assistants come from the same training background, with overlapping skills and knowledge, whereas the personnel involved in intubating a trauma patient comes from different disciplines and backgrounds, possessing a range of skills. The context of our study is therefore highly multidisciplinary and hierarchical, providing an opportunity for new insights about the interplay between embodied action and speech, as well as their use as resources for achieving and sustaining awareness.

Background: Trauma Resuscitation & Intubation Task

The setting for our study is the *resuscitation bay*, a complex but low-technology work setting in which medical team members engage in time-critical, high-stakes management of a critically injured patient. Although team members follow established protocols and guidelines, their performance efficiency primarily rests on their ability to coordinate actions with one another and with the dynamic changes of the patient's physiological systems. Typical trauma resuscitation involves 8 to 12 medical specialists from various disciplines, depending on the hospital size, the severity of injury, and the corresponding level of trauma activation (American College of Surgeons, 2006). A high-level response to a severely injured patient includes an attending surgeon, an emergency medicine physician, surgical and emergency residents, emergency department nurses, a scribe nurse, a radiology technician, an anesthesiologist, a respiratory therapist, a critical care nurse, security officers, and a social worker. In contrast, the resuscitation team response to a less severely injured patient might initially include an emergency physician and nurses until the attending surgeon arrives.

Patients in need of endotracheal intubation are considered critical and usually require full trauma team activation. Trauma teams are formed *ad hoc* upon receiving patient arrival notification, with members called from different hospital units, which makes their prior acquaintance with each other less likely. Teams are also hierarchical, with clear division of labor and delineation of responsibilities. For instance, attending surgeons, surgical fellows or emergency medicine physicians assume the leadership role (*team leader*). Anesthesiologists and respiratory therapists control airway, cervical spine, and ventilation. Surgical residents perform hands-on patient examination (*physician doer*). Emergency department nurses draw and administer medications and fluids, establish intravenous (IV) access, and assist with other hands-on tasks (*medication nurse*, *nurse left* and *nurse right*). The *scribe* nurse is responsible for creating and maintaining the full record of the trauma activation. Each role is strategically positioned around the patient bed to ensure timely and efficient completion of the resuscitation process: respiratory therapist and anesthesiologist are at the head of the bed, physician surveyor is at the right side, bedside nurses stand on both sides, scribe is at the foot of the bed, and team leader stand in the back.

Of all resuscitation tasks and activities, endotracheal intubation—a time-critical, multi-step procedure, with each step comprising several sub-steps—is probably among the most challenging and demanding tasks in terms of team coordination. It starts with the leader and anesthesiologist making a decision to intubate the patient. Depending on the patient's age and medical history, they then agree upon a set of medications to render the patient unconscious and paralyzed. Because medications are usually pushed via intravenous (IV) access, the leader must also ensure that an IV is placed before medications are drawn. The leader will therefore monitor the work of the nurse right, whose task is to place an IV. In the meantime, the anesthesiologist prepares the intubation equipment (laryngoscope handle and blades, stylet, and tubes), while the respiratory therapist performs pre-oxygenation. Administration of intubation medications follows next. Because the use of anesthetic, sedative and paralytic drugs is potentially dangerous given the effects they produce, their preparation and administration are carefully executed and monitored through six steps: they are ordered by the anesthesiologist or team leader, the medication nurse prepares them, gives them to the bedside nurse (nurse left), who then checks them for correctness, administers them, and acknowledges they have been given. The administration of medications and the start of intubation must be tightly coordinated because of the limited duration of drug effects. Right before starting, the anesthesiologist will position the patient, tilting his or her head, lifting chin and thrusting jaw, to ensure smooth insertion of the tube. As the anesthesiologist starts with intubation, the respiratory therapist stops pre-oxygenation and removes the oxygen mask. The anesthesiologist then places laryngoscope in oropharynx, while another team member (usually a nurse or physician doer) applies cricoid pressure. The tube is then inserted and laryngoscope is removed from the patient's mouth. The respiratory therapist immediately connects the tube to oxygen and starts patient ventilation. The anesthesiologist confirms tube placement by reporting its position at the lip. Determining the presence of CO_2 in exhaled air using a small device called CO_2 indicator and auscultating the patient's chest for breath sounds signal the end of endotracheal intubation. In summary, the intubation procedure involves the work of seven medical specialists, whose actions and movements require fine-grained, moment-to-moment coordination. Because mutual awareness of each other's actions is critical for timely and effective completion of the patient's intubation, we felt this procedure provided an ideal case for studying how both vocal and non-vocal actions constitute work practices that are then used to achieve and maintain awareness during a time-critical medical task.

Methods

The core of our data are video records of 11 high-fidelity simulated trauma resuscitations originally performed in a pediatric Level 1 trauma center in the U.S. mid-Atlantic region. A total of nine unique trauma teams performed two clinical scenarios. The first scenario (Scenario A) involved a 5-year-old female injured in a high-speed car accident. Teams were required to respond with interventions including intubation and fluid administration to stabilize blood pressure. The second scenario (Scenario B) involved a 3-year-old male hit by a car. Although teams performing this scenario were expected to carry out only chest decompression and fluid administration to stabilize blood pressure, they also proceeded with patient intubation. Four teams performed Scenario A only, two teams performed both Scenario A and Scenario B, and three teams performed Scenario B only. Because both scenarios involved critically-ill patients, they required full trauma team activations, with eight core team members comprising each team: a team leader (attending surgeon or emergency medicine physician), a physician doer (surgical resident), an airway physician (anesthesiologist or critical care fellow), a respiratory therapist, two bedside nurses, a medication nurse, and a scribe nurse. Participants were recruited from a pool of physicians and nurses who normally serve in these roles and participate in trauma resuscitations in the hospital. Simulations were performed in the actual resuscitation bay using high-fidelity patient mannequins and the usual medical equipment and materials available. Two video cameras captured each simulation—one provided an overhead view and the other provided a side view of both the team and the room.

Patient simulators have been used to teach and evaluate team performance in a range of medical events. Prior research on simulators has shown that participants frequently 'suspend their disbelief' and perform in a manner similar to actual clinical scenarios while fully realizing they are working on the patient simulator (Nackman et al. 2003). Even so, relying solely on simulations poses several limitations. To validate our analysis of simulation videos, we draw from a large corpus of data collected over five years of fieldwork at the same research site. These data include notes from *in situ* observation and video review of tens of live resuscitations, transcripts of interviews and focus groups with clinicians serving in different trauma team roles, and video review sessions with trauma team members commenting on teamwork while watching a resuscitation video.

Video Review of Simulations & Data Analysis

Our primary data analysis involved systematic review of video recordings and transcripts of 11 simulations. We focused on a few minutes of action in each video (i.e., endotracheal intubation fragment), performing moment-to-moment analysis of speech, gesture, gaze and body movement of all team members participating in the task. We considered the fragment starting when a team member (usually team leader) ordered patient intubation or verbally confirmed the need to intubate the patient. The ending point was when the anesthesiologist or bedside nurse reported CO_2 monitor reading (for assessing the adequacy of ventilation), and the physician doer reported the status of breath sounds. On average, video fragments were 3.8 minutes long, ranging from 2 to 6 minutes.

While reviewing the videos, we paid specific attention to instances in which vocal and non-vocal actions were used to achieve an overview of the situation, understand the current status of team members' tasks, display the status of tasks occurring either subsequently or in parallel, and perceive the overall progress of the intubation task. In doing so, we were interested in how the interactions among team members were collaboratively produced with respect to trajectories of actions, team members' verbal and non-verbal communication, and the manipulation of various artifacts. Detailed transcripts of both speech and action served to clarify the character of actions and to explore the relationship between vocal and non-vocal actions. As we progressed with the review, we began to identify common patterns of action and common practices of coordination, as well as how different mechanisms (speech, bodily conduct, gaze) contributed to constructing awareness and accomplishing this time-critical task.

To better illustrate the observed patterns of action and coordination practices, we provide brief excerpts from transcripts that include descriptions of actions (e.g., 'turns gaze toward nurse') and accompanying utterances. Where possible, we also show gestures and body movement through video images, and highlight them by circling the action of interest. Following the human subjects protection rules mandated by the ethics committee approving this study, we anonymized our data and completely blurred the faces appearing in the video images.

Findings

We present findings in three parts. We start with examples of verbal communication as the most common mechanism for achieving and sustaining awareness about the current state of affairs. We then describe how gesture and body movement contributed to work coordination and awareness. By describing these three mechanisms one at a time, we show the strengths and weaknesses of each, highlighting their successes and failures in securing awareness. We conclude with examples of work in which all three mechanisms interacted with each other, allowing for smooth and timely coordination and awareness.

Achieving Awareness through Speech

Successful management of patients during trauma resuscitation is largely reliant on the flow of clear, concise and accurate information among medical team members. To coordinate tasks and make decisions, the leader relies on other people in their designated roles to acquire, retain, validate and report the needed information. When assigning tasks, the leaders often direct orders to the team as a whole rather than to an individual. For instance, a request for the latest set of vital signs is typically given as "*Can we get the vitals*" vs. "*Pat, can you give me the vitals*." Orders and inquires can also be directed to specific individuals when there is a need for specific information or task, such as intubating the patient or establishing IV access. Similarly, when reporting task-related information, a team member can direct his or her report to the entire team (e.g., when administering fluids), or to a specific role (e.g., when working on a task with another team member). In the excerpt below, we show a typical information exchange between the leader, anesthesiologist (Anst), medication nurse (MedN), and left and right bedside nurses (NurseL, NurseR) as they start preparing for patient intubation.

Excerpt #1

00:04:37	Leader	[Turns gaze toward Anesthesia] Prepare to intubate, (name), if you would please.
	Anst	[Gaze goes to Leader, head nod]
00:04:40	Leader	[Orients toward Med Nurse at the workbench on the right, facing away the team] Can I have etomidate and succinylcholine please?
00:04:43	MedN	[Facing away the team, nod]
00:04:44	Anst	I have a 5-O tube ready.
00:04:45	Leader	Okay.
00:04:47	Leader	[Gaze goes to patient] Be careful of the cervical spine obviously.
00:04:48	MedN	[Approaches bedside, medication syringes in hand]
00:04:51	NurseL	[Gaze to Nurse R] Um, do we have access?
00:04:53	NurseR	[Looks down, works on IV access] Not yet.

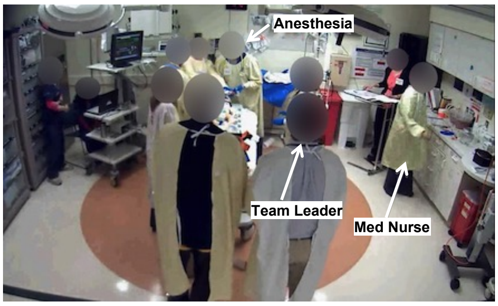
00:05:14	Leader	[Gaze toward Nurse L] And what do we have for access, (name)? Have we been working (…)?
00:05:16	NurseR	I am working on it!
00:05:18	NurseL	[Gaze toward Leader] We're working on it right here, do we want an I/O?
00:05:19	Leader	[Gaze toward Nurse R] Can you get it, (name)? Yeah, let's get something a little bit bigger.
00:05:23	NurseR	Okay.
00:05:24	Leader	Keep me posted on that, okay? If you haven't gotten it within about a minute or two, let's go to I/O access.
00:05:24	NurseR	Alright, I am in!
00:05:30	Leader	[Gaze toward Nurse Right] You're in?
00:05:32	NurseR	[Gaze toward Leader] Yeah, I'm in!
00:05:32	Leader	Okay.

As seen in this example from Team #2, Scenario A, the leader started by asking the anesthesiologist to prepare for intubation. The anesthesiologist acknowledged and the leader then turned to the medication nurse and ordered intubation medications. Soon after, the team's focus turned to the status of IV access and nurse right's work. As soon as the medication nurse approached the bed with syringes ready in her hand, the nurse left, whose task is to administer medications, inquired about the status of IV access. Although potentially visible by just glancing at the patient body, the status of an IV is usually confirmed verbally for a simple reason: the line can be established but it may not work properly, so the nurse right, who either established it or checked it upon the patient arrival (in case IV access was established en route to the hospital), confirms it is set. Here, we saw how both the leader and nurse left inquired about the status of IV access, even though they could see the nurse right working on it. We also saw the nurse right responding to inquiries and, after successfully completing her task, announcing that she was "in". Once the IV was established, the team proceeded with administering fluids and medications, and finally with patient intubation. Although we only showed an excerpt here, this was an example of a heavily verbalized intubation case. Because the leader needed specific information and tasks to be completed, his orders and inquires were directed to specific roles. We also noticed the use of personal pronouns playing an important role in achieving team awareness. Expressions such as "*What do we have for access?*" or "*We are working on it here*", as opposed to "*Can I have etomidate and succinylcholine please*" or "*I am working on it*", served as implicit expressions of responsibility for various actions, thereby making other team members aware of who is in charge of a task.

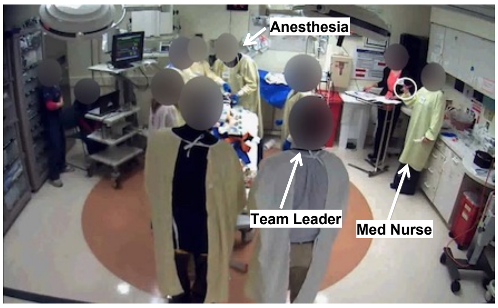
Unlike body movement or gesture that can be easily missed if one is not looking in a particular direction, speech and vocal sounds can reach all actors by being overheard regardless of their targeted direction. Heath and Luff (1992) described how overhearing conversations contributed to peripheral monitoring of the actions in the Line Control Rooms on London Underground. Similarly, we noticed how overhearing exchanges between the anesthesiologists and leaders triggered other team members' actions. Most often, we observed the medication nurse overhearing the leader and anesthesiologist's discussion about the intubation plans. As shown in the excerpt below from Team #3, Scenario B, the medication nurse would immediately start preparing medications using the information she overheard, rather than wait for the leader's direct order:

Excerpt #2

00:08:26	Anst	[Turns gaze toward Leader] Getting drugs? Are we getting any drugs?
00:08:28	MedN	[Gaze toward Anesthesia]
00:08:29	Leader	Yes, what do you think?
00:08:29	MedN	[Turns toward workbench, facing away, starts opening cabinets with syringes]



00:08:30	Anst	I think, uh, we'll get some etomidate and succs to intubate.
00:08:50	MedN	[Turns around facing the team, holds medication syringes in her hand]



Often times, however, speech alone is not sufficient enough for team members to acquire information or achieve awareness about the work status of others. Although important, words are often misheard or lost in the shuffle, especially in the noisy and crowded environment of the resuscitation bay. Another problem is human error; team members often forget to report out loud the status of their activities as they become engrossed in their tasks, or they only provide partial reports (Sarcevic et al., 2012). The challenges in using speech as a sole mechanism for achieving awareness highlight the need for using other channels to convey status of one's activity, including gesture and body movement.

Efficient Uses of Gesture & Movement in the Absence of Speech

In the resuscitation bay, with the patient positioned in the center of the room, trauma team members perform a dynamic set of activities surrounding the patient, such as examining the patient, moving around the patient, assembling and arranging medical tools and equipment, or checking the patient's vital signs by looking at the vital signs monitor. Working side-by-side makes it easier for team members to monitor each other's activities and assess the relevance of those activities to their own work. At the same time, they carry out various embodied actions, indirectly displaying their ability to recognize the trajectory of other team members' actions and to anticipate their next move. This ability to make sense of the current conduct and anticipate future activities helps ensure smooth coordination, even when verbal communication is absent.

Because responsibilities are clearly specified for each role, team members pay particular attention to activities that are highly relevant to their tasks. Often times, however, some roles would assist with tasks that have limited relevance to their own work, as illustrated below in the example from Team #5, Scenario B.

Excerpt #3

00:06:09	NurseR	[At the bedside, standing next to Physician Doer, fetches the IO drill for inserting intraosseous line]
00:06:09	Doer	[Holds the patient's neck, controls for cervical spine]
00:06:10	Anst	[Turns gaze toward Nurse Right]
00:06:10	Doer	[Turns gaze toward Nurse Right]
00:06:56	NurseR	[Orients her body toward Physician Doer, arm with the IO drill extended toward Physician Doer].
00:07:00	Anst	[Takes over cervical spine control]
00:07:02	Doer	[Takes the IO drill from Nurse Right and starts inserting the line]

We enter this sequence as the team prepares to establish interosseous (IO) line to administer fluids and medications. The physician doer has just volunteered to immobilize the patient's cervical spine, while the anesthesiologist prepares intubation equipment and respiratory therapist ventilates the patient. Establishing IO access is the nurse right's responsibility, so we see her taking the IO drill instrument out of the box (action circled in the first video image). It took the nurse about 40 seconds to configure the IO drill. In theory, both nurse right and physician doer can perform this task. In this case, however, the physician doer has easier access, because he is closer to the patient's right leg. Recognizing the situation, the nurse right performs a series of subtle movements, displaying the readiness of the IO drill and implicitly asking physician doer to insert the IO: holding the IO drill in one hand and waiting for a few seconds, orienting her body toward physician doer, extending her arm toward physician doer, and then pulling back (action circled in the second video image). The anesthesiologist also recognizes the nurse's intention, so she takes over cervical spine control. A second later, the physician doer takes the instrument and starts inserting the IO.

This excerpt illustrates how the anesthesiologist, nurse right and physician doer coordinated their activities without talking to each other. They were able to recognize each other's gestures and body movement, making sense of actions around them and anticipating each other's needs. As others have found in similar contexts, this timely and smooth coordination between actors rests on their ability to understand the character and trajectory of actions performed by others to which they can contribute (Hindmarsh and Pilnick, 2007).

Speech, Gesture & Movement Combined for Complete Awareness

In the Excerpt #1 from Team #2, Scenario A, medication nurse approached the bed with prepared syringes, but did not verbally announce this information to the team. Rather, it was nurse left who noticed her presence, 'reading' her gesture as a signal that medications were ready for administration. Although gesture and body movement serve as important mechanisms by which team members can display their status, the crowded nature of the resuscitation room often makes these channels difficult to see. In the cases we reviewed, we noticed how team members crowd around the patient, leaving little room for movement, especially when treating pediatric patients. Because activities happen in parallel (e.g., one nurse may be taking manual blood pressure while another is drawing blood from the same arm), team members push their ways in order to complete tasks.

Combining speech with gesture or body movement provides for a more efficient mechanism for displaying activity status. Preparing medications is a good example, given the many steps in the process and the importance of keeping the team aware of the completion of each step. The following excerpt is again from Team #2, Scenario A, continuing a minute after the first excerpt stopped:

Excerpt #4

00:06:18	MedN	[Stands next to Nurse Left, holds syringes, orients toward her and hands over syringes] That's 8 mg of etomidate and 50 mg of succynocholine.
00:06:22	Leader	Let's just hold those for a second. Let's get a formal

		GCS [neuro] count. Eyes no response, verbal no response, motor no response. So Glasgow is 3, so go ahead.
00:06:32	Anst	[Gaze toward Leader, nod]
00:06:34	Leader	[This] certainly confirms our decision to intubate.
00:06:36	Anst	[Gaze toward Team Leader, another nod]
…		
00:07:06	Leader	[Gaze toward Nurse Right] Are our fluids going in?
00:07:08	NurseR	[Points toward Med Nurse, who is now helping with fluid administration] Nobody started fluids yet, she's getting them.

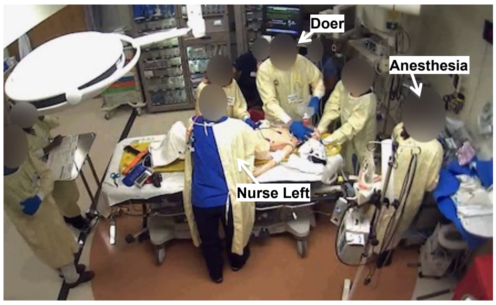
00:07:10	Leader	[Gaze toward Medication Nurse]
00:07:12	NurseL	[Waves hand with medications, orients toward Team Leader, gaze toward Team Leader] And I have an RSI ready.

Here, we could see how speech, body movement and gesture together constituted the work and allowed for smooth and timely coordination of activities. At the beginning of the excerpt, we found the medication nurse standing at the bedside, verbally announcing medication types and dosages. As we described before, such verbal reports serve to make the entire team aware of one's task status, or in this case, of the readiness of intubation medications. The leader, however, asked for a pause before administering medications to first assess the patient's neurological status using Glasgow Coma Scale (GCS). As the leader reported the score, the anesthesiologist turned her gaze toward the leader. Because GCS assessment is a critical step before patient intubation, the anesthesiologist paid particular attention to this information, illustrating again how team members remain sensitive to the specific information or tasks that are closely related to their roles and responsibilities. In addition, the anesthesiologist nodded two times, displaying her agreement with the leader's assessment—that is, the GCS score was critically low and intubation was necessary. Soon after, the leader checked in with nurse right about the status of fluid administration. The nurse right responded using both an utterance and deictic gesture, pointing toward the medication nurse who was assisting with fluids (gesture circled in the second video image). In turn, the nurse's gesture directed the leader's attention to the specific team member (medication nurse), making him aware of who was taking care of the task. At the end of this sequence, the nurse left oriented her body and head toward the leader and waved the hand in which she held medications, displaying their readiness (gesture circled in the third video image). The nurse left augmented her gesture by verbally reporting that medications were ready.

Even with speech and gesture combined, team members can often miss the clues because they are either busy with their own tasks or the person reporting on their status isn't doing enough of "displaying" to be noticed by others. Consider for example an excerpt from Team #8, Scenario A, when the anesthesiologist was busy preparing intubation equipment and missed other activities around the bed:

Excerpt #5

00:05:30	Anst	[Looks at the vitals monitor, turns to Doer] Can you take over the bagging?
00:05:32	Doer	[Gaze toward Anesthesia] Sure.
00:05:33	Anst	[Hands the bag to Doer, turns around toward intubation cart, facing away the bed, starts preparing intubation equipment].
00:05:40	NurseL	[Starts administering medications] Etomidate in. Succs in.



00:05:40	Anst	[Turns back toward patient, intubation equipment ready in her hand]
00:05:52		[Anesthesia puts the laryngoscope on the bed, Doer hands the bag over to Respiratory, Doer starts holding the patient's head, Respiratory starts bagging the patient]
00:06:01	Anst	[Gaze toward Nurse Left] (Name), meds are in?
00:06:03	NurseL	[Gaze toward Anesthesia] Yes, meds are in.

In this excerpt, we saw the nurse left reporting the status of medications two times, first announcing they were ready, and then announcing medication names as she was administering them. Even so, the anesthesiologist was busy with monitoring vital signs and preparing equipment, so she missed these verbal cues. To obtain the needed information, she had to ask nurse left directly if medications were administered. There were cases, however, when the lack of information or when missing a report created bigger commotion among team members. In one live event, for example, we observed the anesthesiologist inquiring about the status of intubation medications six times. Upon closer inspection, we uncovered that team members in charge of preparing and administering medications did not communicate with the anesthesiologist about their work status, leaving the anesthesiologist unsure where they were along the six steps in the medication preparation process.

Comments about closed-loop communication were frequently heard as we interviewed various team members, further confirming how neither of the mechanisms for displaying and monitoring work status can be sufficient alone. In combination, however, these different mechanisms constitute meaningful work practices that help facilitate smooth and timely coordination, as each mechanism helps making up for the shortfalls of the others.

Discussion & Conclusion

In this paper, we conducted a video-based study to examine how medical teams construct and maintain awareness of what is going on in the resuscitation environment during a high-critical, collaborative task—endotracheal intubation. We examined both vocal and non-vocal actions (e.g., speech, body movement, gesture, gaze) of team members working on this task to characterize different types of mechanisms by which they either display the status of their work or monitor the environment to acquire information about the work status of others. To interpret our findings, we drew on the ‘reading a scene’ theme that Suchman (1997) adopted and then used to characterize work practices in collaborative work settings such as centers of coordination.

Our findings showed how the co-present resuscitation team members leveraged different types of ‘immaterial mechanisms’ (Bossen, 2002) to construct and sustain awareness in a time-critical environment. According to Bossen (2002), immaterial coordination mechanisms include routines, procedures and habits like division of labor, peripheral awareness and even knowledge about a worker’s background or experience. Similarly, we observed that team hierarchy and standardized protocols played an important coordinative role in completing complex resuscitation tasks. Here, however, we extended the term immaterial mechanism to also include vocal and non-vocal actions by which trauma team members coordinate their work. As we saw through the excerpts, they took advantage of working side-by-side to not only visually check the status of ongoing activities but to also overhear conversations, which in turn triggered their own actions. The work around and on the patient was dynamically configured through the use of speech, gesture, gaze, and body orientation. While speech was used to obtain or report specific information, gestures and body orientation were used for different purposes. For example, extending one's arm while holding an object expressed an intent of passing that object; nodding was primarily used for simple answers like 'yes' or 'no'; pointing was used to direct one's attention, while hand waving was used to draw attention. Similarly, orienting one's body or head was also used to draw attention. What became clear from our analysis, however, was that each mechanism alone was helpful in constructing awareness to some extent, posing several challenges along the way. For instance, because the resuscitation room could easily become chaotic and noisy, verbal communication was often subject to failure, leading to misunderstanding or information loss. Or, when gestures were unsuccessful in communicating the information, it was because they were missed and rarely because they were misunderstood. To overcome these challenges, team members took advantage of their ability to 'read the scene' and combine speech with gesture or body movement for a more efficient way to achieve awareness about each other's activities and their temporal order.

Prior work has found that maintaining mutual awareness within a team of clinicians is central to the coordination of work in hospitals (Heath et al., 2002). Our data showed that by explicitly requesting information, overhearing conversations, or seeing actions of others, the resuscitation team members were able to obtain information about the status of ongoing activities of each other (i.e., *activity awareness*). Often times, however, while working on their own tasks, team members missed both verbal and non-verbal clues in the environment. As shown above, we observed several cases with the anesthesiologists lacking awareness about the status of medications, which in turn triggered additional (multiple) requests for information.

Temporal awareness is especially critical when working on time-critical tasks such as intubation. Common approaches to keeping track of temporal order of most medical activities include schedules or knowing the temporal rhythms and patterns of work practices (Reddy et al., 2006). In contrast, keeping track of time during intubation relies on intimate monitoring of and being sensitive to another team member's activity in order to project the trajectory of actions and time one's contribution to the task. As our findings showed, the anesthesiologist must know the exact moment of administering medications so that intubation can be performed within the limited timeframe of drug effects duration. Or, as the anesthesiologist is inserting the tube, the respiratory therapist must closely monitor each move that the anesthesiologist makes to be able to attach the ventilation bag to the tracheal tube in a timely manner. One possible explanation for such a relatively smooth coordination between the anesthesiologist and respiratory therapist with almost no conversation at all could be their intimate knowledge and understanding of each other's work, which in turn precludes the need for intense articulation work (Bossen, 2002). In contrast, coordinating the timing of administering medications with intubation requires more effort on behalf of all team members.

The question then is how best to approach the design of computational environments to address the challenges in achieving and sustaining awareness of activities and their temporal order during highly intense and time-critical medical work. On one hand, the activities performed by various team members and the manner in which they were performed showed how the organization of the intubation task unfolded naturally. Clinicians undertook their work by either 'reading' the actions of others and responding to them, or making them visible to others on the team. Most of the time, this visibility of embodied actions allowed for smooth coordination and timely completion of activities such as passing instruments, inserting the tube, or ventilating the patient. It is our belief then that such natural task organization can hardly benefit from any technological intervention, for it would only get in the way. On the other hand, we observed critical moments and commotion among team members when the needed information was not reported, or when it was missed or lost in the shuffle. It is here that we argue for technology support in constructing and maintaining awareness of ephemeral and historic information such as task parameters, timing and types of interventions, and patient data. The challenge is that such information is internalized in memories of those who performed tasks and is available only if reported voluntarily or requested. A possible solution is to externalize this information by augmenting the use of speech, given its key role in making this ephemeral and historic information available to the team. The whiteboard-like, digital wall display has proven useful in supporting awareness of medical teams (Bardram et al., 2006). A quick glance at the wall display to obtain information about different task parameters in real time (e.g., timing, types and dosages of administered medications) may speed up the process and preclude the need for redundant inquires by the anesthesiologist, leader and other roles. The challenge, however, is in accurate and timely capture of such information from the environment. While verbal reports could be potentially captured using speech recognition, this approach can be problematic when we take into account the noise or parallel speech, though vocabulary is rather limited so algorithms could be trained. Manual data entry has been tried, but was found challenging due to the rapid pace of events (Fitzgerald, 2009).

Our findings showed that medical resuscitation teams heavily rely on speech and bodily conduct to communicate the information and keep each other aware of activities during time-critical tasks. Similar behaviors have also been observed in other work domains. There are ongoing efforts in automatic capture and recognition of human activities during collaborative work in order to support teamwork and decision making. Our future work will explore how important it is to capture these actions and the extent to which this can be achieved.

Acknowledgments

This work is supported by the National Science Foundation under Grant No. #1253285. We would like to thank our research team members for their support, as well as to the medical staff at the research site for their participation. Thanks also to the anonymous reviewers for their constructive suggestions and recommendations.

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