Improving Usability and Adoption of Tablet-based Electronic Health Record (EHR) Applications

by

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ABSTRACT

The technological revolution has caused the entire world to migrate to a digital environment and health care is no exception to this. Electronic Health Records (EHR) or Electronic Medical Records (EMR) are the digital repository for health data of patients. Nation wide efforts have been made by the federal government to promote the usage of EHRs as they have been found to improve quality of health service. Although EHR systems have been implemented almost everywhere, active use of EHR applications have not replaced paper documentation. Rather, they are often used to store transcribed data from paper documentation after each clinical procedure. This process is found to be prone to errors such as data omission, incomplete data documentation and is also time consuming. This research aims to help improve adoption of real-time EHRs usage while documenting data by improving the usability of an iPad based EHR application that is used during resuscitation process in the intensive care unit. Using Cognitive theories and HCI frameworks, this research identified areas of improvement and customizations in the application that were required to exclusively match the work flow of the resuscitation team at the Mayo Clinic. In addition to this, a Handwriting Recognition Engine (HRE) was integrated into the application to support a stylus based information input into EHR, which resembles our target users traditional pen and paper based documentation process. The EHR application was updated and then evaluated with end users at the Mayo clinic. The users found the application to be efficient, usable and they showed preference in using this application over the paper-based documentation.

ACKNOWLEDGMENTS

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Chapter 1

INTRODUCTION

In the past decade, smartphones and tablets have completely transformed our lives by changing the way we interact, shop, learn, work and every other aspect of our lifestyle. Health care management industry has started to adopt information technology (IT) in their systems to make their process more efficient. But the adoption rate of Health IT in real-time clinical settings are low, particularly in time-critical environments such as Intensive Care Units. Electronic Health Record (EHR) / Electronic Medical Record (EMR) are software applications that are digital versions of paper charts used to document patient information. Studies have shown that when compared to paper documents, EHRs have fewer data errors, omissions and collected more relevant data. EHR have started to replace the traditional paper-based documentation because it has been proven to improve patient care, patient participation, care coordination, diagnostics, patient outcomes and is also found to be cost effective. The federal government has spent billions of dollars in promoting EHR usage, but the industry is still struggling to achieve nation-wide adoption of EHRs. The objective of the thesis is to improve the adoption of EHRs by identifying the reasons behind the low adoption of EHRs, understanding the clinical process and designing an EHR application with more acceptable usability and User Experience (UX). To achieve this, we make use of an iPad application originally developed by Harsh Damania. It is an impressive iPad application to digitize the code blue resuscitation documentation used in Mayo Clinic Intensive Care Unit (ICU). We make use of this application to identify the limitations in design, areas of improvement and update the application with domain specific feedback from the endusers of this application.

In this research we take a distributed cognition approach which requires us to understand the clinical workflow, nature of work, work environment, individuals involved, tools they use and how each of them interact with each other. This is vital to our research because from a Human Computer Interaction (HCI) perspective, the system is cognitively distributed across the work place and lower adoption of these systems are primarily due to cognitive, technological, social, cultural and other workplace related challenges that are not taken into account while designing the EHR applications that are currently available in the market. Using HCI frameworks we can break the problem down to account for these social, cultural, technical and human factors involved in the system such as usability, workflow, safety and other organizational standards. The application then goes through a heuristic evaluation to identify violations of design principles and AMIA guidelines to designing an EHR. The application is then tested in a simulated work environment with the end users of this application. These usability tests revealed areas of improvement in terms of design and usability heuristics. One major revelation was that in some cases, where EHR usage is mandated by the healthcare organization, the staff followed their usual paper-based documentation and after the procedure, they transcribed it onto the EHRs from the paper documents. This process is obviously time consuming, but more importantly, in-addition to the data errors and omissions present in paper documentation, transcribing data from paper documents to EHRs induces additional errors and 1 in 5 paper documents are lost before they are transcribed into EHRs. The hesitation of users to adopt EHRs into their process is because of the fact that the users have been using paper-based documentation throughout their career, so they are familiar and comfortable with the traditional process and also most EHRs require a learning curve. Unertl *et al.* (2009), in his guidelines to designing EHRs has specified that designers should explore new forms of information input into EHRs in-order to promote adoption. So we implement a new approach for information input into the EHR which is, including a stylus based input where the user writes data into the application using the stylus and the application recognizes these inputs to convert them into machine-readable format. This process is assumed to be as efficient as the previous one, whilst favoring the adoption of this application because it is a culturally relevant solution as it resembles the user's previous mental representations of data input procedures. Our hypothesis is that after addressing these design issues, usability violations and creating an application that resembles end users' previous mental representation of the workflow, will facilitate better adoption (than paper-based) of EHRs in real life settings. The new application is then tested with nurses from the Mayo clinic, who are the actual end-users of this application, to test if the proposed design changes helps the medical staff to adopt this application into their work setting. Results of a survey conducted with the nurses on the updated application shows that the application is consistent with their workflow, is user-friendly and is preferred by them over paper-based documentation.

Chapter 2

LITERATURE REVIEW

2.1 Clinical Environment

In this paper, we study EHR systems that are used in Intensive Care Units of a health care facility. Hospitals use emergency code names in order to alert and inform their staff about a specific situation or a serious patient condition. Blue code is the emergency code name used by hospitals when a patient is in need of resuscitation, which often happens if a patient goes into a cardiac arrest or requires immediate medical attention Eroglu *et al.* (2014). During this code, the protocol requires an assigned code blue team to assess the situation immediately. This team consists of a Primary Registered Nurse (PRN), Secondary Registered Nurse (SRN) and an event recorder. The recorder's responsibility is to document information in the Code Blue paper form. Code Blue forms are used to collect information about a patients medical and health condition during resuscitation. During this scenario, information such as the patients heart-rate, blood pressure, dosage of drugs given and other details that help in assessing the patients current condition are collected. These vital signs are collected every minute because during resuscitation, the patient is unconscious and health indicators are highly unstable. At the end of the code, the documentation is reviewed by the attending MD to verify that American Heart Association (AHA) standards for Resuscitation Recognition Criteria are met. There are multiple tablet based EHR applications currently available in the market and we chose to study the Code Blue application developed by Damania (2016). This application is specifically designed for use during resuscitation scenarios in the Mayo Clinic. The Code Blue application is a digital version of the paper based Mayo Code Blue form in an iPad.

2.2 Cognitive Models and Human Computer Interaction

Bederson and Shneiderman (2003) categorize five types of theories that can inform HCI practice: Descriptive - providing concepts, terminology, methods and focusing further inquiry; Explanatory - elucidating relationships and processes (e.g., explaining why user performance on a given system is suboptimal); Predictive - enabling predictions to be made about user performance or of a given system (e.g., predicting increased accuracy or efficiency as a result of a new design); Prescriptive - providing guidance for design from high level principles to specific design solutions; Generative - seeding novel ideas for design including prototype development and new paradigms of interaction (Kaufman *et al.* (2015)).

These theories have led to constructions of frameworks which is a general pool of constructs for understanding a domain, but it is not sufficiently cohesive or fully realized to constitute a theory Anderson (1983). Application of HCI frameworks in healthcare is complex and diverse in terms of both tasks and activities, due to the broad scope and nature of the health care domain Kannampallil *et al.* (2011). But such frameworks can provide cues to the need for specific design changes and also provide theoretical rationale to introduce innovative design concepts. Furthermore, according to Kaufman *et al.* (2015), these frameworks can become further differentiated into theories that cover or emphasize a particular facet of interaction in the context of a broader framework such as distributed cognition.

Human Information Processing model suggests that human cognition can be categorized into a series of operations that are reflections of computations on an individuals mental model. This model accounts for the sequential and integrated actions that evolve during human-computer interactions and in addition to layout and format of the interface, the models also needed to account for the content that was presented on the interfaces John (2003). As shown in figure 2.1, input to the processor is the perceived stimuli from the external world, which then goes through a series of processing. The processing typically involves encoding the stimuli and is then compared and matched with mental representations in memory, which then leads to selection and execution of a response. In an EHR system, when a user needs to select a medication from a dropdown list, the dropdown menu is the stimuli which matches the users mental representation of a dropdown menu and the user quickly recognizes the need to click the dropdown arrow, which is the action associated with it (Kaufman *et al.* (2015))

Model Human Processor (MHP) is a type of Human Information Processing model that can be described as a set of processors, memories and their interactions that operate based on a set of principles Card *et al.* (1983). According to this model, the human mind has three interacting processors: perceptual, cognitive and motor. These processors can act in a series or in parallel, and the processing occurs in cycles. The perceptual processor retrieves stimuli(input) from the external world and transfers it to the working memory. The cognitive processor performs a recognize-act cycle on this information from the working memory. During this cycle, the motor processor performs the action associated with it, which in-turn modifies the contents in the working memory and results in a new cycle of actions. MHP was used by Saitwal *et al.* (2010) and they successfully characterized the challenges of the user interface and identified opportunities for improvement using the keystroke level model to compute the time taken, and the number of steps required to complete a set of 14

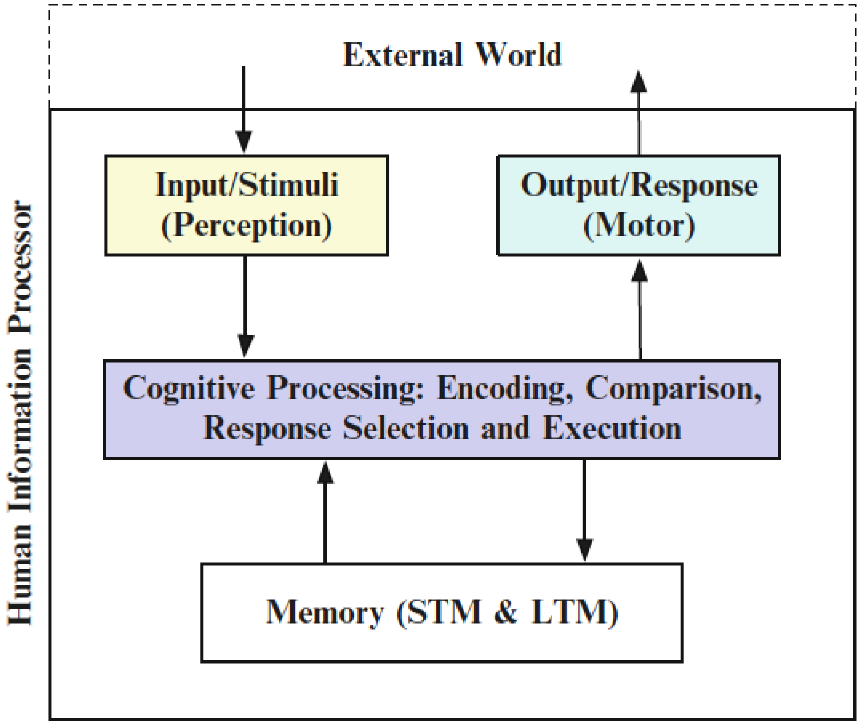


Figure 2.1: Human Information Processing Model (Kaufman *et al.* (2015)). STM - Short-term Memory; LTM - Long-term Memory

EHR-based tasks.

Normans theory of action is a Human Information Processing model that was developed with the intention to understand the fundamental principles behind human action and performance that are relevant for the development of engineering principles of design and to design systems that are pleasant to use. Normans model of action has seven stages, which begins with a generic goal, formation of intention, specification of an action sequence and execution of the actions. A complex task might require nesting of sub-goals which can lead to a series of actions sequences, which may appear as simple to an experienced user, but the action cycle might breakdown for a novice user. Norman proposes that gulf of execution and gulf of evaluation are the two reasons for this breakdown. The gulf of execution reflects the difference between the goals and intentions of the user and the kinds of actions enabled by the system and the gulf of evaluation reflects the degree to which the user can make sense of the state of a system and determine how well their expectations have been met. Though Normans model is similar to MHP, it helps us to understand the discrepancies between psychologically expressed goals and the physical controls and variables of a system. For example, a goal may be to scroll down towards the bottom of a document, and a scroll bar embodies the physical controls to realize such a goal. Goals that involve multiple state or screen transitions can make the system harder to use. Gaps in the two gulfs represent the differences in the designers mental model and users mental model. The designer s model is the conceptual model to be built, based on analysis of the task, requirements, and an understanding of the users capabilities Norman (1986). The users mental models of system behaviour are developed through interacting with similar systems and gaining an understanding of how actions will produce predictable and desired outcomes. Graphical user interfaces that involve direct manipulation of screen objects and widgets represent an attempt to reduce the distance between a designer s and user s model Shneiderman (1982). Bridging this gap will involve changes in system design and training the user on the systems resources.

2.3 Mental Models and External Representation

I want to introduce the concept of a mental model. Mental model is an analog-based construct to describe how individuals form internal representations of a system. These representation models are the users understanding of the system on how it works and the expected outcomes of actions performed on the system. Like other forms of mental representation, mental models are invariably incomplete, imperfect and subject to the processing limitations of the cognitive system (Norman (1983)).

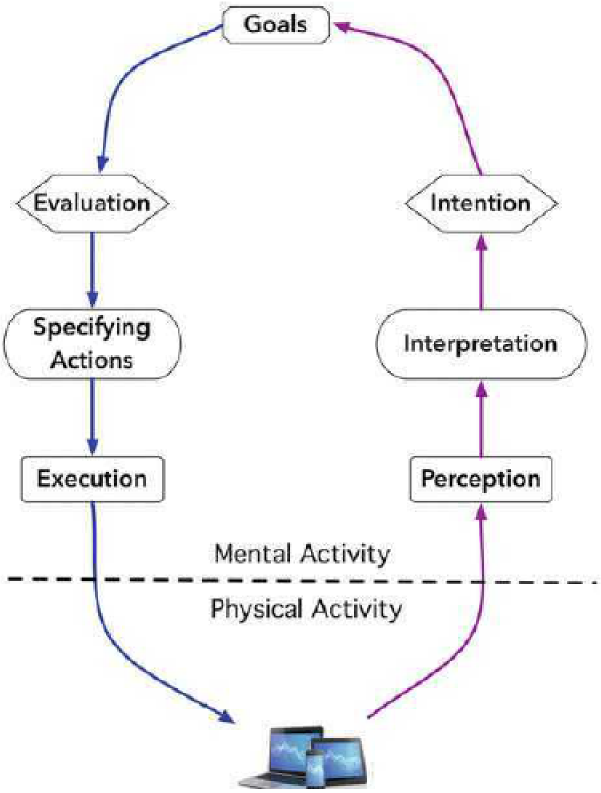


Figure 2.2: Norman's Action Cycle (Kaufman *et al.* (2015))

Mental models can be derived from perception, language or from one s imagination (Payne (2003)). So, these mental models are reflective of an individuals knowledge and belief system, in addition to their predictive and explanatory capabilities of a system. An individuals expertise in a system is reflective of their mental models as experts have more robust and complex models, whereas a novices model is prone to imprecisions and errors. Kaufman *et al.* (2015) characterized clinician s mental model of the human cardiovascular system and documented various conceptual flaws in subjects mental models and how these flaws impacted subjects predictions and explanations of physiological manifestations. Mental models are useful in categorizing errors that occur due to gaps in knowledge and understanding of the system (Kaufman *et al.* (2015)).

External representations are objects in the external world that can be used to augment cognitive processes (Horsky *et al.* (2005)). Icons, images, graphs, alert sounds are some of the external representations. Internal representations like mental models, in combination with external representations aid in better cognition. Larkin and Simon (1987) made an important distinction between two kinds of external representation: diagrammatic and sentential representations. Though they contain the same information, diagrammatic representations require less cognitive effort to process that information. In EHRs, effective displays aid in problem solving by allowing the user to replace effortful cognitive operations with perceptual operations like recognition, thus reducing the amount of time spent in searching for information (Patel *et al.* (2014)), whereas cluttered displays have the opposite effect.

Representational effect is an extension of external cognition, where different forms of representation of information has different effects on the user. Norman (1993) proposed that external representations play a critical role in enhancing cognition and intelligent behavior. External representations are described in the literature to have the following properties: Provide memory aids that can reduce cognitive load, Provide information that can be directly perceived and used such that minimal processing is needed to explicitly interpret the information, Support perception so that one can recognize features easily and make inferences directly, Structure cognitive behavior without cognitive awareness, Change the nature of a task by generating more efficient action sequences.

Kushniruk *et al.* (1996) studied how clinicians learned to use an EHR over multiple sessions. They observed that the users information gathering and reasoning strategies were influenced by the organization of information present in the screen. Similarly, in a study by Patel *et al.* (2000), which contrasts the use of EHRs vs paper based documentation, they found that users entered significantly different information in EHRs and on the paper-based charts, making the two forms of patient documentation to be represented differently. Different representations mean that the patient data interpretations are different. This leads to different patient management plans. This is because the EHR users followed a screen-driven strategy which changed their information gathering and documentation techniques. This screen-driven strategy was shown to reduce the cognitive effort required for their information gathering goals, and helped them recall the types of information that needed to be collected. External representations can also be allowed to be manipulated by the users, which in-turn facilitates creative thinking (Rogers (2012); Zhang and Norman (1994); Kirsh (2005)). This requires people to interact with and create an external representation of their choice, because it allows users to offload data from their head to an external representation and by this way, information can be processed more efficiently and effectively. In this current study, the our EHR application is supposed to serve an external support, which provides help through memory and data organization.

2.4 Distribution Cognition and Human Computer Interaction

Distributed cognition approach extends the internal-external representations theory by re-conceptualizing cognitive phenomena in terms of individuals, artifacts, and internal and external representations and their interactions (Rogers (2012)). This approach describes a cognitive system which involves the individual and the team, interactions among them, artifacts that they use and the environment they are in. Distributed cognition focuses on the social and collaborative nature of cognition as well as the mediating effects of technology or other artifacts on cognition. This framework enables researchers to consider all factors relevant to a task, coalescing individuals, the problem and the tools into a single unit of analysis (Cohen *et al.* (2006);Kaufman *et al.* (2015)).

Wright *et al.* (2000) proposes a distributed resources model to address the question of the information needed to carry out a task and where it should be located: as an interface object or as knowledge that a user brings to the task. The distributed resources model has two primary components: (1) Characterization of information structures, and (2) Interaction strategies that can make use of the information structures to complete a task. These information structures can be embodied into any artifact, which in our case is an EHR. Plans, goals, history and state of a system are considered as information structures and they should be viewed as resources that help facilitate further actions. These information structures can be externalized, manipulated and evaluated (Wright *et al.* (2000)). Horsky *et al.* (2003) used distributed resources model to evaluate the usability of Computerized Physician Order Entry (CPOE) systems. First, they performed a cognitive walkthrough evaluation which was modified based on the distributed resources model. Then, they performed an experiment that involves simulated clinical ordering tasks performed by physicians who are experienced users of CPOE systems. The results showed that the organization and configuration of resources in the screen led to heavy cognitive load on the users and that successful execution of tasks relied on their recall of system related knowledge. This model was also used to explain patterns of errors such as incorrect selection of order set, omissions and redundant entries. The authors concluded that the reconfiguration of resources may yield guiding principles and design solutions in the development of complex interactive systems (Horsky *et al.* (2003)).

According to Rogers (2012), analysis of distributed cognition is conducted by examining the distributed problem solving mechanism of the team, the role of verbal and non-verbal behaviors in the process, the coordinating mechanisms like standards, protocols or rules that they adhere to, and the different ways of communication throughout the process and knowledge transfer or access methods. This is crucial to our research because results of this analysis can be different across different organizations, depending upon how the cognitive workflow is distributed. So our study aims to improve user performance and work practice in this team by exclusively focusing on and working with the end users of this application in one particular organization. Here, the EHR application will a part of the care system in the Intensive ICU, where it will be represented as an external artefact, where the users interact with this system as well as well other tea members within the culture of the ICU environment. Technology and people form an intellectual partnership. This, it is necessary to understand the entire care environment where this application will be used, since any changes in one aspect of this distributed system will affect other parts of the system, including making decisions about patient care.

2.5 Human Factors and Usability

In Carayon *et al.* (2013) the authors reviewed a set of studies that used HFE approaches for designing a range of HIT tools including radiotherapy and telemetry system, Chan *et al.* (2012) used HFE methods to evaluate and re-design a radiotherapy delivery system, Kobayashi *et al.* (2013) redesigned an emergency department (ED) telemetry system using HFE systems analysis methods. In these studies, field observations, heuristic usability evaluations, information discussions, function diagnostic,

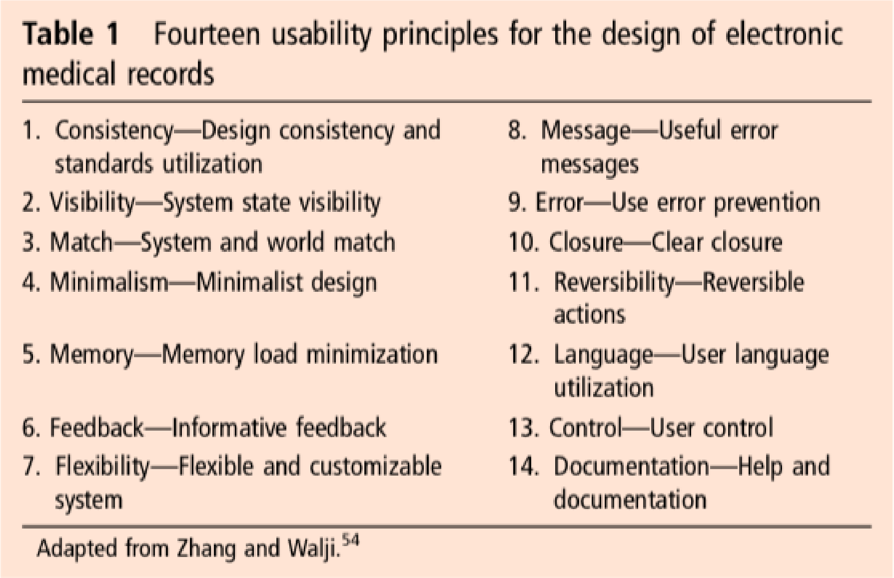


Table 1 Fourteen usability principles for the design of electronic medical records

1. Consistency—Design consistency and standards utilization
2. Visibility—System state visibility
3. Match—System and world match
4. Minimalism—Minimalist design
5. Memory—Memory load minimization
6. Feedback—Informative feedback
7. Flexibility—Flexible and customizable system
8. Message—Useful error messages
9. Error—Use error prevention
10. Closure—Clear closure
11. Reversibility—Reversible actions
12. Language—User language utilization
13. Control—User control
14. Documentation—Help and documentation

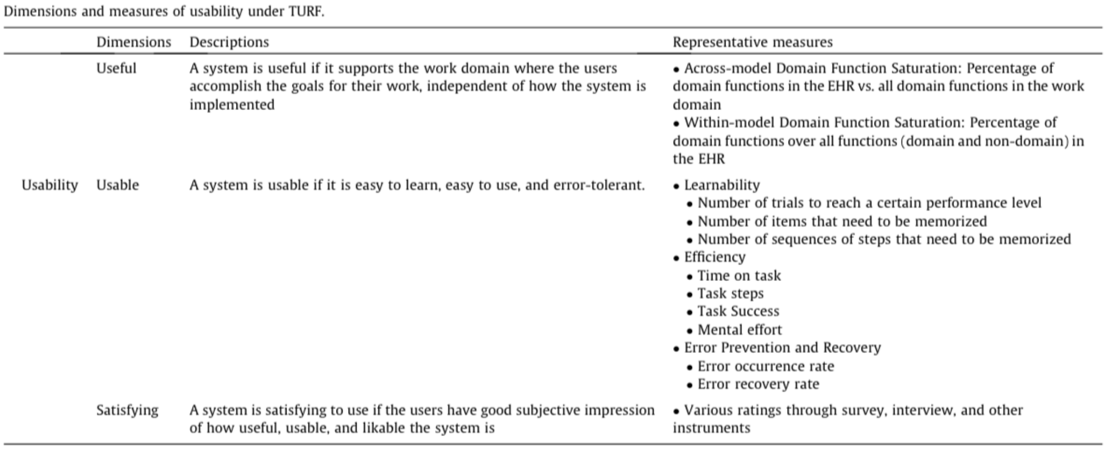
Adapted from Zhang and Walji.[54]

Table 2.1: Usability Principles for the Design of EMRs (Middleton *et al.* (2013))

and surveys were used to identify work flow and usability issues. The redesigned systems were evaluated by using simulated scenarios and the results showed that the use of the redesigned system led to fewer errors and greater efficiency in the workflow. And in these studies, application of HFE methods to redesign a system has been specific, local and within a particular context (Patel and Kannampallil (2014)).

Researchers at the National Center for Cognitive Informatics and Decision Making in Healthcare, based upon an evidence review, proposed 14 usability principles based on evidence reviews that will guide the design and implementation of an EHR system (Middleton *et al.* (2013)). This is shown in the table 2.1

Zhang and Walji (2011) developed an EHR-specific usability framework that measures usability in three major dimensions such as useful, usable and satisfying. Table 2.2 explains these dimensions and how to measure them.



Dimensions and measures of usability under TURF.

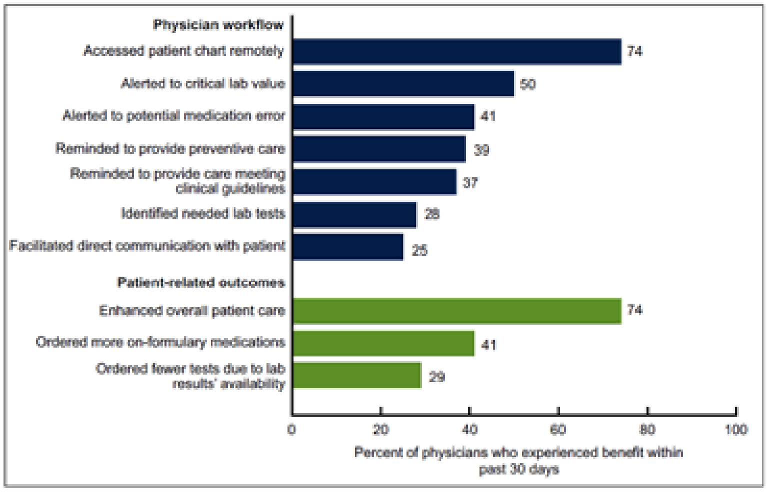
	Dimensions	Descriptions	Representative measures
Usability	Useful	A system is useful if it supports the work domain where the users accomplish the goals for their work, independent of how the system is implemented	• Across-model Domain Function Saturation: Percentage of domain functions in the EHR vs. all domain functions in the work domain • Within-model Domain Function Saturation: Percentage of domain functions over all functions (domain and non-domain) in the EHR
	Usable	A system is usable if it is easy to learn, easy to use, and error-tolerant.	• Learnability • Number of trials to reach a certain performance level • Number of items that need to be memorized • Number of sequences of steps that need to be memorized • Efficiency • Time on task • Task steps • Task Success • Mental effort • Error Prevention and Recovery • Error occurrence rate • Error recovery rate
	Satisfying	A system is satisfying to use if the users have good subjective impression of how useful, usable, and likable the system is	• Various ratings through survey, interview, and other instruments

Table 2.2: Dimensions and Measures of Usability under TURF (Zhang and Walji (2011))

2.6 EHR systems Background

Electronic Health Record documentation is recommended and promoted by almost every Health and Medical organization across the nation because it has its obvious advantages of being easy to maintain, cost effective and quick access. But some key advantages of EHRs are reduced medical errors, reduced data omissions, improved diagnostics, improved patient participation, improved accuracy and reliability as stated by Grigg *et al.* (2013). Figure 2.3 shows a feedback survey submitted by physicians after 30 days into adopting EHRs.

Results of Randomised trial comparing the recording ability of a novel, electronic emergency documentation system with the AHA paper cardiac arrest record by Grigg *et al.* (2013) shows that use of EHRs had 28 percent fewer omission errors, 36 percent decrease in redundant or irrelevant information, 24 percent increase in capturing critical information and one third of specification errors were reduced. Improving the adoption of these application is critical because HIT is a relatively new industry and medical professionals who are used to paper based documentation have a hard time



NOTES: Physicians with electronic health record (EHR) systems whose systems or scope of work did not include a specified capability responded not applicable. These responses are included in the denominator for percentages. Data represent office-based physicians who reported having adopted EHR systems (55% of sample). The sample includes nonfederal, office-based physicians and excludes radiologists, anesthesiologists, and pathologists.
SOURCE: CDC/NCHS, Physician Workflow study, 2011.

Figure 2.3: Physician Feedback on Adopting EHRs (HealthIT.gov (2015))

migrating to newer technologies. So improving the usability and user experience of these applications are vital to improving the adoption of EHRs. Especially in time critical events like resuscitation where the chances of survival for a patient decreases every minute, EHRs can come in handy and help reduce the cognitive load of the users recording the data. In the following section, we will review some of the significant applications in the market that match the scope of this project.

2.7 Existing EHR applications

Full Code Pro

Full Code Pro is an iOS application developed by the AHA for documenting data during resuscitation events. AHA has put in considerable effort to make the application simple and more user friendly. They have updated the application multiple times making the application functionally better than their initial version. But the application still doesn't include all the fields present in a Code Blue paper form. Vitals signs, which are to be recorded at every minute of resuscitation, are absent in

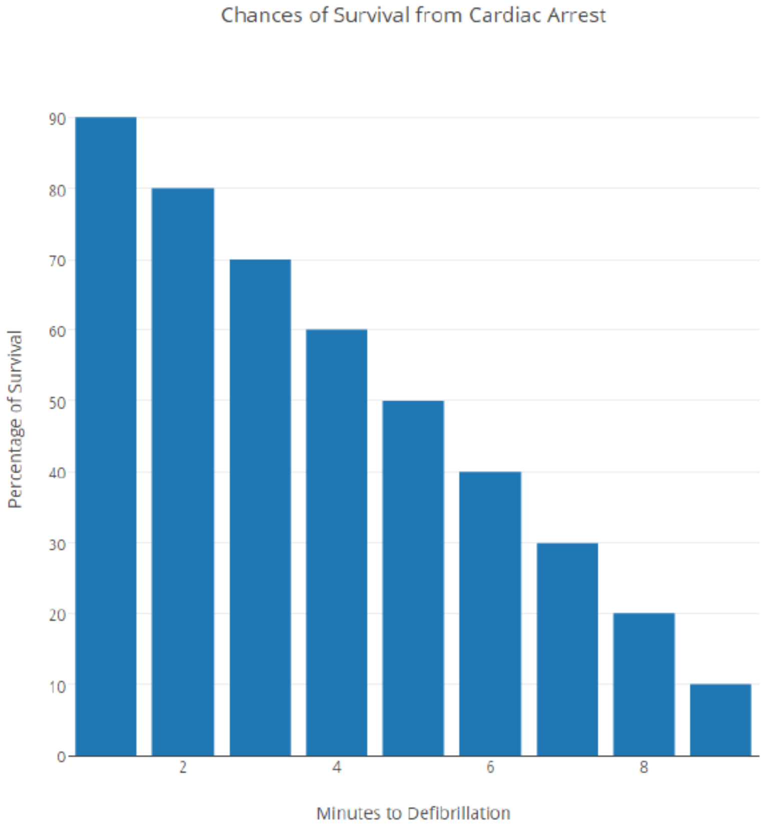


Figure 2.4: Chances of Survival During Resuscitation Bokhari (2015)

the application. Medications are present but it doesn't have the option to include dosages of medication administered. There are multiple clocks for multiple events which has its own advantages and disadvantages.

EventDoc

Researchers at the University of Washington Medical Center found that 30 percent of code blue paper forms were lost before they were transcribed into their respective EHR systems. And from the forms that were not lost, 63 percent of them had errors or missing information in them Grigg *et al.* (2013). This led the team to develop an application called EventDoc to document data electronically during resuscitation events. When compared with Full Code Pro, this application has provisions for

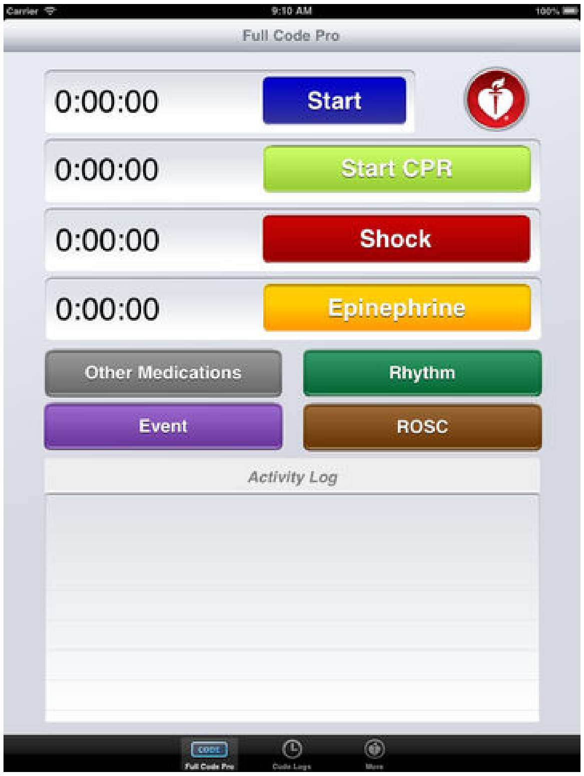
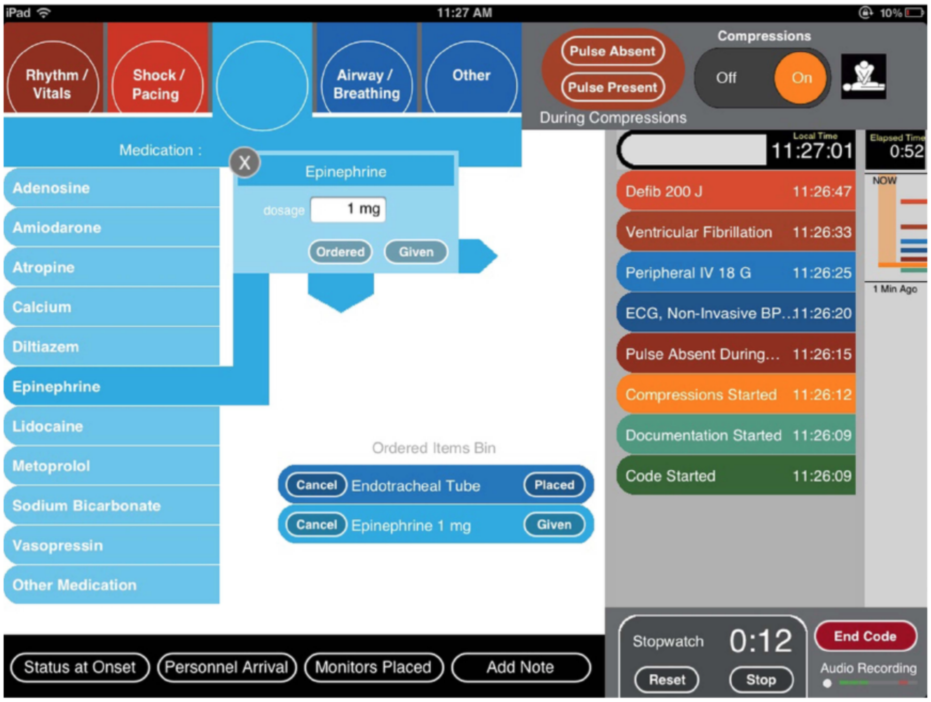


Figure 2.5: Full Code Pro by American Heart Association

detailed documentation of events, which increases the complexity of the application and leads to a cluttered display of information on-screen. The application also has the ability to record audio during a resuscitation event, which can come in handy while reviewing the data later.

Dr. Chrono

Dr. Chrono is relatively new to the EHR applications market. It has an impressive User Interface and is simple enough for medical professionals to understand the workflows. Though it does not cover resuscitation events nor is designed for that, the application is designed with the user in mind. It has incorporated innovative usability features like spaces to include hand written notes for physicians to send to pharmacists and a speech to text conversion feature that allows physicians to talk to the



Defib 200 J 11:26:47
Ventricular Fibrillation 11:26:33
Peripheral IV 18 G 11:26:25
ECG, Non-Invasive BP...11:26:20
Pulse Absent During... 11:26:15
Compressions Started 11:26:12
Documentation Started 11:26:09
Code Started 11:26:09

Figure 2.6: Screenshot of EventDoc iPad Application

application while it converts them to texts for documenting medical records. These features in combination with an intuitive User Interface has made the application famous and has received good reviews and feedback from its users.

Mayo Code Blue

Mayo Code Blue is an iPad application developed as an electronic health documentation application to replace the paper based Code Blue forms. This application was an extension of the study done by Bokhari (2015), where a basic iPad application was developed to test the efficiency of EHRs in a similar scenario. Harsh Damania took up the work from Bokhari and improved this application in terms of UI aesthetics, usability and findings from Bokhari (2015). The current application also has the ability to create other guideline forms and customize the fields but only the Code Blue form is available by default. The app has an in-built timer that can be started

ID: HAMI000001 Gender: Female Age: 26 DoB: 02/15/1986

Chief Complaint: unspecified pain or illness

Lorazepam 2 Mg/MI Or
PO
Indication:
Active
ted: 11/12/2010

Aspirin 975 Mg Or
PO
Indication:
Active
11/12/2010

Paroxetine 20 Mg
PO
Indication:
Active
11/12/2010

For best results, use a headset with a microphone.

Speech to text in progress

0:00:03

Tap to end

Data in this page is persistent across all visits

Figure 2.7: Screenshot of Dr. Chrono iPad Application

manually by clicking on START or it starts automatically when the first data entry happens. Primarily, the screen is divided into three columns. The left most column contains the timer and multiple tabs that contain different events of the form. All data that is entered will appear under the LOGS column in the right hand side of the screen. We have chosen to study this application and improve its usability with the help of medical staff from Mayo Clinic's Intensive Care division.

2.8 Proposed work

The HCI frameworks, theories and guidelines discussed in the previous sections were used to understand the workflow of the code blue team at Mayo Clinic's Intensive Care Unit (ICU) in the context to design the tool, and based on the evaluation, redesign this Mayo Code Blue application. The first step is to understand when and

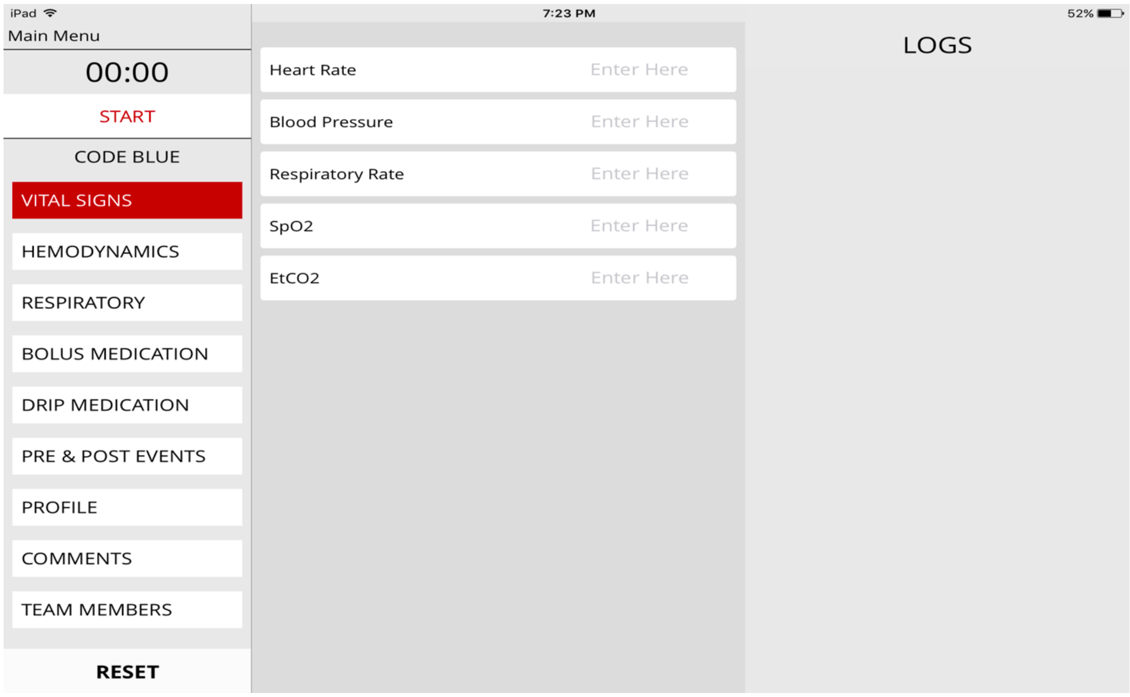


Figure 2.8: Screenshot of Mayo Code Blue iPad Application

where within the clinical workflow of the care providers this code blue application will be used and what would the updated design look like to support their tasks. Next step will be the check that the application does what it is supposed to do, and make any updates as necessary.

We studied the Mayo Code Blue application through a series of Usability evaluation methods that consists of a cognitive walkthrough, heuristic evaluation and usability testing by shadowing in a simulated environment, screen capture, verbal think out loud and surveys. We conducted the initial stages of the usability evaluation and the findings from this usability evaluation study are documented and we brainstormed for solutions in collaboration with the medical staff from Mayo clinic ICU. Details on the usability study and its findings are discussed in later parts of this document. The solutions to identified problems are discussed and they involved multiple changes and additions to the user interface, but one of the main issues that caught our attention was that even when the hospital management asked the clinical recorder to use an EHR application for documenting data, most of the users (nurses) in the code blue team first used the code blue paper form to document all data and they transcribed it to the application at the end of procedure. This process is not only inefficient, but can also be expensive because it is prone to errors while transcribing data into EHRs. Unertl *et al.* (2009) suggests exploring new approaches for information input into the EHRs in their guidelines for designing a HIT system. With the help of Experience Design concepts, in addition to addressing the findings observed, we introduce a handwriting recognition technology that allows the users to input data into the iPad using a stylus. This user experience approach gives the medical staff a familiarity to their mental models of using a pen on paper-based medical records, while recording the data electronically. The updated application is then subjected to another iteration of usability studies to verify the compliance of usability principles and guidelines.

Chapter 3

SYSTEM

3.1 Addressing findings on existing work

Improvements on the existing application are done based on the findings from the first iteration of usability tests. The methods of usability testing and results are discussed in the next chapter. Findings from those results are taken into account while developing the new system in order to improve user experience and reduce the time taken to complete a task.

Cardiac Rhythm signals - SV, ST, SB are added to the Vital Sign tab. These fields were initially present in the Hemodynamics tab, but it was observed during the simulation studies that there were multiple screen transitions from the Vital Signs tab to the Hemodynamics tab, only to access these fields. Reducing the number of steps for a task reduces the cognitive load of the user and thereby improves the usability of the system. Hence, in-order to reduce the number of clicks and keep screen transitions to a minimum, we place a copy of SV, ST, SB fields in the Vital Signs under a Frequently Used row. Figure 3.1 is a screenshot of the proposed change.

Amiodrone medication which is under the Bolus Medication tab, has two buttons - 150mg and 300mg. But selecting the 300mg button logs a 150mg medication. This violates safe usage of EHRs and induces EHR-Usability related medication errors as mentioned in Middleton *et al.* (2013). Though it is a simple technical error, the impact is severe - considering that this procedure happens in an Intensive Care Unit

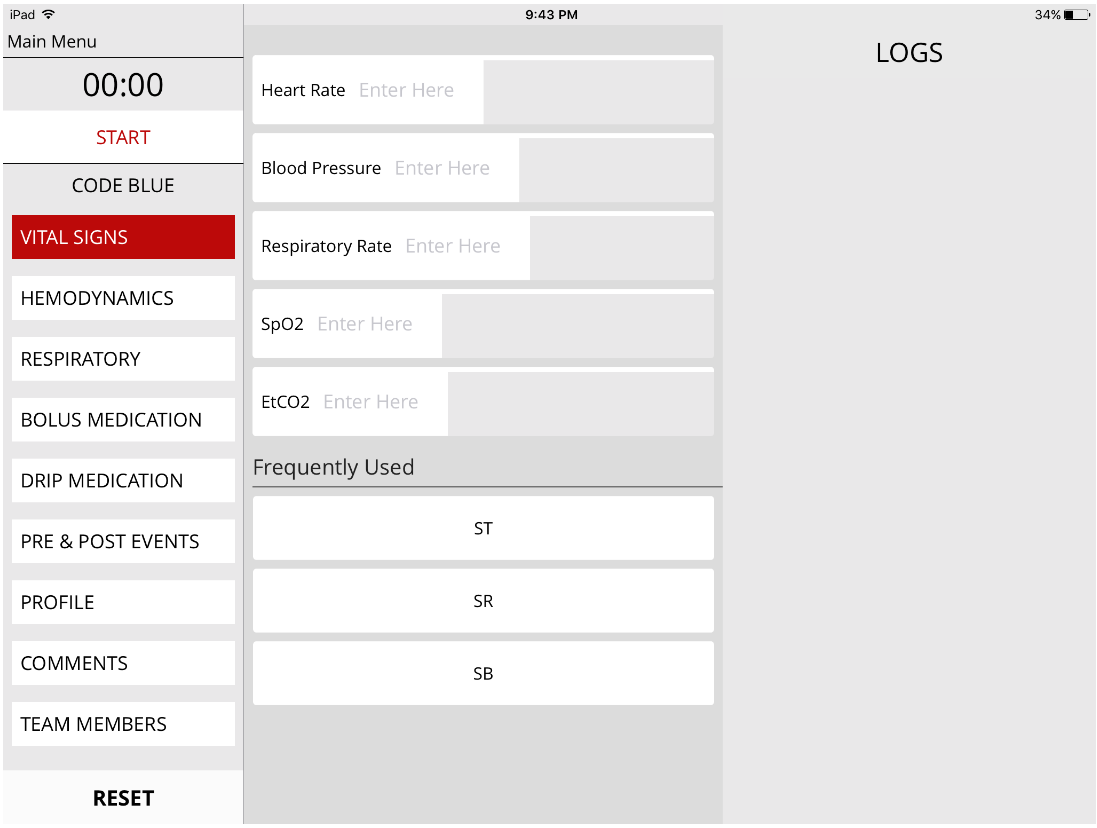


Figure 3.1: Screenshot of Updated Vital Signs Tab

and the error impacts the medication dosage of the patient. This error is fixed and now works as shown in figure 3.2 and figure 3.3

Unertl *et al.* (2009) in his Guidelines for designing HIT systems, mentions that EHRs should be designed so that users are able to search through the EHR. In our system, the LOGS column displays a list of all the data entered throughout the procedure. At the end of each procedure, the staff in-charge of the Code goes through the data entered and verifies the validity of that data. During this process, scrolling through the list of data entered can be time-consuming and tedious. Especially during code blue protocols, because in some cases the procedure might take multiple hours and patient activity is monitored every minute. This results in huge amounts of data

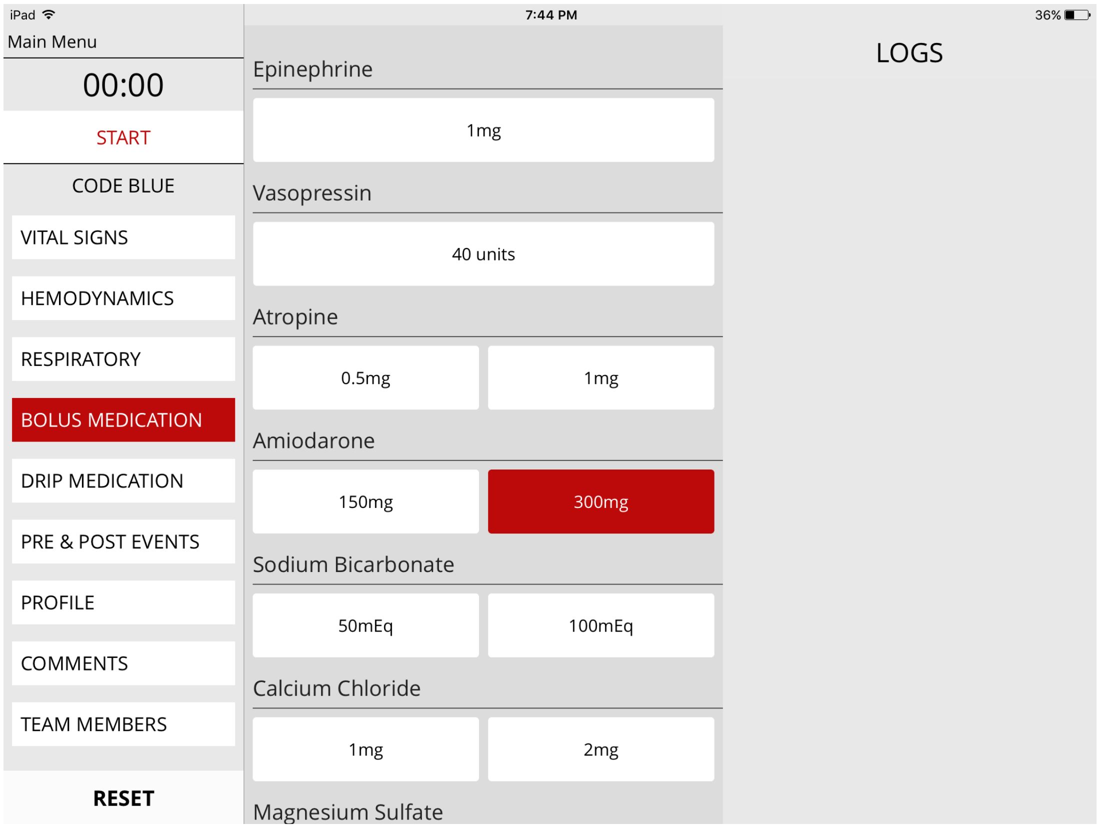
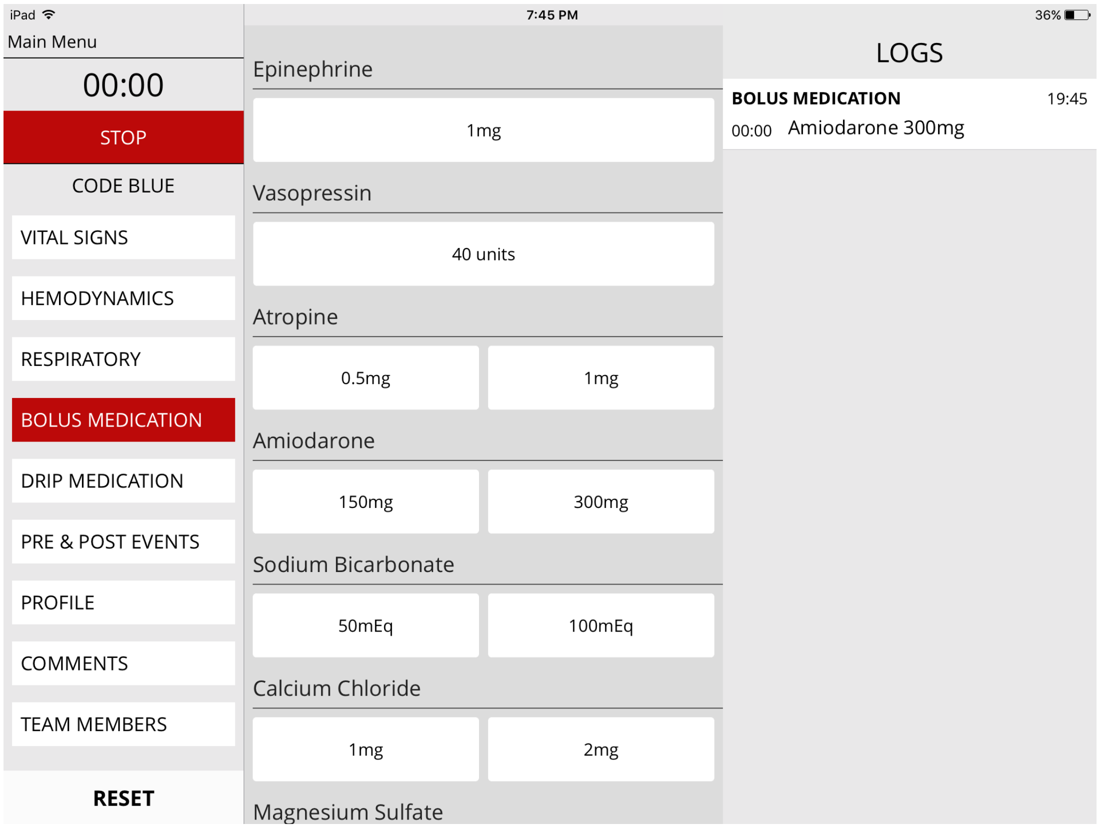


Figure 3.2: Screenshot of Updated Amiodrone Medication

collected and to be verified. Adding a search bar to this field will filter and display only the set of required data. For example, the Figure 3.4 displays a list of just the Heart Rate entries in the log.

The next change is to include buttons for commonly used entries in the comments section. A set of seven buttons were added under the comments sections which represents various activities that are performed during resuscitation. These buttons act as an external representation and has the following properties: provide memory aids that can reduce cognitive load, provide information that can be directly perceived and used such that minimal processing is needed to explicitly interpret the information, support perception so that one can recognize features easily and make inferences di-



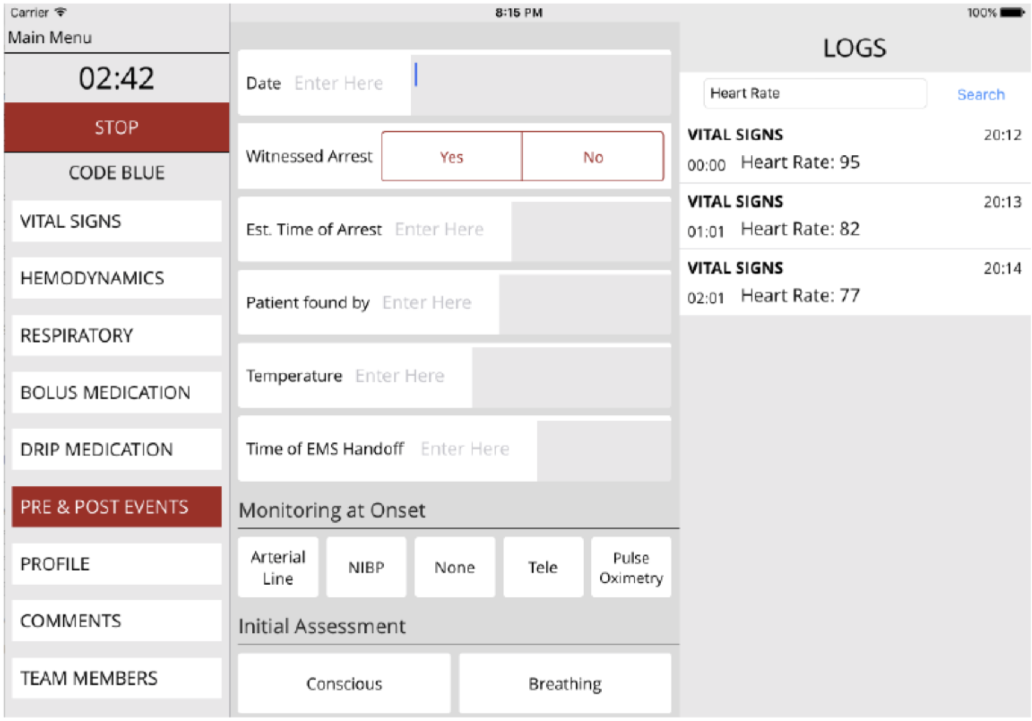
BOLUS MEDICATION 19:45
00:00 Amiodarone 300mg

Figure 3.3: Screenshot of Updated Amiodrone Medication in Logs

rectly, structure cognitive behavior without cognitive awareness, change the nature of a task by generating more efficient action sequences (Kaufman *et al.* (2015)). Figure 3.5 shows the changes made to the comments tab.

3.2 Design Motivation

Distributed cognition framework is a socio-technical approach that demands the study of the healthcare environment and the work-practices of individuals involved. This study revealed that most nurses in the code blue team first used the code blue paper form to document all data and they transcribed it to the application at the end of procedure. This error prone and time consuming process raised the need to



Heart Rate

VITAL SIGNS 20:12
00:00 Heart Rate: 95

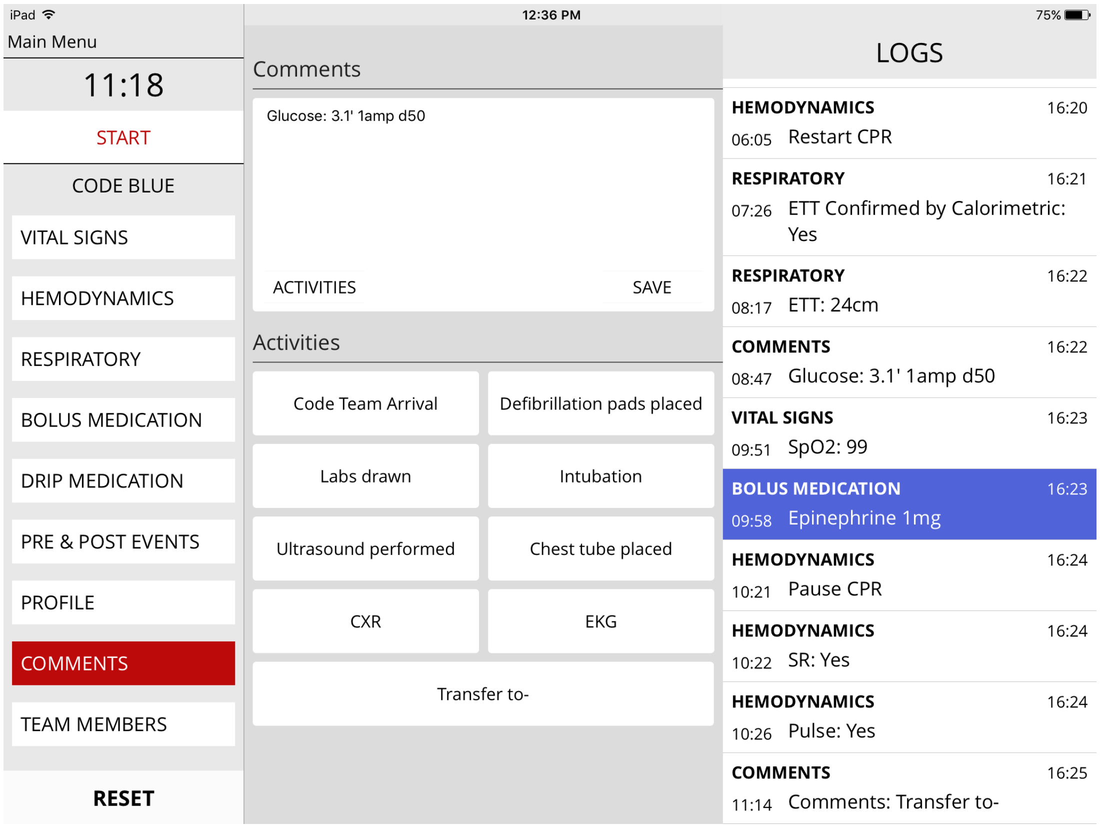
VITAL SIGNS 20:13
01:01 Heart Rate: 82

VITAL SIGNS 20:14
02:01 Heart Rate: 77

Figure 3.4: Screenshot of Integrated Search Bar for Logs

explore a new approach for information input into the EHR that is as efficient as the existing approach and yield significant benefits in-order to promote adoption as suggested by Unertl *et al.* (2009). Experience Design (XD) might offer us a culturally relavant solution to this problem by focusing on the current practices and environment of the product. In Hassenzahl (2015) a three level framework is proposed to design technology mediated experiences - from Why to What and How. What refers to the tasks that users perform on the product, and How refers to actions taken by the user to get that done. The what and how of the product is typically considered the product, but without addressing the Why part of the design, the product looses its meaning and its customers.

One of the examples mentioned in Hassenzahl (2015) is the Budda Machine which typ-



Glucose: 3.1' 1amp d50

HEMODYNAMICS 16:20
06:05 Restart CPR

RESPIRATORY 16:21
07:26 ETT Confirmed by Calorimetric: Yes

RESPIRATORY 16:22
08:17 ETT: 24cm

COMMENTS 16:22
08:47 Glucose: 3.1' 1amp d50

VITAL SIGNS 16:23
09:51 SpO2: 99

BOLUS MEDICATION 16:23
09:58 Epinephrine 1mg

HEMODYNAMICS 16:24
10:21 Pause CPR

HEMODYNAMICS 16:24
10:22 SR: Yes

HEMODYNAMICS 16:24
10:26 Pulse: Yes

COMMENTS 16:25
11:14 Comments: Transfer to-

Figure 3.5: Screenshot of Comments Tab Updated with Frequent Activities

ically functions as an iPod with an in-built speaker. But it only has nine experimental meditation music tracks that plays back in loops. The device was a commerical success and sold more than 50,000 units. Though it was a relatively new kind of product, it coexists with an existing product that people are familiar and comfortable with. This is the kind of culturally relavant solution that an Experience Design can offer us.

In our case, we proposed a new design that accepts a user's hand-written inputs to the iPad using a stylus. We then use Optical Character Recognition (OCR) or Handwriting Recognition Engines (HRE) to convert the free hand sketch into machine readable text, which can then be stored and manipulated. This design solution is culturally relavant because the current clinical environment is used to paper-pen

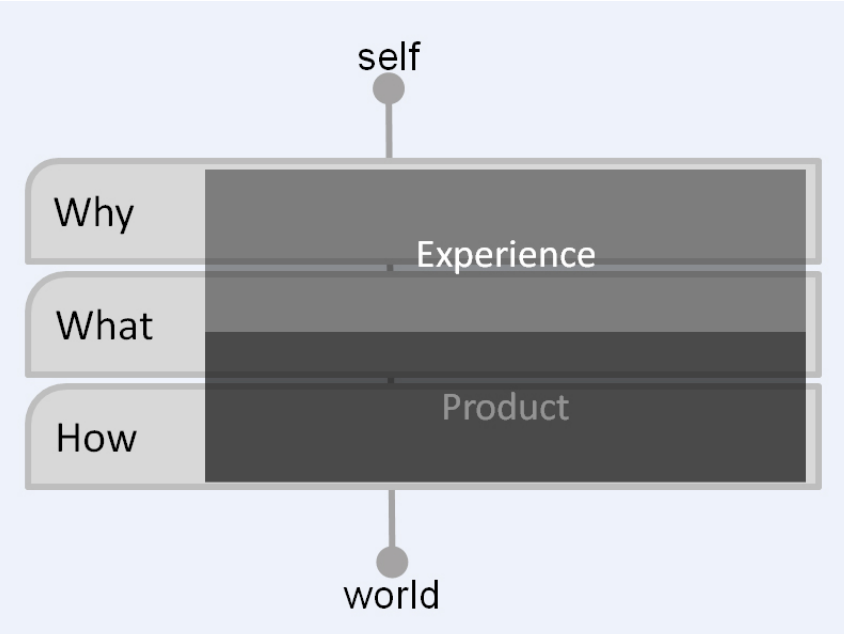


Figure 3.6: Experience Design Hassenzahl (2015)

based procedure. Even though they are asked to use the iPad applications for this process, a majority of the users do not prefer to use this during the procedure. Rather they follow their conventional way of paper-pen forms and then they transfer that data into the iPads after the procedure. Our proposed design, will give them a feel of the environment and practices that they are familiar and comfortable with, thereby improving favorability and adoption of our application.

3.3 Optical Character Recognition

One of the methods to convert free hand sketch into machine readable text format is through Optical Character Recognition (OCR). OCRs are being widely used throughout Health-IT to convert paper medical records into electronic health records (EHRs). It works by scanning the paper entries into an OCR system, and the system converts the scanned images into text entries. Primarily, data in the scanned image is categorized into texts, tables and images. Then the texts are processed line by line, where each line is split into words. Then, the words are split by characters and each character here is compared with an large data-set of character images and when there's a match, the character equivalents are added to the new file.

There are many opensource OCR providers in the market that we can use like Tesseract OCR and Google's Cloud Vision API. In our application, we can make use of the OCR APIs by converting the free hand sketches into an image. We can do this by creating a Signature view field, which allows the user to use a stylus to enter data and is later stored as a signature image. We can feed this image as an input to the OCR API to get the text equivalent of our image.

3.4 Handwriting Recognition Engine

Handwriting recognition engines (HRE) unlike Optical Character Recognition systems perform active on-line recognition of handwritten inputs. The engine sensors pickup the movements of the stylus as they are used on the touch screen. The movements of stylus are recognized as digital ink, which is a digital representation of a user's handwriting. The digital ink is collection of a sequence of pixels that are arranged in the same way as they are written using the stylus. The pixel sequences contain (x, y) co-ordinates and an optional pressure sensor value. The pressure values are optional because they are not required to generate the character, but might be useful in certain cases to improve accuracy of the recognized characters. This digital ink is then used as input to the recognition system. The recognition system then performs preprocessing, feature extraction and classification.

Preprocessing is performed to remove noise and other irrelevant data from the digital ink. This helps in increasing the accuracy and speed of the recognition system.

Preprocessing usually involves resolving skewness, sampling, normalization and binarization Holzinger *et al.* (2012). Then, the preprocessed data is used to perform feature extraction. Feature extraction adds dimensions to the data by including relevant information like the pressure sensor values, direction vector values, orientation, velocity of the digital ink and so on. Output from the feature extraction algorithms are then matched to respective characters using various classification models, which vary across Handwriting recognition engines. There are various Handwriting recognition engines available in the market. In this project, we'll use WritePad's open-source Handwriting recognition SDK.

3.5 Advantages of proposed method

There are trade-offs on our choice of Handwriting Recognition Engines versus Optical Character Recognition. OCRs are widely used across the health-care domain for converting prescriptions and old paper based electronic health records into machine readable format. But OCRs perform off-line character recognition, which means the conversion is done on a static representation of the handwriting. So, the stylus input is first stored as an image, and then the OCR system converts it. In the event of a large dataset of inputs, OCRs create memory overhead issues. On the other hand, Handwriting recognition engines perform on-line character recognition, so the data from digital ink will be freed every time a recognition is performed, thus resolving the memory overhead problem. Built-in HRE engine increases the overall size and complexity of the application but off-line character recognition is comparatively difficult than on-line character recognition, so developing a built-in OCR can be expensive and time consuming. There are top notch OCR APIs offered by companies like Google but using third party APIs in our application can cause issues with Health Information Privacy laws by HIPAA.

Considering the pros and cons of both the technologies, we have decided to move forward with developing a built-in Handwriting Recognition Engine in our application.

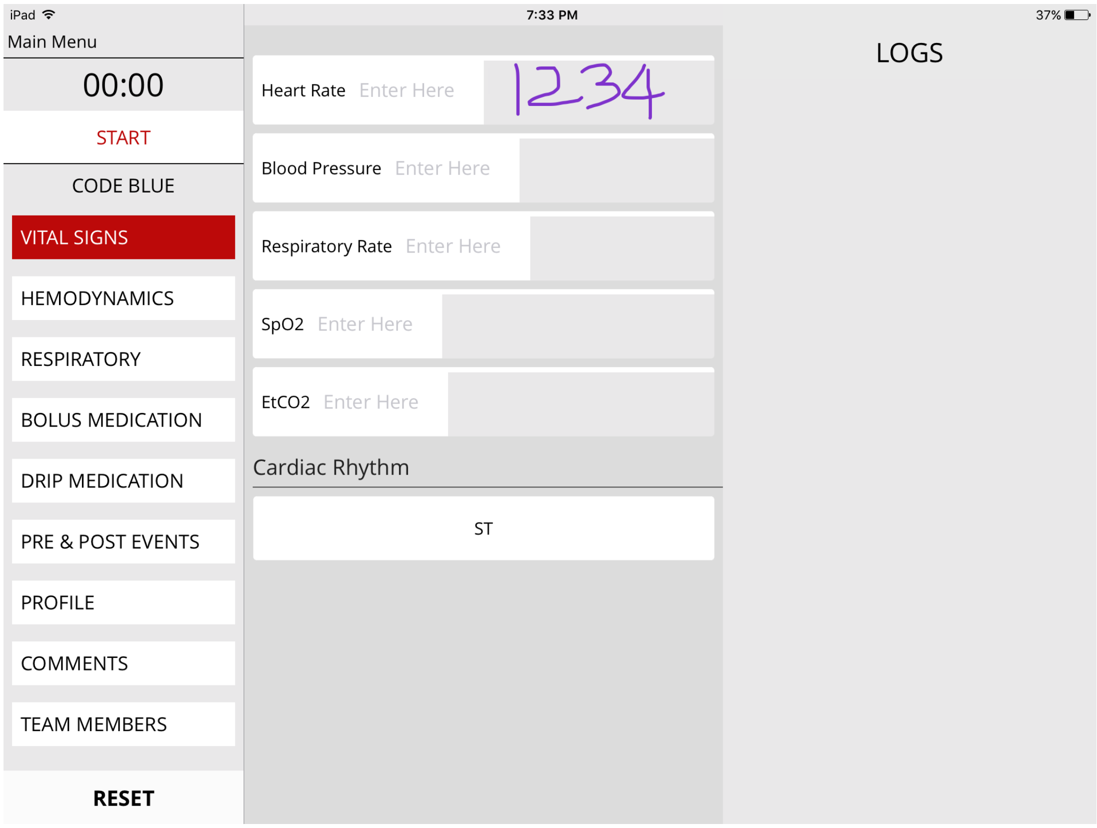
3.6 Development

Handwriting Recognition fields

The first step is to add a free hand sketch field to all the text fields in the application. This field should be able to accept stylus inputs and also show the output (recognized characters). For this, we create a handwriting field which is a combination of text field provided by WritePad SDK and signature item previously used in the application by Damania (2016). Initally, the signature item is active and accepts stylus inputs. When the end of input is detected, the digital ink is passed to the recognition manager and text view is enabled. The output from the recognition manager is passed to the text view, which then displays the recognized characters. The figures 3.7, 3.8 and 3.9 show the working of handwriting fields (grey colored boxes) added adjacent to all existing text based input fields.

Ink Data Object (IDO):

Initially, inputs from the stylus are processed for every single stroke of input from the user. Strokes datastructure contains (x, y) coordinates and the value of pressure, which represents the digital ink. The data structure of our strokes is shown in figure 3.10. An Ink Data Object is a collection of multiple strokes from the user along with other information such as number of pixels in the stroke and width in pixels of the stroke. This IDO is the input to our recognition engine.



Heart Rate 1234

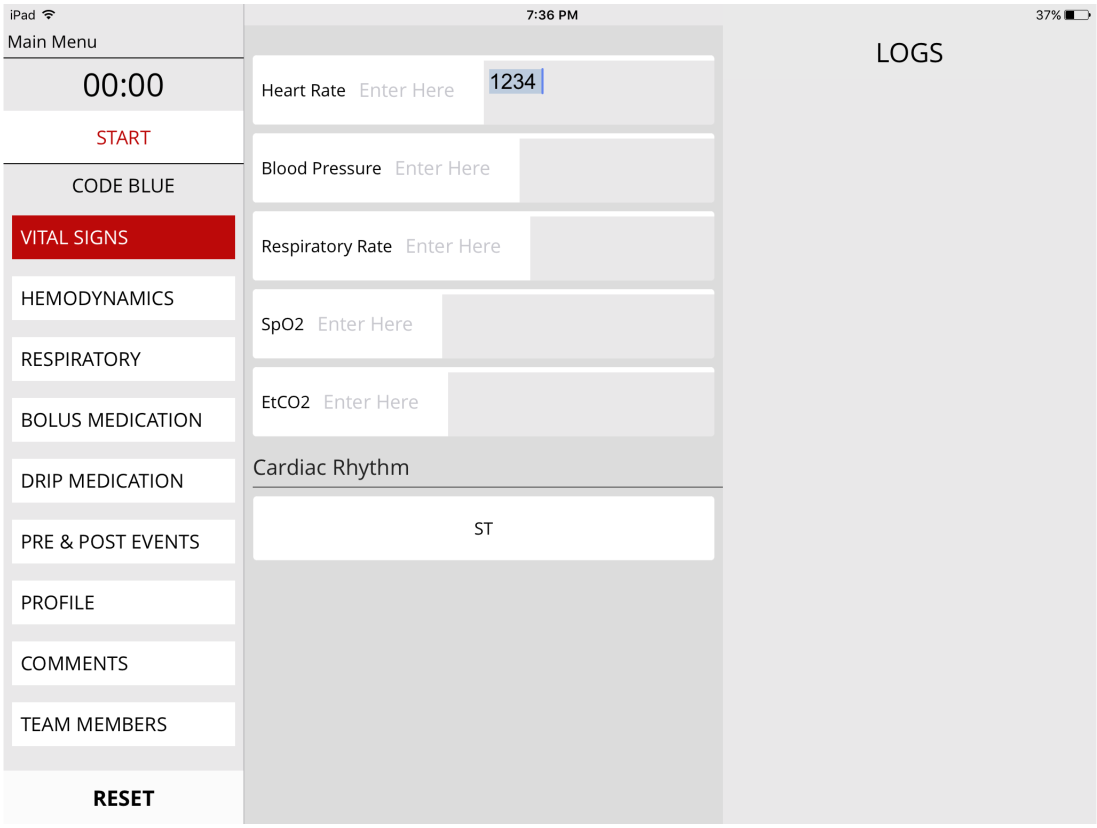
Cardiac Rhythm ST

Figure 3.7: Screenshot of Integrated Handwriting Fields

Recognizer:

When the application is started, the handwriting recognition engine is loaded with language specific dictionary and a user defined dictionary. By default, we have set the language to English (U.S) and a default english dictionary. We have included a user-defined dictionary called 'MedicalUS' which gives the option to include organization or industry specific jargons and abbreviations.

Once the engine is initialized, it is ready to accept Ink Data Objects (IDOs) as inputs. When the user inputs the first stroke, an IDO is created and sent to the recognition engine where a thread is created to recognize the current digital ink. The character recognition thread compares the unidentified set of strokes with the stroke equivalent



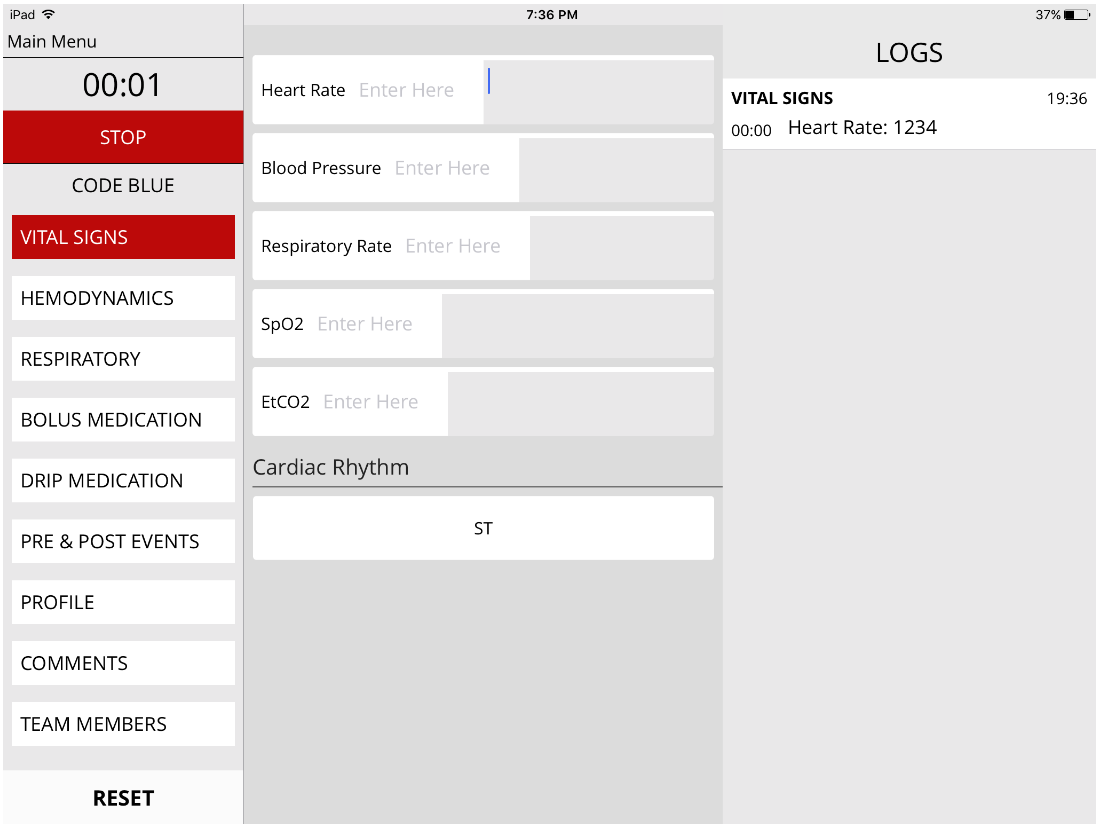
Heart Rate Enter Here 1234

Cardiac Rhythm

ST

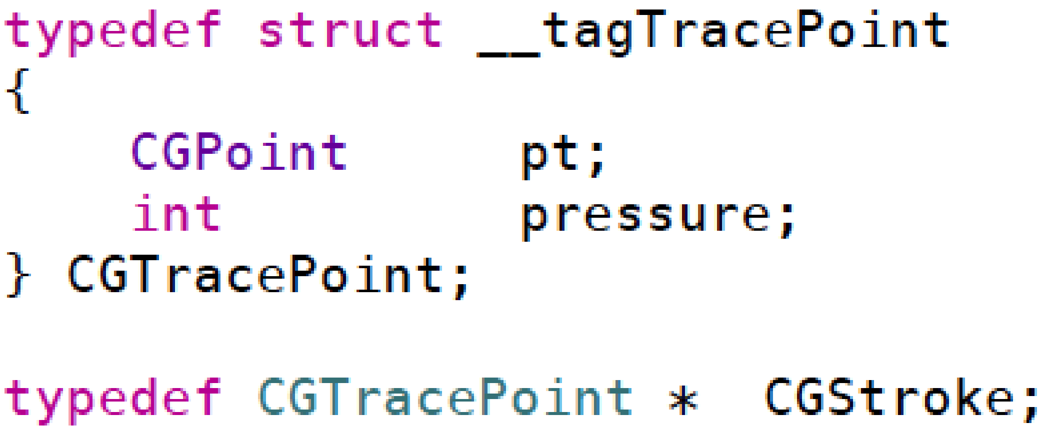
Figure 3.8: Screenshot of Handwriting Recognition of Input

for set of all characters (symbols, numbers and alphabets in the language). Matching characters are stored along with the last stroke index value. If the current stroke is a gesture, the control is transferred to the gesture manager. If the stroke doesn't match a gesture, the digital ink is added to the IDO. This process is repeated till the end of input is detected. At the end of input, the recognition engine identifies the number of potential words in the IDO. The recognition engine then identifies the type of input which could be text only, numbers only, text with symbols, geometric shapes or other possible combinations. In text only type, for each potential word the IDO, start and end values of stroke index for the word is sent as input to the language manager. If the language manager recognizes the word, then it returns the word and will be added to the output string. If the language manager fails to recognize the word, the



```
VITAL SIGNS                19:36
00:00   Heart Rate: 1234
```

Figure 3.9: Screenshot of Saved Handwriting Recognition Input



```
typedef struct __tagTracePoint
{
    CGPoint     pt;
    int         pressure;
} CGTracePoint;

typedef CGTracePoint *  CGStroke;
```

Figure 3.10: Datastructure of a Stroke (23 (2015))

engines checks for alternate word count in the IDO, and the process is repeated for the new word count. On failing to recognize the word with alternate word counts, the recognized characters are added as it is to the output string. Finally, the resultant string is then displayed in the text view field.

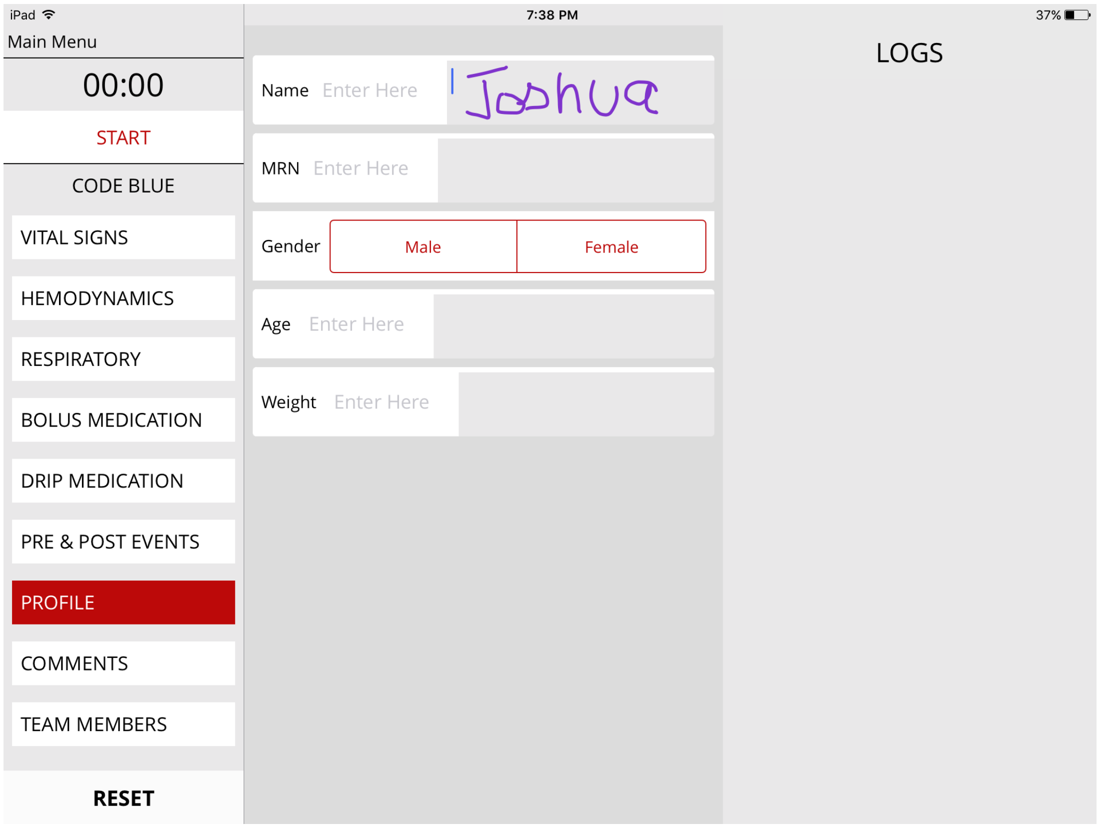
Language Manager

Language manager sets the default language to the language used in the device unless it is explicitly set to a different language. It also loads the language dictionary and user defined dictionary into the application. On receiving an IDO input from the recognizer, the language manager compares the word to the words in the language dictionary. If no match was found, it then repeats the process with our user defined dictionary. When a match is found, it returns the resultant word back to the recognizer. In the event of no matching words, it returns a FALSE statement.

An example of text only type IDO, that uses language manager to get the resultant string is shown in figures 3.11 and 3.12

Gesture Manager

WritePad SDK supports handling gestures with the stylus. So we make use of those gestures controls to perform basic operations on the text view such as backspace, delete characters to the right or insert spaces. When a gesture is recognized by the engine, gesture manager handles the current stroke by comparing it to the strokes that match a gesture that is supported by our application. Figure 3.13 shows a list of gestures included in our project. The code blue application also supports adding new forms to the menu. So, we have integrated our handwriting recognition engine to application's core template by adding the handwriting recognition field adjacent to the input text placeholder. When a new form is created, all text input fields will have



Name Enter Here Joshua

MRN Enter Here

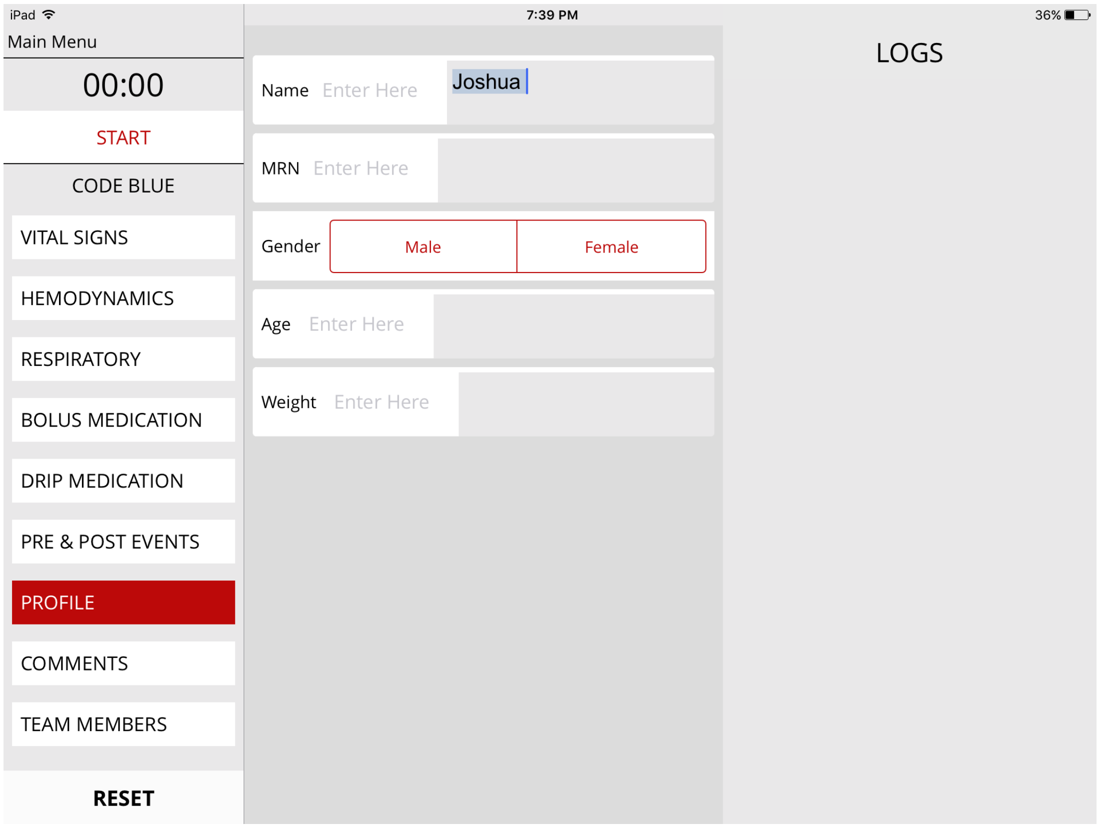
Gender Male Female

Age Enter Here

Weight Enter Here

Figure 3.11: Screenshot of Text-only Type IDO Input

a handwriting recognition field right next to it. Figure 3.14 shows the application's template design, with the 'Write here' field next to the input field's placeholder.



Name Enter Here Joshua

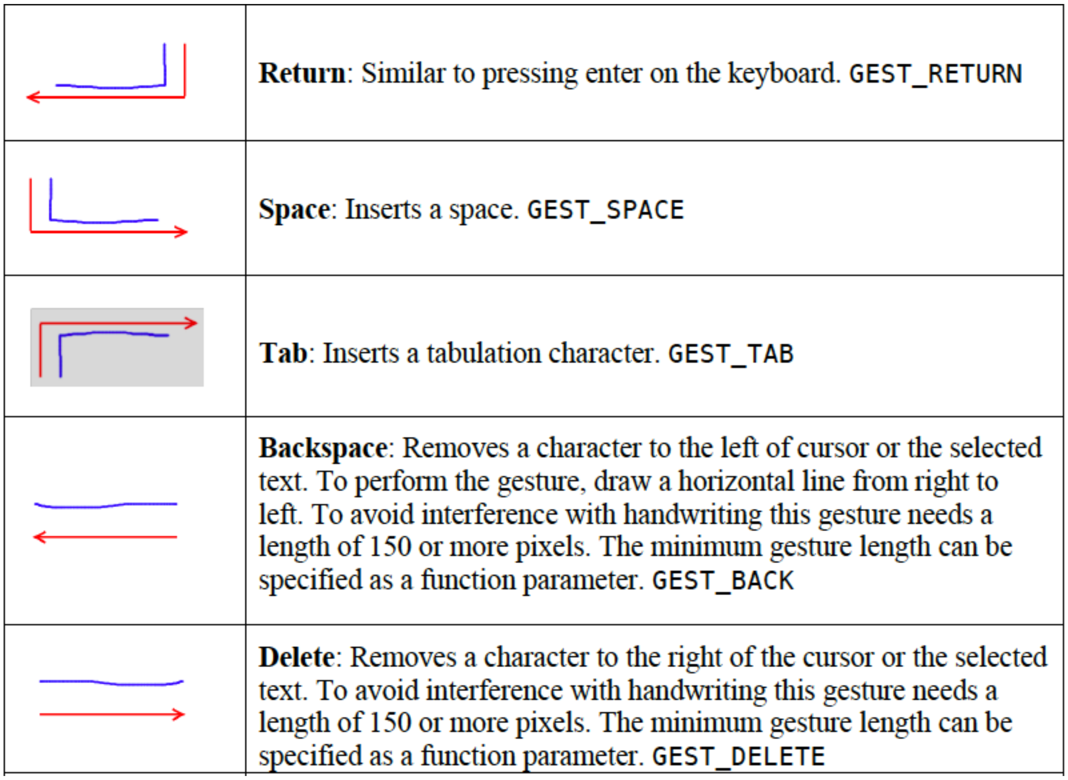
MRN Enter Here

Gender Male Female

Age Enter Here

Weight Enter Here

Figure 3.12: Screenshot of Text-only Type IDO Recognized



	Return: Similar to pressing enter on the keyboard. `GEST_RETURN`
	Space: Inserts a space. `GEST_SPACE`
	Tab: Inserts a tabulation character. `GEST_TAB`
	Backspace: Removes a character to the left of cursor or the selected text. To perform the gesture, draw a horizontal line from right to left. To avoid interference with handwriting this gesture needs a length of 150 or more pixels. The minimum gesture length can be specified as a function parameter. `GEST_BACK`
	Delete: Removes a character to the right of the cursor or the selected text. To avoid interference with handwriting this gesture needs a length of 150 or more pixels. The minimum gesture length can be specified as a function parameter. `GEST_DELETE`

Figure 3.13: Gestures Supported by WritePad SDK (23 (2015))

Lorem ipsum dolor sit er elit lamet, consectetaur cillium adipisicing pecu, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis

Figure 3.14: Handwriting Recognition Field Integrated with Generic Text Fields

Chapter 4

USABILITY EVALUATION

4.1 Usability evaluation on existing work

The first iteration of usability testing was performed on the existing application 'Mayo Code Blue' developed by Damania (2016). Since it was not available on the App Store yet, I requested access to the code repository from the developer. After acquiring his permission to experiment the application, I had to install this application on an iPad Air that runs iOS 10.1. Since this application was built a couple of years ago, it was developed in swift , which is not compatible in the current Xcode version 8. The older versions of Xcode do not support application development for iOS 10, so I had to make use of both Xcode 7 and Xcode 8, to build the executable files required to load the application in our iPad.

Usability testing refers to the evaluation of the system that involves testing of participants who represent the ultimate end user population of the system. This evaluation is done while the participants perform representative tasks using our system in a particular clinical context (Kushniruk and Patel (2004)). With the help of Drs. Vimla Patel and Ayan Sen, usability testing of this application was conducted on professional staff, working with our research team, from the ICU division of Mayo Clinic in Phoenix, Arizona. They were two ICU nurses and both had over 10 years of experience in health-care. They also have previous experience in working with code blue protocol and are familiar with the code blue resuscitation flowsheet. In order to simulate a code blue scenario, we made use of Mock code blue simulation videos.

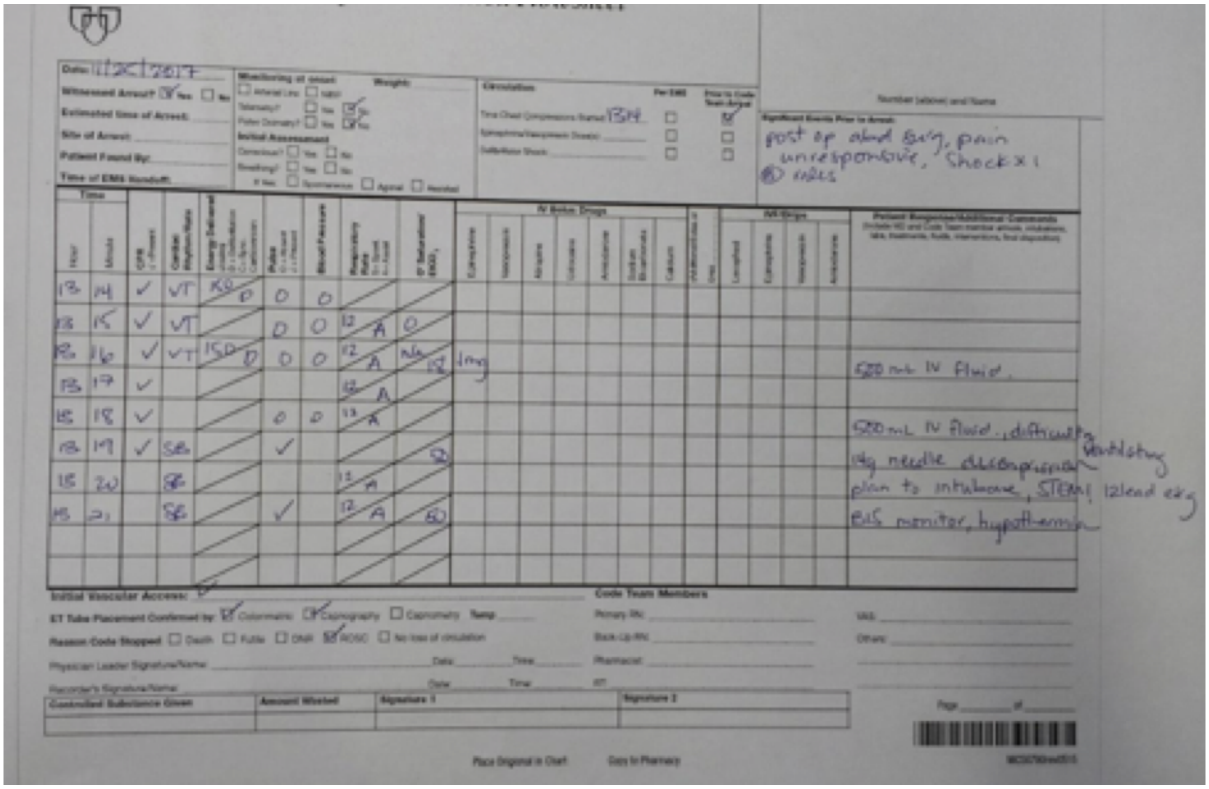
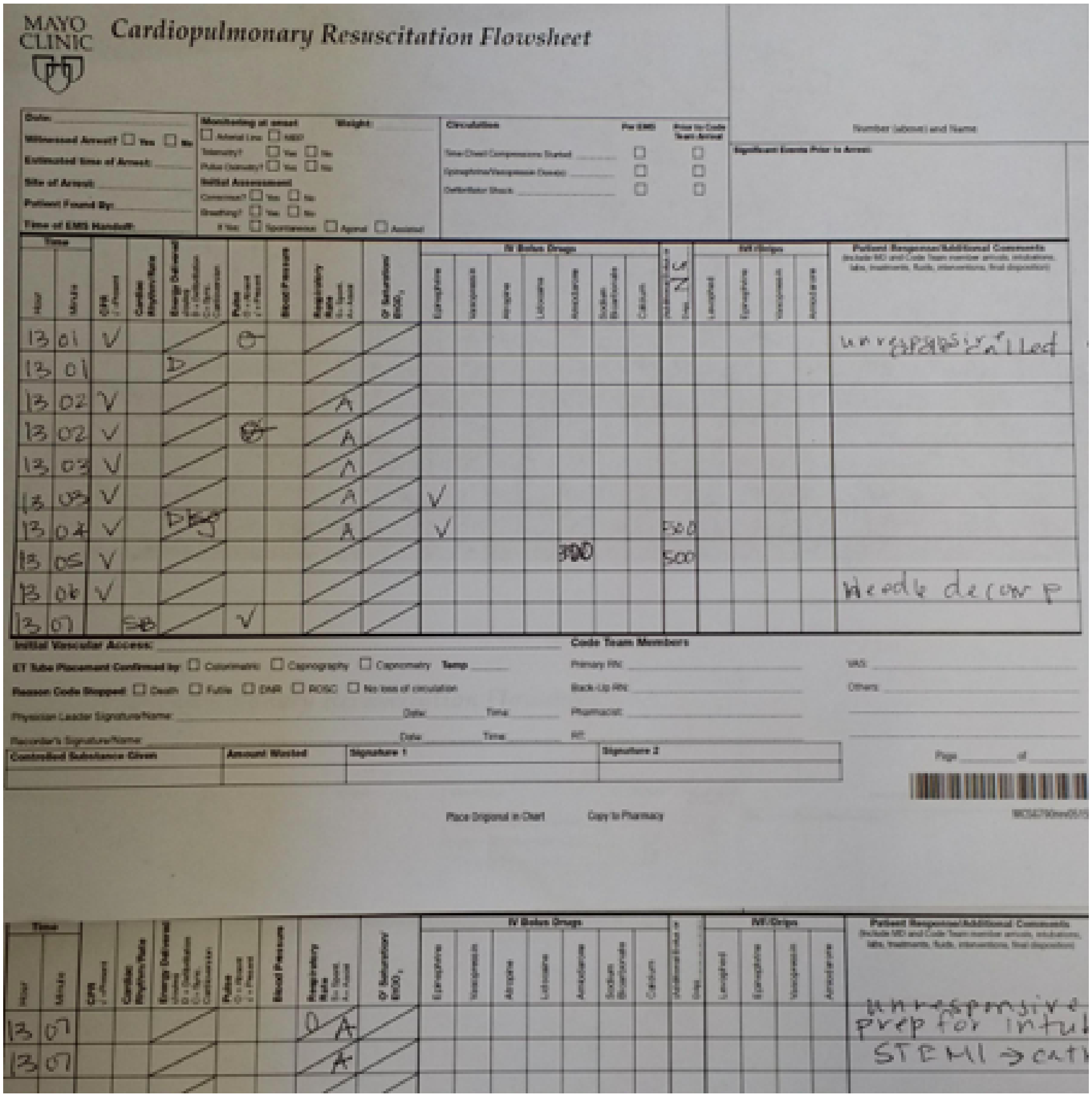


Figure 4.1: Completed Paper-based Code Blue Sheet (Nurse-1)

We began the study with a cognitive walkthrough of the code blue paper sheet and asked the nurses to input data into the sheet as per the instructions in the video. Cognitive Walkthrough is a method of usability evaluation that applies principles from the study of cognitive psychology to simulate the cognitive processes and user actions needed to carry out specific tasks using a computer system (Kushniruk and Patel (2004)). We also asked the participants to think out loud and we had their permission to audio-report this procedure. The completed code blue flowsheets are shown in figures 4.1 and 4.2

After this procedure, we started with usability evaluation of the existing application. We handed over the iPads loaded with Mayo Code Blue app and gave them a



MAYO CLINIC

Cardiopulmonary Resuscitation Flowsheet

Date:

Witnessed Arrest? ☐ Yes ☐ No

Estimated time of Arrest:

Site of Arrest:

Patient Found By:

Time of EMS Handoff:

Monitoring at arrest **Weight:**

Initial Assessment

Circulation

Significant Events Prior to Arrest:

																	NS				
13	01	V			O																unresponsive called
13	01			D																	
13	02	V					A														
13	02	V			Ø		A														
13	03	V					A														
13	03	V					A		V												
13	04	V		Dbg			A		V								500				
13	05	V											300				500				
13	06	V																			Needle decomp
13	07		SB		V																

Initial Vascular Access:

ET Tube Placement Confirmed by: ☐ Colorimetric ☐ Capnography ☐ Capnometry **Temp**

Reason Code Stopped: ☐ Death ☐ Futile ☐ DNR ☐ ROSC ☐ No loss of circulation

Physician Leader Signature/Name: Date: Time:

Recorder's Signature/Name: Date: Time:

Code Team Members

Primary RN:

Back-Up RN:

Pharmacist:

RT:

VAS:

Others:

Controlled Substance Given	Amount Wasted	Signature 1	Signature 2

Page of

Place Original in Chart Copy to Pharmacy

13	07						0 A														unresponsive prep for intub
13	07						A														STEMI → cath

Figure 4.2: Completed Paper-based Code Blue Sheet (Nurse-2)

minute to work around the application. Then, we started the simulation video and performed a cognitive walkthrough by following the instructions in the simulation video to document patient data in the application. As soon as they enter the first data, the timer in the app starts and they continued recording data until the simulation ends. Also, the iPad was connected to a MacBook so that the on-screen activity is video recorded. These recordings are done so that we can analyze it after the simulation to find the tasks that the users had a hard time, or confused and stayed in any particular screen when they're lost on how to complete the current task. We also used these to find patterns in frequent screen transitions between different menus. They were again instructed to think out loud while they used the application, and we had the audio recording turned on. Think out loud is a method used in this study to gather data inusability testingin product design and development. The method was developed based on the techniques ofprotocol analysisby Ericsson and Simon (1980)) where the participants are asked to Talk aloud as they work through to complete the task. This might include what they are looking at, thinking, doing, and feeling. This gives us insights into cognitive process of the user which can reveal areas where the users are confused, struggle to complete the task or do not understand the current state of the system. However, in thus study, given that the task was not too complex, the users did not say much while doing their task except they have problems. After the end of simulation, we gave them some time with the application to browse through it and find technical and/or systemic bugs if any.

Heuristic evaluation is an informal approach to usability evaluation which involves having usability specialists judge the user interface and system functionality as to whether they conform to established principles of usability and good design (Kushniruk and Patel (2004)). Heuristic evaluation on the application can be done by the developers and does not require the involvement of end users. So we performed a Heuristic Evaluation on the application by ourselves to find violations on AMIAs EHR specific usability principles Middleton *et al.* (2013) and HIT design guidelines (Unertl et al. 2009) relevant to our system. Results of this evaluation do not convey how usable the application is, but it shows the areas that can be improved.

After the simulation testing, we conducted an unstructured interview with the participants about their views on the application like areas of improvement and their experience with the application in general. During the interview, we also brought up the issues that we found on the application and asked for their input to determine the seriousness of the findings.

4.2 Results

After a series of usability evaluation studies, we identified and documented multiple issues in the application and in the process of documenting. Below is the list of findings from our usability evaluation study,

1) The cognitive walkthrough revealed that multiple transitions of screen from the Respiratory tab to the Vital Signs tab and vice versa were made. This is because of the presence of certain fields in the Vital Signs tab that need to be entered along with some fields in the Respiratory tab.
Proposed Solution: To add ST, SB and SR fields in both the tabs, so that the fields are readily available in combination with each other and act as a cognitive aid to support the task.

2) The virtual keyboard that appears on the screen, does not hide itself after the data is entered and no longer has any use for a keyboard on screen. This unexpected behaviour of the system imposes a cognitive load on the user and requires the user to explore new actions to solve this problem.
Proposed Solution: This can be addressed as a technical fix or through a design change that limits the use of an on-screen keyboard for these fields.

3) Cognitive walkthrough of the application also revealed that the field 300mg in Amiodarone which is present under the Bolus Medication tab does not function as expected. Selecting that button records the value of Amiodarone as 150mg, but is labelled as 300mg. This causes EHR related medication errors and can impact the safety and quality of patient care.
Proposed Solution: This is a technical bug that can be resolved while updating the application to the next version.

4) Under comments tab, the field Activities has a set of predefined phrases that are most commonly entered in the comments field. Participants in the study were not aware of this feature and had to type everything manually into the comments which violates the visibility principle of EHR usability (Middleton *et al.* (2013)). This is because the activities button functions as a drop down list of values to choose from.
Proposed Solution: Remove the activities button and instead, add individual buttons for every option present under activities. These buttons can be present below the comments text bar, so that when selected, it will be displayed in the comments log.

5) Under Drip Medication tab, Plasmalyte is a frequently administered medication. But it is present at the bottom of the page, so the users had to scroll down every

time to use this field. Since it is a frequently executed task, reducing the number of steps and time spent in this task will improve the usability of the application.

Proposed Solution: Move the Plasmalyte field to the top of the page

6) In Pre and Post events tab, Circulation: Compressions Started, Epinephrine/Vasopressin Dose(s) and Defibrillator Shock headings have a Prior To Code Team Arrival label which is a text field. Yes and No are the only used inputs to this field, but the user has to type in the response every time. During the cognitive walkthrough of this task while they were thinking out loud, one of the participants mentioned this inefficiency of using a text field to enter 'Yes' or 'No' and suggested that a presence Yes/No buttons would be easier for them

Proposed Solution: Include Yes and No buttons for the field and remove the text entry field. These buttons act as external representations that provides cognitive support, thus reducing the time spent in executing this task.

Proposed Design Changes

Heuristic evaluation of the system revealed that the LOGS column, which contains all the data entered, does not allow for the data to be searchable, quickly viewable or accessible (Unertl *et al.* (2009)). Inclusion of a filter in the logs section enables the users to search for and view their particular data of interest, do comparisons between different data, find the previous list of medications administered and so on. The other major design change is introducing a space for the users to enter data into the system using a stylus. The iPad is relatively large and heavy than a paper form. Using our fingers adds to the problem when the virtual keyboard occupies more than 60 percent of the screen space. Furthermore, using our fingers to type in data, while holding the iPad on another hand is an uncomfortable and may be a tedious task. So introducing a stylus based input into the application will improve the overall experience of the application and it resembles the users real world scenario of using a pen to enter data.

4.3 Usability tests on new system

Findings from the previous usability evaluation is addressed and the application is updated with the proposed changes and fixes. The new system was tested for usability with the same team at the Mayo clinic. We performed a cognitive walk-through again of the application where the medical staff followed the instructions of the code blue simulation. Similar to the previous iterations of usability studies, we asked the medical staff to think out loud and we used screen capture to record their on-screen activity. After the simulation, we gave them a feedback survey questionnaire to be answered on a 5-point Likert scale (Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree)

4.4 Results

In this iteration, we found two major areas of improvement. The first update was, under Pre and Post events tab there is a Controlled Substances text field that allows users to type in the name of the substance and amount given to the patient. We found there were only four commonly used controlled substances. So, we created 5 input fields that has the 4 commonly used substances and an 'other' field to include substances other than the commonly used ones. External representations of these activities using a button acts as a cognitive aid to the process and reduced the time and steps in executing such tasks. Figure 4.3 shows the updated Pre and Post events tab.

The second update was, under the same Pre and Post events tab Circulation: Compressions Started, Epinephrine/Vasopressin doses, Defibrillator Shock headings have a 'Prior to Code Team Arrival' text field. Input to those fields are only Yes or No, but the current version has a text field requiring the user to type in the responses every time. So we updated this field to include external representations in the form of two buttons which have Yes and No options. Figure 4.4 shows the updated Prior to Code Team Arrival field.

These are the two major changes after the first iteration. Other minor updates are associated with updating the application to match the Mayo Clinic's standard units for medications administered. Bolus Medication and Drip Medication tabs have a list of medications that can be used in the resuscitation procedure. The units associated with these medications are updated to align with the units that are used in Mayo clinic's Code Blue protocol.

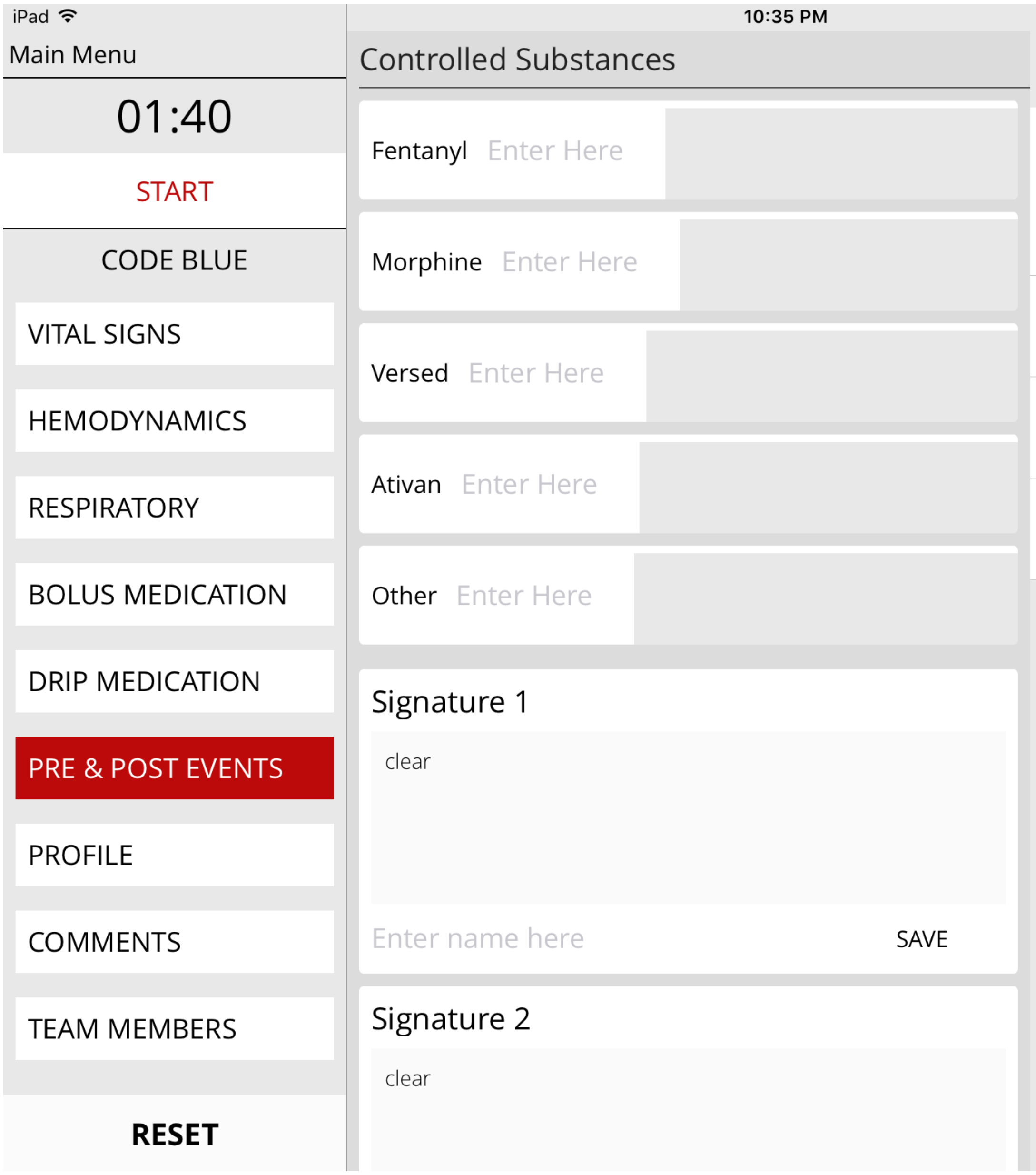


Figure 4.3: Screenshot of Updated Pre and Post Events Tab

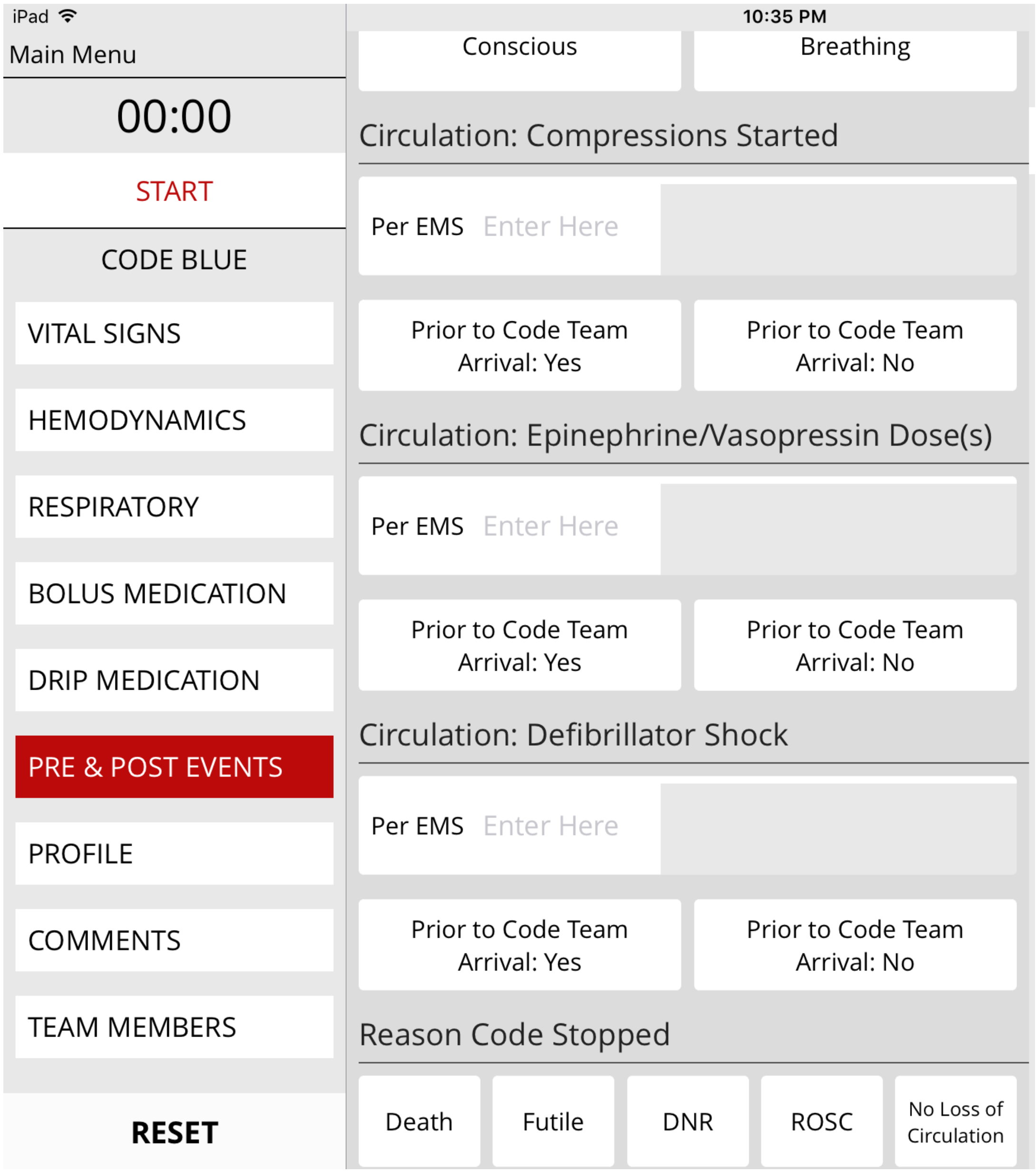


Figure 4.4: Screenshot of Updated Prior to Code Team Arrival Field

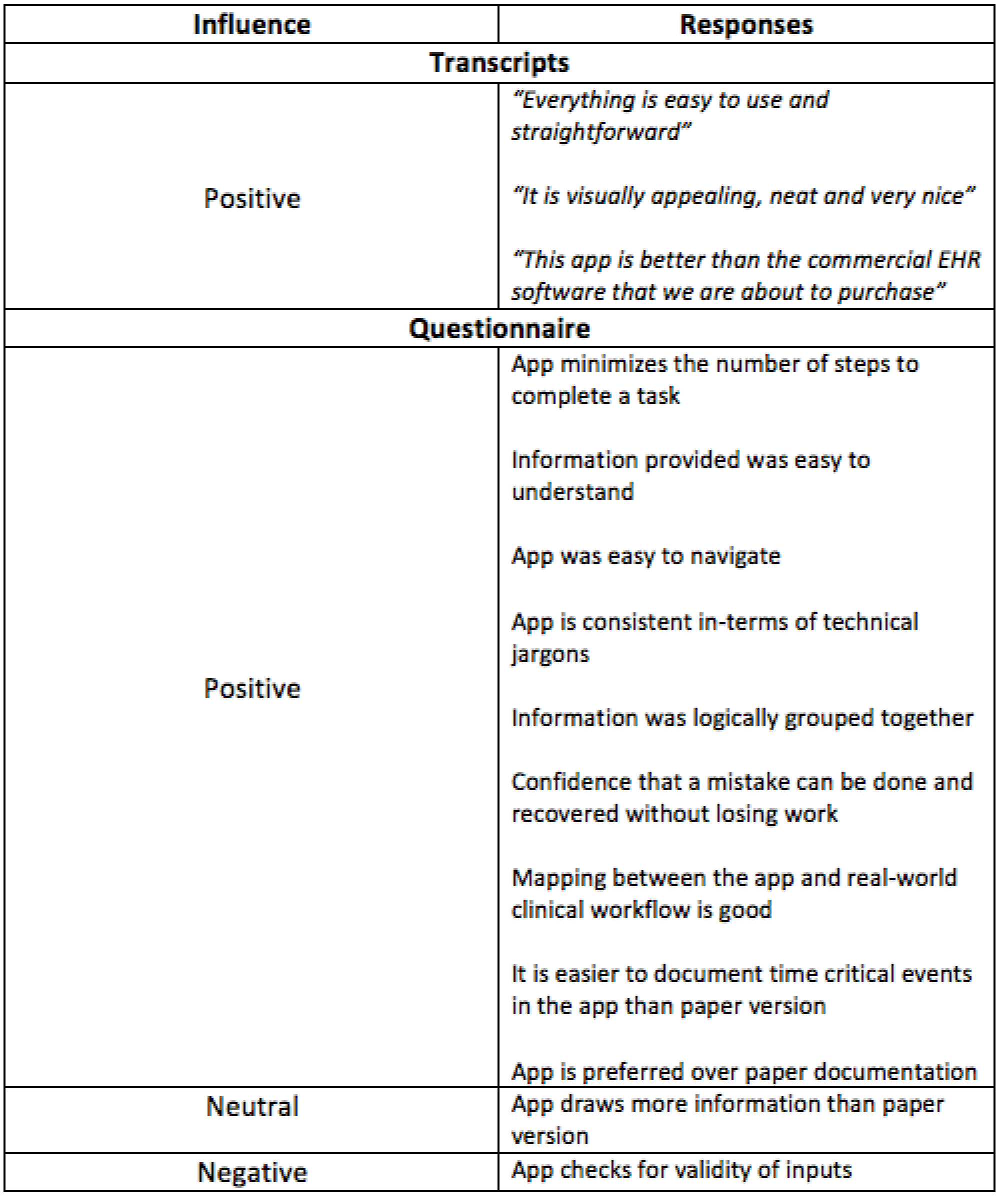
Chapter 5

DISCUSSION AND FUTURE WORK

The updated application received positive feedback from all the participants. The feedback showed that the participants had a positive experience using the updated application, and preferred using this over the paper-based documentation. The survey consists of 15 questions and out of which five questions (Question number 2,3,5,10,11) are adapted from Damania et al. (2009), which were already validated in the present setting, and the remaining questions were developed by brainstorming with experts in ICU to identify and characterize further concerns. These include concerns such as whether the system matches the domain, or is it consistent with their workflow and terminologies, reduces their time to complete the required task and their preference in using this application over paper-based documents. Based on the users responses to the questions (1) App kept screen changes to a minimum until completion of a task, (2) App minimizes the number of steps to complete a task and (13) It is easier to document time critical events in the app rather than paper, we inferred that the updated application reduces the time and mental effort required to complete their tasks. Responses to questions (4) Information was logically grouped together, (7) Mapping between the application and real world clinical workflow was good and (8) Application is consistent in terms of technical jargons shows that the application matches the domain and is consistent with their domain language and terminologies. Responses to questions (3) Information displayed was easy to understand, (10) It is easy to move between tasks, (11) Application was easy to navigate and (13) It is easier to document time critical events in the app rather than paper shows that the application is easy to use, easy to understand, learn and navigate to achieve desired results. The final question in the questionnaire App is preferred over paper documentation reveals that the users strongly agreed that they preferred using this application over paper-based documentation. Table 5.2 shows the feedback from the participants through survey questionnaire, verbal transcripts and their influences

Some participants also mentioned that the Mayo clinic is working with a large software organization to license and use a similar application and our participants had the opportunity to test and use the new application. They felt that our application was much more user-friendly and they preferred this application over the commercial one. This is attributed to the fact that we worked closely with the ICU team in their environment, and used cognitive and HCI principles to guide the design, as well as usability testing by real end user, leading to the final modification of the application accordingly (iterative design). Most commercial applications are not modifiable through feedback and thus inflexible to use. They also do not reflect what the nature of the workflow is, where the application will be inserted, thus changing the distributed nature of the work.

Observations while testing the application showed that the handwriting recognition field has one second latency while writing the input, which is due to the use of a generic third party stylus. This will be resolved and the overall experience can be improved drastically by using this application on an iPad pro with their proprietary Apple pencil. I consider this as a usual update required as new technology comes in the market. One other unexpected observation was that the use of a stylus in general improved the user experience of the application. Since the participants were asked to use the stylus because of the presence of handwriting recognition, they also continued to use it for other fields as well. This is a very important finding, showing the deep



Influence	Responses
Transcripts	
Positive	*"Everything is easy to use and straightforward"* *"It is visually appealing, neat and very nice"* *"This app is better than the commercial EHR software that we are about to purchase"*
Questionnaire	
Positive	App minimizes the number of steps to complete a task Information provided was easy to understand App was easy to navigate App is consistent in-terms of technical jargons Information was logically grouped together Confidence that a mistake can be done and recovered without losing work Mapping between the app and real-world clinical workflow is good It is easier to document time critical events in the app than paper version App is preferred over paper documentation
Neutral	App draws more information than paper version
Negative	App checks for validity of inputs

Table 5.1: Participant Feedback and Influence

cognitive impact of the tool. Patel *et al.* (2000), showed similar findings with the use of electronic and paper based record by clinicians in a Diabetic outpatient clinic.

An IRB approval (Code Study: ID :15-001034) for this proof of the concept study at Mayo Clinic requested by Dr. Ayan Sen, the clinical member of my committee, was sought. It comes under the umbrella of Code Study, and it covered pilot usability work (as described earlier), but did not cover a formal usability research.

We have developed this software application after working hard to understand what the ICU nurses do in clinical settings, which too few people who build software for the clinical world ever do adequately. I modified his software based on the feedback from key nurses, who are a part of our research team and are the end uses of this system. This work is intended to be a proof of the concept study using smaller sample for this improved software. Further studies could be done using formal usability evaluation techniques, and finally testing in a computer-simulated environment.

Code Blue software is much improved from what Harsh Damania had developed; it has much more flexibility in data input as well as the use of the stylus, which makes it more natural. From the users perspective, the application was much improved and has excited some of the clinicians who have seen it and used it.

In the future as the process, standards or the clinical workflow changes, developers need to work closely with the clinical team to identify these changes and update the application to suit the current scenario. It may also require further testing to identify precisely these changes before any implementations are done. In this current study, errors were not monitored, but this is an important aspect to consider. Implementing new tools or processes in a system can result in unintended consequences due to this introduction. Likewise, the introduction of this modified tool, including the handwriting recognition engine, should be monitored after the introduction to check for any errors, including the severity of these errors that may be introduced. Future research should focus on the following areas: (1) Performing the usability study in a computer generated virtual environment that resembles a real-life ICU environment that can yield significant insights into perfecting the application. Use of technologies such as Eye Trackers and EEG headsets can provide quantitative data on the users cognitive process and aid in improving the real time usability of the application, (2) Conducting Near Field Communication (NFC) or Bluetooth based medical devices (sensor-based) related studies that can be made to communicate with the EHR application to document medical data directly into an EHR, thereby promoting data privacy, (3) Exploring new forms of information input into the EHRs such as a speech recognition system that can perform data documentation on voice commands. This can be useful especially in time-critical environments such as, ICU and specific task such as, resuscitation. Health IT developers in general should try to leverage and inherit recent technological advancements into their systems wherever it can be effective.

Chapter 6

CONCLUSION

This thesis identifies the struggle of Health IT applications to be effectively implemented across the health care industry. Just like any other market segment, Health IT has been struggling to cross the chasm from early adopters of the market to the early majority. But unlike other markets, Health IT applications like EHR and EMR is a part of an organization or a team rather than an individual. Also there may not be a one size fits all model, because every team and organization can function slightly differently than the other due to a number of reasons. So in-order to improve adoption of such applications, developers need to work closely with their end users and provide exclusive and customized versions of the application that suits their specific set of end users. This thesis does exactly that by working closely with the resuscitaion team at the Mayo Clinic in Phoneix, Arizona. The results from evaluating the updated application shows that the targeted end users of the application are satisfied and prefer to use the updated application than their conventional documentation methods.

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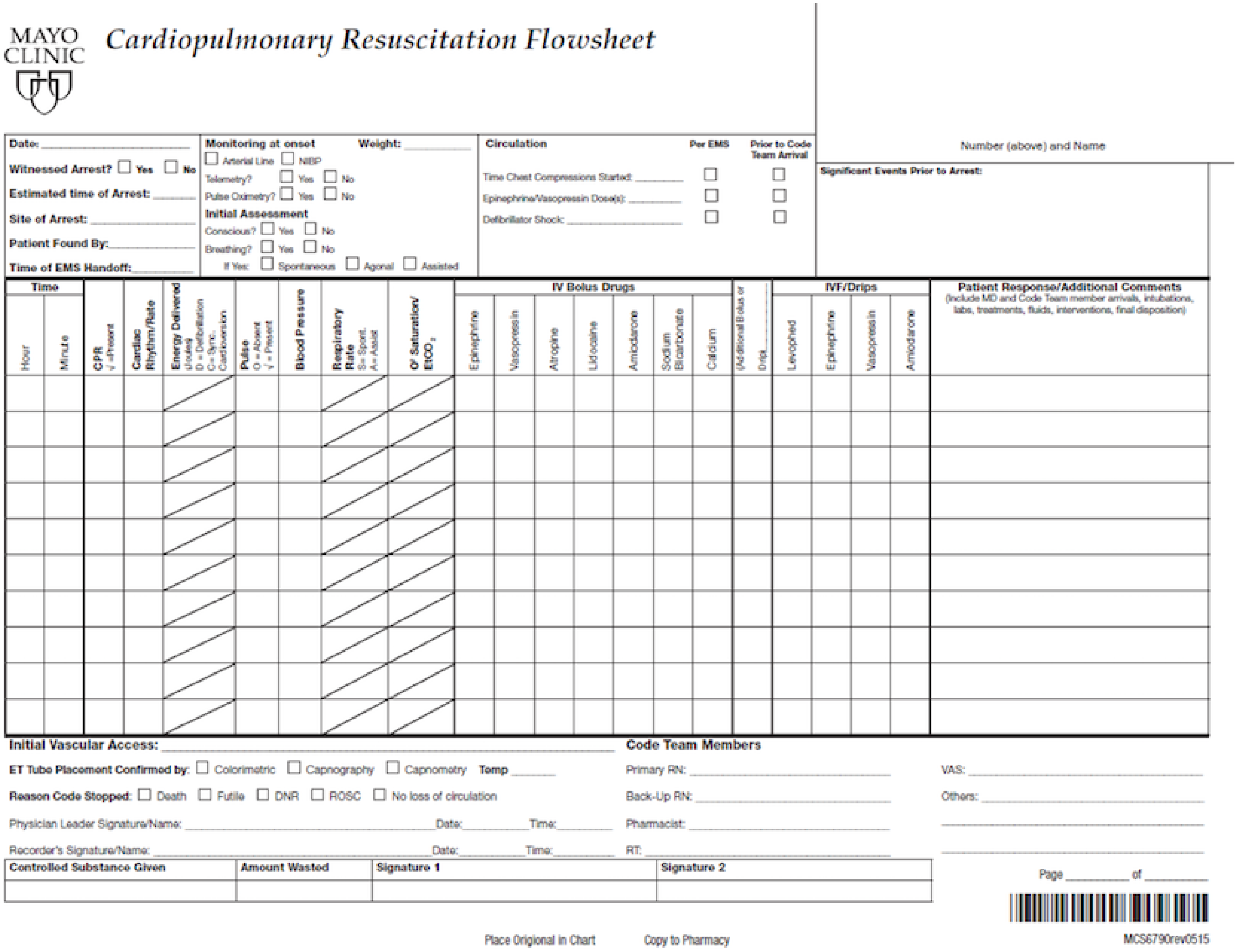
APPENDIX A

MAYO CLINIC - ICU PAPER RESUSCITATION DOCUMENT



MAYO CLINIC

Cardiopulmonary Resuscitation Flowsheet

Number (above) and Name

Date: ____________________

Witnessed Arrest? ☐ **Yes** ☐ **No**

Estimated time of Arrest: ________

Site of Arrest: ____________________

Patient Found By: ____________________

Time of EMS Handoff: __________

Monitoring at onset **Weight:** __________

☐ Arterial Line ☐ NIBP

Telemetry? ☐ Yes ☐ No

Pulse Oximetry? ☐ Yes ☐ No

Initial Assessment

Conscious? ☐ Yes ☐ No

Breathing? ☐ Yes ☐ No

If Yes: ☐ Spontaneous ☐ Agonal ☐ Assisted

Circulation	**Per EMS**	**Prior to Code Team Arrival**
Time Chest Compressions Started: __________	☐	☐
Epinephrine/Vasopressin Dose(s): __________	☐	☐
Defibrillator Shock: __________	☐	☐

Significant Events Prior to Arrest:

Time									**IV Bolus Drugs**								**IVF/Drips**				**Patient Response/Additional Comments** (Include MD and Code Team member arrivals, intubations, labs, treatments, fluids, interventions, final disposition)
Hour	Minute	**CPR** √ =Present	**Cardiac Rhythm/Rate**	**Energy Delivered** (Joules) D = Defibrillation C= Sync. Cardioversion	**Pulse** O = Absent √ = Present	**Blood Pressure**	**Respiratory Rate** S= Spont. A= Assist	**O² Saturation/ EtCO₂**	Epinephrine	Vasopressin	Atropine	Lidocaine	Amiodarone	Sodium Bicarbonate	Calcium	(Additional Bolus or Drip)________	Levophed	Epinephrine	Vasopressin	Amiodarone	

Initial Vascular Access: ________________________________

ET Tube Placement Confirmed by: ☐ Colorimetric ☐ Capnography ☐ Capnometry **Temp** _______

Reason Code Stopped: ☐ Death ☐ Futile ☐ DNR ☐ ROSC ☐ No loss of circulation

Physician Leader Signature/Name: ____________________ Date:__________ Time:__________

Recorder's Signature/Name: ____________________ Date:__________ Time:__________

Code Team Members

Primary RN: ____________________

Back-Up RN: ____________________

Pharmacist: ____________________

RT: ____________________

VAS: ____________________

Others: ____________________

____

____

Controlled Substance Given	**Amount Wasted**	**Signature 1**	**Signature 2**

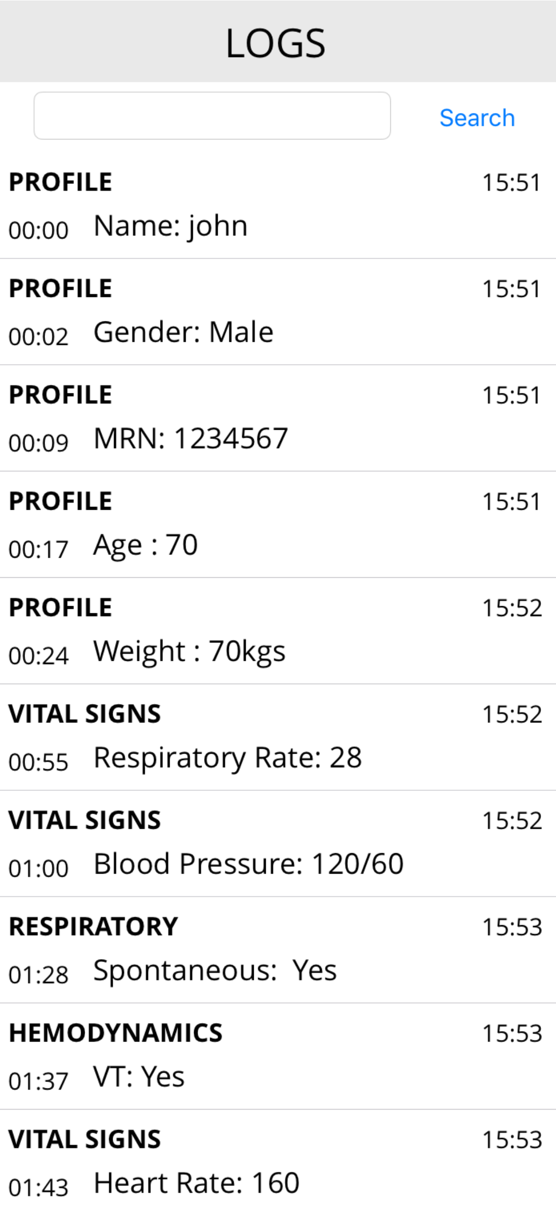
Page __________ of __________

MCS6790rev0515

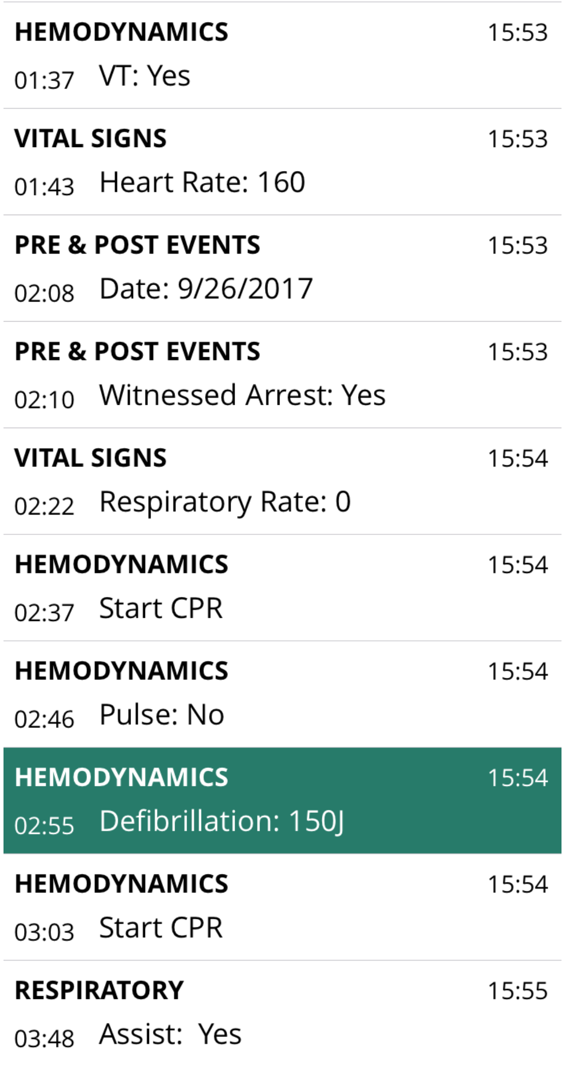
Place Origional in Chart Copy to Pharmacy

APPENDIX B

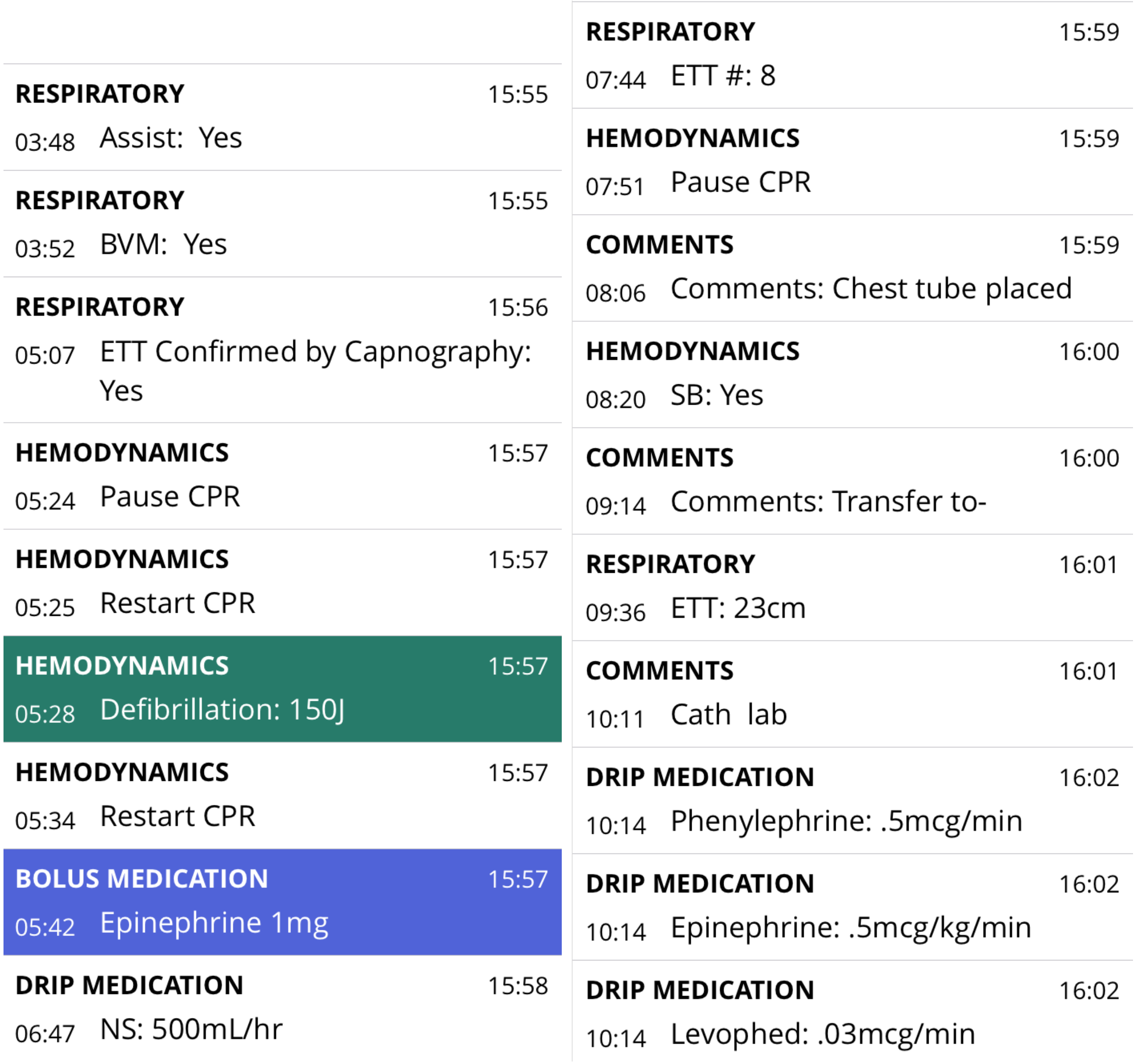
SAMPLE DATA LOG FROM USABILITY TESTING



```
PROFILE                     15:51
00:00  Name: john
PROFILE                     15:51
00:02  Gender: Male
PROFILE                     15:51
00:09  MRN: 1234567
PROFILE                     15:51
00:17  Age : 70
PROFILE                     15:52
00:24  Weight : 70kgs
VITAL SIGNS                 15:52
00:55  Respiratory Rate: 28
VITAL SIGNS                 15:52
01:00  Blood Pressure: 120/60
RESPIRATORY                 15:53
01:28  Spontaneous:  Yes
HEMODYNAMICS                15:53
01:37  VT: Yes
VITAL SIGNS                 15:53
01:43  Heart Rate: 160
```



```
HEMODYNAMICS                15:53
01:37  VT: Yes
VITAL SIGNS                 15:53
01:43  Heart Rate: 160
PRE & POST EVENTS           15:53
02:08  Date: 9/26/2017
PRE & POST EVENTS           15:53
02:10  Witnessed Arrest: Yes
VITAL SIGNS                 15:54
02:22  Respiratory Rate: 0
HEMODYNAMICS                15:54
02:37  Start CPR
HEMODYNAMICS                15:54
02:46  Pulse: No
HEMODYNAMICS                15:54
02:55  Defibrillation: 150J
HEMODYNAMICS                15:54
03:03  Start CPR
RESPIRATORY                 15:55
03:48  Assist:  Yes
```



RESPIRATORY 15:55
03:48 Assist: Yes

RESPIRATORY 15:55
03:52 BVM: Yes

RESPIRATORY 15:56
05:07 ETT Confirmed by Capnography: Yes

HEMODYNAMICS 15:57
05:24 Pause CPR

HEMODYNAMICS 15:57
05:25 Restart CPR

HEMODYNAMICS 15:57
05:28 Defibrillation: 150J

HEMODYNAMICS 15:57
05:34 Restart CPR

BOLUS MEDICATION 15:57
05:42 Epinephrine 1mg

DRIP MEDICATION 15:58
06:47 NS: 500mL/hr

RESPIRATORY 15:59
07:44 ETT #: 8

HEMODYNAMICS 15:59
07:51 Pause CPR

COMMENTS 15:59
08:06 Comments: Chest tube placed

HEMODYNAMICS 16:00
08:20 SB: Yes

COMMENTS 16:00
09:14 Comments: Transfer to-

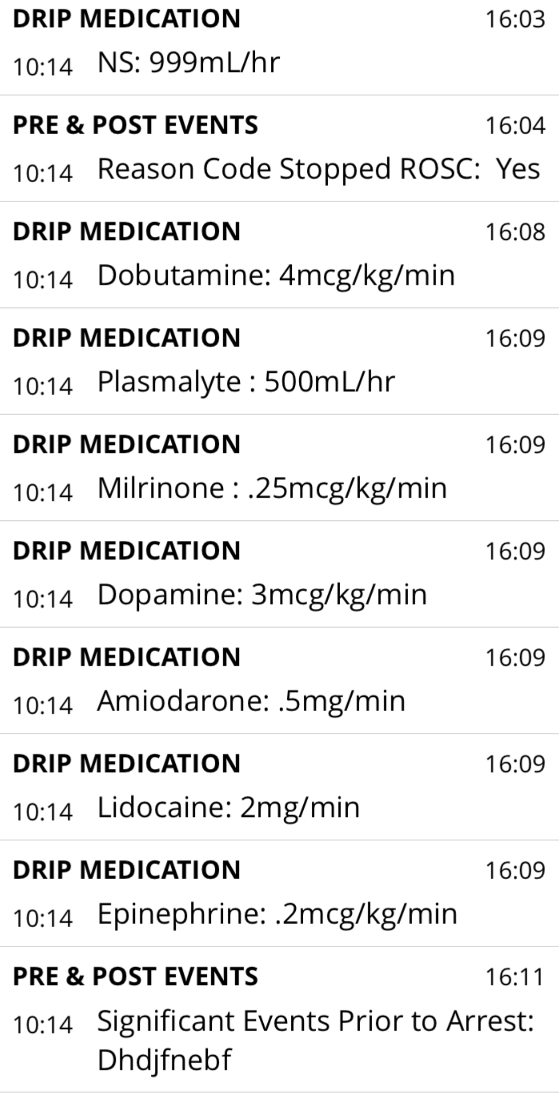
RESPIRATORY 16:01
09:36 ETT: 23cm

COMMENTS 16:01
10:11 Cath lab

DRIP MEDICATION 16:02
10:14 Phenylephrine: .5mcg/min

DRIP MEDICATION 16:02
10:14 Epinephrine: .5mcg/kg/min

DRIP MEDICATION 16:02
10:14 Levophed: .03mcg/min



DRIP MEDICATION 16:03
10:14 NS: 999mL/hr

PRE & POST EVENTS 16:04
10:14 Reason Code Stopped ROSC: Yes

DRIP MEDICATION 16:08
10:14 Dobutamine: 4mcg/kg/min

DRIP MEDICATION 16:09
10:14 Plasmalyte : 500mL/hr

DRIP MEDICATION 16:09
10:14 Milrinone : .25mcg/kg/min

DRIP MEDICATION 16:09
10:14 Dopamine: 3mcg/kg/min

DRIP MEDICATION 16:09
10:14 Amiodarone: .5mg/min

DRIP MEDICATION 16:09
10:14 Lidocaine: 2mg/min

DRIP MEDICATION 16:09
10:14 Epinephrine: .2mcg/kg/min

PRE & POST EVENTS 16:11
10:14 Significant Events Prior to Arrest: Dhdjfnebf

APPENDIX C

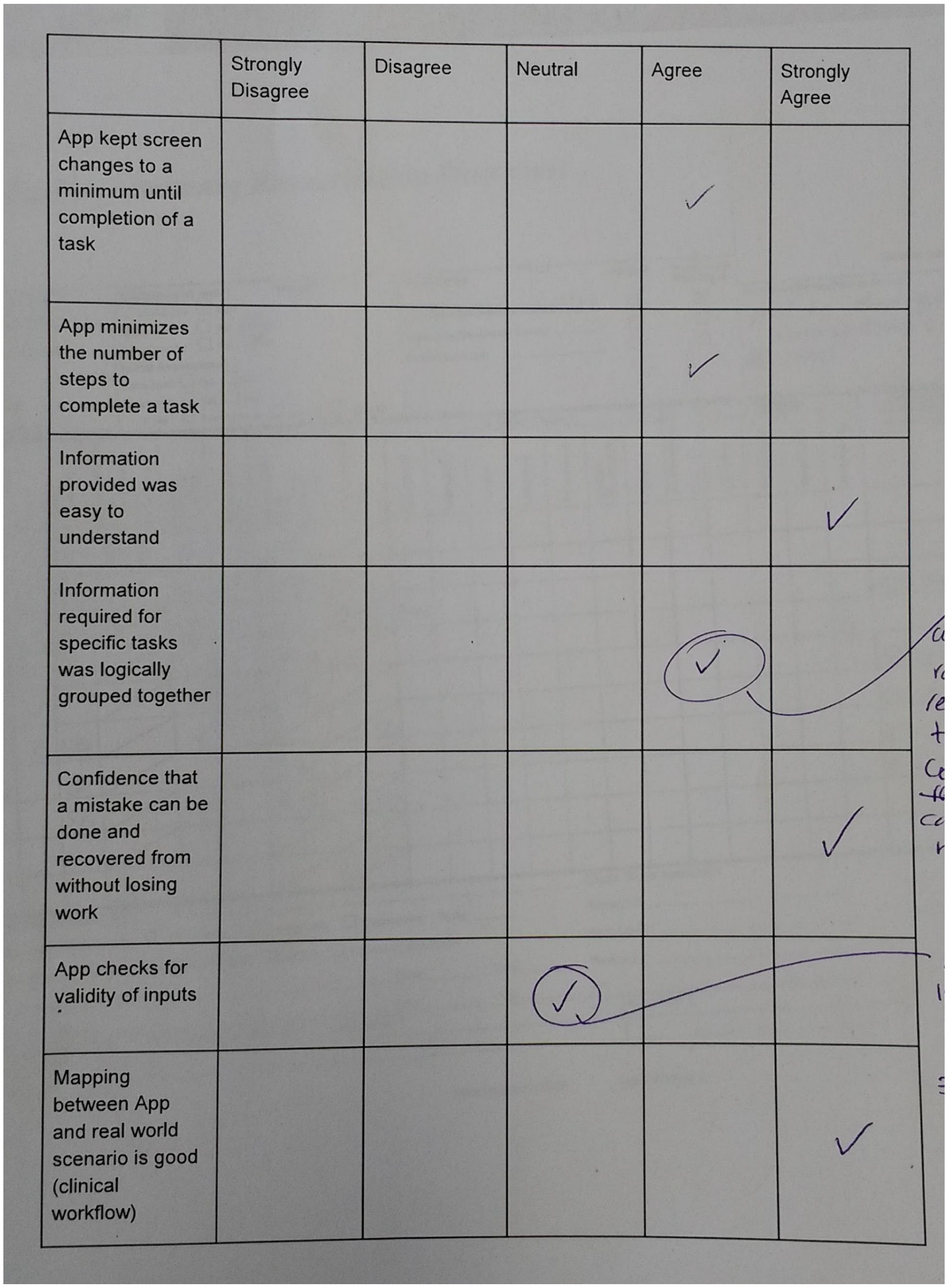
QUALITATIVE SURVEY

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
App kept screen changes to a minimum until completion of a task					
App minimizes the number of steps to complete a task					
Information provided was easy to understand					
Information required for specific tasks was logically grouped together					
Confidence that a mistake can be done and recovered from without losing work					
App checks for validity of inputs					
Mapping between App and real world scenario is good (clinical workflow)					

Is app consistent in terms of technical jargon					
App draws more information than paper version					
It is easy to move back and forth screens					
App was easy to navigate					
Amount of Information displayed in all interfaces was apt					
It is easier to document time critical events in app rather than paper					
Timestamp recorded data was clearly distinguishable					
App is preferred over paper documentation					

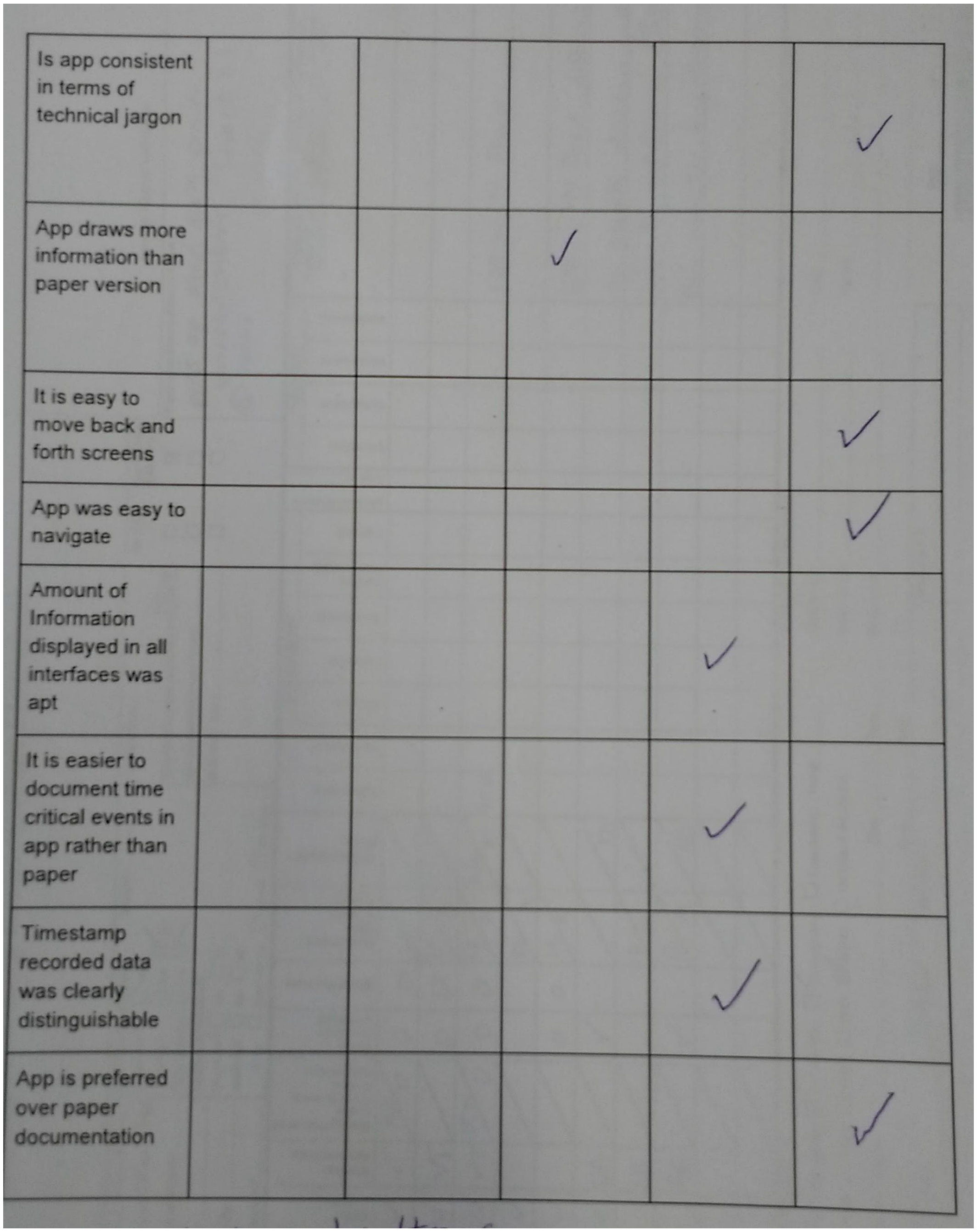
APPENDIX D

SURVEY RESULTS



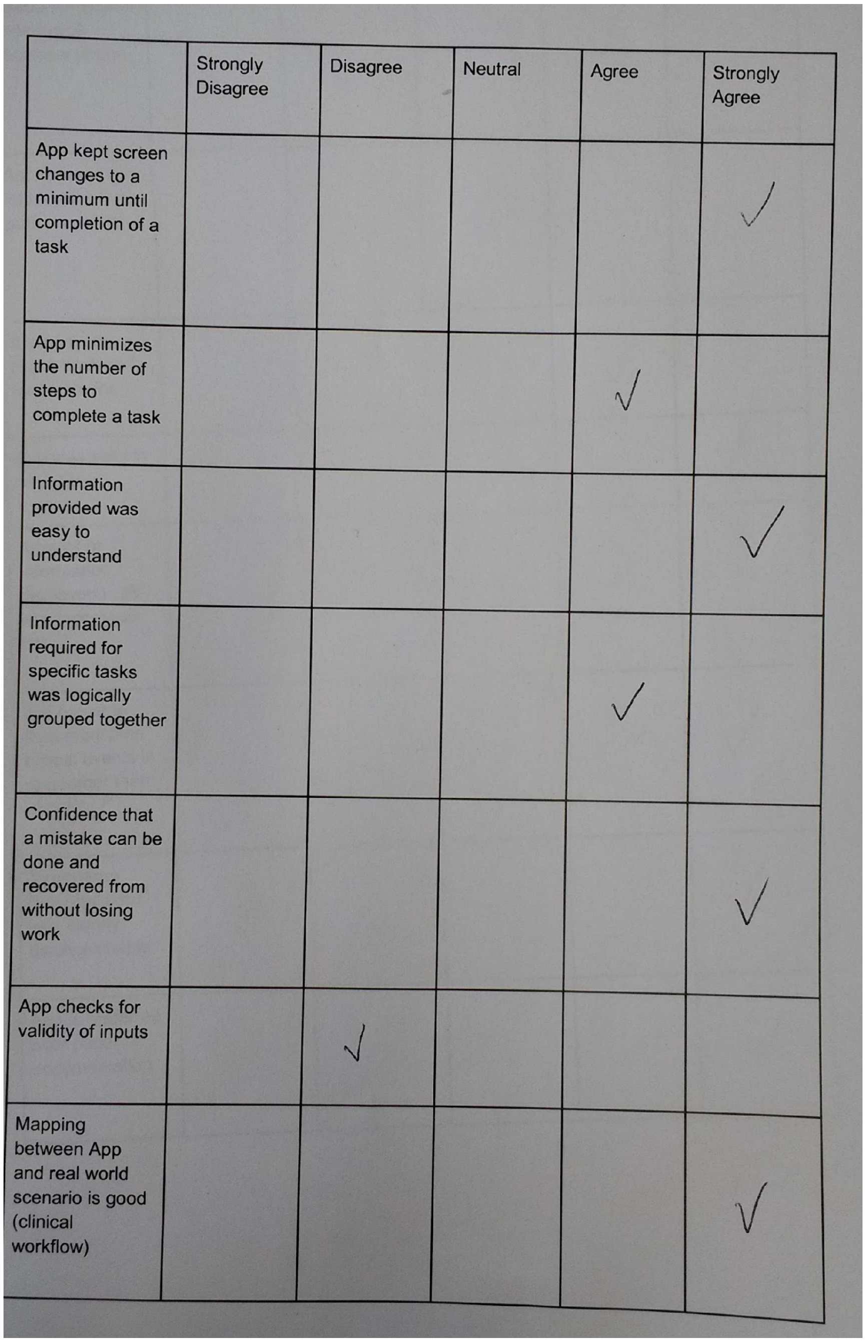
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
App kept screen changes to a minimum until completion of a task				✓	
App minimizes the number of steps to complete a task				✓	
Information provided was easy to understand					✓
Information required for specific tasks was logically grouped together				✓	
Confidence that a mistake can be done and recovered from without losing work					✓
App checks for validity of inputs			✓		
Mapping between App and real world scenario is good (clinical workflow)					✓

Nurse-1-Feedback (Page 1)



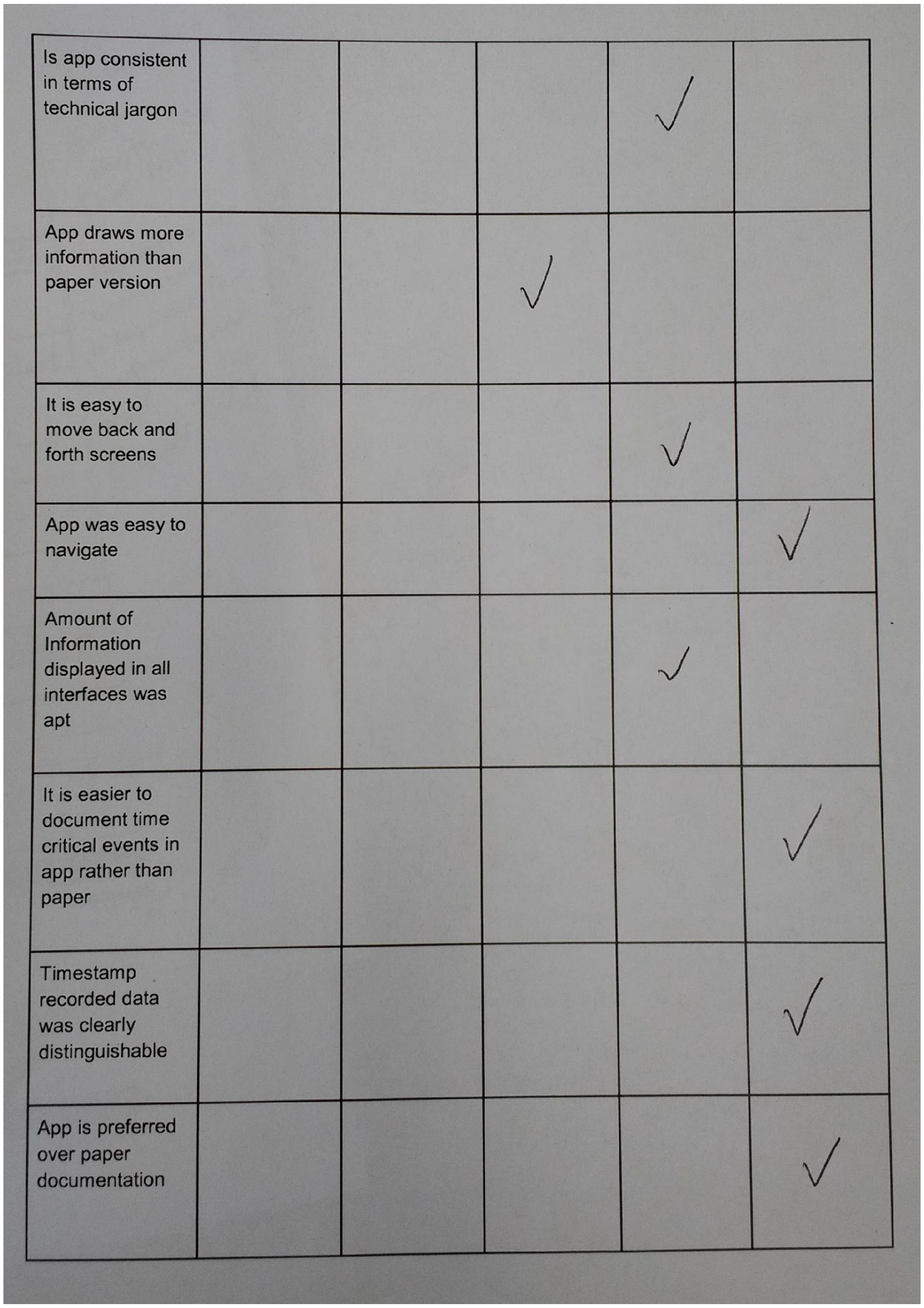
Is app consistent in terms of technical jargon					✓
App draws more information than paper version			✓		
It is easy to move back and forth screens					✓
App was easy to navigate					✓
Amount of Information displayed in all interfaces was apt				✓	
It is easier to document time critical events in app rather than paper				✓	
Timestamp recorded data was clearly distinguishable				✓	
App is preferred over paper documentation					✓

Nurse-1-Feedback (Page 2)



	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
App kept screen changes to a minimum until completion of a task					✓
App minimizes the number of steps to complete a task				✓	
Information provided was easy to understand					✓
Information required for specific tasks was logically grouped together				✓	
Confidence that a mistake can be done and recovered from without losing work					✓
App checks for validity of inputs		✓			
Mapping between App and real world scenario is good (clinical workflow)					✓

Nurse-2-Feedback (Page 1)



Is app consistent in terms of technical jargon				✓	
App draws more information than paper version			✓		
It is easy to move back and forth screens				✓	
App was easy to navigate					✓
Amount of Information displayed in all interfaces was apt				✓	
It is easier to document time critical events in app rather than paper					✓
Timestamp recorded data was clearly distinguishable					✓
App is preferred over paper documentation					✓

Nurse-2-Feedback (Page 2)