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A mobile application to support collection and analytics of real-time critical care data

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ABSTRACT

Background and objectives: Data collection, in high intensity environments, poses several challenges including the ability to observe multiple streams of information. These problems are especially evident in critical care, where monitoring of the Advanced Trauma Life Support (ATLS) protocol provides an excellent opportunity to study the efficacy of applications that allow for the rapid capture of event information, providing theoretically-driven feedback using the data. Our goal was, (a) to design and implement a way to capture data on deviation from the standard practice based on the theoretical foundation of error classification from our past research, (b) to provide a means to meaningfully visualize the collected data, and (c) to provide a proof-of-concept for this implementation, using some understanding of user experience in clinical practice.
Methods: We present the design and development of a web application designed to be used primarily on mobile devices and a summary data viewer to allow clinicians to, (a) track their activities, (b) provide real-time feedback of deviations from guidelines and protocols, and (c) provide summary feedback highlighting decisions made. We used a framework previously developed to classify activities in trauma as the theoretical foundation of the rules designed to do the same algorithmically, in our application. Attending physicians at a Level 1 trauma center used the application in the clinical setting and provided feedback for iterative development. Informal interviews and surveys were used to gain some deeper understanding of the user experience using this application in-situ.
Results: Activity visualizations were created highlighting decisions made during a trauma code as well as classification of tasks per the theoretical framework. The attendings reviewed the efficacy of the data visualizations as part of their interviews. We also conducted a proof-of-concept evaluation by way of usability questionnaire. Two attendings rated 4 out of the usability 6 categories highly (inter-rater reliability: $R = 0.87$; weighted kappa $= 0.59$). This could be attributed to the fact that they were able to fit the use of the application into their regular workflow during a trauma code relatively seamlessly. A deeper evaluation is required to answer explain this further.
Conclusions: Our application can be used to capture and present data to provide an accurate reflection of work activities in real-time in complex critical care environments, without any significant interruptions to workflow.

1. Introduction

Critical care environments, such as emergency departments (ED), intensive care units (ICU) and trauma critical care may be modeled as complex adaptive systems [1,2]. Plesk and Greenhalgh [3] define complex adaptive systems as “a collection of individual agents with freedom to act in ways that are not always predictable, and whose actions are interconnected so that one agent's actions change the context for other agents”. Critical care systems are particularly complex and dynamic due to the relatively fre-

Abbreviations: ATLS, Advanced cardiac life support; ABCDE, Airway, Breathing, circulation, Disability, Exposure; GCS, Glasgow Coma Score.

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quent changes in staff that continually alter team dynamics and the surplus of technology and equipment that create unanticipated demands on clinicians. Such environments tend to be unpredictable and inherently non-linear leading to a multitude of adaptations and consequently emergent behaviors [2,4]. These adaptations ("deviations" from standards) provide the real insights into the processes that shape the system.

1.1. Empirically-based theoretical foundations for error classification

Our previous research by Mithra Vankipuram and colleagues [5] and Kahol and colleagues [6] found that much of the error research in clinical systems has modeled errors as deviations from standard practice [7–9].

Standard protocols and guidelines assist in providing consistency of care. However, to adapt the guidelines in any complex environment such as critical care, deviating from the standard procedures is sometimes unavoidable, since the complex clinical environment dynamically changes. In our empirical study, 30 trauma cases were audio-recorded for team management procedures in real-time in a level-1 trauma center [5]. The data was analyzed as a team (cognitive scientists, clinicians and biomedical informaticians) to capture the number of deviations (152) from the standard ATLS protocols. These deviations were classified as either errors or suitable innovations (i.e., beneficial deviations that ended in better outcome). For example, when attempting to evaluate a patient from ED with a head injury, a resident noticed that the patient had a high Glasgow Coma score, a week-old wound on the leg, and high fever. Instead of just performing the guideline-required head X-ray, the resident deviated from the protocol by first requesting blood cultures. The culture result showed acute blood-borne infection and appropriate antibiotics were instituted, thus resolving the problem [10].

The authors found that when trauma physicians (experts), deviated from standardized protocols, made significantly fewer errors as compared with first-year and second-year residents (comparative novices). The deviations occurred under conditions of complexity, as well as in the presence of high levels of uncertainty about the patient's condition. These deviations were mostly related to strategic planning (called proactive deviation), whereas deviations by the novices were mostly procedural in nature and reactive to specific events that occurred during patient management (called reactive deviation) [5]. This study supports the claim that deviations from protocol do occur in critical-care environments, but that not all deviations are errors; some reflect deliberate and appropriate actions or judgments by expert clinicians under atypical conditions.

In summary, when standard patterns do not fit or match the patient's problem, possible alternate concepts get generated. This is what one would call the process of "innovation", which is not possible without deviations from what is "usual". Given the number of standardized guidelines that are extensively used across clinical settings, this conceptualization of 'deviations as innovations' provides a new lens for interpreting atypical actions rather than just categorizing them as errors [5] Such innovative deviations are also learning opportunities that may contribute to our knowledge and to revisions of protocols.

1.2. Methodological rationale for tool development for data collection and analysis

To analyze such deviations and processes in critical care as described above, the assessment of events in this complex system is the critical first step; one that is affected by the inherent dynamic properties of the environment. The disassociation between the non-linearity and unpredictable nature of the environment, and the tools available to analyze cognitive and workflow processes make the dynamic activities difficult to understand [11]. The tools currently used for analyzing processes in these environments include qualitative methods such as ethnographic observation, shadowing of individual clinicians, surveys, and questionnaires [12]. While these methods provide rich descriptions of clinical workflows centered on an individual or team [13], the methods do not scale very well. Data cleaning, aggregation and processing typically follow the data collection process. Each of these steps can take a significant amount of processing time depending on the availability of resources. This latency, between data collection and providing the clinical team with insights from the analysis, can significantly reduce the impact of the findings as the events may have been forgotten.

Video recorders have also been utilized to capture events in critical care for teaching purposes and for enabling decision support [14–16]. While the automated analysis of video data may not have significant time gains on analysis of observations, the retrospective review of videos by an expert has been shown to deliver near real-time insights about adherence to guidelines in critical care environments [17,18]. These methods, however, require an expert reviewer to be permanently available which may be practically unfeasible due to the unpredictable nature of trauma events. In addition, the videos have been analyzed to identify errors as deviations from accepted guidelines as opposed to deviations that may be necessitated by the dynamic and complex nature of the critical care environment.

During the process of error classification described above [5], the data collection for 30 cases was conducted by notetaking while observing the trauma code and supplementing the notes with informal interviews with nurses, as well as perusal of various forms completed by nurses during a code. This was a complex process and prone to error itself, since missing a single task may have led to an inaccurate interpretation of a deviation when there was none. The process of mitigating these risks required significant time expended in ensuring sanctity of collected data. It therefore became clear from our earlier work that continuation of this research required a streamlined and possible automated process of data collection, taking a great deal of the burden of the observer and reducing the potential for error. Furthermore, we felt that many of the deviations described could be automated by developing them directly into the data collection tool. The tool would need to be able to interpret deviations based on the data collected and either report them instantaneously or as a summary. We also considered the fact that a data capture medium would be most effective if clinicians and researchers of different backgrounds could use it seamlessly. To achieve this, there was a clear need to design the tool with constant feedback from clinical professionals that met a basic criterion for usability. Additionally, we felt that the elements of decision support could be integrated into the tool to give real-time feedback or summary feedback of a code that could be used by clinicians such as trauma leads and attending to provide feedback to trauma teams to effect positive workflow modifications.

In this paper, we present a framework and the design and development of a theoretical-driven rapid data capture in clinical environment. We developed this system to be used to potentially assess adherence to ATLS guidelines and other derived quality measures. We also present the summary results of data collection using the visualization backend and a pilot usability evaluation to show the feasibility of using this system by physicians at Banner Good Samaritan Trauma Center in Phoenix, AZ.