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Designing for Temporal Awareness: The Role of Temporality in Time-Critical Medical Teamwork

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Abstract

This paper describes the role of temporal information in emergency medical teamwork and how time-based features can be designed to support the temporal awareness of clinicians in this fast-paced and dynamic environment. Engagement in iterative design activities with clinicians over the course of two years revealed a strong need for time-based features and mechanisms, including timestamps for tasks based on absolute time and automatic stopclocks measuring time by counting *up* since task performance. We describe in detail the aspects of temporal awareness central to clinicians' awareness needs and then provide examples of how we addressed these needs through the design of a shared information display. As an outcome of this process, we define four types of time representation techniques to facilitate the design of time-based features: (1) timestamps based on absolute time, (2) timestamps relative to the process start time, (3) time since task performance, and (4) time until the next required task.

Keywords

Temporality; time; awareness; information displays; trauma resuscitation; participatory design; emergency medicine

INTRODUCTION

Temporal information provides clinicians with awareness about the timing of past, present, and future activities [5], and is critical in prioritizing tasks, especially in time- and safety-critical settings such as trauma resuscitation—a rapid evaluation and management of critically injured patients. Medical personnel in general often use time as a frame of reference to evaluate team performance, gauging and adjusting their actions accordingly [3]. Such use of temporal information is particularly evident in an emergency. The first hour after trauma injury—the Golden Hour—is a critical period that is indicative of patient outcomes [24]. Trauma resuscitation lasts 20–30 minutes on average and must take place

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within this hour to increase the chances of patient survival. It is therefore critical that the total time spent on diagnosis, treatment, and patient monitoring is kept as short as possible [24]. While training and low-tech interventions, such as clocks and stopclocks, have been used for improving team coordination, errors and inefficiencies are still observed even among experienced teams. Computer-based coordination mechanisms can provide a degree of visibility and flexibility to their analog counterparts [23], but their design first requires an understanding of how time is perceived and managed in actual work.

In this paper, we present the findings from a study of temporal awareness in time-critical medical teamwork that emerged through the iterative design process of an information display to support situation awareness during trauma resuscitation. We examined how trauma resuscitation teams (a) experience and perceive time, (b) construct their own time-keeping mechanisms, (c) communicate temporal information, and (d) respond to different presentations of temporal information. To gain this understanding, we conducted a series of participatory design workshops, video review sessions with interviews, and simulated resuscitations. Because this study was part of a larger effort to design an information display, we experimented with different presentations of temporality in a simulation setting. As an outcome of this process, we defined four types of time representation techniques to facilitate the design of time-based features in a time-critical, collocated teamwork: (1) timestamps based on absolute time, (2) timestamps relative to the process start time, (3) time since task performance, and (4) time until the next required task. Our work has three contributions to CSCW:

- Four time representation techniques separated into static and dynamic categories of temporal information features.
- Description of how clinicians perceive, communicate and manage time within an emergency medical context.
- Implications for designing information displays to support temporal awareness in time-critical, collocated contexts.

RELATED WORK: TEMPORALITY IN CSCW

The nature of temporality in cooperative work has been of interest to CSCW since its beginnings. Early CSCW work defined “coordination mechanisms” as the different temporal artifacts that have been used for coordinative purposes in cooperative settings for centuries: timetables, schedules, checklists, routing schemes, catalogues, and classification systems in large repositories [23]. Seminal studies of time-critical work settings described other coordination mechanisms designed to reduce the time it takes to perform recurring tasks, such as flight strips that provide the controllers with dynamic representations of each flight [6], or timetables to coordinate traffic flow in the underground lines service [13]. While these studies offer important design principles for coordination, they are based on a scale both temporally and spatially larger than the fast-paced, collocated medical resuscitation context.

CSCW Studies of Temporality in Medical Teamwork

Several CSCW studies of medical work have looked closely at temporality [2,3,5,7,11,18,20]. We roughly divide this body of work into studies of temporal coordination and scheduling, and studies of temporal rhythms.

Coordination and Scheduling—CSCW studies of coordination in medical work describe activities occurring over several hours, days, weeks, or even months. Bardram and colleagues discussed temporal coordination for scheduling patient care, synchronizing actions, and time allocation [2,5]. Bardram and Hansen emphasized the importance of work articulation around scheduling in surgery called “situated planning” [3]. Egger and Wagner examined the social and cultural complexity of time management and creating schedules for surgeries due to the different work routines of clinicians [11]. They discussed the inherent problems of collaborative time management in complex organizations: temporal ambiguity, conflicting temporal interests and requirements, and scarcity of temporal resources. To address those problems, they developed a prototype, called “operation book,” which resembles the document used in a clinic’s daily planning sessions. The spatial and temporal scale of the medical work contexts described in these studies, however, is larger than that of trauma resuscitation. The activities described are being coordinated across a department, rather than within a collocated team. We build on this work by discussing the role of temporality in coordinating highly time-sensitive tasks among a team of clinicians within the scale of minutes. In addition, scheduling and coordination in trauma resuscitation are not a primary concern because teams are collocated (though task coordination is still required) and their formation is *ad hoc*.

Temporal Rhythms—There are several studies of temporal rhythms in clinical and emergency medical contexts. A classic study by Zerubavel described the rhythmic structures of social organization in hospital life as characterized by five major social cycles: the year, the rotation, the week, the day, and the “duty period” [27]. Reddy and Dourish focused on the role of rhythms and temporal patterns in information seeking of clinicians in an intensive care unit (ICU) [18,20]. They found that temporal rhythms orient members of the ICU towards likely future activities and information needs, forming patterns that characterize the work in the unit, such as large-scale rhythms (e.g., nursing shifts, rounds) and finer-grained rhythms (e.g., lab results, medication administration). Some medications are ordered based on urgency and circumstances, like they are in trauma resuscitation, but because medications in the ICU are given on a known schedule, nurses can arrange their activities around this schedule. Temporal awareness has also been considered as an essential dimension of “achieving overview” in medical work, especially when achieving a shared overview of the patient status that requires convergence of multiple schedules [7]. Through our study, we identified a different set of temporal awareness issues that are unique to collocated, time-critical collaboration: perceptions of time are skewed; clinicians often lose track of time, which makes it challenging to maintain temporal awareness during time-sensitive procedures; and, the short time period and too recent information make continuous monitoring for trends in the data difficult.

The CSCW studies reviewed in this section differ from the studies of temporality and temporal artifacts in the medical sciences due to their greater focus on teamwork and coordination. In medical research, there is more emphasis on (1) the importance of time to measuring clinical performance [24,25]; (2) the completeness and accuracy of documentation for medical records, research, and cross-referencing events between different units [12]; and (3) the accuracy and synchronization of timepieces, especially pre-hospital and across hospital departments [10,12]. Although not focused on the design of time-based features for medical work, these studies point to the importance of time and the need for considering temporality in systems design.

RESEARCH DOMAIN: TRAUMA RESUSCITATION

Based on our prior fieldwork, long-term engagement with the domain, and review of medical and CSCW literature, we uncovered a number of factors that can complicate clinicians' ability to maintain temporal and situation awareness during trauma resuscitation. The resuscitation process is fast-paced and requires the focused, collocated effort of seven to 20 specialists from various disciplines. Clinicians start with a rapid evaluation of major physiological systems to identify life-threatening injuries, followed by a thorough head-to-toe evaluation for other injuries. Teams are formed *ad hoc* upon receiving patient arrival notification, with members called from different departments, making their prior acquaintance with each other less likely [17,22]. A typical trauma team consists of surgical attending physicians or fellows (team leaders), emergency medicine physicians (co-leaders), surgical residents (bedside physicians), bedside nurses, an anesthesiologist, a respiratory therapist, a scribe nurse (for documenting the process), and critical care technicians.

Resuscitation rooms are generally noisy because of the frequent communication to coordinate complex tasks distributed among team members. To complete their work, teams need to detect patterns and changes in patient status, as well as filter out irrelevant data [1]. Clinicians often miss important clinical events due to increased noise levels, resulting in repeated requests for information and interruptions [1,21]. Any inefficiency in communication and task completion can contribute to adverse outcomes.

To be efficient in treating severely injured patients, teams must also use directives that communicate priority, urgency, and time frame expectations, which is based on the timing of previous activities. Clearly indicating the speed and urgency of the requested task in turn allows for proper timing [9]. Priorities in trauma resuscitation, however, change dynamically and may not always be the same across all team members at all times [14]. It is important to ensure that priorities are articulated and frequently updated to support team situation awareness.

Although *information-rich* with constantly changing vital signs, bedside reports of patient status, and multiple treatments being ordered and given at different times, resuscitation settings are also *information-poor* in that they have few information technologies for synthesizing patient information and monitoring team activities. Resuscitation room instruments, such as the vital signs monitor, provide data about patient status but do not track work processes or communication. Monitoring of instruments is visual (e.g., looking at

the monitors) or aural (e.g., listening for the tone of the pulse oximeter). Patient data are recorded manually even when digital devices are used for data acquisition.

Clocks, Timers and Stopclocks as Temporal Artifacts

Because time is a major factor in high-risk, safety-critical patient management, most resuscitation settings are equipped with several types of temporal artifacts. First, there are *clocks* presenting the *absolute time* (Figure 1(a)), which is important for coordinating work not only within the room, but also with other hospital departments. Scribe nurses rely on the clock to manually document the timestamps for procedures and trends in vital signs on paper flowsheets. Second, there are *timers* that *count down from a specified amount of time* to automatically read blood pressure every five minutes and remind clinicians to check vital signs. When time permits, the bedside nurse setting up the vital signs monitor will configure the amount of time between reminder alerts to suit their work style preference (typically between 3–5 minutes). Finally, there are *stopclocks* mounted to the wall that show the *resuscitation time* (time since the resuscitation started), an important feature for presenting the temporal context of the resuscitation (Figure 1(c)). Teams are instructed to have a team member manually turn on the stopclock by pressing a button on the stopclock upon patient arrival and turn it off upon patient discharge.

These temporal artifacts are essential for team efficacy, yet little is known about how clinicians perceive and manage time during high-risk, safety-critical patient care. To design time-based features that will enhance their work, it is necessary to first understand the current work practices surrounding clinicians' use of the existing temporal artifacts and their perceptions of time. Peripheral information displays can serve as a useful mechanism for presenting temporal information and reducing the amount of missed or forgotten information that is easily lost [5].

METHODS

This two-year study is part of a larger research effort to develop a shared information display to support situation awareness of trauma resuscitation teams that has involved several years of fieldwork and user-centered development activities. Through this fieldwork, we gained a better understanding of teamwork practices and issues in the trauma resuscitation domain, and found significant clinician emphasis on temporality that we further explore through this study. The data presented in this paper focus on describing the nature of temporality in a time-critical medical setting and how best to support temporal awareness in such domains through the development of time-based design features for a shared information display.

Research Site

Research activities were conducted at a pediatric teaching hospital with a Level I (highest) trauma center in the U.S. Mid-Atlantic region. Each year, the center admits about 1,000 children with trauma and burn injuries. Patients are treated in two adjoining resuscitation rooms in the emergency department by dedicated specialists in trauma and burn care. The main room has three large wall-mounted monitors installed for augmenting vital sign information and showing the overhead view of the patient. During our simulation studies,

two of the displays at the front and back of the room presented our design (front display shown in Figure 1(1)). An auxiliary display to the right of our display was used to show the overhead view of the patient (Figure 1(2)). Vital sign data were presented on a separate vital signs monitor. Both resuscitation rooms have two temporal artifacts installed—a clock and stopclock (Figure 1(a,c))—currently the only mechanisms for time management.

Participants

A total of 43 clinicians that typically serve on trauma resuscitation teams at our site were recruited to participate in our research activities (Table 1). For group-based participatory design workshops and simulated resuscitations, participants were recruited to represent an entire resuscitation team. Several clinicians participated multiple times throughout the study. One of the main benefits of continued participation was that we received feedback from those who saw the evolution of the design in addition to those seeing it for the first time.

Data Collection

We conducted three types of data collection activities between November 2012 and April 2014 that elicited discussions about temporal awareness: participatory design workshops (PDW), video review sessions with interviews (VRS), and simulated resuscitations (SIM) (Figure 2). Coupled with fieldwork, these activities provided a holistic approach to conceptualizing, designing, and evaluating the information display and its time-based features.

Participatory Design Workshops—Participatory design workshops brought clinicians together to determine and discuss the requirements of the information display. Each participant was asked to sketch an individual display to support the information needs of their particular role. Clinicians then worked together as a group to create a shared display design that combined and prioritized the information needs of the team. During these design activities, clinicians were asked to discuss their work challenges, information needs, time management, and the features they believed would support their work.

Video Review Sessions with Interviews—Video review sessions involved individual clinicians narrating a 10-minute video of a simulated resuscitation. Clinicians were asked to comment on things they found unusual or important as they observed the resuscitation and teamwork. Examples included what they thought about the performed tasks, the information that emerged, what the team did well or what needed improvement, and team awareness of what other team members were doing. During each session, we asked clinicians how they adjust and manage their awareness in different situations (e.g., when arriving late to a resuscitation).

Simulated Resuscitations—High-fidelity simulations were developed to engage clinicians in realistic and challenging clinical scenarios to evaluate the usefulness and effectiveness of our display. Simulations were conducted in the main resuscitation room of the emergency department using a high-fidelity simulation mannequin and the existing wall monitors (Figure 1). A physician researcher acted as a “Wizard of Oz” and entered display information using a computer interface. Following each scenario, we asked clinicians to

discuss their experiences using the display within the context of work. We also asked questions specific to the time-based features of the display to elicit targeted feedback about temporal awareness support.

Data Analysis

We conducted a thematic analysis [8] of discussions to identify patterns in how clinicians perceive temporal aspects of their work and the ways in which they need temporal awareness support. Each transcript was first reviewed for the context and flow of the discussion. In subsequent passes of each transcript, we identified parts that focused on temporal aspects of work and time-related design features. Relevant quotes were extracted and analyzed for themes across discussions. The following aspects of the statements were considered during analysis: type of the statement (e.g., if it was about a perception, experience, or design suggestion), timing of the statement in the design process, role making the statement, and the nature of what was being discussed about time.

RESULTS: TEMPORALITY IN TRAUMA RESUSCITATION

Teams must understand and maintain awareness of information according to various time dimensions. Time dimensions range from individual task duration to overall resuscitation duration. In this section, we describe how clinicians perceive and manage their work in relation to time. We present our results in two parts. First, we describe the perceptions and experiences of time discussed in participatory design workshops and video review sessions. Second, we describe how these perceptions and experiences materialized during simulations when clinicians used the display and time features within the context of their work. Using this mix of clinicians' input, we were able to validate data across different data collection activities, as well as to ensure a holistic approach to design while minimizing methodological biases tied to each of the approaches.

Part 1: Experiencing and Communicating Time

A major theme that emerged from analyzing discussions, particularly from participatory design workshops and video review sessions, was how clinicians experience and communicate time during resuscitations. In this subsection, we illustrate three important aspects of maintaining temporal awareness in trauma resuscitation: (1) perceiving and representing time, (2) monitoring continuously to identify trends, and (3) conveying speed and urgency.

Perceiving and Representing Time—Clinicians' perceptions of time during these high intensity situations are often skewed. Each person's experience of time passing is different—whether they experience time as being shorter or longer than actual may depend on the tasks they are performing. It is therefore important that teams have time presented accurately and intuitively so they can pace themselves accordingly. A respiratory therapist (RT) commented in one of the workshops about how perceptions of time can be warped during the event:

Three minutes can feel like five seconds, or three minutes can feel like three hours just depending on the situation that you're in. (RT, PDW #1)

Most clinicians agreed that the existing stopclock showing the resuscitation time is useful for their overall temporal awareness because it helps them gauge the progress of the resuscitation. An emergency medicine (EM) physician highlighted the importance of having the stopclock in the room (Figure 1(c)):

Just starting a zero clock is important. [...] So it's like a stopwatch. (EM Physician, PDW #1)

A respiratory therapist also noted the value of the stopclock in helping teams maintain temporal awareness:

Honestly if you tell me he showed up at 6:10, I don't remember what time I came downstairs. I'd rather just know for the minute, like when the patient arrives, click, and now there's a running stopwatch saying we've been running for ten minutes. (RT, PDW #1)

These comments also imply that resuscitation time can be used as a feedback mechanism for assessing team performance. An entire resuscitation should generally be completed within 20–30 minutes, with the initial evaluation completed within the first 7–10 minutes [24]. The amount of time to complete an intervention or perform the initial survey can give the team a sense for how they are performing, so they can adjust their pace as necessary. All resuscitations are unique, and the actions that take place require unique judgments about patient response and team performance according to the particular scenario. Awareness of resuscitation time can help teams interpret their actions and progress regardless of the way they individually experience time.

While teams are instructed to manually start the existing stopclock upon patient arrival (Figure 1(c)), participants suggested integrating this feature into the display (Figure 1(b)). This was a plausible suggestion because team members often forget to start the manual stopclock and no specific role is assigned to this task, making this approach somewhat unreliable. Implementing a stopclock that starts automatically would help teams by reducing the cognitive load of remembering to turn on the stopclock.

Time was also discussed in the context of time-sensitive, multi-step tasks, when team members must keep track of how much time has passed since the last step so they can proceed with the next step. Administering the medication epinephrine (an emergency drug for treating cardiac arrest) was a useful example for discussing these types of tasks because it needs to be performed every three minutes until the patient's status improves. A bedside nurse commented that supporting awareness of time since epinephrine (epi) has been administered would be helpful because they often lose track of time due to the hectic nature of the process:

What does need to be on the screen is the fact that it's been three minutes since [epi], or this is the time you are aside. Because the time is so skewed in the midst of all of this, you lose track. (Bedside Nurse, PDW #2)

Monitoring Continuously to Identify Trends—Trends in patient data can also provide clinicians with feedback on the effectiveness of their treatments and the big picture of what

has occurred during the event. Maintaining awareness of the status of the patient, such as monitoring vital signs is important, but subtle changes over time can be easily missed if a lot of information is presented and if the information is too recent. A bedside nurse described:

I think the trending is important. [...] The most recent, of course, [...] and then the initial maybe always needs to be up there, because we don't notice trends if they're casual. [...] If I'm taking a heart rate every minute, I'm only going to have room for like five sets [on the trauma flowsheet], so I'm not going to see a trend. I'm just going to see an increase of five, whereas maybe an increase actually of 40 from when they got here, that would be important. (Bedside Nurse, PDW #1)

Presenting trends from a short period (i.e., 20–30 minutes) in a form useful for supporting awareness is challenging. Scribes document vital signs data onto a paper flowsheet, but this information is not visible to other team members. A scribe noted that they are often responsible for alerting the team when there are noticeable changes in patient status:

I mean we rely so much on whoever is documenting to notice all the trends and to notice when it's three minutes from medication [epi]. But I think that other people need to also be aware. (Scribe, PDW #2)

There are already built-in alerts and functions in the vital signs monitor to help teams continuously track vital signs. These alerts and functions, however, need to be set manually for individual patients and are rarely activated due to the lack of time. Instead, scribes and bedside nurses monitor trends in vital signs and indicate to the team when there is a change. A scribe participating in a video review session commented:

If you have a really good [bedside nurse], they're really keeping track because they're either hitting the button or they're the one that has set it up for 'cue 5.' [...] The good ones will keep an eye on the vital signs. Every five minutes, like blood pressures and all. (Scribe, VRS #5)

Bedside nurses will set timers to automatically run the blood pressure cuff, which also function as reminders for the team to review vital signs. These reminders present important temporal information for promoting awareness.

Conveying Speed and Urgency—Conveying expectations for speed and a sense of urgency—and communicating in general—is challenging in the resuscitation context due to the increased pace, noise, and intensity. A bedside nurse described the nature of communication during severe trauma cases as follows:

Communication tends to be very good when kids aren't sick. They just seem to stay quiet, and then you can move slower. [...] It's when something, a rare event happens. Somebody needs a chest tube. Even intubating, that will throw a wrench. But the more rare opportunities hit, the more panic the room gets, the less communication happens, and the more the occasion tends to fall apart a little bit. (Bedside Nurse, PDW #1)

Managing tasks that are similar in urgency and priority is difficult for teams, especially when more complicated procedures such as endotracheal intubation to treat an obstructed

airway dominate the team's focus, as described by an anesthesiologist during a video review session:

The other thing is [they're] so focused on the airway now. [...] I would be looking up at the blood pressure making sure my fluids were hung. [...] He [the leader] doesn't need to wait until after intubation to hang fluids. They're not going to risk the intubation by just hooking up an IV. [...] Blood pressure was dropping, so I would've expected one of these nurses already to be hanging fluids instead of feeling for pulses and finishing taping up the IV. (Anesthesiologist, VRS #1)

Urgency of tasks can also be lost, especially when there are competing tasks that require immediate attention. Expectations of speed can vary greatly depending on different people's perception of time and urgency, as well as training background and work style. The need for clinicians to clearly specify the necessary speed of tasks to the team became apparent during a video review session when a participant described how the team leader in the video managed competing demands:

The team leader is asking for fluids to go in as fast as possible. Well something I think he could do better would be how he wants those fluids to go in. What that means. There's a couple of ways to get fluids in fast. One is a pressure bag. But in what seems like probably a 20-kilo kid, you probably want to do a push-pull method. To be able to specify that would be better because you get [fluids] in faster that way. [...] Just to kind of up the ante too by "let's get fluid going through both IVs." (EM Physician, VRS #4)

It is therefore important for clinicians to specify what they mean by "fast" such as the rate at which fluids should be administered or indicate a specific time frame during which a task should be completed. Knowing how long fluids have been running and at what rate can help clinicians gauge whether the treatment is effective by monitoring the trends in blood pressure. If the blood pressure does not increase within a certain time frame, they may choose to increase the fluid administration rate, or start another bag of fluids if the patient shows no sign of improvement after the first bag.

Having learned these important aspects of experiencing and communicating time that clinicians described, we iteratively designed and evaluated the time-based features for our information display to better support temporal awareness during trauma resuscitation, as described next.

Part 2: Supporting Temporal Awareness

We now describe how the design of the time-based features evolved during the iterative design and evaluation of our information display to support temporal awareness in the high intensity, fast-paced environment of trauma resuscitation. To illustrate this process, we show five designs (out of 14 iterations) that were evaluated in a simulation setting (Figure 3 and Figure 4).

In the early stages of the design, the emphasis of discussions was mainly on determining which information features to include on the display. Participants in general responded positively to the inclusion of initial time-based features such as administration times for

medications and fluids (Figure 3, v.4 and v.6). As the design progressed through testing in a simulated resuscitation environment, clinicians were able to see how different time presentations function within the context of their work, allowing us to focus on fine-tuning specific temporal awareness support features. We experimented with three different methods of presenting temporal information: (1) timestamps based on resuscitation time, (2) timestamps based on absolute time, and (3) time since critical tasks or treatments.

Timestamps Based on Resuscitation vs. Absolute Time—Indicating treatments according to resuscitation or absolute time was debated throughout the design process. In participatory design workshops, clinicians discussed their individual display designs in terms of timestamps for treatments, such as medications and fluids, relative to patient arrival time or absolute time (i.e., exact time administered). The first nine of 14 display designs incorporated temporal representations using timestamps for treatments based on resuscitation time (Figure 3, v.4 and v.6; Figure 4, v.10). The stopclock on the display prototypes started automatically when the physician researcher began entering patient information into the display input interface upon patient arrival. Treatment timestamps for display design versions #1 through 9 were automatically recorded when the physician researcher began inputting information about a treatment, which they tended to do when the treatment was first ordered.

Although participants did not express dissatisfaction with timestamps being relative to resuscitation time in the first two simulations, conflicting views on presenting temporal information about treatments started to emerge through discussions from simulation session #3 onward. It was confusing for clinicians to calculate how much time has passed since a particular task was completed when looking at the timestamps while also considering the overall stopclock for resuscitation time as a reference. If they have to calculate time, clinicians prefer to do it in terms of absolute rather than relative time, because they are used to working with absolute time (e.g., documentation is in absolute time). A bedside nurse noted:

Knowing if it's been more than three minutes, you have to do some subtraction too, right, so you have to say that it has been four minutes since the last epi, you can't just tell how long ago it was (Bedside Nurse, SIM #5)

Scribe nurses generally preferred absolute time because it is the standard format for recording time information on the paper flowsheet ("*Should be just time it was given 'cause that's when I am documenting'*" SIM 3), even though they also keep the team aware of time since the last task for time-sensitive treatments. An emergency medicine physician agreed:

Yeah, so the absolute time is your reference time... whatever time you walked through the door, because if you go back and try to review, you could learn the times it was given, not how long it would take to give it. (EM Physician, SIM #3)

Representing events according to absolute time then seemed to be the most straightforward way to present temporal information for tasks and treatments. We therefore experimented by using absolute time for timestamps in simulation session #4 (Figure 4, v.13).

Time Since Critical Tasks or Treatments—While some clinicians continued to value information as a log of time-stamped tasks based on absolute time, the majority of participants in simulation session #4 found it more important to have awareness of time since the last task. For time-sensitive treatments in particular, clinicians preferred to interpret time according to the amount of time since the treatment was completed, not as a timestamp given in absolute or resuscitation time. Participants noted that the amount of time since treatment administration would be most accurate if it is based on when treatments are actually administered, rather than automatically recorded when the physician researcher begins inputting the treatments as they are ordered. In display design versions #10 through 14, selecting an “administered” checkbox on the input interface triggered the treatment administration times. As we learned through further discussion, clinicians currently calculate time since treatments based on absolute time, but would prefer a stopclock feature that shows the interval since the last treatment to avoid calculation:

Even when we do epi we don't say at minute five epi was given. We say epi was given two minutes ago based on the actual time (Bedside Nurse, SIM #3)

Some time-sensitive medications turned out not to be critical for displaying with “time since administered” because their effectiveness wears off quickly (within a minute or so). Displaying “time since” for medications that were not time-sensitive was also unnecessary because the need for additional doses is more apparent based on the patient’s response to the treatment. Using this feedback, we implemented stopclocks for presenting temporal information (Figure 4, v.14) and tested them in simulation session #5, the final simulation. Participants overall responded positively to using a stopclock feature instead of absolute timestamps to convey time since the last treatment. Showing time in this dynamic form (i.e., time is actively counting up) proved to be an important mechanism for coordinating future tasks. As participants commented, awareness of time since the last treatment assists in managing the complexity of tasks and remembering to check if the patient needs more medication or additional time-sensitive treatments.

We also found that having a log of all the times for repeated treatments was not necessary for planning or remembering future treatments. Given the number of treatments administered in a typical resuscitation, the list would become long and it would take longer to find the last treatment given. Most participants suggested that only the recent instance of time-sensitive treatments was the most important to display. A respiratory therapist commented:

Is there any way you can roll it from the last epi instead of ‘having done’...when you give the next one, the other one moves off? It rolls off so then you won't have so many. (RT, SIM #5)

Participants noted that this presentation would be enough to understand what the team has done and make decisions about the next step. In a future iteration, we plan to modify the display to present the count of times the same treatment was previously performed. The decision about when to administer the next dose is based on the time since the most recent dose was administered. Furthermore, the dosages are likely to be the same because they are weight-based, so there is no need to show all instances for each treatment.

Getting the Terminology for Temporal Features Right—We did not notice until simulation sessions #4 and #5 that the terminology for time features may not have been clear to participants and even among our own research team members. When discussing how to program the functionality of the display within our team, there was confusion about whether the time representation for treatments (e.g., fluids and medications), would be a “stopclock” measuring time by counting *up* from zero or a “timer” measuring time by counting *down* from a specified amount of time (e.g., 3:00, 2:59...0:01, 0:00). In some cases, the term “timer” was used to describe both the functionalities of a timer and a stopclock, which was discovered after reviewing transcripts, even in the initial participatory design sessions:

See like for me, I think of it more of a time of arrival or a timer. [...] I'd rather just know for the minute, like when the patient arrives, click, and now there's a running stopwatch saying we've been running for ten minutes, we've been running for fifteen. I like the timer idea versus time of arrival. (RT, PDW #1)

This participant described the functionality of a stopclock and used the term “timer” and “stopwatch.” Clinicians were familiar with the idea of the stopclock at the top right of our display because it assumed the metaphor of the physical stopclock already in use.

DISCUSSION: DESIGNING FOR TEMPORAL AWARENESS IN DYNAMIC AND FAST-PACED EVENTS

Presenting temporal information is challenging when designing for highly dynamic and time-critical events. In these environments, perception of time is skewed, priorities change rapidly [14], information is easily lost in the shuffle [5], and it is difficult to identify trends as time passes. It is thus important to carefully decide which time-based features should be used to support temporal awareness. Experimenting with time-based features in trauma resuscitation has allowed us to understand the fundamental differences between these features as *static* and *dynamic* time representation techniques. Below we discuss four time-based features falling into these two categories (Figure 5). These insights have implications for the design of information systems in domains where time plays a critical role in collocated collaboration.

Implications for Presenting Temporal Design Features

We found that using and explaining specific terminology is important for facilitating accurate and focused discussions about temporal features during display design activities. Confusion and lack of awareness about time-related terminology, such as the use of “timer” and “stopclock” interchangeably, delayed our progress on developing these features. As an outcome of the design process, we present four types of time representation techniques that can help designers facilitate both the design and discussions of time-based features: (1) timestamps based on absolute time, (2) timestamps relative to the process start time (in our case, resuscitation time), (3) time since task performance (in our case, completed treatment or evaluation step), and (4) time until the next required task (Figure 5). These techniques can then be separated into static and dynamic categories of temporal representations.

Static Temporal Representations—The first two techniques, *timestamps based on absolute time (wall clock)* and *timestamps relative to the process start time*, can be considered as static techniques where temporal representations are based on unchanging timestamps to indicate a fixed point on the timeline of a process. These techniques require users to calculate the amount of time that has passed (by subtracting the time when a task was performed from the present time) when deciding what future tasks are necessary and at what speed, which makes it difficult to quickly interpret, analyze, and use the information on the display [15]. *Timestamps based on absolute time* take more screen real estate because it is necessary to include the hour even when the whole process is completed within an hour. Screen real estate is even more limited when trying to present information about tasks on peripheral displays in contexts spanning longer periods. *Timestamps relative to the process start time* were confusing because they not only require subtraction, but also conversion to the same time axis because the present time is shown in relative time units and the record about the task performance time is kept in absolute time units. It is important to note that clinicians in our domain still found it helpful to see the absolute time of the patient's arrival to situate their temporal awareness within the larger temporal context and rhythms of their workday [18,20].

Dynamic Temporal Representations—The second two techniques, *time since task performance (stopclock)* and *time until the next required task (timer)*, can be considered as more dynamic time representation techniques where time is shown as ticking and temporal information is based on intervals between tasks (or steps). These techniques remove the requirement for users to calculate how much time has passed since the last task in comparison to the static techniques. *Time until the next required task* is less preferable because when the time reaches zero, it stops counting, making it difficult to keep track of how much time has passed since it stopped. This could mean the difference between a few seconds or several minutes past the expiration time. A common remedy is to use periodic alerts indicating that timer has expired, but even these alerts do not allow for time tracking. Active alerts can also become distracting or overlooked in an environment that is already noisy, hectic, and intense [26]. When designing for information displays that can be referenced quickly, we found that using *time since tasks* is the most effective time representation technique for supporting temporal awareness in our context because it does not require any calculation and it supports background monitoring for awareness. Contexts spanning time periods longer than an hour may also benefit from this time representation technique because it can help condense information.

The accuracy and reliability of all four temporal representation techniques depend on the mechanism for setting the reference points (i.e., patient arrival and task completion) by which times are calculated. Although automatic methods such as recording patient arrival time upon the start of documentation seem advantageous, there is a higher possibility that they will be inaccurate in emergency medical work. While the exact time of patient arrival is not as difficult to determine, a few minutes passing between the start and end of a task can make a significant difference in temporal awareness, especially for time-critical tasks. Clinical expertise is still required due to variability and subjectivity in determining the actual

task completion. A manually selected mechanism (e.g., checkbox, button) for indicating task completion appears most feasible.

Implications for Peripheral Information Displays

The information display we designed is meant to be a quick reference for busy medical teams. Clinicians in the trauma resuscitation environment generally allocate their visual attention to information sources (e.g., the vital signs monitor) for approximately 1–3 seconds [16]. The information on the supplemental displays, especially for updating temporal awareness, therefore needs to be accessible and absorbable at a glance. Too much detail about tasks would require clinicians to spend time looking and analyzing the display to gain situation awareness, which can be hazardous to patient safety [4].

Because many tasks and treatments are repeated throughout the process, it is important to not only provide a sense for what has been completed, but also what is the current status of the patient and the resuscitation, all within a limited amount of space. An overview of critical tasks to remind clinicians of what was recently completed turned out to be more useful than a detailed log of events, as also concluded by Bardram and Hansen [4]. In our case, however, we found that the time since a completed task is still helpful, but only for select tasks—time-sensitive treatments. Through trial and error, we were able to identify “time since task performance” as the suitable time-based feature for our problem domain. We also found it was more useful to present temporal information of iterative tasks by showing the most recent task iteration, but then also by indicating the number of times the task has been performed. This presentation method not only saves space on the display, but also time when searching through a task list.

CONCLUSION

In this paper, we examined the temporal awareness of clinicians in a regional trauma center. We conducted participatory design workshops, video review sessions with interviews, and simulated resuscitations to understand how clinicians experience and perceive time, communicate temporal information, and respond to different presentations of temporal information. Analysis of the discussions revealed the aspects of maintaining temporal awareness that clinicians perceived as important in trauma resuscitation. These findings then contributed to the design of time-based features that evolved during the iterative design of an information display to support the temporal awareness of clinicians. Using the insights from the design process, we discussed four different types of time representation techniques and offered guidelines for deciding which time-based features should be used when designing information systems to support temporal awareness in time-critical, collocated teamwork.

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Figure 1.

Display and temporal artifacts setup in the resuscitation room during simulation sessions: (1) our information display, (2) auxiliary display for vital signs or overhead view, (a) absolute time, (b) time since patient arrived (starts when data is inputted on the back end interface of the display), (c) time since patient arrived (manual start). Room stopclock (c) was not synchronized with our display stopclock (b) due to the technical constraints of our prototype and room stopclock hardware.

Figure 2. Data collection sessions and number of participants (includes participants that participated multiple times).

Version 4, Evaluated in Simulation #1

WEIGHT 26 kg	AGE 8	MECHANISM MVC: Rear passenger Hip belt only Airbag	PRE-HOSPITAL +LOC Seizure CPR in transit, field	Broselow ORANGE
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A Patent Supported Collar	B Uneven rise Trachea midline SOUNDS Decreased L ▶ Intubated ▶ Chest tube	C PULSES Apical: 2+ Distal: 2+ Femoral: 2+ ▶ ECG: 6:00 ▶ ECG: 8:00	D GCS 6 08:00 8 05:00 8 02:00 PUPILS 5/5 nonreact 4/4 sluggish 4/4 sluggish	MEDICATIONS Succinylcholine 26 mg 06:30 Etomidate 3.9 mg 06:30 Atropine .26 mg 06:30
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FLUIDS NS 200 cc 12:00 NS 200 cc 08:00	RADIOLOGY C x-ray C-spine C-spine Head CT	LABS Comp.	DISPO PICU
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Version 6, Evaluated in Simulation #2

WEIGHT 26 kg	AGE 8 y	MECHANISM MVC	Rear passenger Hip belt only Airbag	ORANGE	10:58 TIME (since arrival)
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A ☒ Airway protected ☒ C-spine immobilized ☒ GCS assessed before RSIs ☒ ET tube reported ☒ ETCO ₂ reading confirmed ☒ Chest x-ray ordered ▶ INTUBATED	C ☐ Check distal pulses ☒ IV/IO access established ☒ Fluid bolus or blood given ▶ IV #1 ▶ IO
B ☒ O ₂ placement confirmed ▶ CHEST TUBE #1	D ☐ State GCS ☐ State pupil size and response ▶ GCS: 6 03:45 3 10:15 3 07:25

Figure 3.

Time-based design features on display versions # 4 and 6. Timestamps (outlined by dashed red boxes) indicate time reported or administered relative to resuscitation time.

Design Version	Time-based Design Feature	Type of Time Representation
	Version 10, Evaluated in Simulation #3	
	Treatments (medications, fluids, cardiac treatments)	Timestamps based on resuscitation time
	Stopclock	Resuscitation time (Time since patient arrived)
	Version 13, Evaluated in Simulation #4	
	Treatments (medications, fluids, cardiac treatments)	Timestamps based on absolute time
	Stopclock	Resuscitation time (Time since patient arrived)
	Version 14, Evaluated in Simulation #5	
	Treatments (medications, fluids, cardiac treatments)	Time since treatment was last administered (only for fluids & time-sensitive treatments)
	Stopclock	Resuscitation time (Time since patient arrived)
	Patient arrival time	Timestamp in absolute time
	+ Rate of fluid administration	mL per hour
	Separated treatments: time-sensitive, intubation related, fluids	

Figure 4. Time-based design features (outlined by dashed red boxes) on display versions #10, 13, and 14. Plus and minus signs ('+' and '-') indicate the features added to or removed from each display design version.

Figure 5.
Four different types of time representation techniques for time-critical, collocated teamwork.

Table 1

Participant count.

Roles	Participants (N=43)
Anesthesiologist	5
Bedside nurse *	9
Emergency medical physician	5
Bedside physician	7
Respiratory therapist	6
Scribe *	3
Surgical team leader	8

* Some bedside nurses also served as scribes, but were only counted once as bedside nurses.