Design and Evaluation of a User Interface to Facilitate Cardiac Monitoring

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Abstract

Patient monitoring devices are complex and highly specialized systems. We present an enhanced display of the alarms that facilitates cardiac monitoring and supports the clinicians during the diagnosis process. Three different interactive user interface prototypes were developed using web technologies. To maximize acceptance among professionals, we extended the ECG parameter of an existing monitoring interface with visual cues directly at the wave, to show where exactly an alarm happened, an alarm timeline beneath the wave (showing the last events) and an animated detailed view of an event. The new user interface lowered the perceived cognitive load and accelerated the detection of abnormalities in the wave.

1 Motivation and Approach

The operating room is a prime example for a complex environment. It is noisy and frantic, and lives depend on the precise work of the staff. Patients are routinely connected to a monitoring device, which displays and records their life signs. Current systems show over 17 parameters on one screen with an upward tendency (Kamaleswaran and McGregor, 2016) and especially anesthetists have to constantly filter and reevaluate information, with a high degree of flexibility, as task interruptions and multitasking skills are required (Pfeffer et al., 2012). Our goal was to redesign the monitoring user interface to lower perceived cognitive load (Sweller, 1988) and to increase diagnostic accuracy and speed by using a new display for alarms.

We built three prototypes using HTML, CSS, JS and SVG as well as jQuery[1] and Velocity.js[2] to accelerate animation and Tweenmax[3] to control the timing of the animation with a virtual timeline. Every prototype displays the same parameters: Heart Activity (ECG), Blood Pressure (ABP) and Blood Oxygen Level (SpO_2). Our enhancements are only implemented into the ECG wave. The prototypes display artificial data that consists of a small snapshot of the monitoring history of our chosen scenarios: 1. Myocardial Infarct, 2. Long QT Syndrome and 3. Cardiac Arrhythmia (Phase 3). We did not use real patient data, since the symptoms of these diseases can

[1] http://jquery.com
[2] http://velocityjs.org
[3] https://greensock.com/tweenmax

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Figure 1: Different States of ECG Parameter of Prototype C during Scenario "Cardiac Arrhythmia (Phase 3)" 1: No Alarm, 2: Alarm State with Cue and Timeline, 3: Detailed View of an Event

last for days, until they evolve to a critical state. Horsky et al., 2012 identified in their survey paper design principles to improve the usability and lower cognitive load of clinical decision support (CDS) systems, which include patient monitoring devices. We used among others the following principles in our prototypes: 1. Consistent use of elements, icons and colors throughout the user interface. 2. Use of color to indicate "importance level, hierarchy, category or to differentiate data with different attributes" (Horsky et al., 2012). 3. Use of visual cues as simple elements to attract attention (Harry and Sweller, 2016). 4. Sort alerts by importance and align their styling to it. Also adequate choice of color or effects such as flashing may be used (Wogalter et al., 2002).

Prototype A is identical to the design and alarm system of current monitoring systems. Colors are used solely to differentiate the parameters. Prototype B introduces red and blue color coded waves to indicate the normal and alarm states. There are frames around the numeric value to separate the parameters from each other. The update of the wave has a white spot at the beginning of the wave and at the end a gradient fading to black to make it easy to distinguish the newest and oldest data. If an alarm is triggered, the background of the numeric is fading from black to red and back. Prototype C (Figure 1) adds visual alarms, which consist of a rectangle (cue) around the spot in the wave where an abnormality occurred, a timeline which displays the last events of a parameter and a detailed view, which shows more information about an incident, visualized with an animated illustration. If no alarm is triggered, the timeline is hidden to clean up the user interface. Icons illustrate the most important traits of an event.

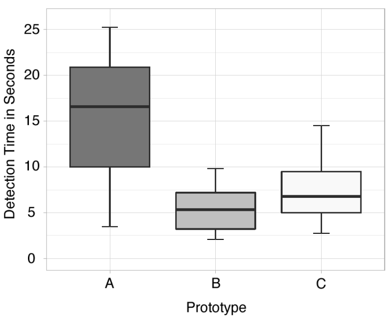

Figure 2: Detection time of events located in the wave

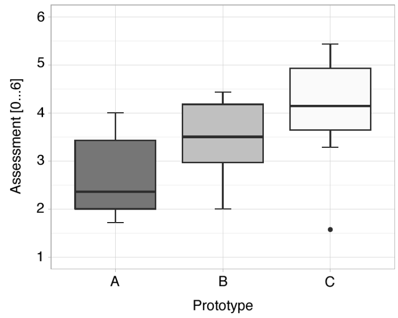

Figure 3: Utility assessment by type of design

2 Evaluation

11 medical students and one paramedic participated on our experiment. Average experience with ECGs was reported 1.33, where 0 equals <10 and 3 equals 30+ analyzed ECGs per year. A 15,4" widescreen notebook (glossy screen, 1366x768px) was used during the whole experiment. Each experimental session consisted of three blocks. In each block, one design with one scenario was tested. The order of the designs was randomized to avoid biases, but the order of the scenarios remained the same. Using this method, each of the 9 possible design-scenario combinations was tested by 4 different participants. During each block, the time to detect and time to verbally diagnose a critical event, was measured by pressing D or respectively K on the keyboard. Proceeding the same way as Charabati et al., 2009, we used a score for correct (20), incomplete (10) or incorrect (0) responses to calculate the overall accuracy of answers for each prototype. Also, the participants worked simultaneously on a part of the German Standard Assessment Test for Medicine Students to deduct attention from the monitoring and to simulate multi-tasking. Perceived cognitive load was quantified after each block using a translated and modified version of the NASA-TLX questionnaire (Hart and Staveland, 1988). At the end of each experimental session, utility and usability of the prototypes was measured with a self-made questionnaire.

The overall time to detect changes showed no significant differences. However, when categorizing into wave and numeric related events, participants needed more time to detect events in the wave using A (M=15.08s) compared to B (M=5.53s) or C (M=7.31s) (Figure 2). There was no significant difference found regarding events in the numeric value, since our improvements mainly applied to the wave display. The analysis revealed that events could overall be faster diagnosed verbally when using A (M=14.49s) or B (M=19.2s) compared to C (M=25.47s). However, the collected data included 5 (A), 4 (B) and 2 (C) incorrect responses. In total, there were 60 events to be diagnosed (5 events per session). The overall correct response rate was 52% (31/60), incorrect 18% (11/60) and 30% (18/60) incomplete. The accuracy of answers was higher using C (M=15.5) than A (M=12) or B (M=12.5). More expertise in ECG interpretation favored a higher accuracy (p=0.13). Perceived cognitive load was decreased with B (M=2.9) and C (M=3.03) compared to A (M=3.45). Participants tended to be better in diagnostic analysis, when their load was lower (p=0.07). B (M=3.5) and C (M=4.1) were rated to have higher utility, than A (M=2.7) (Figure 3).

3 Discussion

Prototype A performed in almost every tested issue worst, showing that there is clearly potential to improve the current user interface. Surprisingly, participants where the fastest to respond in this version. Our results show that faster response time does not correlate with the correctness of the answers, since A had the most incorrect answers and least accuracy of all prototypes. Note that the accuracy score that we calculated includes not only incorrect answers, but correct and incomplete answers too. The improved color scheme and overall cues in B made an impact, since participants needed the least time to detect changes in the wave. However, the accuracy of the answers was slightly worse than A, suggesting that the user interface was either too unfamiliar or too inaccurate in the display of events, since it only used the red color in the wave and no additional cues to show that something is not right. The perceived cognitive load in B was slightly lower than in C, showing that the added enhancements in C did not manage to lower the load, but either they did not increase it significantly. With C, participants needed the longest time to diagnose, but answers were mostly correct. Besides, the answers have the highest accuracy score of all prototypes. Utility of C was further confirmed since it was rated as providing significantly more support than A or B. This shows that our enhancements are a solid foundation for further development. Nevertheless, our work has some limitations regarding the experimental design used in this study. We must be aware that real clinical environment is much more complex and clinicians need to pay full attention over a monitoring task across several hours. Instead of performing a complete physiological monitoring task, participants only conducted cardiac monitoring.

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