Exploring the Design of Streaming Data Interfaces for Emergency Medical Contexts

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ABSTRACT

In this late-breaking work, we describe the design of an interface for displaying streaming vital sign data on a digital checklist used in the emergency medical setting of pediatric trauma resuscitation. We used feedback from interviews and participatory design workshops with clinicians to develop two prototypes of the streaming vital sign interface. We evaluated these prototypes in design-walkthroughs, finding that clinicians preferred the design displaying trend graphs for all four vital signs at once. We discuss how streaming data interfaces on interactive mobile devices can be used to provide situational awareness while unobtrusively supporting different levels of clinical experience.

CCS CONCEPTS

• **Human-centered computing**; • **Human-computer interaction (HCI)**; • **HCI design and evaluation methods**;

KEYWORDS

User experience (UX) design, digital checklist, trauma resuscitation, interviews, design walkthroughs, participatory design workshops, design principles

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Figure 1: Current UI for the Vitals section on the checklist

1 INTRODUCTION

Pediatric trauma resuscitation is a time-critical medical process of rapidly diagnosing and treating children with life-threatening injuries. To increase efficiency of trauma team performance, we developed and implemented a digital checklist on a tablet for trauma team leaders [9]. The leader (an attending surgeon, fellow, or senior resident) is responsible for overseeing patient care, assigning tasks, and making decisions. The digital checklist is based on the Advanced Trauma Life Support (ATLS) protocol [1] and contains five sections: Prearrival tasks to prepare the team, Primary survey to guide the initial patient evaluation, Secondary head-to-toe survey, Vitals to assess the patient's vital signs, and Prepare for travel to guide the patient's discharge. The Vitals section contains six checkboxes, where team leaders can check off and manually enter the four vital sign values (heart rate, blood pressure, oxygen saturation, and respiratory rate), patient weight, and temperature (Figure 1). Although the digital checklist improved team performance [8], we found in our prior work that leaders delayed or omitted checking off vital signs [10]. Vital signs are continuously evaluated during resuscitations, but the static checklist design prevents checking off an item multiple times and later visualizing the trends.

In this late-breaking work, we describe our ongoing research on redesigning the vital sign interface for the resuscitation checklist to better support the dynamic nature of evaluating vital signs. Based on interviews and participatory design (PD) workshops with 23 clinicians, we identified issues with the current checklist interface. We then created two prototypes for a new vital sign display, which uses streaming data automatically pulled from the vital sign monitor in the room. An initial evaluation of these prototypes showed that streaming vital sign data on the digital checklist reduced the documentation burden, while helping clinicians recognize abnormalities. Interaction afforded by the mobile device also allowed for dynamic displays that aided clinicians in understanding different information levels. Throughout this process, we explored two research questions: (1) how to design a real-time streaming data interface for medical checklists on a mobile device, and (2) how to move this mobile design beyond the limited data currently shown on standard vital sign monitors.

2 RELATED WORK

To increase adoption and avoid checklist fatigue, checklist designs must address user needs and better integrate into workflows [3]. A recent study found that anesthesiologists commonly experience alarm fatigue and information overload when monitoring patient vitals [14]. Prior studies have shown that displaying data graphically and numerically better supported rapid data interpretation [5, 11]. For example, web-based visualizations allowed users to retrospectively review stroke treatment timings to better understand factors causing delays [12]. In another study, a tool for monitoring physiologic patient data in a pediatric intensive care unit helped

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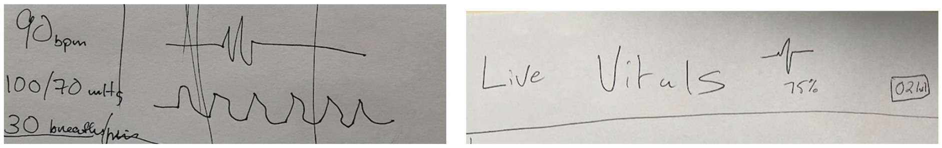


Figure 2: Sketches of an automatic vitals interface from two clinicians in the participatory design workshops.

clinicians better visualize the vitals [11]. Visualizations of streaming data can help users maintain awareness, monitor and track events, and recognize important changes [4, 7]. Streaming data visualizations in medical settings have been limited to conventional desktop computers and monitors. Similarly, studies of streaming data visualization for tablets have mainly focused on nonmedical domains. Our work addresses these gaps by bringing together these two research areas and exploring the design of a streaming data interface for the checklist tablet used in real time during a medical event.

3 DESIGN RESEARCH: METHODS AND RESULTS

Throughout 2017 and 2018, we conducted interviews with 15 team leaders who had used the digital checklist at a level one trauma center in a pediatric teaching hospital. In the hour-long interviews, we asked the leaders about their experiences using the checklist and how the checklist impacted their work practices. We also asked if they would prefer recording trend values for each vital sign, as vitals are repeatedly evaluated throughout the resuscitation. We learned that leaders could overlook salient changes in vital sign values from the monitor and fail to document them on the checklist. Leaders also described that manually typing the values onto the checklist is time consuming and that pulling vital sign data automatically from the monitor would be helpful. In 2019 and 2020, we ran four one-hour PD workshops with a total of eight leaders across the sessions. We asked leaders to use cardboard cut-outs to redesign the checklist and sketch solutions for the identified challenges. In one activity, we asked how vitals could be re-designed on the checklist. Participants sketched the vitals automatically flowing in from the monitor, with a section for the most recent values and graphs displaying trend information (Figure 2). We used these findings to redesign the vital signs section of the checklist to draw from the monitor data instead of requiring manual data entry from users.

4 DYNAMIC VITAL SIGN DATA DISPLAY: DESIGN APPROACH AND CONSIDERATIONS

We approached this research with design thinking in mind, where we considered design principles in developing two mockups for the vital sign interface (Figure 3). Both mockups contain a section with recent vital sign values and a trends section with line graphs displaying the values over time. In the first prototype, upon clicking on the "Trends" button under the heart icon (Figure 3), the graph is displayed beneath the recent vital sign values and users can view other graphs by selecting from different vital sign boxes. In the second prototype, a screen appears above the interface displaying smaller versions of the four graphs at once. Users can view the individual graphs in detail by selecting one of the graphs. We considered design principles, such as visibility of system status and communicating changes, when designing specific features on the mockups.

4.1 Visibility of System Status

Our guiding design principle was the *visibility of system status* [13], which focuses on effectively communicating the state of a system with appropriate feedback. We used this principle to inform the leaders (a) when the patient is disconnected from the room monitor, (b) of any Bluetooth errors preventing the vitals from being transmitted to the checklist, and (c) about the severity level for each vital sign. To convey the first two types of status, we designed icons to inform users that the patient is disconnected from the monitor (Table 1.1) or that Bluetooth errors are blocking the connection (Table 1.2). We communicated the severity status of the vital signs through colors to support rapid processing of information [6]. Because most people associate severity levels with red, yellow, and green (e.g., triage systems in mass casualty), we used these same colors. Each vital sign value was colored to indicate if it is normal (green), concerning (yellow), or far outside the normal limits (red). A colored bar with red, yellow, and green sections was placed below each vital sign in the summary section (Figure 3). The section in bold corresponds to the latest status of the vital sign. Users can click on each section to see the corresponding range of values. We also applied the color scheme to the background of the trend graphs, creating two design options—one with flat colors and one with gradient colors (Table 1.3).

4.2 Communicating Salient Value Changes through Trends Graph

Vital signs change throughout resuscitations. The room monitor now displays only the most recent values. The monitor can also show trends, but setting up the monitor takes time. For this reason, vital sign trends are rarely used in real time during patient care. In redesigning the vital sign interface, we addressed user needs by pulling the vital sign trends from the monitor. Based on the ideas from the PD workshops, we created one section with the most recent values for all four vitals and a separate section displaying the trend graphs for each vital sign. We planned to have the data automatically refresh at a predetermined interval, while also giving users the ability to manually pull in the latest vitals on demand with a button (Table 1.4). Events with dramatic changes can be easily missed if they occur rapidly. To address this limitation, we displayed the values as a line graph [4], where time is spatially encoded with the respective value (Figure 3). Users can click on data points on

Figure 3: Prototypes 1 & 2: Two potential designs for the dynamic vital sign data display.

the graph to see the specific value at that time (Figure 3). In the upper right corner of the graph, we included additional information about vitals (the minimum and maximum values). In response to user feedback from the initial evaluation sessions, we created two designs for manipulating the graph's timeline (Table 1.5). The first option is a toggle that allows users to switch the graph between recent data points vs. data points from the entire resuscitation. In the second option, users select a specific time range using a slider.

5 DYNAMIC VITAL SIGN DATA DISPLAY EVALUATION: METHODS AND FINDINGS

To evaluate our prototypes and design options, we ran remote usability sessions over Zoom with four residents and fellows in August 2020. All participants were team leaders who had used the checklist during past resuscitations. In the first part of the session, the participants explored the two prototypes through the Adobe XD link. We asked participants to screenshare with us to observe their interactions in real time. After exploring each prototype, we asked how this new interface might impact their work and if they had any design changes. We then ran A/B testing to determine UI design preferences (Table 1). While sharing our screen, we asked participants which design they preferred for each feature and why (Table 2). In the first two interviews, we also solicited feedback on data manipulation within the vitals trend graphs. We then incorporated this feedback for the last two sessions, where we asked participants to consider two different designs for time manipulation (Table 1.5). Clinicians' thoughts on how this new interface might impact their work practices suggested a lightweight design that should reduce the leader's cognitive burden and aid in decision making.

5.1 Prototype Preferences

One participant preferred the first prototype, while the other three preferred the second. The first participant liked having the graph directly below the vital signs. Other participants preferred the second prototype because it displayed all four graphs at once, with one participant stating how seeing them at once provided "*a global picture of what's going on*." Another participant stated that seeing the four graphs at the same time "*help[ed] correlate things between vitals*," as vitals can affect one another. Users also preferred arranging the blood pressure and heart rate values next to each other to see any correlations, as these vitals are closely related.

5.2 Color Scheme and Icons

One participant liked the flat color scheme because it showed the exact distinctions between the ranges, while the other three thought the gradient color scheme was more aesthetic. All participants thought that the three-level color scheme was appropriate for this context. One of the participants stated: "*It's hard for some residents to keep in mind the different normal values for the different age ranges. I think it's good to have the colors so they can associate that.*" Participants also found the colored bars with the reference ranges useful as a training tool, saying that "*it's a good idea. . . especially for [leaders] who come through, who are not really interested in pediatric surgery.*" Another participant highlighted that the color coding could help alert users to concerning vital sign values, explaining: "*It would be good to have the vitals brought in [automatically], but one of my concerns was that. . . you can overlook them and they don't necessarily catch your attention, and I think it's good that we have the different colors stating whether it's in abnormal limits. I think that would help to catch your attention more if something's really abnormal.*" All participants stated they would want to be alerted if the values were abnormal or declining, suggesting a pop-up alert or pulsing of the concerning vital sign.

5.3 Timing and Time Manipulation

Obtaining the vital sign data automatically provides a continuous stream of data, while the manual data entry resulted in only one

Table 1: Design options for features of the dynamic vital sign data interface.

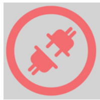
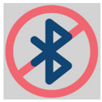
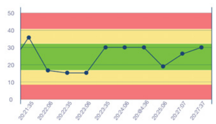
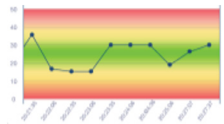
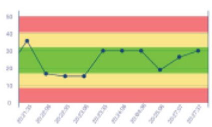
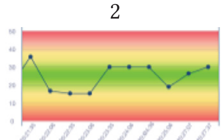
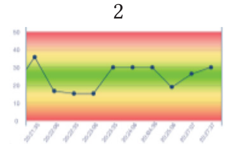
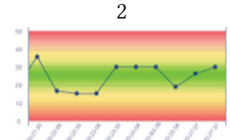
Disconnected Icon	a. 	b. 	c. 
Bluetooth Error	a. 		
Gradient vs. Flat Color	a. 	b. 	
"Data on Demand" Icon	a. 	b. 	
Time Manipulation	a. 	b. 	

Table 2: Design preferences from user interviews and design walkthroughs

	Participant A	Participant B	Participant C	Participant D
Prototype 1 vs. 2	1	2	2	2
Gradient vs. Flat Color				
"Disconnected Monitor" Icon				
"Data on Demand" Icon				
Time Manipulation Design 1 vs. 2	N/A	N/A		

data point per vital sign. One interview participant highlighted this advantage of streaming data, explaining that one number may "*not be the best representation*" of the whole resuscitation. When asked about their preferred approach for manipulating time in the trend graphs, all participants opted for the one-touch "All" button (Table 2.5). Participants considered scrolling through the timeline "*tedious*" and did not want the interaction to be "*complicated*." When asked about any other information that could be displayed as part of the graph, three participants said that just the maximum and minimum values were sufficient. One participant suggested adding the normal range below the maximum and minimum to support less experienced leaders.

6 DISCUSSION

From our findings, we discuss the importance of ensuring that users recognize values and key changes when integrating streaming data into a static checklist. We also explore how the interactive nature of the tablet allows for displays that can provide varying levels of information to support different levels of experience.

Figure 4: Final design of the automatic vitals interface.

6.1 Integrating Streaming Data into a Static Patient Record (Checklist)

We altered the vital signs section on the digital checklist from being manually entered to being automatically obtained as streaming data. As participants noted, this continuous stream of data provided a better representation of the resuscitation and reduced the data entry burden. However, participants also highlighted that manually entering vitals forces the user to recognize the values, while automatic data requires less user attention. Color and trend graphs are one non-intrusive way of bringing user attention to the latest vital sign data. A change in colors indicates a change in status, while the angle of the line graph informs of any rapid changes in data [4]. While the streaming data display provides more information and reduces data entry effort, it is important to ensure that users recognize the vital sign values and notice any key changes.

6.2 Building on the Interactive Nature of the Tablet for a More Supportive Interface

The vital sign monitor is located next to the patient and is only touched by the nurse when entering the patient's age. The team leader stands at the foot of the bed, holding the tablet with the digital checklist. Because they are already using the checklist, it is easier for the leader to interact with vital sign data on the checklist than on the monitor. Although the tablet has a smaller screen size, its interactivity provides many benefits. We discuss how this interactivity allows for displaying different information and supporting different experience levels.

6.2.1 Connect Information to Provide a Global Picture. Clinicians have to gather information from different sources to identify issues and make decisions about a patient, a process termed "achieving overview" [2]. Most participants preferred seeing the trends graphs for all vitals at once because it allowed them to notice relationships and better understand the state of the resuscitation. Our findings also suggested that leaders wanted to achieve an understanding of the patient status first, and then, if they were concerned or curious about certain vitals, see more details by viewing the graphs. In our initial interviews, the leaders discussed how

they struggled to recall the history of the vitals from the start of the resuscitation and could forget when drastic changes occurred. In design walkthroughs, leaders preferred seeing data from the entire resuscitation to understand how the vital sign values were trending over time. Trend graphs with data from the entire resuscitation allow users to review historic data (from the start of the case to current time), reminding them of past events or any concerning values they possibly overlooked. Checklist data could also be incorporated into the trend graphs to provide more context about a change in vital signs. For example, times when medications were given could be highlighted on the graph to better help clinicians understand how medications affected patient vitals. When selecting what information to display to achieve overview, we considered the tablet's limited screen size. This constraint led to a display of simple graphs of the four vital signs. The interactive nature of tablets also allowed us to create graphs that can be viewed together first, and then if desired, zoomed in to the individual graphs for more information.

6.2.2 Unobtrusively Support Different Levels of Experience. Checklist users are all physicians with training in trauma resuscitation, a more homogenous group than users of most applications. However, we learned that some users may not be familiar with pediatric vital sign ranges and struggle to recall the vital sign thresholds when determining the patient status. The color-coding of the vital sign values and trend graphs help users understand the significance of different values. Physicians can also tap on the colored bar to see the reference ranges that are initially hidden, making this information helpful for leaders with less experience, while not forcing the information on leaders who do not want it or need it. This experience contrasts with viewing vitals on the monitor, where customizing views and granularity of data for different user types is more challenging.

7 REVISED VITAL SIGN DISPLAY DESIGN AND FUTURE WORK

We used findings from the evaluation sessions to revise our design of the streaming vital sign data interface (Figure 4). In the section showing the latest four vital sign values, the heart rate and blood pressure have been rearranged to be next to each other. Tapping the "Trends" button displays four-line graphs at once to provide an overview with the ability to tap a graph to access an enlarged, interactive view. Users can manipulate the time display using the toggle button to show "All" of the data pulled from the resuscitation or "Recent" data from the past 5 minutes. In our future work, we will release this new interface on the digital checklist at the hospital to evaluate its effects on the leader's work and the potential ways the design can be improved.

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