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Sketching Awareness: A Participatory Study to Elicit Designs for Supporting *Ad Hoc* Emergency Medical Teamwork

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Abstract. Prior CSCW research on *awareness in clinical settings* has mostly focused on higher-level team coordination spanning across longer-term trajectories at the department and inter-department levels. In this paper, we offer a perspective on what awareness means within the context of an *ad hoc*, time- and safety-critical medical setting by looking at teams treating severely ill patients with urgent needs. We report findings from four participatory design workshops conducted with emergency medicine clinicians at two regional emergency departments. Workshops were developed to elicit design ideas for information displays that support awareness in emergency medical situations. Through analysis of discussions and clinicians' sketches of information displays, we identified five features of teamwork that can be used as a foundation for supporting awareness from the perspective of clinicians. Based on these findings, we contribute rich descriptions of four facets of awareness that teams manage during emergency medical situations: *team member awareness*, *elapsed time awareness*, *teamwork-oriented and patient-driven task awareness*, and *overall progress awareness*. We then discuss these four awareness types in relation to awareness facets found in the CSCW literature.

Key words: Awareness, Collocated teams, Information displays, Participatory design, Work coordination, Emergency medicine

1. Introduction

The concept of awareness has become critical in CSCW research in healthcare. The increasing specialization of medical knowledge and services, as well as the distributed nature of collaboration and communication in hospital work, have led to a large number of CSCW studies highlighting the challenges of maintaining awareness and coordinating activities (Fitzpatrick and Ellingsen 2013). This body of research has identified different facets of awareness that require information technology support, including social, temporal, spatial, activity, and process awareness. The ways in which awareness is achieved in medical work, however, have been examined mostly from department or inter-department level coordination of teams with longer or asynchronous time trajectories. For example, Bardram et al. (2006) studied how clinicians in an operating ward achieve social, spatial, and temporal awareness through large interactive displays situated around the ward. Although emergency

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medical situations share several characteristics with previously studied hospital settings such as surgery and critical care (e.g., multidisciplinary teams, division of labor), awareness requirements differ in emergency medical work due to the *ad hoc* team formation, collocated nature of teamwork, lack of information technologies, and tighter time constraints.

Our focus in this work is on two emergency medical domains—trauma resuscitations and emergency medical resuscitations (also called medical alerts). Both events represent fast-paced and dynamic processes, requiring medical specialists to administer life-saving treatments by following a set of established protocols for patient evaluation and management. The protocols in turn serve as mechanisms by which medical teams manage the complexity of articulating their own work (Schmidt 2002). Unlike other medical settings, emergency resuscitations require intense, collocated cooperation among clinicians from multiple disciplines brought together *ad hoc* at the time of the resuscitation. Even with a protocol defining how and in what order each physiological system must be evaluated, task coordination is still dynamic and changes with patient needs.

In addition, the resuscitation environment has few information technologies designed to support teamwork (Xiao et al. 2006). Teams rely on verbal communication to coordinate their work and report findings from patient examination, but information communicated verbally is often misheard or simply lost in the shuffle (Bergs et al. 2005). Whiteboards and information displays are well-known mechanisms for supporting communication, work coordination, and awareness in emergency departments (Wears et al. 2007; Xiao et al. 2007), operating rooms (Bitterman 2006; Parush et al. 2011), and anesthesia (Drews et al. 2006). There are few studies, however, on the design of information displays for *ad hoc*, collocated teams working on patients with time-critical needs (Wu et al. 2013). Our previous study on visual attention in trauma resuscitation has found that clinicians usually glance at the vital signs monitor for 1–3 seconds, but sometimes spend up to 26 seconds analyzing monitor data (Kusunoki et al. 2013). These findings suggest that additional displays with more contextualized information may be viable in emergency medical environments.

In this paper, we report findings from four participatory design workshops conducted with clinicians at two regional hospitals to further understand the ways in which we can support awareness with information displays during *ad hoc*, collocated teamwork in emergency medical situations. We contribute detailed discussions and contextualized examples of coordination challenges and awareness needs of emergency medical teams. In doing so, we are addressing three gaps in the CSCW research, while also responding to calls for studies of awareness at the micro level in healthcare settings:

- First, as recently pointed out by the editors of the special *CSCW Journal* issue on awareness, there is a need for understanding how technologies can be designed to support awareness and to be specifically adapted to the "concrete

conditions of tasks and their social, spatial and organizational context" (Kolfschoten 2013, p. 109). A recent review of 25 years of awareness research in CSCW also indicated that there is a notable "design tension" between creating technologies that can "span across time, distance, and domains," but still address requirements that are highly specific to the domain (Gross 2013, p. 459). Furthermore, CSCW studies in the medical literature have argued for understanding awareness needs at the micro level, as well as the details of what information is needed, when, how, and from whom (Pratt et al. 2004; Tjora and Scambler 2009).

- Second, according to a 25-year review of CSCW research in healthcare (Fitzpatrick and Ellingsen 2013), there is a need for studies that take on participatory or action research approaches to engage clinicians in the design of the information technologies that will inevitably shape their work practices. Emphasis has been placed on understanding work practices through observations and interviews, but less research has focused on designing and eliciting clinician-generated designs (Fitzpatrick and Ellingsen 2013).
- Third, there is a need for more multi-site studies in order to validate and determine the generalizability of the findings across a particular type of setting (Fitzpatrick and Ellingsen 2013; Randell et al. 2011). Transferability of findings to other settings is still, however, a methodological challenge in practice-oriented research (Wulf et al. 2011).

1.1. Research goals and contributions

This study is part of a larger research program to iteratively design and evaluate information displays to support the awareness of teams in emergency medicine. Our previous work involved interviews, direct observation, and extensive video analyses of resuscitation events (Kusunoki et al. 2013; Sarcevic and Burd 2008; Sarcevic and Burd 2009; Sarcevic 2010; Sarcevic et al. 2011a; Sarcevic et al. 2011b). Although it highlighted issues that are relevant to awareness support, this prior work has mainly focused on information and coordination behaviors by looking at communication practices and questions posed during resuscitations. In this paper, we take a more holistic approach to system design. We build on our previous work as well as on existing literature, and report the results from participatory design workshops conducted with emergency medicine clinicians to understand how the previously observed practices relate to awareness needs and how these needs materialize through direct input from clinicians. Subsequent studies in the research program will focus on iteratively developing an information display prototype based on the knowledge accrued through years of fieldwork coupled with results from participatory workshops, then testing the prototype in a simulated resuscitation environment.

Our goal in this paper is twofold. First, we use participants' perspectives to characterize teamwork during emergency resuscitations, and identify features of *ad*

hoc, collocated teamwork that require support through information technology. Five features of teamwork emerged from clinicians' sketches: (1) accessing patient information and pre-hospital data; (2) identifying leaders and other roles; (3) monitoring patient status in real time and trends over time; (4) keeping track of tasks and team progress; and (5) managing orders and coordinating work with other hospital units. The sketches also revealed the differences in both awareness needs and priorities for different information types based on role. Second, we use this understanding of *ad hoc*, collocated emergency medical teamwork to contribute rich descriptions of four facets of awareness that medical teams manage during emergency situations—team member awareness, elapsed time awareness, teamwork-oriented and patient-driven task awareness, and overall progress awareness—and discuss them in relation to awareness facets found in the CSCW literature. Using these findings, we then offer guidelines for how designs can be shaped to address the issues that clinicians describe about their work.

In addition to addressing the gaps in CSCW research mentioned above, this paper further contributes:

- An analysis of design sketches elicited through participatory design workshops about clinicians' perceptions on awareness.
- New insights into awareness by examining *ad hoc*, collocated emergency medical teamwork.
- Design implications for supporting awareness during *ad hoc*, collocated teamwork.
- Qualitative comparison of clinician perspectives across two institutions about information requirements for supporting awareness.

1.2. Awareness in CSCW literature

The literature on awareness in CSCW has pointed to the notable lack of agreement on what awareness is and what about awareness is important to understanding and supporting cooperative work through technology (Carroll et al. 2006; Gutwin and Greenberg 2002; Heath et al. 2002; Kolfschoten 2013; Schmidt 2002). There have also been debates in the field of human factors about whether situation awareness is a state that can be shared and maintained, or a dynamic process of continually achieving understanding (e.g., Endsley 1995; Salmon et al. 2007). In our research, we view awareness as an ongoing and dynamic process that is being shaped by emerging information and events.

Among the many different facets of awareness that have been proposed and discussed in CSCW and, more specifically, in healthcare studies, we found six facets that relate to the characteristics of awareness in the emergency medical setting: social, temporal, spatial, activity, articulation and process awareness. *Social awareness* has been described in contexts where actors are often distributed but generally

know each other. To coordinate work, actors need to know who is around, where and how far, and what is their current status and availability (Bardram et al. 2006; Carroll et al. 2003; Prinz 1999). *Temporal awareness* was discussed in studies focused on non-emergency settings characterized by long-term collaborations (Bardram 2000; Reddy and Dourish 2002; Reddy et al. 2006). To manage their work and facilitate scheduling, actors need to know the status of past, present, and future activities, as well as the urgency of each activity. *Spatial awareness* was referred to as knowing what activities are taking place within a space and how people are interacting with the space itself, but in contexts where actors or teams are distributed to varying degrees (Bardram et al. 2006; Gutwin and Greenberg 2002). *Activity awareness* has been described in both synchronous and asynchronous contexts as knowing what others did, are doing, or what needs to be done (Cabitza et al. 2007; Dourish and Bellotti 1992; Prinz 1999). *Articulation awareness* was characterized as knowing information necessary for coordinating tasks and managing task interdependencies in collocated teamwork (Cabitza et al. 2007). Similarly, *process awareness* has been defined as knowing where the team is in the overall process in collocated, asynchronous, and synchronous contexts (Cabitza et al. 2009a).

While these facets of awareness have been described in detail with regard to collocated, distributed, synchronous, and asynchronous contexts, few studies directly examined the details of awareness in short-term, *ad hoc* contexts. Two main characteristics of short-term, *ad hoc* contexts introduce potential risks to providing meaningful and useful awareness information. First, there is a lack of information available before events to firmly establish common ground that awareness can be built upon (Argote 1982; Xiao et al. 2007). The amount and type of information available for supporting awareness varies depending on the available preparation time, urgency, and complexity of the event. Second, when team composition fluctuates, communication becomes less efficient (Lee et al. 2012). Team members arrive late and at different times, and may leave in the middle of events. Information must then be repeated, resulting in bad communication redundancy, interruptions, or miscommunications. In some cases, team members might continue working without the information they need, which may lead to misguided decisions and errors. It is therefore important to understand the types of information that drive awareness needs and the ways in which awareness unfolds in short-term, *ad hoc* contexts. Further investigation of these low-level details about awareness allows us to propose more meaningful and useful mechanisms to address interruptions and missed information for supporting the awareness of *ad hoc* teams.

The purpose of this paper, however, is not to define awareness, identify new facets of awareness, or conduct an extensive review of awareness (see Carroll et al. 2009; Salmon et al. 2007; Schmidt 2002 for more detailed discussion). Our analysis of awareness centers on understanding the details of what types of information are necessary to support teamwork from the perspective of *ad hoc*, multidisciplinary teams in emergency medicine, and how information displays can then be used as mechanisms to present this information. We further discuss our contributions to the

existing awareness literature within the context of our findings in the Discussion section.

2. Background: overview of emergency resuscitations and teams

Trauma and emergency medical resuscitation are specialized domains in which critically ill patients are treated in a dedicated facility in the emergency department, called the resuscitation bay (Burd and Elliot 2011; Ludwig and Lavelle 2010). Resuscitation teams treat patients on a case-by-case basis, depending on the severity of the injury, the patient's demographics, and medical history. While trauma resuscitations address life-threatening blunt or penetrating injuries, such as those sustained in motor vehicle accidents or falls, medical alerts are more complex because they treat an underlying medical cause (e.g., cardiac arrest or seizure) that can complicate the dynamics of the patient's illness, and subsequently the teams' performance.

Although focusing on different types of illness, the two domains share several attributes. First, they are both safety-critical, emergency medical events dealing with competing priorities, unpredictable problems, and incomplete information (Faraj and Xiao 2006). Second, teams in both events adhere to evaluation protocols that focus on major physiological systems (or ABCDs), including Airway, Breathing, blood Circulation, and Disability or neurological status. Trauma teams follow the Advanced Trauma Life Support (ATLS) protocol (Burd and Elliot 2011), whereas medical alert teams follow the Advanced Life Support (ALS, or PALS for resuscitating children) protocol (Ludwig and Lavelle 2010). Finally, both events involve multidisciplinary teams consisting of emergency medicine physicians, nurses, critical care specialists, respiratory therapists, anesthesiologists, and surgeons (surgical staff is present during trauma resuscitations only). Each team member has a specific role and a set of defined tasks. For instance, anesthesiologists and respiratory therapists manage the patient's airway. Physician surveyors examine the patient to identify injuries. Scribe nurses document all of the findings, interventions, and outcomes of the event. Bedside nurses make sure intravenous (IV) access is established, and medications and fluids are administered. Attending surgeons, emergency medicine physicians, and critical care specialists make decisions and facilitate the process. Team members are called from different departments and may not necessarily know each other or have enough time to introduce themselves (Sarcevic et al. 2011b). This lack of deep ties and common experiences in learning from each other may make the teams less efficient in establishing common ground, integrating knowledge, and reaching coherent solutions (Majchrzak et al. 2012).

Currently, emergency resuscitation teams achieve awareness through verbal communication. Dedicated roles call out and report different types of information. For example, the physician surveyor calls out findings from the physical exam as they emerge, while bedside nurses report on the status of their tasks. Because few mechanisms exist to help externalize information and distribute team cognition (Sarcevic et al. 2012), leadership roles must internally synthesize information

reported by multiple team members. There are several information resources for documenting patient information, including a medical flow sheet and resuscitation checklist, but these resources are not visible to all team members and do not update dynamically. High levels of verbal communication are still required to help get and keep team members on the same page, often resulting in repeated questions, repeated reports, noise, and lost information. To inform the design of meaningful awareness mechanisms for *ad hoc*, emergency medical contexts, we looked at previous work on awareness in CSCW, and more specifically in healthcare, and then built on this understanding of awareness in other contexts by examining awareness needs of emergency resuscitation teams at the micro level.

3. Methods

3.1. Research setting

This study was conducted at two freestanding pediatric hospitals (Hospital 1 [H1] and Hospital 2 [H2]) with Level 1 trauma centers in the US Mid-Atlantic region, and was approved by Institutional Review Boards (IRB) at both hospitals. Level 1 trauma centers provide the highest level of definitive, comprehensive care for severely injured adult and pediatric patients with complex, multi-system trauma. The emergency department at Hospital 1 performs about 600 trauma and emergency medical resuscitations annually. Similarly, the emergency department at Hospital 2 serves over 80,000 patients per year, of which about 430 require trauma or emergency medical resuscitation. Each hospital has its own set of tools and technologies that assist teams during resuscitations. These include paper-based flow sheets and checklists, sign-in boards, wall-mounted timers and clocks (to keep track of time), vital signs monitors, and Electronic Medical Record (EMR) systems. By involving medical experts at two regional hospitals, we were able to observe how our findings from different settings exhibited noticeable convergences, allowing us to infer that many of our findings would potentially emerge in other, comparable settings.

3.2. Participants

Participants were recruited to represent the core team member roles required during trauma resuscitations or medical alerts including: anesthesiologist, bedside nurse, critical care physician or fellow, physician surveyor (surgical resident or nurse practitioner), respiratory therapist, scribe nurse, emergency medicine physician, and team leader (surgical attending or fellow). Participants were asked to represent the roles in which they normally serve on a daily basis. Recruitment is challenging in this setting because clinicians are busy and work long, odd hours. With assistance from research coordinators at both hospitals, we posted calls for participation using internal listservs and bulletin boards. A total of 23 participants with experience levels in emergency medicine ranging from several months to 30+ years signed up to

participate in our workshops (Table 1). Most participants dedicated an extra 2 hours before or after their shifts, or came in on their off-days to participate in our study. All participants received symbolic, monetary compensation for their time. Only three roles had fewer representatives in the workshops (two anesthesiologists, two physician surveyors, and one critical care physician). The mixture and variation of participant roles and levels of experience represented in the workshops replicated the real-world composition of *ad hoc*, multidisciplinary resuscitation teams.

3.3. Data collection

We conducted four participatory design workshops—two at Hospital 1 and two at Hospital 2 between November 2012 and February 2013. We audio and video recorded discussions during each workshop and also took photographs of activities and outputs. Video records supplemented audio records by helping us distinguish who said what, see what people were doing or pointing at, and match participants' roles from the transcripts. Photographs helped us analyze the design outputs in greater detail.

Each workshop lasted 2 hours and was split into five different activities with short breaks in between. We employed the participatory design technique called PICTIVE to provide an environment where participants with diverse perspectives have equal opportunity to engage in the design process (Muller 1993). PICTIVE was selected over other participatory design techniques such as CARD (Muller and Druin 2012) because of its greater emphasis on participant-generated design prototypes rather than collaborative analysis and planning of workflow. Participants used low-tech design objects such as pens, pencils, paper, and post-it notes to create design sketches (Figure 1). We focused on information needs and general layout, and did not cover the functionality of the display, which is the topic of future participatory design workshops.

Table 1. Participants breakdown: workshop # and site, # of participants, roles present, and average years of experience.

Wksp. No.	Total partic.	Roles present	Avg. Exper.
1 [H1]	7	1 scribe and 1 bedside nurse, 1 anesthesiologist, 1 respiratory therapist, 1 surgical resident, 1 surgical fellow, 1 emergency medicine physician	6 years
2 [H1]	5	1 scribe, 1 anesthesiologist, 1 respiratory therapist, 1 surgical fellow, 1 emergency medicine physician	5 years
3 [H2]	6	1 scribe and 2 bedside nurses, 1 respiratory therapist, 1 surgical fellow, 1 emergency medicine physician	9 years
4 [H2]	5	1 scribe and 1 bedside nurse, 1 surgical attending, 1 emergency medicine physician, 1 critical care specialist	9 years

Figure 1. Workshop participants engaged in design activities.

Five different workshop activities were carefully constructed to elicit participant perceptions, each building on the next, allowing us to compare findings within and across workshops: quick survey (15 minutes), individual designs (30 minutes), group design (30 minutes), information ranking (5 minutes), and discussion of concerns (20 minutes). The survey was implemented to prompt participants to think critically about their work. We asked participants to recall the most recent resuscitation they were part of (which was sometimes only a few hours before the workshop) and provide brief answers about what worked and what did not, what issues they encountered, and what they would change. Each participant was then asked to discuss their experiences with the group. Reflecting on their work through discussing recent events helped participants ground their design thinking in real, concrete scenarios that provided the basis for design, evaluation of their designs, and discussion of their concerns (Carroll 2000).

Following this quick survey, participants were given sheets of construction paper to create a design for their personal information display. We asked participants to think about the critical pieces of information they would need and what the display would look like (Figure 2). The objective here was to understand what features of teamwork require support through information types needed by each role. Participants discussed their individual designs with the group and all of the designs were posted on the wall for reference during subsequent workshop activities.

Participants then worked together as a group to create a display design that incorporated the ideas from their individual designs. Teams in each workshop nominated a scribe to translate the design ideas from the entire group into one display design (Figure 3). Designing displays as a group prompted participants to discuss their decisions in detail and reach consensus on the most important design features that would incorporate the main information needs of all roles. Group designs helped us understand which types and forms of information needs were shared among roles.

Based on their role, each participant was then given color-coded stickers labeled 1 through 5 and asked to rank the information pieces on the group display. This activity

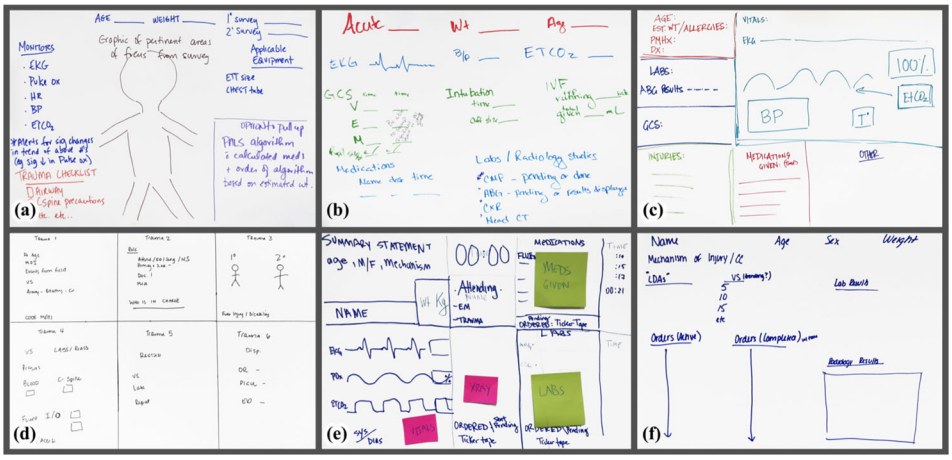

Figure 2. Examples of individual sketches from hospital 1 (**a, b, c**) and hospital 2 (**d, e, f**), out of 23. Roles are (**a**) emergency medicine fellow, (**b**) scribe nurse, (**c**) anesthesiologist, (**d**) surgical resident, (**e**) critical care specialist, and (**f**) bedside nurse.

allowed each person to voice his or her opinion during the group activity (Muller and Druin 2012). The rankings also allowed us to discuss the design with regard to what participants felt were the most important types of information to include on the display (Table 2).

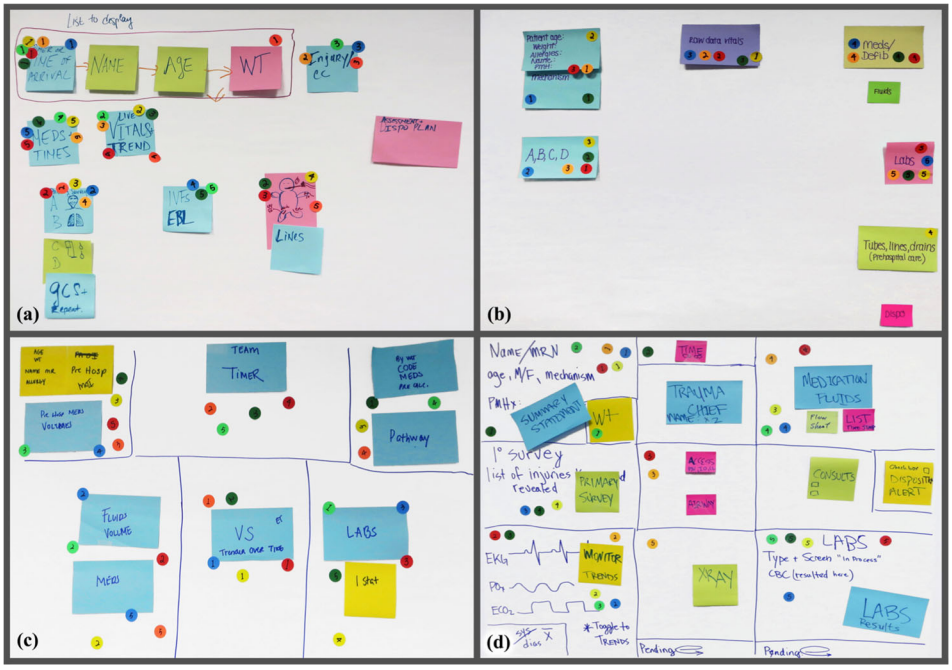

Figure 3. Group designs from hospital 1 (**a, b**) and hospital 2 (**c, d**).

Table 2. Individual rankings by team roles of the top five information types.

Rank	Information	Anesth.		Bedside nurse			Crit. Care	EM physician				Phys. Surveyor		Respiratory				Scribe nurse				Team leader			
	Hospital #	H1		H1	H2		H1	H1		H2		H1	H2	H1		H2		H1		H2		H1		H2	
	Workshop #	1	2	1	1	2	2	1	2	1	2	1	1	1	2	1	2	1	2	1	2	1	2	1	2
1	Patient info.	1	1	1	3	1	1	1	2	4	1	1	2	1	2	3	1	1	1	2	1	1	1	4	1
2	ABCD	3	3	–	–	–	–	2	1	–	–	2	–	–	2	–	3	–	2	–	3	2	2	–	3
3	Vital signs	2	2	2	–	2	2	3	2	1	2	3	1	2	3	1	2	2	3	1	2	–	3	1	2
4	Meds & fluids	4	4	3	2	3	3	4	4	2	3	–	3	3	4	–	–	3	4	–	–	3	4	2	4
5	Lab results	–	5	–	1	4	–	–	5	3	4	–	–	–	5	3	4	–	5	3	4	–	5	3	5

Following the group design, we asked participants to write on individual post-it notes any concerns about having the display during emergency resuscitations. We grouped concerns into themes and asked participants to explain their reasoning. This discussion prompted participants to think critically about their display designs and the implications for actual practice.

3.4. Data analysis

Outputs from the workshops and discussion transcripts were analyzed using a grounded theory approach (Corbin and Strauss 2008). The main objective for conducting these analyses was to identify and understand coordination challenges, information needs, and different aspects of emergency medical teamwork using clinicians' perspectives.

3.4.1. *Analysis of design sketches and concerns*

We first analyzed participants' sketches by extracting the critical types of information from individual and group designs, and grouping them into larger themes. The frequencies of information types were analyzed across themes to identify which types were most salient to each theme. Information types were also analyzed across roles to identify which types were most important to each role. Rankings of information types on group designs helped us determine the most salient types from participants' perspectives (Table 2).

We used the same analysis technique to extract issues and concerns from participants' post-it notes and then group them into larger themes. The frequencies of issues and concerns were analyzed across themes to identify which issues and concerns are most salient to each theme. We then analyzed issues and concerns by frequency to identify which issues and concerns were most important to each role.

3.4.2. *Analysis of discussion transcripts*

Two researchers independently conducted open coding of statements from the discussion transcripts. A statement was considered as one conversational turn where one person was speaking. In the first pass of open coding, the researchers created and applied codes to represent each statement. These codes were iteratively refined throughout the coding process, going back and forth to update existing codes or apply new codes to statements as necessary. Multiple codes were allowed depending on the length and complexity of the statement. For example, a statement in which a surgical fellow talked about blood transfusion and his need to know how much fluid has been administered, if fluids were still running, and if blood had been ordered, was coded as 'fluids,' 'blood,' 'awareness of task status,' 'urgency,' and 'coordination with another hospital unit.' The resulting lists of codes from both researchers were discussed as a group to determine which codes to keep, remove, or merge. This process led to a total of 85 codes, such as codes for critical pieces of information (e.g., patient demographics, ABCD findings, raw vital signs, medications, fluids), codes

Table 3. Summary of information types, roles favoring those types, and position on the display for each feature of teamwork.

Features of teamwork		Priority information types	Roles favoring this information	Position on display
Accessing patient information and pre-hospital data		•Demographics (age, weight) •Mechanism of injury •Pre-hospital interventions •En-route changes in patient status	•Scribe and bedside nurses •Leadership roles •Physician surveyor	Top left
Identifying leaders and other roles		•Names of supervisory roles •List of team roles present in the room	•Leadership roles •Scribe and bedside nurses •Anesthesiologist •Respiratory therapist	Top center
Monitoring patient status in real time and trends over time		•Raw vital signs •Vital sign trends	•Leadership roles •Anesthesiologist •Respiratory therapist •Scribe and bedside nurses	Right or middle center
Keeping track of tasks and team progress	*Sequential dependency of tasks*	•Medications (name, dosage); IV access (type, placement); fluids (type, amount)	•Scribe and bedside nurses	Bottom center or right
	Elapsed time	•Timestamps for medications, fluids •Timer	•All roles	Top center
	Abnormal patient findings	•Abnormal findings from patient evaluation (ABCD protocol steps)	•Leadership roles	Bottom left
	Periodic checklists	•Completed tasks, tasks in progress and remaining tasks	•Leadership roles	Bottom left
Managing orders and coordinating with other hospital units		•Lab orders and results (e.g., blood gas level) •Radiology orders and results (e.g., x-rays, CT scans)	•All roles	Bottom right

for different aspects of teamwork (e.g., provider rotations, leadership, decision making, patient monitoring), codes for managing and coordinating work (e.g., role distinction, communication, documentation, short pre-arrival notice), and codes for characterizing the environment (e.g., noisy, chaotic, dynamic, urgent). The researchers then updated the transcripts with these final codes in the second pass to reflect the changes.

Upon completing the open coding, participants' statements were analyzed by code similarity to identify emerging concepts and their relationships through axial coding. The codes were grouped and organized into four higher-level categories including: challenges of emergency medical teamwork, features of teamwork that require support, concerns about using the display, and purpose of the display. Sub-themes to describe each category were identified and supplemented with awareness and team coordination concepts from the CSCW literature (Table 3).

4. Findings

We report our findings in two parts. First, we describe the five features of teamwork requiring support that emerged from clinicians' sketches (Table 3). We then discuss participants' concerns about using the display during emergency medical situations.

4.1. Features of teamwork requiring support

Based on our analysis of discussions, individual sketches, and group designs, we identified five features of emergency medical teamwork that require support (Table 3): (1) accessing patient information and pre-hospital data, (2) identifying leaders and other roles, (3) monitoring patient status in real time and trends over time, (4) keeping track of tasks and team progress, and (5) managing orders and coordination with other hospital units. We observed that needs and priorities for different information types varied across roles (Table 2). We also saw a pattern in information arrangement across different design layouts. One participant nicely described the flow of the displayed information using her sketch; when looking at the individual and group designs, they generally fit this higher-level theme (Figures 2 and 3):

> "So this is information that's known. This is information we're discovering. This is what's actual and then this is what's revealed. So left to right, just like you would read, what you know and then what you're discovering… The things that we find most important are on the top left and the things that we're going to eventually act on are in the bottom right." [H2-2 Critical Care Specialist]

It is important to note that within the scope of this project, team members did not need or want help with how to complete their tasks. As previously mentioned, clinicians follow the protocols and have the medical expertise to perform resuscitations. We next discuss each feature of teamwork in greater detail.

4.1.1. *Accessing patient information and pre-hospital data*

Critical information about the patient is reported at the beginning of the resuscitation, as the Emergency Medical Services (EMS) team hands the patient over to the resuscitation team. Patient information includes demographics (e.g., age, weight), mechanism of injury (i.e., how the patient got injured), pre-hospital interventions, and en-route changes in patient status. Most of the individual sketches and all four of the group designs had patient information and pre-hospital data in some form, usually at the top left (Figures 2 and 3). Participants emphasized the importance of including this information on the display for two reasons. First, because patient information is reported early in the event and only once, team members have difficulty accessing this data later as they evaluate and treat the patient. For example, bedside nurses insisted on displaying age and weight to reduce the need for questions about these parameters when they draw medications or prepare fluids (medication dosages and fluid volumes depend on the patient's age and weight). Leadership roles and physician surveyors agreed with nurses, but also added a brief summary of the injury mechanism to be able to anticipate treatments and diagnoses. A physician surveyor explained:

> "Usually, I would like the weight and age of the patient, the mechanism of injury, what was done from the scene to the hospital. So that would be basically all of the extraneous stuff on top. As soon as the patient gets in, the story changes a lot of times… I've noticed that at least four times since I've been here. But the paramedic would tell us a story, and that would often not pan out towards the end. So I would just like to know the actual mechanism [of injury]." [H1-1 Physician Surveyor]

Participants' comments about pre-hospital data as well as pre-hospital information from individual sketches resonate with findings from our previous studies (Sarcevic and Burd 2008; Sarcevic and Burd 2009). By observing live resuscitations in an adult trauma center, we found that team member inquiries about patient medical history, mechanism of injury, and patient demographics ranked third, fifth, and seventh by frequency out of 16 question categories, respectively (Table 2 in Sarcevic and Burd 2008). Questions about medications and fluids and their timing were also found critical to ensuring efficient patient care. Our subsequent study of information handover further highlighted the importance of pre-hospital information about patient demographics, sustained injuries, and treatments en route to the hospital (Sarcevic and Burd 2009). Through an analysis of questions posed to EMS crews during or immediately after information handover (while the EMS crews were still present) and questions asked among team members after EMS crews left, we found that trauma teams faced significant challenges in retaining the information reported. Participants in the current study confirmed these prior findings, but also provided concrete examples of why they needed patient information and pre-hospital data, and when in the process—an insight we could not obtain by observing team communications and activities.

Workshop participants further commented that information about the patient's name, allergies, and past medical history would help teams get a better sense of how to treat the patient, but noted that this information was not essential. It was just as important to decide what information will not be on the display as what information will:

> "I think that just overall, not having [the top part of the display] be just a summary of the flow sheet is really important because there is a lot that you need for documentation, but it's not going to affect your decision making." [H1-1 Scribe Nurse]

Second, *ad hoc* team formation makes it common for some team members to arrive later than others and miss important information (Lee et al. 2012). When team members arrive late, the team leader must temporarily shift his or her focus to update latecomers about the patient's status. Patient age, weight, and especially mechanism of injury, were therefore seen as important pieces to display to fill in clinicians who were coming in late on the story, as explained by participants across workshops:

> "[In] the major traumas, the problem is that every time someone new comes on the scene, like the ICU attending or the surgery attending, I have to tell the story again. It kind of throws everybody off of the already in progress resuscitation. That's my main problem." [H1-1 Surgical Fellow]

> "This is supposed to be a quick overview if I walked in the room ten minutes late because I was doing something somewhere else." [H1-1 Respiratory Therapist]

> "It could decrease repetitive questions because every time a new person walks into the room you have to say the whole thing all over again." [H1-2 Emergency Medicine Physician]

> "There's certain information that just gets buzzed around that room. People come in and say, 'What's the mechanism [of injury]? What do we do? What's this? What's that?' That [weight] could be there [on the display]. Just look there for weight." [H2-2 Scribe nurse]

Patients and family members were also noted as an important source of pre-hospital and medical history information. Patients are often able to respond to questions (i.e., what happened, what level of pain they are in) or provide some feedback through sounds, movement, and facial expressions that allow teams to adjust their care. Family members are especially helpful when the patient is unconscious, cannot speak, or does not have a record at the hospital:

> "Usually I have a team member talk to the family and they come back to me and tell me what the history was and then whatever's pertinent I try to announce to everyone so that they know." [H2-1 Emergency Medicine Physician]

4.1.2. *Identifying leaders and other roles*

Resuscitation teams are organized hierarchically to ensure that all tasks are distributed and it is clear who is leading and who is performing certain tasks (Burd and Elliot 2011; Ludwig and Lavelle 2010). Strong and effective leadership is especially important in cases with critically injured patients and inexperienced teams, when the most skillful and experienced team member, typically the attending surgeon, needs to personally take charge of the resuscitation to provide the highest level of treatment (Xiao et al. 2004; Yun et al. 2005). While surgical leadership is common in most US trauma centers, many centers have emergency medicine programs with emergency department (ED) physicians and fellows regularly assuming leadership roles. The resulting leadership structures can therefore include leaders from different specialties with differing levels of experience (Sarcevic et al. 2011a). Although intended to provide complementary expertise, these leadership structures often cause confusion among other team members about the designated leader (Sarcevic et al. 2011a). Similarly, the high turnover among trauma team members and the *ad hoc*, multidisciplinary nature of team composition often lead to coordination difficulties, highlighting the need for role identification. Roles of individual team members can usually be inferred from their initial positioning around the patient stretcher, but constant movement around the room makes positioning an unreliable cue (Sarcevic et al. 2011b). These prior studies have mostly focused on understanding leadership effectiveness and behaviors, as well as coordinative mechanisms and team interactions, but did not discuss coordination issues with regard to awareness support. Furthermore, few studies directly tackled ways of providing concrete design solutions to address awareness issues that emerge with *ad hoc*, collocated teamwork.

Organizational practices at our research sites (Hospitals 1 and 2) recommend that both surgical and emergency medicine physicians share leadership during trauma resuscitations, but not during medical alerts. Depending on the severity of the patient's injury, assistance from additional specialists (e.g., critical care, neurosurgery) may be necessary. In most cases, surgeons lead trauma resuscitations while discussing decisions with emergency medicine physicians and other specialists. Medical alerts, by contrast, are led by one or more emergency medicine physicians. These supervisory roles usually stand at the foot of the bed, overseeing the rest of the team. Even so, the presence of multiple leaders may make others in the team unsure of whose orders to follow, especially if the leader is not clearly identified. An emergency medicine physician commented:

> "A lot of times when it's more difficult, it's because there are multiple attending [physicians] in the room and that can work well when they're standing together and working together, but sometimes, when there are so many people in the room, it's just much harder and it feels a lot more chaotic." [H2-1 Emergency Medicine Physician]

The *ad hoc*, multidisciplinary nature of team composition highlights the importance of understanding, at the very least, who the leaders are, what roles are present in the room, and their level of experience to facilitate teamwork among clinicians who may not have worked together before:

> "It's helpful when we know each other and that's why I feel like… if we can all come into the room and say I'm so and so, I'm the fourth year surgical so we know that's different from the 7 year rotator, and we'll be like 'okay what you [surgical fellow] say stands better than what a 7 year surgical rotator is going to tell me.' So I think there are differences when you know and are comfortable with people. [H1-2 Emergency Medicine Physician]

> "I agree with all of that. I think in the end it's going to come down to who's liable or who's running the show." [H1-2 Surgical Fellow]

Team member introductions are now common across US trauma centers to help teams establish role delineations, understand the level of experience of teammates, and even learn each other's names. Depending on how quickly EMS is able to transport the patient, teams usually have between five to 20 minutes to make introductions. Often times, however, patients arrive unannounced, leaving little or no time for team introductions (Sarcevic et al. 2011b).

Although all four groups discussed these challenges, only participants from Hospital 2 expressed the need for specifically identifying leaders and other roles on the display, usually at the top center of their sketches Figures 2(d, e) and 3(c, d)):

> "Just a little area where it says who's who, who the leader is, the nursing roles, the surveyor… there's the swipe machine when you walk into the trauma bay where people swipe their ID. So if it was possible to connect the display so that it automatically displays who's in the room, because there are times when another person walks into the room and starts giving orders or giving recommendations and you have no idea who they are." [H2-1 Emergency Medical Physician]

Furthermore, participants from Hospital 2 proposed a technological solution to this challenge: using their badges equipped with radio-frequency identification (RFID) sensors to automatically identify team members as they walk into the room, displaying their name, photo, and the typical roles they assume. Team members would then be shown on the information display to support the team's social awareness of who is present in the room, what roles are filled, and what roles are missing.

Two explanations may account for this difference in role identification needs between Hospital 1 and Hospital 2 participants. First, there are two large, sign-in

boards situated near the entrance to the resuscitations bays in Hospital 1, where team members write their names, roles and arrival times. Second, a few years ago, Hospital 1 instituted the practice of role-tagging—attaching a self-adhesive paper tag indicating each member's role—to assist teams with role identification (Sarcevic et al. 2011b). None of these mechanisms exist in Hospital 2. Note, however, that even with these low-tech solutions, clinicians at Hospital 1 continue to face the challenge of identifying leaders and other roles in the room: sign-in boards proved to be of little help when situated outside the rooms and role-tagging proved to be ineffective when there was insufficient time to put on the tags.

4.1.3. *Monitoring patient status in real time and trends over time*

Physiological parameters, such as heart rate, blood pressure, or pulse are the most commonly used indicators for monitoring and assessing the patient's status. It was no surprise then that almost all of the sketches included patient vital signs in some form, mostly in the center or on the right side of the display (Figure 2). Two findings stand out in relation to patient monitoring.

First, four out of 23 sketches did not include any information about the vital signs; they were created by two surgical leaders and one physician surveyor at Hospital 1, and one physician surveyor at Hospital 2. Although vital signs are important to these roles, it appears that they conceptualized their information displays as an addition to the current monitors rather than a replacement:

> "So the first thing to note is I have zero vitals on [my design] because there's a tele[meter] separately, I'm assuming this [display] is not replacing a tele[meter]." [H1-2 Surgical Fellow]

This finding suggests that some participants saw information distributed across the room, whereas most roles assumed that the new display would synthesize all of the information they needed. Respiratory therapists and anesthesiologists were concerned about the placement of the vital signs and how easy would it be for them to see the display from the head of the bed. This concern was also manifested through their sketches, which prominently featured the vital sign data (e.g., Figure 2(c)):

> "If I have a head injury, and I'm trying to trend my vitals, and if I can't see that, because there's one screen here, and there's one screen there. But I'm going to assume that they're doing the same thing, so whoever is at the head of the bed can still see what's at least on one of them." [H1-2 Respiratory therapist]

Second, roles that included vital signs in their sketches suggested two ways in which this information can support patient monitoring: (1) show raw vital signs with live waveforms and values like those on the vital signs monitor (e.g., Figure 2(e)), or (2) show vital sign trends over the course of the event (e.g., Figure 2(f)). Respiratory

therapists and anesthesiologists requested raw vital signs because they provide immediate feedback on the effectiveness of their treatments:

> "I like the raw data because it truly tells me if my bagging is effective, or if it's not, just a large verification of if I'm doing something right or if I'm doing something wrong, or what's going on with the patient." [H1-2 Respiratory Therapist]

Scribe nurses, on the other hand, expressed the need for the vital sign trends. Although vital signs monitors can display trends over time, they are rarely set to that mode. To help teams keep track of trends, part of the scribe nurses' role is to document patient vitals every few minutes and provide alerts when there is a change (Sarcevic 2010). With the amount of information they are managing, however, it is difficult for scribes to recognize and announce trends while keeping up with other aspects of the resuscitation:

> "I actually like the idea of having previous vital signs to be able to compare because I feel like that's a huge responsibility that I have. I'm the only person in the room that has right in front of me all the vitals. I'm trying to document all the other things but at the same time look at the vitals when I'm writing it down and compare it to what they were before, and notify someone if something's changed. But it would be helpful if everyone could see more of that information." [H1-2 Scribe Nurse]

4.1.4. *Keeping track of tasks and team progress*

Participants' sketches and workshop discussions revealed four task-determining factors that play an important role in helping teams keep track of tasks and team progress: (1) sequential dependency of tasks, (2) elapsed time, (3) abnormal patient findings, and (4) periodic checklists. Together, these factors determine the next steps or tasks that the team will perform and are thus critical for team coordination.

(1) *Sequential dependency of tasks*: There are a number of tasks that are dependent on other tasks being performed first. For example, nurses cannot administer medications before IV access is established; anesthesiologists cannot start patient intubation before medications are administered (in fact, any tasks that require sedation cannot begin before IV access is established and neurological status is assessed); and, x-ray technicians cannot take x-ray images before the initial survey is completed. To plan and coordinate their work, team members need to know the status of these sequentially dependent tasks—that is, whether these tasks have been completed. This need was articulated by sketching information about administered medications (name, dosage, and time), administered fluids (type, amount, and time started), established IV access (type and placement), and completed protocol steps (Figure 2). Roles that were

particularly interested in this information included nurses, airway physicians (respiratory and anesthesia), and team leaders:

"Medication and what we've given, what time it was given, and the dose that was given. […] The conversation between [emergency medicine physician] and I doesn't need to be on the screen. But what does need to be on the screen is the fact that it's been three minutes since [epinephrine], or this is the time you are inside [the trachea]. Because the time is so skewed in the midst of all of this, you lose track." [H1-1 Bedside Nurse]

"It's just fluids, blood, pressers, meds if they're given, because sometimes we miss that or we are not sure is it still running, is it in, when was it given and those things are very important." [H2-1 Surgical Fellow]

(2) *Elapsed time*: Time is an important dimension related to keeping track of tasks and team progress. Clinicians often lose track of time and how long it has been since the patient arrived or since time-dependent interventions were performed. For example, certain medications need to be administered in time intervals. Teams also need to know when defibrillation was last performed and at what voltage to determine the next set of defibrillations until normal cardiac rhythms are reestablished. Leaders have to keep the big picture in mind, but this makes it more difficult to keep track of other resuscitation dimensions:

"The biggest thing I think as the leader that you're trying to put everything, the whole picture together all at once and you sometimes lose the little things like the timing of medication epinephrine, the last dose that was given or when the last fluid bolus was given." [H2-2 Emergency Medicine Attending]

In addition, knowing how much time has elapsed since the patient arrived gives a sense of how the resuscitation is progressing:

"Three minutes can feel like five seconds, or three minutes can feel like 3 hours, just depending on the situation that you're in." [H1-1 Respiratory Therapist]

The need for time keeping was expressed on both individual and group designs by including timestamps next to the administered medications and fluids (to keep track of time-dependent interventions) and timers (to keep track of time since the patient's arrival) (Figures 2 and 3). As we observed earlier, wall-mounted timers in the rooms currently serve this second function, but teams often forget to turn them on.

(3) *Abnormal patient findings*: Emergency medicine physicians, surgical leaders, and physician surveyors noted that information about each of the ALS/ATLS protocol steps (ABCDs) do not need to be shown in great detail, but should

instead show whether each step has been completed and what are the abnormal results from examining the patient, if any:

"We shouldn't forget the ABCs. That's a major portion of what we're doing in the first few minutes." [H1-2 Emergency Medicine Physician]

As discussed by different groups, abnormal findings help teams (especially leaders) localize patient injuries, which in turn helps determine what tasks to perform next. For example, asymmetrical breath sounds may be a sign of internal chest injury and usually require chest decompression or chest tube insertion. Other abnormal findings include obstructed airway, weak pulses, and deteriorating neurological status. We found these findings consistent with those reported in Sarcevic and Burd (2008), where questions about evaluation steps and abnormal findings ranked first, comprising 33 % of all questions asked during ten real resuscitations. The current study, however, helped uncover why teams, and leaders in particular, inquired frequently about abnormal findings, offering concrete insights into awareness needs and how best to translate them into design solutions.

(4) *Periodic checklists*: Leadership roles wanted information about what tasks have been completed so they can move onto the next task (especially sequentially dependent tasks), what tasks are in progress, and what tasks remain to be done. As we previously observed, their practice is to periodically provide short verbal summaries to the team by listing major findings, critical vital signs, treatments and interventions, tasks in progress, and incomplete orders (Kusunoki et al. 2013). Teams can then take a brief step back and revisit the "big picture." Most leaders conceptualized these verbal summaries through digital checklists on their displays, providing a good example for what the display should present and the potential benefits:

"The best run scenarios are the ones that have multiple summaries throughout the resuscitation because that allows the whole team to just realize where we are at that particular point in time, what has been done, what needs to be done, just it's a really important thing." [H2-2 Emergency Medicine Physician]

Completed tasks and steps were even conceptualized through a visualization of the body with all the tubes, lines, and drains depicted (Figure 2(a,d)). Participants in Workshop 1, Hospital 1 described this idea to use an image of the patient as follows:

"I think there is some method too, to having an image of the patient because there are so many numbers and other information being displayed." [H1-1 Emergency Medicine Physician]

> "If you had an image, your lines could just be a picture [with] a tube that comes out of the mouth." [H1-1 Bedside Nurse]

> "You could sort of highlight where there was a pertinent finding from survey on a graphic of the patient, then that would help people to remember don't grab that arm if we think it could be broken." [H1-1 Emergency Medicine Physician]

4.1.5. *Managing orders and coordinating with other hospital units*

Most participants viewed the display as a way to manage many laboratory and radiological studies performed during resuscitations—that is, to know what should be ordered, what has been ordered, if the results are back, and what are the results. Nurses fulfilling these orders saw the benefits of seeing orders on the display instead of asking and interrupting the team. Being able to quickly pull up the results for everyone to see was important to nurses, respiratory therapists, and leadership roles because they currently have to go to another computer (sometimes outside the room) and look them up:

> "Right now we have to walk out of the room, go to the computer, log into the computer and wait for all that to happen to see an image. Even once we've intubated, let's see what the chest x-ray is like just to confirm [tube] placement. If it's something that would be easy to put up and kind of take away again very quickly." [H1-2 Emergency Medicine Physician]

Although nurses call out the results to the team when they arrive, some results may not become relevant until later, so there could be an option to toggle between radiology images, lab results, and other content on the display.

Facilitating communication with other hospital units and people outside the room was also emphasized because of the need to coordinate with clinicians waiting at the next hospital unit:

> "And [the next] destination is alerted so that the PICU knows we're coming or the OR knows we're coming or CT scan knows we're coming, so that we've made the decision for our next stop and we've alerted that stop." [H2-2 Surgical Attending]

> "My biggest thing is, we get yelled at all the time for not having the proper equipment set up upstairs. But if we know what room number [the patient is going to], we can just have a ventilator sitting in the hallway […] and I can just call my [respiratory] upstairs saying 'go set it up.'" [H1-2 Respiratory Therapist]

4.2. Concerns about using the display in emergencies

Participants expressed concerns about many topics, including data input, accuracy, reliability, technical difficulty, compatibility with existing systems, and training. Here we highlight three that teams perceived as directly related to awareness and the extent to which the display may affect it: (1) real-time adaptability to dynamic changes, (2) information overload and visibility, and (3) replacement of verbal communication. These three concerns highlight the need for information prioritization and process-dependent adaptation of the display.

4.2.1. *Real-time adaptability to dynamic changes*

Emergency medicine physicians and physician surveyors were concerned about the display's ability to update or adapt to different types of patient injuries or resuscitations, as trauma resuscitations sometimes turn into medical alerts and vice versa. Teams must reassess the patient's status throughout the resuscitation and information captured three minutes earlier may no longer be accurate:

> "If a trauma turns into a medical resuscitation, [the display] needs to be an adaptable screen that can now become support for the [medical alert]." [H1-1 Emergency Medicine Physician]

Participants also expressed concerns about the mechanics of how the information will be updated, the efficiency of updating information, how often the information will refresh, and if there will be a time delay. The display should dynamically adapt to the severity of the patient's injury:

> "Is it feasible to say that this [display] could change depending on the patient? And so as a [scribe], if it's something that was important to this patient, there would be a box I could hit that says 'display'? […] If I had a kid that was very routine, maybe just some routine stuff went up on there […]. If it was a kid who was much sicker, […] as the certified coordinator, we could say 'let's display this, it's important for people to know'." [H1-1 Bedside Nurse]

4.2.2. *Information overload and visibility*

Participants were concerned about encountering information overload if the design is cluttered with too much information. They felt it would be difficult to make critical information stand out on the display without causing alert fatigue. The use of images was also related to visibility; if images are used

in the design, they must be large enough to be useful, such as x-ray and scan results or an image of the patient indicating where tubes, lines, and drains are placed (Figure 3(a)). Leadership roles were particularly concerned about the visibility of the information:

> "If you put too much, then everything gets smaller so you can't read it and then it's messy and jumbled, and where's my information? This needs to be so simple and so convenient as to not provide too much information and get distracted on it." [H1-2 Surgical Attending]

> "I think simple is better in my eyes because if you get too much information in one place then it's going to kind of distract people. Obviously we need a lot of information, but I think trying to keep it to what we really need to know is important." [H2-2 Emergency Medicine Physician]

Positioning of the display with relation to where team members normally stand in the trauma bay had a large factor in how they discussed visibility. Respiratory therapists and anesthesiologists were particularly concerned about the location of the display(s) and how easy would it be for them to see the display from the head of the bed. Splitting information into multiple displays was mentioned as a way of increasing visibility, but some team members objected:

> "I would caution against having [display] split up into different parts only because I feel like that makes you lose the whole picture. So even though it is helpful for the airway to have specific things, I think it's still more helpful to have the whole picture so that the person at the head of the bed knows 'oh the blood pressure is this.' I just feel like it is better or more useful to have that whole synthesis than to have split portions for different roles." [H1-2 Emergency Medicine Physician]

4.2.3. *Display as a fixation and substitute for communication*

Both leadership and nursing roles were concerned that the team would become distracted by the display. This already happens with the vital signs monitor and they were worried that another type of display would introduce a new fixation:

> "You have to remember because it's a pediatric patient, there isn't much space along the bed and so you're usually relying on other people to tell you what's going on and you may not be able to see the patient as well. So you rely on the things like the screens to kind of supplement your vision as well, but you have to

remind yourself to keep your eyes on the patient consciously." [H1-2 Emergency Medicine Physician]

Participants also agreed that the display should not replace or decrease verbal, person-to-person communication, a view that has been supported by previous literature. Coiera (2000), for example, suggested that in contexts where team actors must engage in "just-in-time grounding," a higher amount of communication is required to establish common ground at the beginning of teamwork or a particular task. There are times, however, when technological interventions cannot replace verbal communication. Participants were worried that if people became fixated and dependent on the display, they may defer verbalizing important findings to the team:

"When they're doing the airway, the entire room needs to shut up. And I need to know if you can see the airway, whether you anticipate difficulty, if you have the right equipment, because I'm going to feed that back to other people, whether it means someone runs out to go get a correct tube, or I'm telling the medication nurse we're going to drop this med instead. They are the people that I care the most about. And I don't want any screens, any papers, anything between us. We just need to talk." [H1-1 Emergency Medicine Physician]

Providing information for "pre-emptive grounding" as suggested by Coiera (2000), such as pre-hospital information and patient demographics, can reduce the costs of future grounding. In the case of late team members, the display can act as a pre-emptive measure to reduce the need for redundant verbal communication.

5. Discussion

Although there are differences in institutional norms and practices, as well as perceptions about awareness among roles, we found less variation in perceptions within roles across institutions. Most of the clinicians' main concerns and features of teamwork that need to be supported either emerged through sketches or were discussed in the workshops. Results from our previous work involving observations and video analyses of live resuscitations not only support these findings, but also those found through the participatory approaches applied in this study. As we described earlier, the need for patient data and pre-hospital information, vital sign data, medications, and fluids was also confirmed by observations of real resuscitations reported in Sarcevic and Burd (2008). Issues with multiple leaders and role identification were confirmed by our observational studies of leadership structures (Sarcevic et al. 2011a) and role coordination (Sarcevic et al. 2011b). Similarly, our prior work also identified the challenges in information retention (Sarcevic and Burd 2009). These observations, however, were limited in that we could only see what information or issues were emerging from the process. Participatory workshops reported in this study added new insights by allowing us

to obtain contextualized examples of awareness needs, gain a deeper understanding of users' concerns in relation to their work, and brainstorm the specific design solutions that can address their needs. In eliciting users' concerns, we were also able to determine potential ways to evaluate the display and determine if their needs are met. The issues and concerns clinicians raised were telling of how the display would impact their work. Moreover, we were able to elicit details and examples of how clinicians want information to be presented beyond what information is important. For example, we knew from previous studies that they needed information about medications, but we did not necessarily know the specifics of how to address this need through design, such as in what order medications should be displayed, what format to use for dosages, and what timestamps to highlight. The debates that came out of the workshops helped us determine the similarities and differences in how each role wanted information presented, and then reach a preliminary design that addresses the most needs of all roles. In short, participatory workshops coupled with prior observations and video analyses allowed us to conduct a holistic approach to system design.

The work reported here has two implications for research in CSCW and healthcare. First, we highlight four facets of awareness from the CSCW literature that medical teams manage during emergency resuscitations. We extend these facets by providing contextualized examples of what awareness means within an *ad hoc*, emergency medical setting. Our findings show that in this context, awareness is ongoing and dynamic, emerging from the tasks performed, patient response, and information coming from various sources. Second, based on clinicians' designs and role-based awareness needs, we discuss the implications for designing dynamic displays for emergency medical domains. Participatory design workshops played an important role in eliciting the nuances of the similarities and differences in awareness needs by providing the structure for collaboratively addressing design issues with clinicians.

5.1. Implications for CSCW: insights into awareness from the perspective of *ad hoc*, collocated teams in emergency medical settings

Our findings (Table 3) suggest that clinicians manage four aspects of awareness at the team level in order to coordinate their work during emergency resuscitations. These four facets of awareness can be mapped to the existing facets found in the CSCW health-related literature as follows: (1) *team member awareness* (i.e., social and spatial awareness), (2) *elapsed time awareness* (i.e., temporal awareness), (3) *teamwork-oriented* and *patient-driven task awareness* (i.e., activity and articulation awareness), and (4) *overall progress awareness* (i.e., process awareness). We extend the existing facets of awareness by offering a micro-level perspective on what these facets mean in the context of *ad hoc*, multidisciplinary, and collocated medical teamwork.

5.1.1. *Social and spatial awareness—team member awareness*

'Social' and 'spatial awareness' are popular concepts in CSCW studies of distributed teamwork. These concepts have been defined as knowing the availability of a person, with whom a person is coordinating work (or will coordinate work in the case of asynchronous collaboration), where they are located, and how they are interacting with the space (Bardram et al. 2006; Carroll et al. 2006). In contrast, resuscitation team members are collocated and coordinate their work synchronously. Their general availability is visible and determined by their presence in the room, but their immediate availability may not necessarily be apparent due to visibility and spatial issues in the room. Social and spatial awareness in the context of *ad hoc*, emergency medical teamwork can then be conceptualized as *team member awareness—that is*, *knowing who is leading the event*, *who is responsible for certain tasks*, *who is available to assist with additional tasks*, *and what roles are present*, *absent*, *or en route*.

Participants in this study tended to draw the distinction between inside and outside the resuscitation room when discussing social and spatial awareness. As our findings show, most of the information that emergency medical teams need is inside the room. Teams are mainly concerned with the people in the room at the moment and which roles are missing to determine how they must compensate. Because team membership depends on providers' availability and scheduling, there is no set group of people on a team so it is not possible, or even necessary, to know who is coming from where. The information needed for achieving social and spatial awareness outside the room is mainly about who is bringing in the patient, who is coming in to consult, and if the next hospital unit is ready for the patient. These needs, however, emerge either initially or at the end, but not as much during the resuscitation.

For resuscitations to run smoothly there has to be a kind of implicit trust that everyone knows what they are doing, even though they may not necessarily know each other, their background, training, and experience. Teams do their best to introduce themselves before resuscitations, but as our participants mentioned, time to prepare is often limited and latecomers are common. Clinicians from the same specialization may work together on a daily basis, but only one or two people from each specialization are present during resuscitations. Unlike surgical (Bardram et al. 2006) or ICU teams (Cabitza et al. 2007; Reddy et al. 2006) that have the opportunity to develop a shared, implicit understanding of each other's work habits while working together on a regular basis or on long-term projects, emergency medical teams cannot rely on this established rapport, trust, and understanding. Each time team members enter the room, they need to build common ground, and each time a latecomer arrives, extra effort is required to bring them up to speed. This *ad hoc* and collocated nature of the team introduces a potential risk to establishing awareness, making it challenging to support meaningful social awareness beyond knowing roles and levels of experience without existing connections and relationships on which to build.

5.1.2. *Temporal awareness—elapsed time awareness*

'Temporal awareness' of past, present, and future actions during synchronous and asynchronous collaborations is particularly crucial in medical work (Bardram 2000; Reddy et al. 2006), as our findings have also confirmed. Time and temporal awareness in the CSCW literature are mainly discussed in relation to schedules, rhythms, patterns, and cycles that span hours, days, or months (Bardram 2000; Carroll et al. 2006; Reddy and Dourish 2002; Reddy et al. 2006). Although clinicians in the emergency resuscitation setting are also concerned with synchronous communication and coordination, previously discussed aspects of temporal awareness may not become relevant until the end of or after the resuscitation. They nevertheless face the challenge of coordinating work under greater time pressure because their objective is to stabilize patients as quickly and safely as possible. The need for awareness of past, present, and future actions is thus situated within the condensed timeframe of minutes and even seconds, where elapsed time is critical. *Elapsed time awareness in emergency medical settings can therefore be considered as knowing the estimated time of the patient's arrival*, *time since the patient arrived*, *time since interventions or certain tasks*, *and time since changes in patient status*. The *ad hoc* aspect of resuscitation teams also makes awareness of elapsed time all the more important because it allows latecomers to synchronize their awareness of the tasks and overall progress of the resuscitation with the rest of the team. Time is also a universal metric by which team members can gauge their activity and overall progress, even though they may not have previously worked together.

Elapsed time awareness information is used for synchronizing tasks, especially those that are sequentially dependent. For example, certain medications need to be administered before intubating the patient, but the anesthesiologist must complete the intubation within three minutes or the medication will lose its efficacy, requiring a new round of medications. This task interdependency in turn requires close coordination between the anesthesiologist and nurses who are preparing and administering medications. Not only each part of the task needs to be completed in the correct order, but also in a timely and efficient manner. Elapsed time awareness is also important because certain procedures and orders require extra time to prepare and perform. Finally, awareness of elapsed time combined with vital signs feedback such as dropping oxygen saturation over time can allow clinicians to recognize subtle changes in patient status that could result in clinical errors and react accordingly.

5.1.3. *Activity and articulation awareness—teamwork-oriented and patient-driven task awareness*

Studies on 'activity', 'articulation', and 'task' awareness in CSCW describe individuals as 'displaying' their own actions and 'monitoring' the actions of others so that team members can articulate their work accordingly (Cabitza et al. 2007; Prinz 1999; Schmidt 2002; Schmidt and Bannon 1992). In contrast, and as pointed out by our participants, resuscitation teams work in a crowded space, with team members gathering around the patient bed and having limited visibility of both the patient

and other team members. It may also be the case that *ad hoc* team members have difficulty monitoring each other for visual, non-verbal cues because interpreting them accurately can be problematic without having first established rapport and common ground. Rather than continually checking for visual cues that will help them align their actions, team members rely on verbal communication (Bergs et al. 2005). Verbal communication thus acts as a mechanism for displaying actions for others as well as for monitoring the actions of others. For example, a bedside nurse will display his or her actions by verbally reporting when IV access is established; the medication nurse and other bedside nurse will monitor for this verbal clue, and will administer medications and fluid immediately after hearing it. When team members arrive late or leave early, especially during critical resuscitations, this verbal coordination mechanism becomes heavily strained with redundant and lost communications. To articulate work, emergency medical teams require the knowledge and awareness of many interdependent activities to complete tasks based on the context and requirements of the resuscitation. Furthermore, teams must actively seek, evaluate, confirm, and manage patient data and evidence to make diagnoses and decisions. Activity or task awareness in this context can therefore be defined as *teamwork-oriented and patient-driven task awareness—that is*, *knowing contextual information about the patient* (*object of work*), *feedback information for task completion*, *the status and progress of individual tasks*, *and how each task affects the progress of other tasks*.

Teamwork-oriented information provides awareness of *task status*, *progress*, *and interdependency*. Teamwork during the intubation procedure is again a useful vehicle for understanding the complexities of coordination and the types of awareness information needed to support the activities. To proceed with intubation, anesthesiologists need to know when intubation medications are administered by bedside nurses; bedside nurses need to know when medication nurses have medications and IV access ready; medication nurses need to know which medications to prepare from anesthesiologists; anesthesiologists need to decide together with team leaders whether or not to intubate; and team leaders need to know the status of the patient's airway and breathing, a finding reported by physician surveyors. The status and progress of each of these tasks are currently conveyed through verbal reports; if the reports are missing, team members inquire until hearing them. Although some non-verbal 'displays' of these actions occur—if near the patient, a person can see an IV line on the patient's body—the actual status of an action may not be clear until confirmed by a team member (i.e., the IV line may be visible, but it may be malfunctioning). Verbal communication helps clinicians articulate their work by providing updates to team members' awareness about task progress, allowing them to determine the necessity, priority, speed, or timing of their actions.

Patient-driven information provides awareness of the *context and requirements of tasks*. Our previous research on how emergency medical teams use vital signs monitors has shown that maintaining awareness of changing feedback about the patient's status is critical to decision making and evaluating the effectiveness of

treatments (Kusunoki et al. 2013). The patient is a critical source of information and feedback in medical work. Contextual information provides background about the patient including patient demographics, mechanism of injury, pre-hospital interventions, and pertinent medical history; it also serves as the base on which subsequent, emerging information builds. Feedback information includes real-time vital signs and trends, and results from patient evaluation, labs, and imaging studies. It is important for clinicians to see not only what the team is doing in response to the patient's needs, but also how the patient is responding to the treatments and procedures performed by the team. For example, feedback such as dropping blood pressure (or no improvement) can allow teams to identify that an IV line is malfunctioning and resolve the issue. These objective values and outcomes change throughout the resuscitation, requiring clinicians to dynamically adapt their care. Even factual information such as patient age or weight can change, as EMS reports en route to the hospital or during handover sometimes contradict those of the patient or a family member. Changes in both contextual and feedback information highlight the fact that awareness in emergency medical settings is ongoing and dynamic. Most participants sketched patient-driven information as a persistent section with contextual information on the top for at-a-glance viewing and feedback information as a section at the center or right side for dynamic, real-time monitoring (Figures 2 and 3). Contextual information and feedback help clinicians to (1) diagnose illnesses and injuries, (2) make decisions about which tasks to perform and how, (3) monitor the patient's response to treatments and procedures, (4) evaluate the effectiveness of their actions, and (5) decide to continue their actions when receiving positive feedback or revise their actions when observing negative outcomes.

5.1.4. *Process awareness—overall progress awareness*

Related CSCW literature has used 'process awareness' to describe knowing the general sequence of main tasks, tasks due next, and current status of the process (Cabitza et al. 2009a). Process awareness may take place asynchronously or synchronously over varying amounts of time depending on the context. In emergency resuscitations, teams work synchronously, but the process timeline is condensed, requiring clinicians to frequently refresh their overall awareness of the resuscitation's progress. Clinicians must aggregate their awareness of tasks, elapsed time, and other team members to gain a holistic understanding of the resuscitation at a certain point in time. The team leader's main responsibility is to orchestrate the team by continually reassessing overall progress. *Overall progress awareness can then be described as knowing what procedures and interventions have been performed, what protocol step the team is currently working on, and what still needs to be completed to stabilize and transfer the patient.*

Similar to Cabitza et al. (2009b), we found through the analysis of display sketches that there is a need for periodic checklists of ATLS protocol steps (ABCD) so that the 'big picture' of the resuscitation progress is maintained at all times to plan and dynamically manage individual tasks. Our participants also felt that

the display could reduce bad redundancies in communication increased by latecomers. Participants discussed losing track of time and procedures that other team members did while they were engaged in the task they were performing. Patient status can also change at any time and teams need to be aware of when they must collectively return to a step. For example, the team may be working on Circulation (step C), but the patient's airway suddenly deteriorates and they must all revise the focus of their tasks and give priority to readdressing the Airway (step A). While the resuscitations protocols guide teams in delivering optimal patient care, they also make *ad hoc* work possible, despite some inefficiencies. Regardless of their experience working together, different experience levels, or changing leadership, there are still general guidelines of which they all have the same knowledge.

5.2. Summary

Tailoring awareness support is important for creating useful information systems. The contribution of this research is not necessarily that we identify a new type of awareness to add to the literature, but that we provide a way for adapting the current facets of awareness characterized in the literature to understand the micro-level awareness needs of teams working in a particular context (Kolfschoten 2013)—one characterized by intense *ad hoc*, collocated teamwork. By designing and consulting with clinicians through participatory design workshops, we were able to compare each role's perceptions on awareness, how they would like to receive awareness support, and identify concrete design strategies to manage the differences in their awareness needs.

5.3. Implications for design: displays to support awareness

Based on our findings and discussion about awareness, we now present two implications for designing displays in the emergency resuscitation setting: display content and display positioning.

5.3.1. *Display content*

Participants' sketches and group designs showed different prioritization of information types based on role, suggesting different preferences for the kinds of awareness each role needs to maintain. For example, anesthesiologists and respiratory therapists cared the most about patient and physiological status data to be able to assess the effectiveness of their treatments, while leadership roles most needed the information about the overall progress of the event. These findings suggest that it may not be necessary to support all four facets of awareness that emerged from our data by showing all of the related information on one display. After all, participants also expressed their concerns about making critical information stand out on the display if too much information is shown. Rather, we propose organizing the display(s) by team-centered and patient-centered information.

The *team-centered* section would indicate team activities in chronological order, showing: (1) a list of team members with roles, names, experience levels, and photos for team member awareness (while also showing missing roles); (2) a list of completed procedures and treatments for teamwork-oriented task awareness; and (3) the time of arrival, timer, and timestamps of treatments for elapsed time awareness. The combination of these three facets of awareness would then help support overall progress awareness.

The *patient-centered* section would incorporate emerging patient-driven information from multiple sources to support team activities. One subsection could be more static with contextual information, including: demographics, mechanism of injury, pre-hospital interventions, and pertinent medical history. Another subsection could be dynamic with requirements feedback, showing raw vital signs and trends from patient response, findings from physical examination, values from laboratory studies, and x-rays and CT-scans from imaging.

Together, these two kinds of displays (or display modes) could support the awareness of emergency resuscitation teams as they coordinate their work.

5.3.2. *Display positioning and form factor*

The question of whether there should be multiple displays presenting different information for different roles is still debatable, as is the form factor. Team members stand in a circular formation around the patient bed, making it difficult to design a display or set of displays that will be visible by everybody at all times. As we discussed previously, different roles expressed different preferences for information types, so there is no need for a 'visible-by-all' kind of display. Given the relatively consistent positioning of roles during resuscitations, it may be possible to tailor displays to particular roles and their information and awareness needs (some roles even suggested distributing information across the room). These displays may appear in different forms (e.g., wall displays, tablets, or wearable displays), which will again depend on the work and space constraints around each role. Distributing displays with different information would still require clinicians to look in different directions to gather information, albeit from less disparate sources.

There is also a design tension between teams being collocated, but *ad hoc*. The act of collocating from different areas of the hospital and emergency department to the resuscitation bay itself poses a design challenge. While core team members are in the same room when engaging in teamwork during the resuscitation, team members inevitably arrive late. Even though team members would mainly need displays while they are in the room, team members on their way may also benefit from another form of information display (e.g., wearable displays or displays in other departments) that would allow them to mentally prepare and update their awareness before arriving. The other aspect of *ad hoc* team formation is that even though clinicians must work closely with one another in the same room, team member composition is continually changing, making it difficult to allow individuals to customize shared displays in the room to suit their needs and preferences (or even have the time to do so). Future work

might explore displays that accommodate multiple user profiles, showing role-specific or individualized information to supplement information on shared displays.

6. Conclusion and future work

This research has implications for how information displays can be designed to support the awareness of medical teams performing emergency resuscitations. We conducted four participatory design workshops, addressing the need for participatory research approaches and going beyond observation for holistic system design. These workshops elicited clinician-generated sketches and detailed discussion that allowed us to characterize five features of *ad hoc*, collocated, multidisciplinary, and time-critical teamwork that require support through information displays. We then used this understanding to address the need for tailored awareness support based on concrete, contextualized tasks by providing rich descriptions of four facets of awareness from clinician's perspectives. These descriptions helped us develop design guidelines for display content and positioning. By conducting our research at two institutions, we were able to observe important similarities in our findings that suggest the need for more multi-site studies to increase the generalizability of findings in this type of setting. We also validated our findings within workshops using different techniques to elicit perceptions and design ideas. Our findings built on and validated the findings of previous work from observations and video analyses to provide new insights into supporting the awareness of emergency medical teams.

Our future research in this area will move in two directions. First, we will continue our work on display design to support the awareness of emergency medical teams. This work will involve iterative, participatory design and evaluation of an information display prototype in a simulated environment. We will also use the insights gained through this study to develop formative evaluation methods for prototype testing. Discussions about clinicians' issues and concerns already suggested several metrics we can use for assessing the success of the display (e.g., is the display accurate, reliable, easy to interpret, and responsive to changing scenarios). Second, based on our understanding of awareness developed in this study, we want to examine the awareness of teams before and after real-world implementation of the display. Placing the display in the real environment will allow us to assess whether what we observed and what participants sketched in the workshops is what they actually need in action.

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