8-2013

ORGANIZATION OF INFORMATION FOR REVERSIBLE CAUSES OF PULSELESS IN-HOSPITAL CARDIAC ARREST: A RANDOMIZED CONTROL TRIAL USING A COGNITIVE AID

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ORGANIZATION OF INFORMATION FOR REVERSIBLE CAUSES OF PULSELESS IN-HOSPITAL CARDIAC ARREST: A RANDOMIZED CONTROL TRIAL USING A COGNITIVE AID

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Industrial Engineering

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by
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August 2013

Accepted by:
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ABSTRACT

More than 200,000 in-hospital cardiac arrests are treated each year in the US with 21% survival rate. According to American Heart Association (AHA) guidelines, many causes for these arrests could be successfully treated if identified early. Such causes can be generalized as “reversible causes”. Medical doctors identify the reversible causes associated with an arrest by recalling them from memory, using a mnemonic. In this study, using a cognitive aid such as an iPad application, the mnemonic was modified and causes were displayed alphabetically, and tested along with a new method that rank-ordered the reversible causes based on the patient context, known as the context-sensitive scheme. Both methods were implemented electronically in an iPad application and presented in a counterbalanced order to 11 anesthesia medical residents using simulated scenarios. Performance and usability measures were recorded and analyzed.

It took significantly longer for the participants to identify the reversible causes using the context-sensitive scheme. However, the scheme resulted in significantly lesser number of unnecessary keystrokes when compared to the alphabetical scheme. Some of these unnecessary keystrokes could affect the patient’s outcome. Both the schemes agreed in terms of usability. The above results indicate the potential of the context-sensitive scheme of the reversible causes to be useful when applied during an emergency scenario when refined further. A combination of both methods is suggested.

DEDICATION

This thesis is dedicated to my loving parents, my late mother Meenakshi Ramachandran, my father V.G. Ramachandran, my grandmother Parvathy Subramaniam and my sister Priya Ramachandran, and my loving friends.

ACKNOWLEDGMENTS

There are two important people involved in this research. One of them is Dr. Joel Greenstein, Assistant Professor and my advisor at Clemson University, and Dr. Matthew D. McEvoy, M.D, both of whom helped formulate, develop and shape this research into a success. This research could not have been made possible without their help. Dr. Greenstein's valuable guidance, continuous support, patience through unexpected problems has been invaluable. Dr. McEvoy, on the other hand, extended his support by all his means possible from the clinical side and played a commendable role coordinating the work between the two universities and making this a success. Words are not enough to thank them.

Mr. Michael McEvoy, the systems programmer who helped program this application definitely needs to be thanked. Dr. Anand K. Grampoadhye and Dr. Paula J. Watt both played key roles supporting this study, especially in communicating with the Institutional Review Boards and helping me better the research process. Ms. Barbara Ramirez cheerfully helped structure my document and taught me how to write effectively. Dr. Patrick Rosopa provided with guidance in choosing an appropriate statistical methodology. I wish to thank them immensely.

My colleagues, Sanjaykumar Ranganayakulu, Reshmi Koikkara, Sumonthip Chompoodang helped me starting from the planning stages right through the implementation and analysis stages. Special thanks to Sanjaykumar Ranganayakulu, who provided insightful ideas at every stage and helped cheer me up whenever I felt down. I am deeply indebted to him. Special thanks to Sumonthip Chompodang who played the co-researcher role during my data collection. Reshmi Koikkara, Kapil Chalil Madathil and Kevin Juang were all of invaluable help at various stages by providing insightful advice, especially regarding statistical methodologies.

TABLE OF CONTENTS

Table of Contents (Continued)

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

List of figures (continued)

CHAPTER I

INTRODUCTION

Cardiac arrest, the primary cause of death in the United States, is caused by the malfunction of the electrical system of heart. According to the American Heart Association (AHA), the number of deaths due to cardiac arrest has declined since 2007, in part because of technological advancements and improvements in the treatment procedures; however, the burden from high death rates for cardiac disease remains (Roger et al., 2011).

The Centers for Disease Control and Prevention and the National Institute of Health in conjunction with the American Heart Association estimates that each year, approximately 785,000 Americans suffer a first coronary heart attack and approximately 470,000 a recurrent one (Roger et al., 2011). Cardiac arrest is classified as a serious medical emergency-the chance for survival declines by 7-10% with each passing minute without performing Cardio Pulmonary Resuscitation (CPR) and defibrillation (Chan & Nallamothu, 2012). In-hospital cardiac arrests number between 370,000 and 750,000 (Sandroni, Nolan, Cavallaro, & Antonelli, 2007) each year and out-of-hospital cardiac arrests between 235, 000 to 325,000 (Nichol et al., 2008). Cardiac operations increased by 27% during the years 2007 to 2011(Roger et al., 2011).

Higher survival rates exist for treatments related to in-hospital cardiac arrests for obvious reasons including documented known risk factors as well as resuscitation by ample numbers of highly trained personnel. However, the in-hospital cardiac arrest survival rates are still low, as only 15-17% of the patients survive to discharge (Peberdy et al., 2003) & (Sandroni et al., 2007). It is thus important to develop strategies to improve care for such hospitalized patients.

Diagnosis of cardiac arrest

Cardiac arrest is typically caused by abnormal or irregular heart rhythms. In the early recognition phase of a cardiac arrest, it is critical to prevent cardiac failure. The AHA has provided a set of clinical interventions for the treatment of cardiac arrest, stroke and other life threatening medical emergencies known as the Advanced Cardiovascular Life Support (ACLS) in the form of an algorithm. Healthcare providers are trained in ACLS to begin chest compressions if there is no palpable pulse for 10 seconds. Resuscitation is a complicated event that requires the completion of a distinct series of actions for it to be effective (Luten et al., 2002).

Cardiac arrest can be defined as the documented cessation of cardiac mechanical activity, determined by the absence of a pulse. Pulseless cardiac arrest can be caused due to one of the four most common types of abnormal rhythms: Pulseless Electrical Activity (PEA), Pulseless Ventricular Tachycardia, Asystole, or Ventricular Fibrillation. According to the guidelines of the cardiac arrest management protocol below in Figure 1.1, arrest may be treated or reversed by identifying and treating any of the reversible causes. Part 8 of the Advanced Cardiac Life Support guidelines (ACLS) (Neumar et al., 2010) lists the most common specific reversible cause associated with a particular type of rhythm.

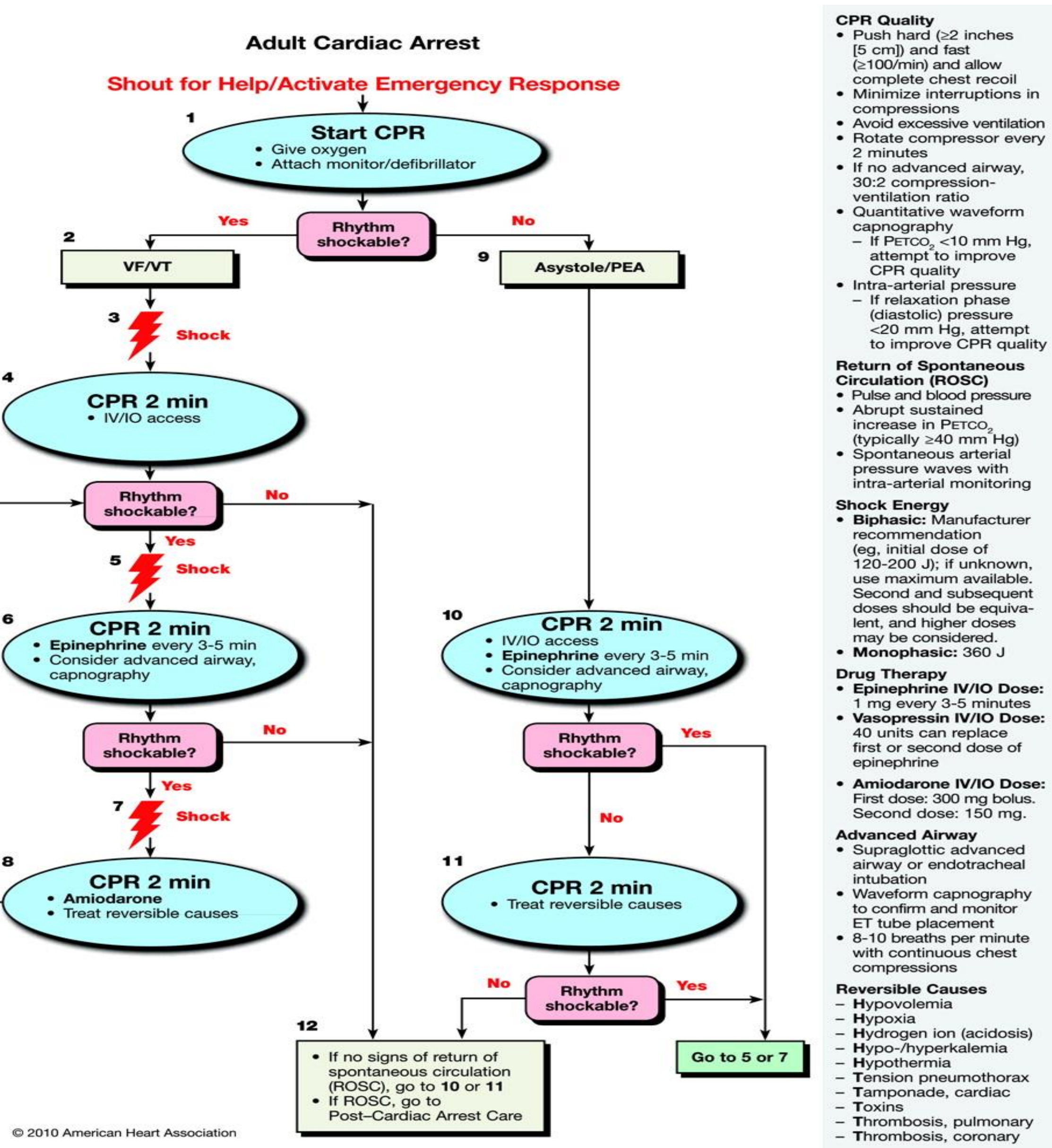

Figure 1.1 Advanced Cardiac Life Support pulseless arrest algorithm

Note. From "Part 7.2: Management of cardiac arrest.2005a, American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care" by the ECC Committee, Subcommittees and Task Forces of the American Heart Association, 2005, *Circulation, 112*(24), p.IV-59. The American Heart Association has listed these 12 common and potentially reversible causes:

1. Hypothermia: A low core body temperature
2. Hypokalemia: Inadequate serum potassium levels
3. Hyperkalemia: Excess serum potassium levels
4. Hypoxia: Decreased O2 delivery to cells
5. Acidosis: An abnormal body pH
6. Trauma: Traumatic injury to the body
7. Cardiac Tamponade: A buildup of fluid or air in the pericardium
8. Coronary Thrombosis: Blockage of one or more coronary arteries
9. Tension Pneumothorax: Buildup of air in the pleural cavity
10. Pulmonary Embolism: Pulmonary artery is blocked by thrombosis
11. Toxins: Reaction due to toxic substances
12. Hypovolemia: Decreased circulating volume

Note. From “Cardiac arrest: know your hs and ts" by Garner K., 2008, Retrieved from <http://www.ceuprofessoronline.com/onlinecourses.php>

Even though the Advanced Cardiac Life Support treatment guidelines have been available for a number of years, according to Kurrek et al., (1998), their adherence is often poor. Even experienced teams often perform sub-optimally in both simulated and actual resuscitation scenarios (Brown et al., 2006). Difficulty determining the correct rhythm and associating it with the corresponding treatment procedure is significant to the outcome. The AHA recommends using specific physical signs and the patient's history to guide the management of Pulseless Electrical Activity (PEA) and asystole (Cummins et al., 1997). However, many physicians may withhold therapy for a fear of causing harm if uncertain of the cause of cardiac arrest (MacCarthy, Worrall, McCarthy, & Davies, 2002).

Clinical decisions could be supported by cognitive aids. Cognitive load describes the mental burden experienced by the decision maker (here, the healthcare provider) and will be higher when the task is less familiar or more demanding (Luten et al., 2002). Making ongoing decisions for each of the various steps of procedural interventions is thus a complex and potentially a difficult task in such life-threatening situations (Luten et al., 2002). It is compounded by the complexity of the associated treatment procedure. The AHA has recently approved the use of cognitive aids during actual resuscitation (Bhanji et al., 2010). Research has suggested the use of cognitive aids or memory aids can reduce the mental workload of the caregivers and increase performance (T. K. Harrison, Manser, Howard, & Gaba, 2006). Their use is highly recommended in order to improve performance in resuscitation (Andersen, Jensen, Lippert, Østergaard, & Klausen, 2010).

In 1997, the American Heart Association recommended one such method to remember the reversible causes in the Advanced Cardiac Life Support algorithms by grouping them with their starting letter (Hs and Ts) as a mnemonic (Kloeck et al., 1997).

Roediger, (1980) concluded that mnemonic aids have greater effects on the recall of a number of ordered words than the recall of a number of non-ordered words. The reversible causes are independent of each other and thus can be regarded as non-ordered. According to a study by Grześkowiak, (2011) fewer than 25% of graduate doctors could identify the correct reversible cause associated with the patient when provided with such a cardiac arrest scenario. Thus, the use of mnemonics to recall information from memory is not always effective.

To improve their effectiveness, the mnemonics can be supplemented by paper cognitive aids (Luten et al., 2002). Dyson, Voisey, Hughes, Higgins, & McQuillan, (2004) compared the effectiveness of the "Hs and Ts" with that of an institutionally created paper based aid and concluded the paper-based aid was more effective in identifying the reversible causes when compared to the mnemonics. However, findings by L. Wu et al., (2011), showed there was very little time spent by doctors looking at a paper based aid.

With the advent of mobile information technologies, an interactive cognitive aid may offer advantages over a paper-based cognitive aid. A large screen, rich graphical user interface and the possibility of being used as a reference to a particular diagnostic process whenever needed as facilitated by easy navigation, may provide timely access to appropriate information, otherwise not possible with paper. An interactive aid can be in the form of a PDA or a tablet PC, for example an iPad. iPads were first introduced in the US as a tablet PC in the year 2010 (N. Harrison & Kerris, 2010) and soon their applicability was extended to various fields like aviation, law, and healthcare, in the form of specific customizable applications (known as apps).

A prospective pilot study by Harvard Medical School regarding the tablet PC usage by physicians in an emergency department indicated that tablet PCs dramatically improve clinical bedside information retrieval (Horng, Goss, Chen, & Nathanson, 2012). According to Dasari, White, & Pateman, (2011), about 60% of doctors use specific anesthesia apps useful for clinical practice in the UK and about 47% use apps for clinical educational purposes. Dine et al., (2008) concluded that CPR with audiovisual feedback and debriefing may serve as a powerful tool to improve rescuer training and care for cardiac arrest patients.

Few clinical studies have examined the impact of the design of an interactive cognitive aid on clinician performance; in particular, no studies have examined alternative methods to represent reversible causes of cardiac arrest using an interactive cognitive aid.

Aim of this study

This study aimed to analyze different methods of organization of the reversible causes of cardiac arrest by applying human factors principles to design, implement, and test methods of information presentation with an interactive digital cognitive aid (iPad application) for emergency cardiac arrest treatment. Simulation in healthcare attempts to recreate treatment and diagnostic procedures. One type of simulation is the use of mannequin to recreate life-threatening emergencies like cardiac arrest. Simulation of cardiac arrest elicits lifelike behavior and may ensure quality management of cardiac arrests (Lighthall, Poon, & Harrison, 2010). The performance of the iPad application was compared using different organization schemes aid in a high fidelity simulation using scenarios depicting different reversible causes.

CHAPTER II

LITERATURE SURVEY

In hospital cardiac arrest treatment is a team-based procedure that involves 5-6 people-- a team leader (usually an anesthesiologist, physician or a hospitalist), in addition to various other medical professionals including a first responder performing CPR, and nurses to manage defibrillation, airways, drugs and Intra-Venous fluids. During such an emergency, the identification of the correct reversible cause and corresponding treatment from memory alone is potentially a difficult task (Dyson et al. 2003, Bortle, 2010 and Greszkowiak, 2011). To assist in decision-making during such emergency scenarios, memory aids are often used to enhance either internal techniques to supplement memory or external techniques in the form of cognitive aids. The use of such internal memory and external cognitive aids in clinical practice has been increasing over the past two decades and their effectiveness in medical practice has been demonstrated by numerous studies.

In 1997 the AHA recommended the use of a mnemonic referred to as the Hs and Ts for remembering all the reversible causes of cardiac arrest based on their starting letters. A mnemonic (derived from the Greek word *mnemonikos* meaning: of memory) links new data with previously learned information. Mnemonics are useful in medicine as they facilitate effective recall by reducing cognitive load (Caplan and Stern, 2010).

In 1998, Hughes and McQuillan argued that though the recommendations by the AHA and the Resuscitation Council were to be appreciated, many doctors might struggle to list all eight of the causes associated with Pulseless Electrical Activity or Electro-Mechanical Dissociation. They suggested an alternative system aimed at encouraging clinicians to remember the most common and most easily reversible causes first, leaving the more complex to the last. Thus, hypoxia, which is very readily reversible by administering oxygen, was listed first, and hypovolemia, treated by a rapid fluid administration was second. Pneumothorax, tamponade and pulmonary emboli, all of which respond to the more involved and time-consuming thrombolytic therapy were listed as third, fourth and fifth, respectively. The remaining causes, which are less amenable to cure, were grouped together as miscellaneous in no specific order.

In the following year, Rosenberg, Levin and Myerburg developed a new mnemonic, different from the Hs and Ts, for remembering the reversible causes for easy retention by the students-- matchhhhed, created by expanding the word *matched* was believed to be easily remembered, improving the medical response to Pulseless Electrical Activity.

To analyze further the effectiveness of mnemonics in medical practice, Fernandes and Speer (2002) created a mnemonic to aid medical students in memorizing sequential information regarding neonatal resuscitation as a part of the Neonatal Resuscitation Program (NRP). They found that medical students showed more confidence and decisiveness in their treatment management as reported by the instructors who conducted the practical sessions when they used mnemonics. Additional evidence indicates that most medical practitioners use some type of acronym routinely (http://www.medicalmnemonics.com). Though the use of mnemonics can improve recall, several studies question the effectiveness of the Hs and Ts mnemonic.

Bortle (2010) explored the role of mnemonic acronyms in the practice of emergency medicine; specifically how medical practitioners at various experience levels use acronyms for critical thinking and bedside decision-making. A survey was sent to 80 respondents, including residents, nurses and paramedics supplemented by focus groups, face-to face interviews and the maintenance of a clinical diary by a sub-group of 10 clinicians on the perceived frequency of use of the AHA recommended mnemonics. The results indicated that the average length of mnemonic that could be remembered easily was proportional to the level of clinical education and experience. All 28 AHA recommended mnemonics obtained through the survey were analyzed for their perceived frequency of use initially and again after 30 days. The analysis showed that 20% of respondents did not use a mnemonic, while 60% were moderate users and another 20% were frequent users. Specifically, the mnemonic Hs and Ts were used by 7 of 50 residents, indicating that only 14% of the medical doctors recalled and actually used it despite its recommendation by the AHA.

Jones, Lammas and Gwinnutt (2010) explored the knowledge of the reversible causes of cardiac arrest among the doctors who participated on a cardiac arrest treatment team. Thirty-seven doctors were asked to recall the four Hs and four Ts mentioned by the

European Resuscitation Council. The time taken to recall them as well as their date of completion of an Advanced Life Support (ALS) course were recorded. Of the thirty-seven doctors, 38% could only partially recall the causes and four (11%) were unable to recall any. The time since the ALS course was completed was not related to success of recall.

Grześkowiak, (2011) conducted a between-subjects study aimed at determining the retention of the Hs and Ts mnemonic for the reversible causes of cardiac arrest for two groups of medical doctors: 50 fourth-year students and 50 medical doctors five months after graduation, were first tested on their knowledge of the reversible causes on a written test consisting of open-ended questions. Results found that while 90% of the fourth-year students could identify the causes on the written test, only 9% of the doctors were able to do so. These groups then participated in a simulated practical session where they had to determine the cause of a cardiac arrest in a scenario. Two extreme causes--hypovolemia, one of the easiest to identify, and tension pneumothorax, one of the most difficult to identify, were used. The results indicated that on an average, 40% of the 4th year students could identify them correctly while only 25% of the medical doctors could. Contrary to Gwinnutt's study, this indicated that there might be a relationship between the retention of the mnemonic with the time of learning.

Learning theory provides clues explaining why results by these four studies indicate that the effectiveness of the mnemonic is not guaranteed. The seminal 1956 paper by George Miller discusses the finding that only about 5 to 9 individual pieces of data can be easily remembered. This would suggest that one of the issues in using the mnemonic Hs and Ts is the fact that it includes 12 individual pieces of data. Secondly, this mnemonic uses only two letters, which can be problematic. According to Caplan and Stern (2010), nonrepeating letters would facilitate the recall of the linked data, allowing each letter to provide a distinct cue without any clouding by redundancy. Finally, recall of the reversible causes is made more difficult because of the information overload that exists during an emergency scenario (McDaniel and Einstein, 2007).

In addition to the internal memorization techniques facilitated through mnemonics, external techniques, such as cognitive aids, have been shown to produce an increase in performance in medical diagnosis. These aids, which are structured pieces of information designed to enhance cognition and adherence to medical best practices, can be as simple as a piece of paper serving as a written reminder to something as complicated as an interactive and dynamically changing computer-driven interface (Cognitive aids in medicine, 2012).

Paper- Based Cognitive Aids

To test the effectiveness in remembering the 8 causes of the Pulseless Electrical Activity rhythm of cardiac arrest, Dyson et al., (2003) conducted a randomized control trial comparing the effectiveness of an institutionally created paper-based cognitive aid, called an EMD-aid, with that of the AHA recommended Hs and Ts mnemonic. The EMD-aid categorized the reversible causes of cardiac arrest by their frequency of occurrence and ease of reversibility into four groups organized by shape, color, position, numbering, and sequence as seen in Figure 2.1. The octagon in the center enumerates the causes from most frequent to the lease frequent, in a clockwise order. The two most common and most easily reversible causes, hypoxia and hypovolemia, represented by a circle and oval respectively, are located at the top of the cognitive aid, while the less common causes requiring a longer treatment period to respond to treatment, are represented by triangles, at the bottom. Blue represents hypoxia, signifying lack of oxygen; white represents hypovolemia that results in pallor, with red and green, used for the remaining two groups for no specific reason mentioned.

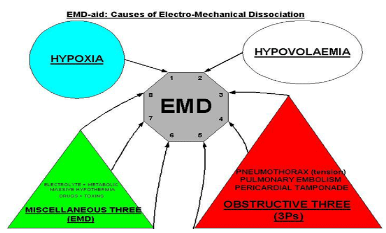

Figure 2.1 EMD-aid design

Note. From “Educational psychology in medical learning: a randomized controlled trial of two aide memoires for the recall of causes of electromechanical dissociation” by Dyson et al., 2003, *Emergency Medicine Journal*, *21*(4), p.458.

A population sample of 149 resident physicians were randomly assigned to either the 4Hs+4Ts (n=74) or the EMD-aid group (n=75). The number and sequence of recall of the reversible causes both within one minute and overall was recorded. After four weeks, the recall ability of the reversible causes was retested. It was found that the median number of causes recalled was greater for the EMD aid group. According to the authors, the performance improvement for the EMD aid may be related to the organization and pictorial presentation of the aid. However, the time spent looking at the EMD aid was significantly longer than the recall time of the Hs and Ts group (p = .01). The study did not conclude if the improved recall for the EMD aid was facilitated by the extra time was the design of the EMD aid, suggesting a need for examining the design of the information of the reversible causes.

Recent advances in technology have led to the use of digital hand-held devices for the diagnosis of medical illnesses. Initial research indicates dynamically changing, hand held digital cognitive aids increase performance when compared to memory alone (Low et al., 2011) and when compared to a static cognitive aid like paper (R. Wu & Straus, 2006).

For example, in a randomized controlled trial that involved the Resuscitation Council UK's iResus© app, iResus demonstrated a significant performance improvement when compared to memory (Low et al., 2011). iResus is an iPad application that depicts the steps in the Advanced Cardiac Life Support treatment guidelines by means of checklists. The reversible causes are listed using the Hs and Ts mnemonic mentioned in the ACLS guidelines. Thirty-one doctors who were advanced life support-trained within the previous 2 years were recruited, all receiving identical training on the iResus application. The participants were then randomly assigned to a control group (memory alone) and a test group (access to iResus on smart phone). Both groups were tested for their adherence to the guidelines using a scoring system. The scores were significantly higher for the smart phone app group (p = .01) when compared with the control group, indicating that the use of the smartphone application significantly improved the performance of an advanced life support-certified doctor during a simulated medical emergency.

In summary, reversible causes of cardiac arrest are difficult to recall from memory. The use of mnemonics, paper-based, and digital aids have been found to be effective so far. However, limited research has focused on alternative information organizations of the reversible causes in a simulated scenario using an interactive cognitive aid. To address this need, this research uses an interactive cognitive aid for the iPad, called Rapid Rescue, currently being developed by physicians at the Medical University of South Carolina, to examine the effectiveness of alternative information organizations for the reversible causes of cardiac arrest.

CHAPTER III

DESIGN OF ORGANIZATION SCHEMES

The goal of this research was to design the portion of the RapidRescue iPad application that represented the reversible causes of cardiac arrest based on a User-Centered Design (UCD) methodology in consultation with healthcare professionals at the Medical University of South Carolina. The research was conducted in two phases: the first phase, involved the design of the different information organization schemes following a user-centered design approach (Chapter III) and the second involved an experimental study to test the performance of the schemes in a simulated cardiac arrest event (Chapter V). Two organizational schemes were conceptualized using a UCD methodology. This methodology, adapted from Ulrich and Eppinger (Ulrich & Eppinger, 2012), was customized* to suit the needs of this research and included the following steps:

1. Identification of user needs
2. Identification of metrics
3. Concept generation, detailed design and refinement
4. Concept testing

Phase I of this research involved Steps 1 and 2 and was based on interviews conducted on 12 July 2012. Phase II of this research, which involved Steps 3 and 4, focused on generating, refining and testing the design schemes with representative users in simulated cardiac arrest events.

*Certain steps of the U and E methodology such as competitive benchmarking were excluded from this study because they were not applicable.

Identification of user needs--card sorting and focus groups

Step one began with interviews of fourteen medical professionals, after receiving joint approval from the Institutional Review Boards at the Medical University of South Carolina and Clemson University. To identify effective alternative organizational schemes based on user needs, a card sorting activity was used. Several studies have indicated this technique is effective for determining the information architecture of a system (Nielsen & Sano, 1995), (Harper et al., 2003) and (Faiks, 2000).

The card sorting activity was conducted with 6 representative users from the 14 interviewed-- 3 residents and 3 nurses each doing one card sort, to determine their preferred organizational schemes and the bases for their preferences. At the beginning of the activity, the researcher introduced the card sorting procedure by demonstrating different methods for sorting the face cards in a stack of playing cards. To give the participants experience in performing a card sorting activity, they were then asked to sort cards containing grocery items into different categories. This activity was followed by the sorting of cards containing the 12 actual common reversible causes of cardiac arrest. Figure 3.1 depicts an unsorted pile of cards containing the reversible causes prior to sorting.

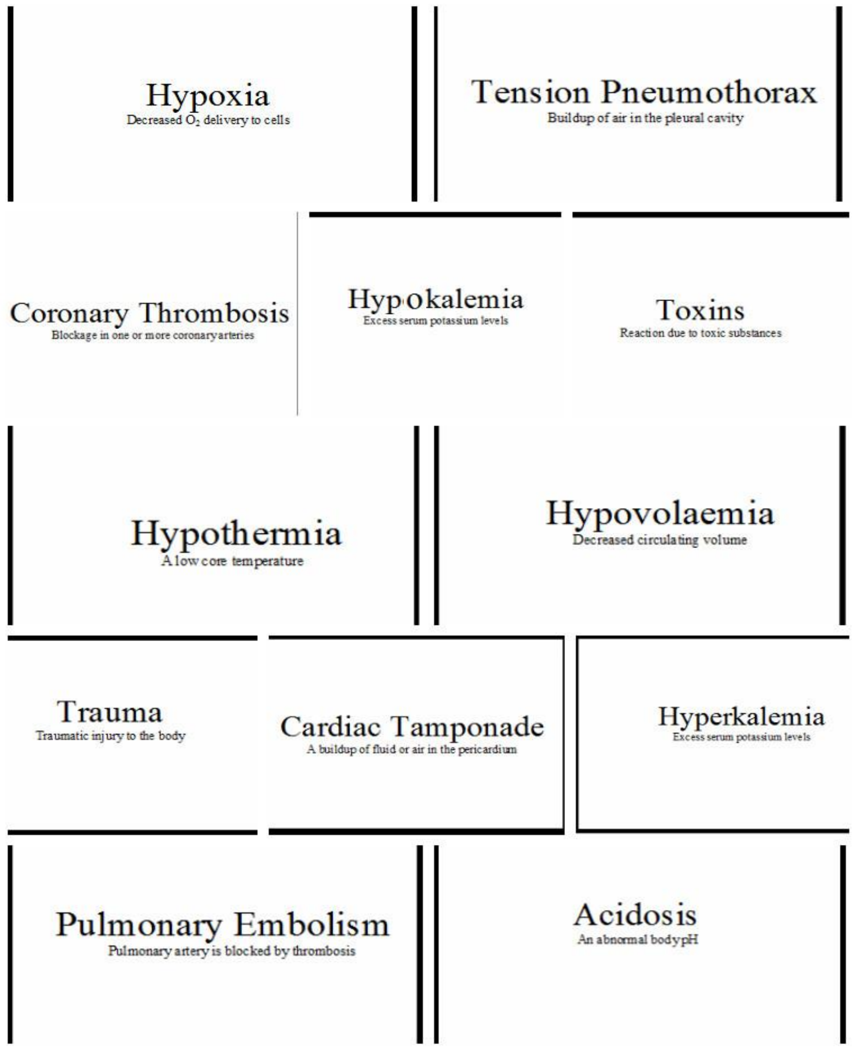

Figure 3.1 Pile of the cards containing reversible causes before sorting

Results of Phase-I

The card sorting results were recorded and upon analysis resulted in the following three organizational structures:

Mnemonic-based scheme (currently used)

One participant, an Advanced Cardiac Life Support instructor, said that she followed this system as is because she had memorized the causes this way for teaching purposes.

The systems-based scheme

Three participants indicated that they used a systems-based approach to identify the reversible causes, based on the cardiac, pulmonary and metabolic/endocrine systems. This scheme is referred to here as the systems-based scheme.

The mixed design scheme

Two participants used a mixed approach including both a systems-based approach for assessing the cardiac and pulmonary causes and a lab results approach for the metabolic/endocrine causes. This scheme is referred to here as the mixed design scheme.

Following the card sorting exercise, the remaining 8 professionals were divided into two focus groups, each with a set of 2 doctors and 2 nurses. All members of both groups were considered to be experts with extensive experience. They were shown the three design schemes that resulted from the card sort exercise and asked if they would be practical during a real-life code event. The first set of participants agreed that the organizational schemes resulting from the card sorts were logical and that the current Hs and Ts scheme was not very practical. However, they recommended testing it along with the other two because they believed that the instructor who used it represented many people across other hospitals that use mnemonics to remember the reversible causes in general practice. The second set of participants developed a different organizational scheme that involved an extensive use of reversible causes including ones not part of the American Heart Association (AHA) guidelines. Since this study aims to organize the causes recommended by the AHA guidelines, this scheme was not considered for further development.

The next step was the identification of need statements based on these results. Ulrich & Eppinger (2011) state "a need statement is a high-quality information channel that runs directly between the users of a system and the developers of a system" (p. 74, Ulrich and Eppinger, 2011). Table 3.1 presents the comments of the users during the card sorts and focus groups and the resulting need statements interpreted by the researcher.

Table 3.1

User responses and interpreted needs

Question/Prompt	***Sample user statement***	***Interpreted Need***
Do you think the Hs and Ts mnemonic is a practical approach for remembering the reversible causes? Why?	"No. There are too many Hs and Ts for me to remember." (3 of 6 users agreed)	The information organization of reversible causes reduces the users' mental workload.
	"They don't match the arrangement of systems such as the cardiac, pulmonary and metabolic systems in the body." (2 of 6 users agreed)	The reversible causes are organized in a manner that is easy-to-use.
	"I am an instructor, so I already have the causes memorized according to the Hs and Ts mnemonic method."(1 user)	The information organization of reversible causes is easy to adopt.
On what basis did you group the causes together?	"I think of what is readily available to me in terms of a patient, for e.g. lab reports, to assess causes based on them first." (2 users agreed)	The information organization of reversible causes works well with the available data sources.
	"On a systems basis because I assess the reversible causes by considering the systems of the body." (4 of 6 users agreed)	The information organization of reversible causes supports identification of a patient's condition.
Do you think it would help you if the reversible causes were arranged in the way you arranged them today for use during a code event?	"The systems based approach would help me more than the current Hs and Ts approach because I think through the causes this way most of the time."(4 of 6 users agreed)	The information organization of reversible causes encourages users to use it frequently.

Identification of metrics

The second step based on UCD methodology involved the identification of metrics resulting from the need statements, i.e. those testable measures that characterize what the desired system should do. Ulrich and Eppinger state that "the need statements generally expressed in the language of the customer may leave too much margin for subjective interpretation" (p. 92, Eppinger and Ulrich, 2011).

The metrics describe what a product or a system is expected to do in measurable detail from a designer's perspective. The translation of the needs into appropriate metrics, along with their measurement tools is shown in Table 3.2. The performance of the different organization schemes on each metric will be measured in Phase II by means of appropriate subjective and/or objective measures.

The responses to the subjective items/questions listed in Table 3.2 will be used to investigate how well the system addresses the interpreted needs. Responses to all items/questions in these questionnaires will be analyzed to calculate the overall system usability and overall workload from the System Usability Scale and from the NASA-TLX, respectively.

Table 3.2

Translation of the need statements into metrics

Need Statements	***Metrics***	***Measurement Tool***
The information organization of reversible causes reduces the users' mental workload.	Workload	Item No. 1, NASA-TLX: How mentally demanding was the task?
		Item No.5, NASA-TLX: How hard did you have to work to achieve this level of performance?
		Number of correct final diagnoses of reversible causes
The reversible causes are organized in a manner that is easy-to-use.	Ease-of-use	Question No.3, SUS: I thought the system was easy to use.
The information organization of reversible causes works well with the available data sources	Match with available data sources	Question No. 9, SUS: I felt very confident using the system.
The information organization of reversible causes is easy to adopt.	Adoptability	Question No. 7, SUS: I would imagine most people would learn to use this system quickly.
The information organization of reversible causes supports identification of the patient's condition.	Support of identification of patient condition	Time taken to identify the reversible cause in seconds
The information organization of reversible causes encourages users use it frequently.	Frequency of use	Question No.1, SUS: I think I would use this system frequently.

Concept generation, detailed design and refinement of the schemes

The next step began with the development of the concepts for information organization based on the data collected in Phase I, beginning with the creation of their prototypes using Task Architect®.

Discussions with the experts determined that the mnemonic scheme should be included in the concept testing since it has been used since 1997 in general practice emergency medicine as recommended by the American Heart Association. However, this scheme required modification of the names for some of the causes in order for them to fit into the Hs and Ts family for easy recollection. Since the study reported here involved a cognitive aid with the capability of displaying all the causes simultaneously, this research retained the actual starting letters of the reversible causes, not renaming them to begin with an H or a T. Thus, acidosis, coronary thrombosis, cardiac tamponade, and pulmonary embolism were considered as is, and not renamed as hydrogen ions, thrombosis (coronary), tamponade and thrombo-embolism, respectively. These causes were then arranged alphabetically. This design is known as the alphabetical scheme. An image from the application containing the alphabetical scheme after implementation is shown in Figure 3.2.

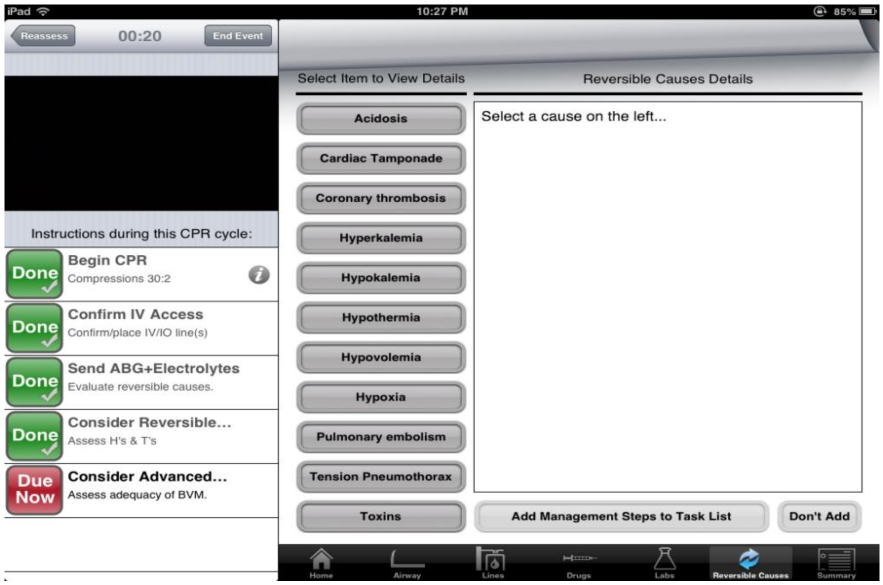

Figure 3.2 Reversible causes organized by the alphabetical scheme

The selected reversible cause is highlighted upon selection and a panel containing more details related to it is displayed in the box to the right as shown in Figure 3.3. Each cause was provided with a small description of its signs and symptoms to aid easy diagnosis. The description to the right was validated by an expert at the medical university.

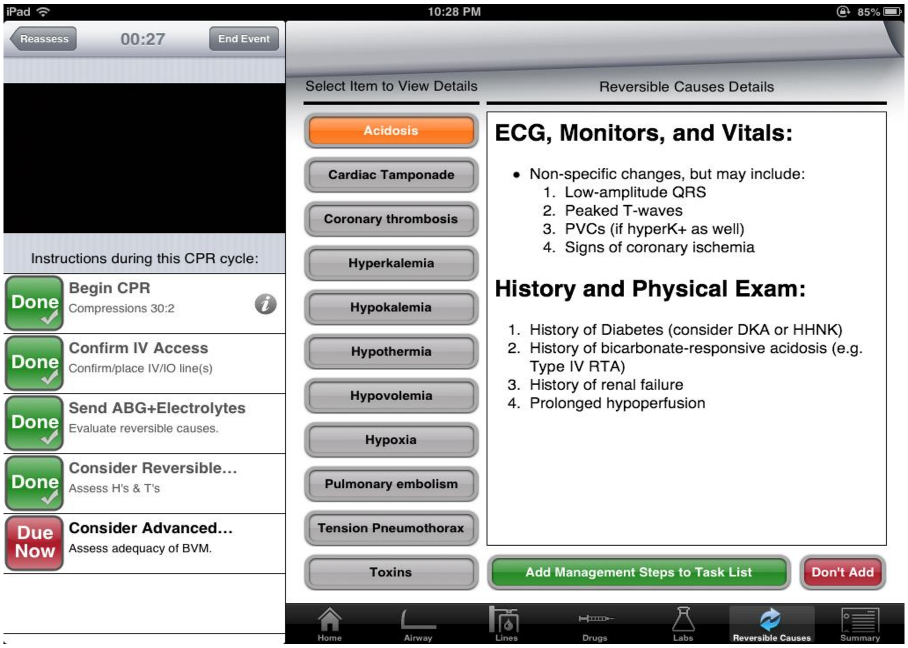

Figure 3.3 Alphabetical scheme showing more details of reversible causes

After refining and reaching agreement by the researcher on the design of the alphabetical scheme with the medical expert, the next step was to conceptualize and design the alternate organizational scheme namely, the context-sensitive scheme.

In order to do so, both the user and need statements from Phase I were further analyzed, resulting in several observations about alternate schemes in general.

- The systems-based method was a sub-set of the mixed design scheme.
- The mixed design scheme essentially organized those causes that could easily be diagnosed based on what is readily known and available first.

  This supports the importance of providing as many cues related to the patient's condition as possible in schemes.

- The mixed-design scheme was essentially a combination of the other two schemes.

  It was selected for further consideration. The mixed-design scheme was refined to incorporate contextual cues about the patient. This was referred to as the context-sensitive scheme, and was subsequently prototyped on paper as seen in Figure 3.4.

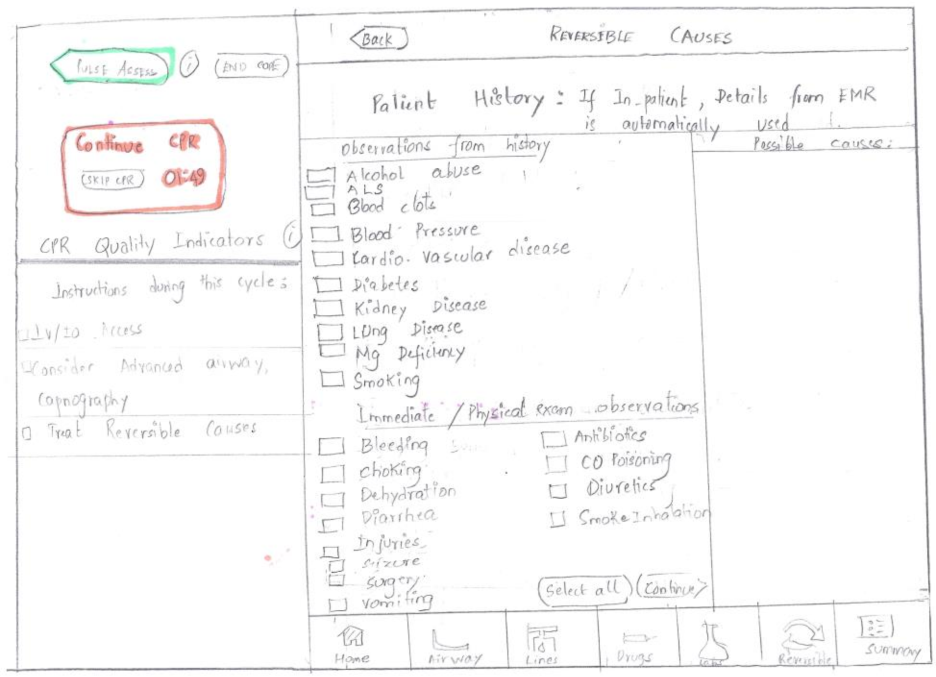

Figure 3.4 Paper-prototype for the context-sensitive scheme

The design of the context-sensitive scheme

To design the context-sensitive scheme, further analysis helped in the identification and development of cues pertaining to the context. First, the Medline Plus and NCBI databases were searched to identify the signs, symptoms and other information relating to the reversible causes during an emergency situation. The patient's past medical history, recent surgery, known medications, allergies and/or other hereditary diseases were also considered. An exhaustive list of such cues was then generated, with similar or related cues combined. Medical symptoms involving long words were abbreviated, taking into account the emergent nature of the situation. The list was then refined and organized with the help of a medical expert at the Medical University of South Carolina. A screenshot depicting some of the contextual cues that were implemented is shown in Figure 3.5.

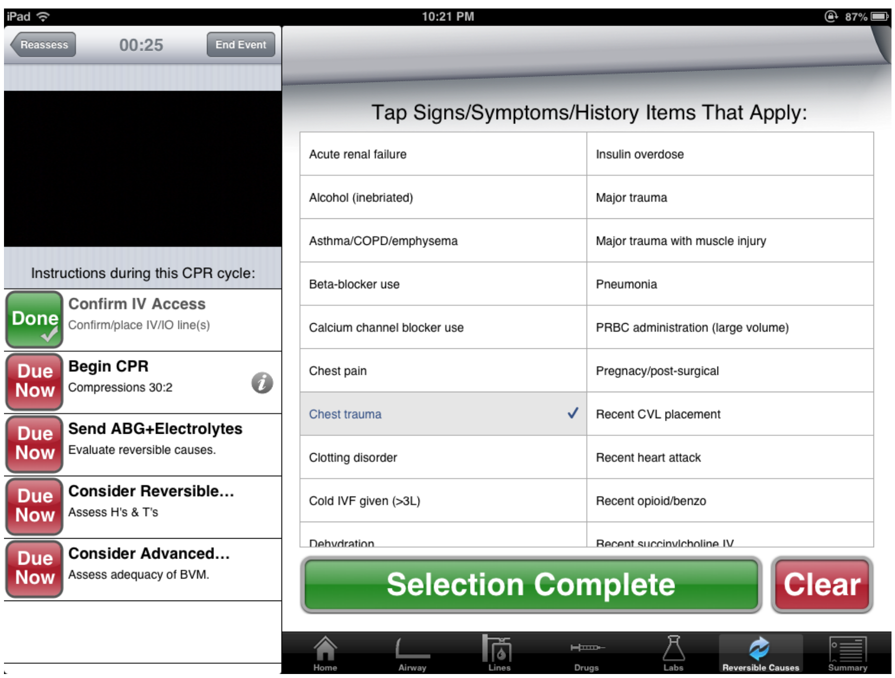

Figure 3.5 Cues for the context-sensitive scheme

This scheme was then refined to display a rank-ordered list, organizing the causes from the most likely to the least likely based on the cues checked as being applicable to the case as shown in Figure 3.6. Similar to the alphabetical scheme, upon selection of a cause, its details are displayed in the space provided on the right.

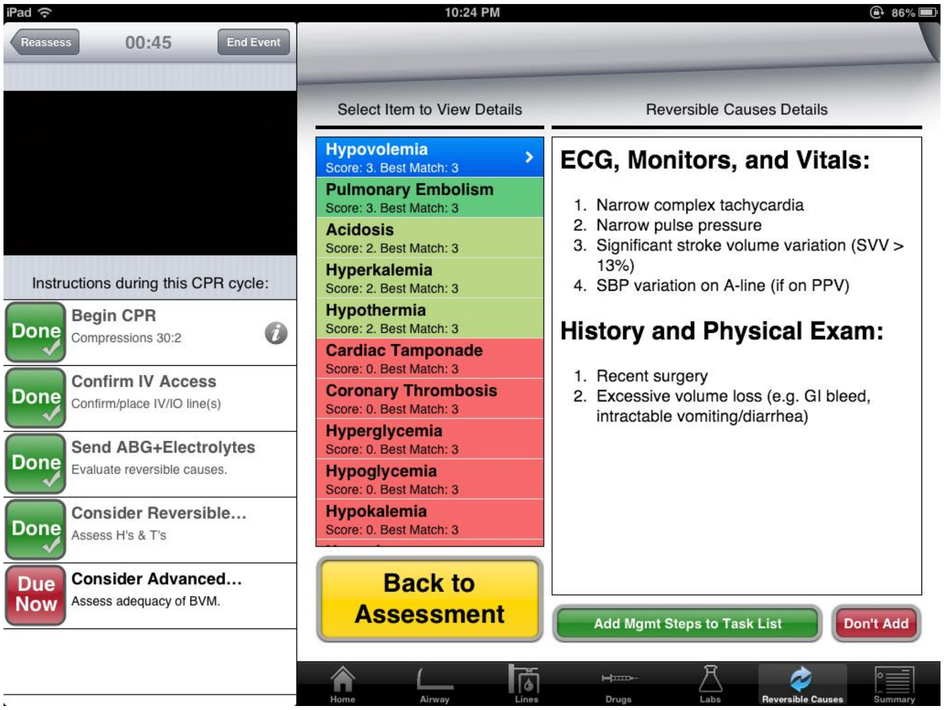

Figure 3.6 Context-sensitive scheme showing more details

Each reversible cause was assigned an association score for each contextual cue, a higher score representing a higher association of cues with the cause. For the purposes of this research, the range of the individual scores that could be assigned for each cue was 0-3. This scoring system was determined by experts at the Medical University based on evidence from the literature, experience and the standards of medical practice.

Scoring system

To illustrate how the scoring system works, an arbitrary case using the 6 cues of - Alcohol inebriated, Asthma/COPD/Emphysema, Beta-blocker use, Insulin overdose, Major trauma, and Major trauma with bleeding is considered as seen in Figure 3.7 below:

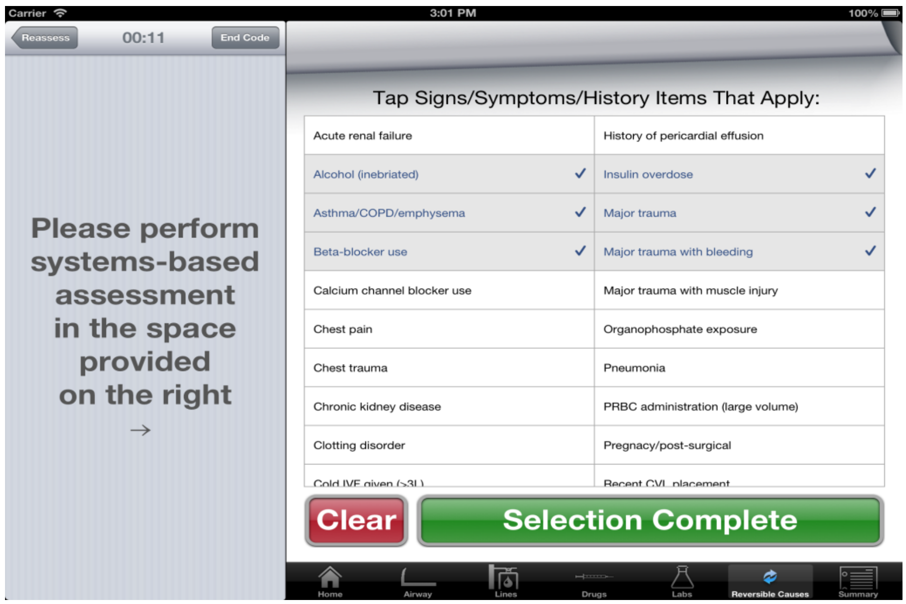

Figure 3.7 An example to illustrate the scoring system in the context-sensitive scheme

The scores assigned for each selection are shown in the Table 3.3.

Table 3.3

Relative scores assigned to reversible causes for each selected cue

Cue #	Name	Reversible causes associated	Score for the associated cause
1	Alcohol inebriated	Acidosis	1
2	Asthma/COPD/Emphysema	Hypoxia	2
		Tension Pneumothorax	1
3	Beta-blocker use	Hyperkalemia	1
		Toxins	1
4	Insulin overdose	Hypoglycemia	2
		Hypokalemia	3
5	Major trauma	Hypovolemia	3
6	Major trauma with bleeding	Trauma	2

Note: All other causes are assigned a score of 0.

As this table shows, some cues resulted in a relative score of 3 for some causes, 2 for others and 0 for some others. A moderate association, such as the one between insulin overdose and hypoglycemia, resulted in a score of 2 for hypoglycemia while a high association of the same cue with hypokalemia, resulted in a score of 3. A second example of a relatively low score is seen in the case of beta-blocker use and hyperkalemia.

Then, a sum of scores of the cues for each individual reversible cause was calculated, with the cause with the highest total score being the best match. If two different cues are associated with the same reversible cause, the sum of their association scores would be calculated. The reversible causes are then displayed in the descending order of their scores as shown in Figure 3.8.

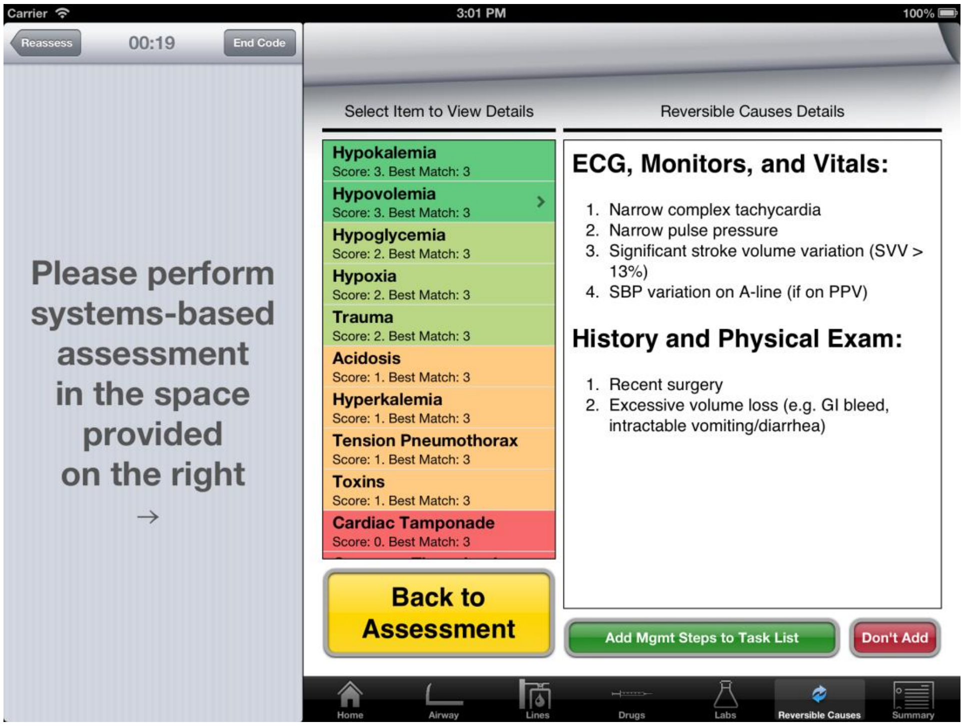

Figure 3.8 Example showing rank-ordered scores in the context-sensitive scheme

If two causes have the same score, they are sub-sorted alphabetically. The causes are also assigned a background color based on a cue's score relative to the best match score.

Both schemes, the alphabetical and context-sensitive, were then implemented in the Rapid Rescue iPad application with the help of a Systems Programmer at the Medical University of South Carolina.

CHAPTER IV

HYPOTHESES

To determine the most effective organizational scheme between the alphabetical and the context-based schemes, both developed based on results obtained in Phase I, the following hypotheses were investigated during Phase II.

Hypothesis: It is hypothesized that in terms of the time taken to identify a reversible cause, the number of errors, the number of keystrokes needed to identify a reversible cause, the number of deviations from recommended treatment steps completed after identifying a reversible cause, the perceived usability and the perceived mental workload:

The currently used Hs and Ts mnemonic based alphabetical scheme will result in more time to identify a reversible cause, a higher number of errors, a lower number of keystrokes, a higher number of deviations from recommended treatment steps completed after its identification, fewer correct identifications of reversible causes, a lower perceived usability in using the scheme and a higher perceived mental workload.

The results for the performance measures of the time taken to identify a reversible cause, the number of keystrokes, number of errors, and the number of deviations from recommended steps after identification are expected because it was identified from the card-sorting activity that the Hs and Ts are not organized in a way that makes them easy for medical professionals to conceptualize and use. Moreover, the majority of users agreed that the Hs and Ts scheme is not very effective during the card sort.

The results for the subjective satisfaction measures of perceived usability and perceived mental workload are expected because the mnemonic based alphabetical scheme does not match the mental model of the users based on the results of the card sort and the focus groups. Research has shown that a method of presentation without an intuitive organizational scheme can reduce usability while simultaneously increasing workload and frustration (Otter & Johnson, 2000).

CHAPTER V

INVESTIGATION OF THE ORGANIZATION SCHEMES

Concept Testing

This final step of the UCD methodology adapted for this research, concept testing, was conducted using simulated cardiac arrest scenarios with 11 representative healthcare professionals serving as team leaders. These Advanced Cardiac Life Support (ACLS) trained resident physicians were recruited via email or word-of-mouth to participate in these simulations. An additional member, a simulation specialist, trained in the MUSC Standardized Patient and Standardized Healthcare Worker Programs was recruited to be a part of the research team to assist in setting up and administering the scenarios.

Testing Environment

The simulated scenarios took take place in the SimLab in the Storm Eye Institute at the Medical University of South Carolina. This lab, used in medical education, is fully equipped with all the necessary equipment to simulate a cardiac arrest event, including cardiac monitors, airway management devices, and a crash cart to carry the necessary drugs, intra-venous lines, defibrillators, and other items that might be required for the scenario. The layout of the SimLab is shown in Figure 5.1.

Figure 5.1 The simulation room at MUSC with related equipment and mannequin

Personnel and their roles

Each scenario involved four personnel:

- Participant—a doctor/ team leader responsible for managing the cardiac arrest event
- Reader—the researcher, playing the role of a real-life nurse-responder who helped the team leader with the iPad application
- Simulation specialist—a fellow researcher responsible for setting up, beginning, changing, and ending the scenarios

- Co-researcher—a graduate student colleague of the researcher, responsible for performing chest compressions during CPR, airway management and shock administration

Experimental Design

This study used a within-subjects design with two-factors. The information organization scheme and scenarios were the two within-subjects factors. The order in which the participants saw the two organization schemes was counterbalanced: The odd numbered participants saw the alphabetical scheme first while the even numbered saw the context-sensitive scheme first. All participants were given a 4-minute break after the first scheme before using the corresponding alternate scheme. The scenarios were assigned randomly to the participants. The order of assignment for the organizational schemes and scenarios are detailed in Table 5.1. The computer program `Ranper.exe` was used to generate the random order for the scenarios.

Table 5.1

Random assignment order for organization schemes

P#	***Interface1***	***Scenario1***	***Scenario 2***		***Interface 2***	***Scenario 3***	***Scenario 4***
1	Alphabetical	Hyperkalemia 1	Hypovolemia 1	Break	Context-sensitive	Hypovolemia 2	Hyperkalemia 2
2	Context-sensitive	Hypovolemia 1	Hyperkalemia 1		Alphabetical	Hypovolemia 2	Hyperkalemia 2
3	Alphabetical	Hyperkalemia 1	Hypovolemia 1		Context-sensitive	Hypovolemia 2	Hyperkalemia 2
4	Context-sensitive	Hypovolemia 1	Hyperkalemia 1		Alphabetical	Hypovolemia 2	Hyperkalemia 2
5	Alphabetical	Hyperkalemia 1	Hypovolemia 1		Context-sensitive	Hyperkalemia 2	Hypovolemia 2
6	Context-sensitive	Hypovolemia 1	Hyperkalemia 1		Alphabetical	Hypovolemia 2	Hyperkalemia 2
7	Alphabetical	Hyperkalemia 1	Hypovolemia 1		Context-sensitive	Hypovolemia 2	Hyperkalemia 2
8	Context-sensitive	Hyperkalemia 1	Hypovolemia 1		Alphabetical	Hypovolemia 2	Hyperkalemia 2
9	Alphabetical	Hyperkalemia 1	Hypovolemia 1		Context-sensitive	Hypovolemia 2	Hyperkalemia 2
10	Context-sensitive	Hyperkalemia 1	Hypovolemia 1		Alphabetical	Hypovolemia 2	Hyperkalemia 2
11	Alphabetical	Hyperkalemia 1	Hypovolemia 1		Context-sensitive	Hypovolemia 2	Hyperkalemia 2

Note: Suffixes 1, 2denote variant scenarios to hyperkalemia and hypovolemia that are clinically distinct.

See Appendix C for descriptions of scenarios.

Independent Variables

The two independent variables in this study were the information organization scheme at two levels and the scenarios depicting the two most common reversible causes as identified by the American Heart Association (Neumar et al., 2010).

The two levels of the first independent variable, the information organization scheme, were as follows:

1. Information organization using the alphabetical scheme
2. Information organization using the context-sensitive scheme

The two levels of the second independent variable, the scenarios, are as follows:

1. Hyperkalemia
2. Hypovolemia

Dependent Measures

Both objective and subjective measures were collected for this study. The objective measures were categorized into efficiency--how efficient the participants were in identifying a reversible cause--and effectiveness --how effective the scheme was in helping them identify the cause as described below:

Efficiency measures:

- Time taken by each participant to provide a correct diagnosis of the reversible cause associated with the scenario

- Number of keystrokes needed to identify the reversible cause
- Number of unnecessary keystrokes
- Time saved by avoiding unnecessary keystrokes

Effectiveness measures:

- Number of errors in identifying a reversible cause for a scenario
- Number of deviations from recommended treatment steps

The subjective measures were:

- Perceived system usability
- Perceived workload
- Preference ranking.

Procedure

The research involved meeting the participants across two weeks. During the first week, the participants were trained on the use of the app as a cognitive aid and performed a few brief simulated scenarios. Data were collected, but were not considered for further analysis as it was a training session to control for individual differences due previous experience with the use of an iPad. In the first week, before the scheduled arrival of the participant at the SimLab, the reader (researcher), co-researcher and simulation specialist coordinated and practiced conducting the scenarios. Upon arrival, each participant was given a brief introduction on the purpose of the research and an overview of the iPad application. Then, he/she read and signed the informed consent form (Appendix A) and completed a pretest questionnaire asking for demographic data (Appendix B). Next, the participant proceeded to use the application in simulated cardiac arrest scenarios, the aim being to practice using it while managing the scenarios.

During the second week, the participants performed 4 simulated cardiac arrest scenarios in the order seen in table 5.1. Data collected on the dependent measures were used for analysis. Upon arrival, the participant was briefed on the tasks. After being given the opportunity to ask any questions, he/she then proceeded to perform four simulated cardiac arrest scenarios, 2 scenarios involving hypovolemia and 2 scenarios with hyperkalemia. A 4-minute break (corresponding to 2 CPR cycles) was provided between the administrations of the two schemes (after the first set of two scenarios).

All four scenarios—2 variations of hyperkalemia and 2 variations of the hypovolemia--are detailed in Appendix C, along with the lab reports used for them. These scenarios representing a pulseless cardiac arrest and the corresponding causes were derived from Section 8 of the American Heart Association guidelines (Neumar et al., 2010). Despite being variations of the same two causes, the scenarios are regarded clinically distinct by medical practitioners due to differences in patient circumstances, symptoms and setting.

The simulation specialist read the scenario (Appendix C) aloud to the participant. The co-researcher provided simulated chest compressions and followed the procedures as instructed by the participant during CPR. As CPR continued, the reader read the treatment procedures from the app until he/she reached the "reversible causes" portion of the application. The reader then handed the iPad to the participant, who was asked to determine the reversible cause associated with the scenario.

Each scenario lasted 4 minutes (2 CPR cycles), with the participant being instructed to provide his/her final determination of the reversible cause within that time limit. Following the determination of the reversible cause, the participant was asked to administer the treatment steps pertaining to the reversible cause selected, again within the 4-minute time period allotted for this scenario. Then, the participant completed the next scenario immediately following the first scenario. After completing both scenarios following this procedure, the participant was transferred to the adjacent room where he/she completed the NASA-TLX workload questionnaire (Appendix D) and the System Usability Scale questionnaire (Appendix E). The 4-minute time interval was tracked using a stop watch. At the end of 4 minutes, the participant was invited back into the simulation room to continue with the remaining two scenarios, this time using a different organization scheme for the reversible causes. Upon completion of the remaining two scenarios, the participants once again completed the NASA-TLX and SUS questionnaires. In addition, the participants also completed a preference ranking questionnaire, asking them to rank the organization schemes in terms of their preference (Appendix F).

CHAPTER VI

RESULTS

All the datasets containing all the steps performed by the participants along with their timestamps were organized, reviewed and consolidated into groups based on the dependent variables. These consolidated datasets were then checked for statistical consistency with normality and sphericity assumptions. For the dependent measures that satisfied these two assumption, IBM- SPSS 19 was used to conduct a 2-way within-subject analysis of variance (ANOVA) to determine the presence of statistically significant differences along the dependent measures across the 2 organization schemes and scenarios. Where appropriate, when the intent was to compare the measures between the two schemes and not between the scenarios, a one-way repeated measure ANOVA was used. For measures that did not satisfy the normality and /or sphericity assumption, first, appropriate transformations were applied. If transformations were ineffective, non-parametric tests, specifically either a Friedman's test, a non-parametric analog of 2-way repeated measures ANOVA, or a Wilcoxon's signed-rank test, a non-parametric analog of the dependent samples t-test, was used to determine the presence of significant differences. Of the 11 participants, the one whose time for identifying the reversible causes was excessively longer (t=164s) than the others (M=31.345) was determined to be an outlier and thus, was not considered for analysis.

Time

Methodology:

The time taken to identify a final reversible cause in each scenario was measured using a timer embedded along with the Rapid Rescue application in the iPad. It was measured from when the participant highlighted “consider reversible cause” until he/she pressed “add to treatment steps.” It was found that the normality assumption was not valid initially as the distribution was moderately positively skewed. The subsequent application of square root transformation normalized the distribution. The sphericity assumption was verified by Mauchly’s sphericity test.

Analysis of the results for time taken to identify the reversible causes:

A 2-way repeated measures ANOVA was conducted, and a significant difference was found between the time taken to identify the causes in the two schemes, $F(1, 8) = 6.958$, $p = .027$. Users took significantly less time to identify the reversible causes using the alphabetical scheme ($M = 21.95$, $SD = 2.07$) than with the context-sensitive scheme ($M = 40.72$, $SD = 2.94$). The descriptive statistics and the results of the 2-way ANOVA are listed in Tables 6.1 and 6.2, respectively. A graph showing the mean values for the time taken across the schemes and scenarios is displayed in Figure 6.1.There were no significant differences observed between the two types of scenarios, hypovolemia and hyperkalemia. The interaction effect between the time and the type of scenario was not significant.

Table 6.1

Descriptive statistics for the transformed data for time

	Mean transformed time(actual time in seconds)	Std. Deviation of transformed time(actual time in seconds)
Alphabetical scheme hyperkalemia	4.93(24.30)	1.59(2.52)
Alphabetical scheme with hypovolemia	4.42(19.60)	1.28(1.63)
Context-sensitive scheme with hyperkalemia	7.00(49.09)	1.05(1.10)
Context-sensitive scheme with hypovolemia	5.68(32.35)	2.19(4.79)

Table 6.2

Two-way ANOVA results for the transformed time

Source	Type III Sum of Squares	df	Mean Square value	F	Sig.
Schemes	27.821	1	27.821	6.958	.027
Scenarios	8.304	1	8.304	3.545	.092
Schemes * Scenarios	1.663	1	1.663	.938	.358

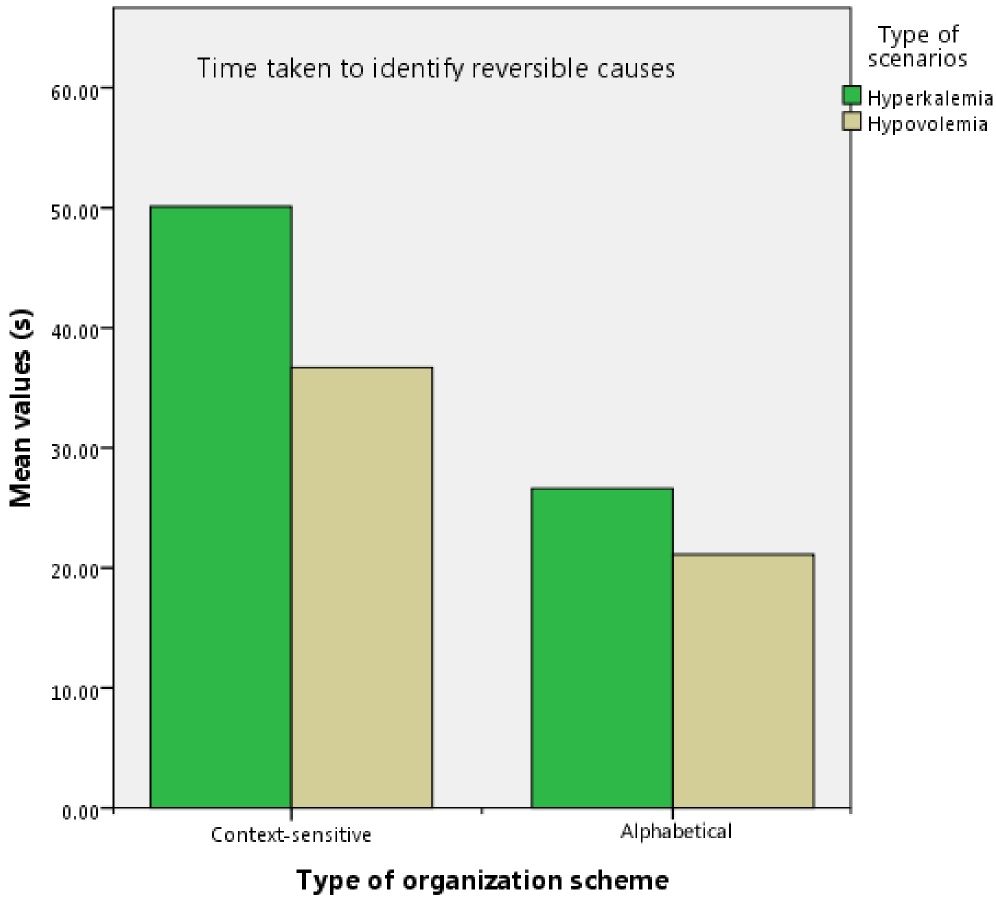

Figure 6.1a Mean time taken to identify a reversible cause

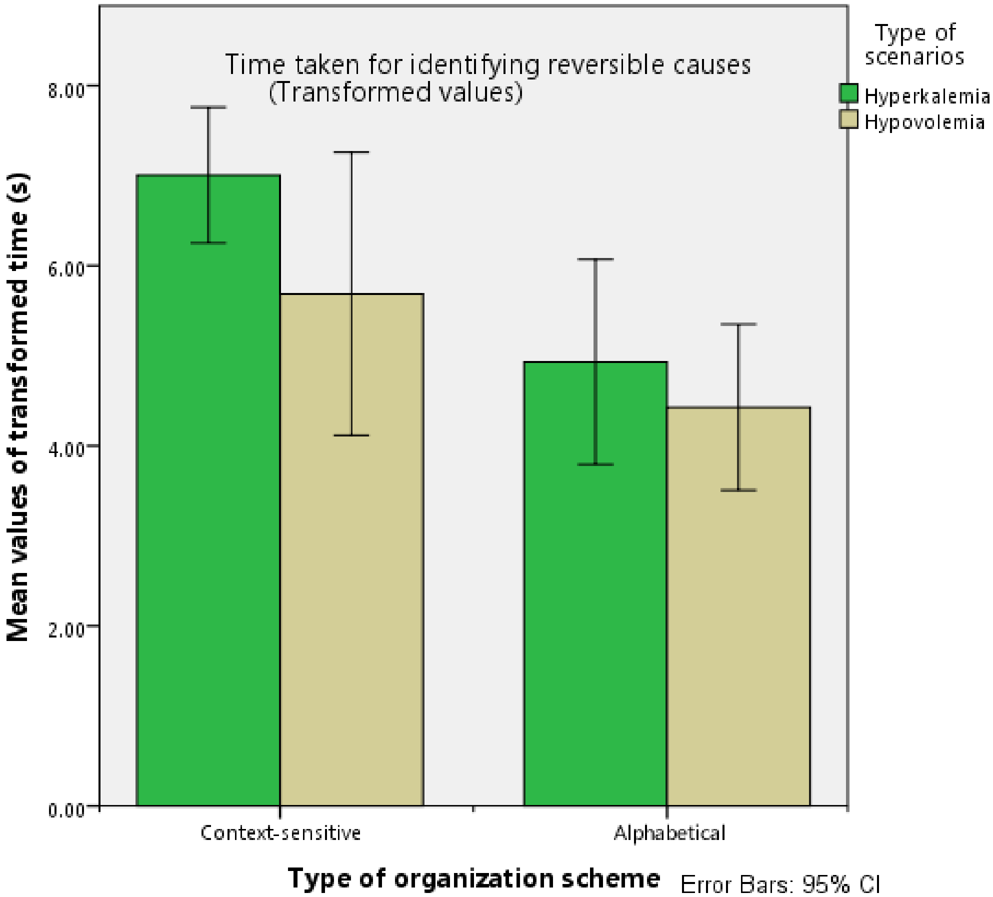

Figure 6.1b Mean transformed time taken to identify a reversible cause

Number of errors

The total number of incorrect final identifications of reversible causes for each participant was tracked and recorded. All participants correctly identified the definitive reversible cause and proceeded with the treatment steps within the time allotted of 2 CPR cycles. Thus, the number of errors was 0, for all four treatment conditions.

Number of keystrokes

Methodology:

The total number of keystrokes from the first step ("consider reversible cause") until definitive final identifications of the reversible causes for each participant was tracked and recorded. The number of keystrokes may function as a measure of efficiency of a system, potentially affecting its usability. The data were non-normal and remained so even after applying appropriate transformations.

Results of the analysis for number of keystrokes:

A Friedman's test revealed that the number of keystrokes for the alphabetical scheme was significantly lower than for the context-sensitive scheme, χ^2 (3, *N* =10) =1 6.055, *p* = .001. The post-hoc pairwise comparisons test using a Wilcoxon's signed-rank test revealed that the number of keystrokes for hyperkalemia in the alphabetical scheme (*Mdn* = 1.70) was significantly lower than the number of keystrokes for hyperkalemia in the context-sensitive scheme (*Mdn* = 3.55), *Z* = -1.850, *p* =.008. A significant difference was also observed between the number of keystrokes for the hypovolemia scenario of the alphabetical scheme and for hyperkalemia in the context-sensitive scheme; however, this finding was of no value in terms of this research because the comparison involved two different schemes. The descriptive statistics for the Friedman's test are provided in Table 6.3, and the descriptive statistics for the pair-wise comparisons using a Wilcoxon's signed rank test are shown in Table 6.4. Mean values for the number of keystrokes are displayed in the graph in Figure 6.2.

Table 6.3

Descriptive statistics for the Friedman's test for number of keystrokes

N	10
Test Statistic	16.055
Degrees of freedom	3
Asymptotic Sig.(2-sided test)	0.001

Table 6.4

Pairwise comparisons results from Wilcoxon's signed-rank test for number of keystrokes

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Keystrokes_AlphabeticalHyper-Keystrokes_AlphabeticalHypo	-.100	.577	-.173	.862	1.000
Keystrokes_AlphabeticalHyper-Keystrokes_ContextHypovo	-1.250	.577	-2.165	.030	.182
Keystrokes_AlphabeticalHyper-Keystrokes_ContextHyper	-1.850	.577	-3.204	.001	.008
Keystrokes_AlphabeticalHypo-Keystrokes_ContextHypovo	-1.150	.577	-1.992	.046	.278
Keystrokes_AlphabeticalHypo-Keystrokes_ContextHyper	-1.750	.577	-3.031	.002	.015
Keystrokes_ContextHypovo-Keystrokes_ContextHyper	.600	.577	1.039	.299	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

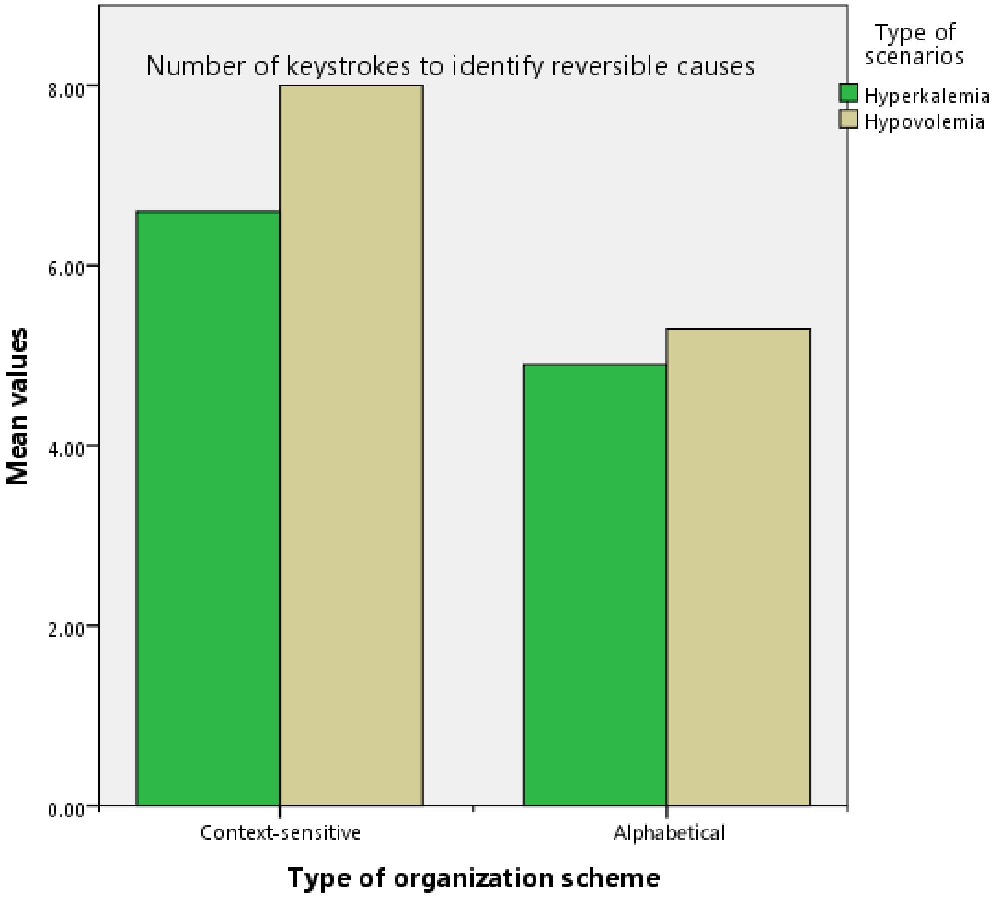

Figure 6.2 Mean number of keystrokes taken to identify a reversible cause

Number of unnecessary keystrokes

Methodology:

Even though the participants identified all of the definitive causes correctly using both schemes, some participants performed unnecessary keystrokes. Two participants added irrelevant diagnostic keystrokes in the iPad application termed here as close calls, which could potentially affect the outcome of the patient. See Figure 6.3 below for an example.

1. User highlighted reversible cause: Hyperkalemia PART 8 ***to be for both pulsatile and pulseless***. (Preferred step)
2. Add Steps pressed for: Hyperkalemia PART 8 ***to be for both pulsatile and pulseless***.(Preferred step)
3. User highlighted reversible cause: Coronary Thrombosis PART 8. (Unnecessary step)
4. Add Steps pressed for: Coronary Thrombosis PART 8. (Unnecessary step)

Figure 6.3 Example of a close call

Here, keystrokes 3 and 4 were unnecessary, because they were added after adding the correct reversible cause already. Since such steps might influence the task saturation of the physician, the usability of the system, and, thus, potentially the reliance on the decision aid, they were analyzed for both schemes. The distribution of the number of unnecessary keystrokes data was not normal, and subsequent transformations were not effective; therefore, the data were analyzed using non-parametric tests. Since the intent of this dependent measure was to identify the differences in unnecessary keystrokes between the two schemes focusing on their usability, not between the scenarios, data for the scenarios were combined and the analysis conducted with respect to the schemes.

Analysis of the results for the number of unnecessary keystrokes:

A Wilcoxon's signed rank test indicated that the median differences between the number of unnecessary steps in the context-sensitive scheme vs. the alphabetical scheme was significantly greater than 0 ($Z = -2.081$, $p = .037$). The descriptive statistics for the number of unnecessary keystrokes are found in Table 6.5. The results of the statistical test can be seen in Table 6.6, and a graph showing the mean numbers of unnecessary keystrokes across all conditions is given in Figure 6.4.

Table 6.5

Descriptive statistics for Wilcoxon's signed rank test for the number of unnecessary keystrokes

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
						25th	50th (Median)	75th
Unnecessary keystrokes in alphabetical scheme	20	.5000	.82717	.00	2.00	.0000	.0000	1.0000
Unnecessary keystrokes in Context-sensitive scheme	20	.0500	.22361	.00	1.00	.0000	.0000	.0000

Table 6.6

Wilcoxon's signed rank test results for the number of unnecessary keystrokes

N	20
Test Statistic	2
Standard error	5.766
Standardized test statistic	-2.081
Asymptotic Sig.(2-sided test)	0.037

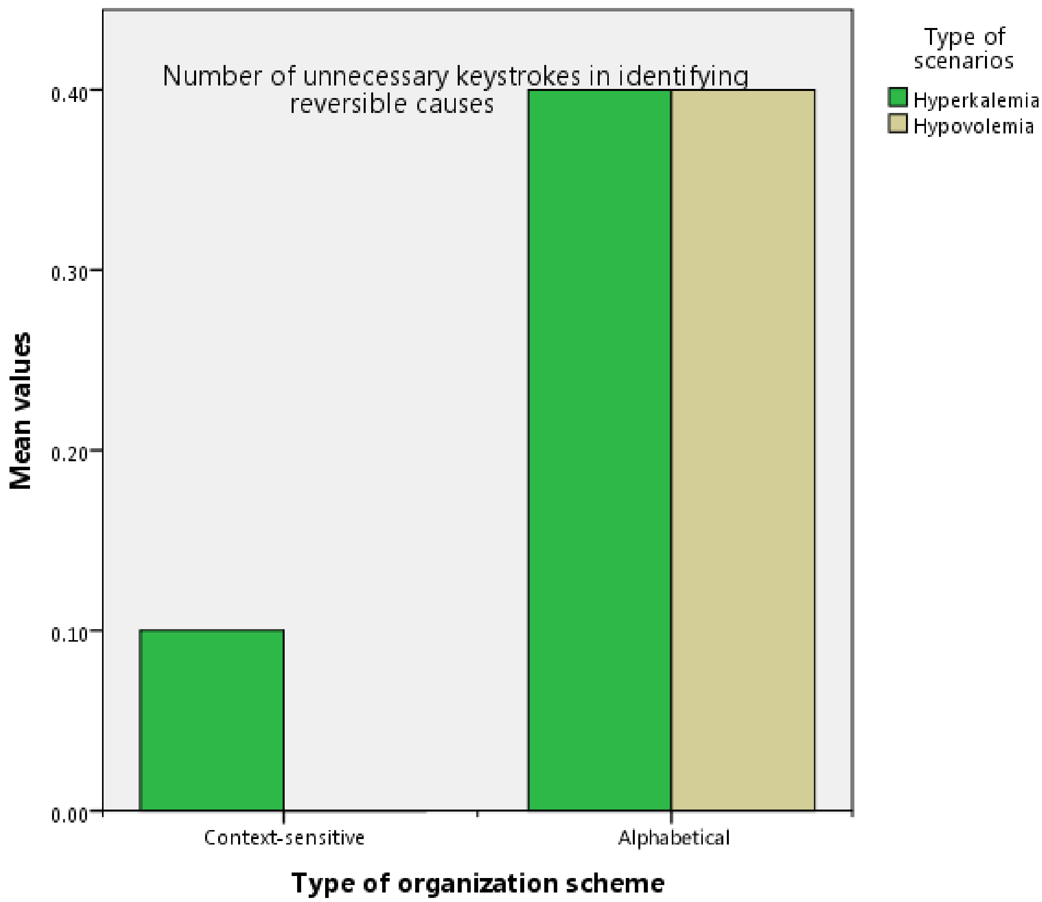

Figure 6.4 Mean number of unnecessary keystrokes taken to identify a reversible cause

Time spent on unnecessary keystrokes

Methodology:

The total time spent on unnecessary keystrokes was examined to determine if these unnecessary steps affected the time taken. Similar to the number of unnecessary keystrokes, the data for the scenarios were combined and the analysis was conducted only with respect to the two schemes. As the data were non-normal and transformations were ineffective, they were analyzed using a Wilcoxon's signed rank test.

The analysis of the results for time spent on unnecessary keystrokes:

A Wilcoxon's signed-rank test determined that the median differences between the time spent on unnecessary keystrokes in the alphabetical scheme vs. the context-sensitive scheme was significantly greater than 0 ($Z = -1.997$, $p = .046$). Table 6.7 shows the descriptive statistics for the time spent on unnecessary keystrokes, while Figure 6.5 displays the mean times for the two schemes.

Table 6.7

Wilcoxon's signed-rank test results for the time spent on unnecessary keystrokes

Test Statistics[b]

	Time spent using alphabetical scheme – Time spent using Context-sensitive scheme
Z	-1.997[a]
Asymp. Sig. (2-tailed)	.046

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

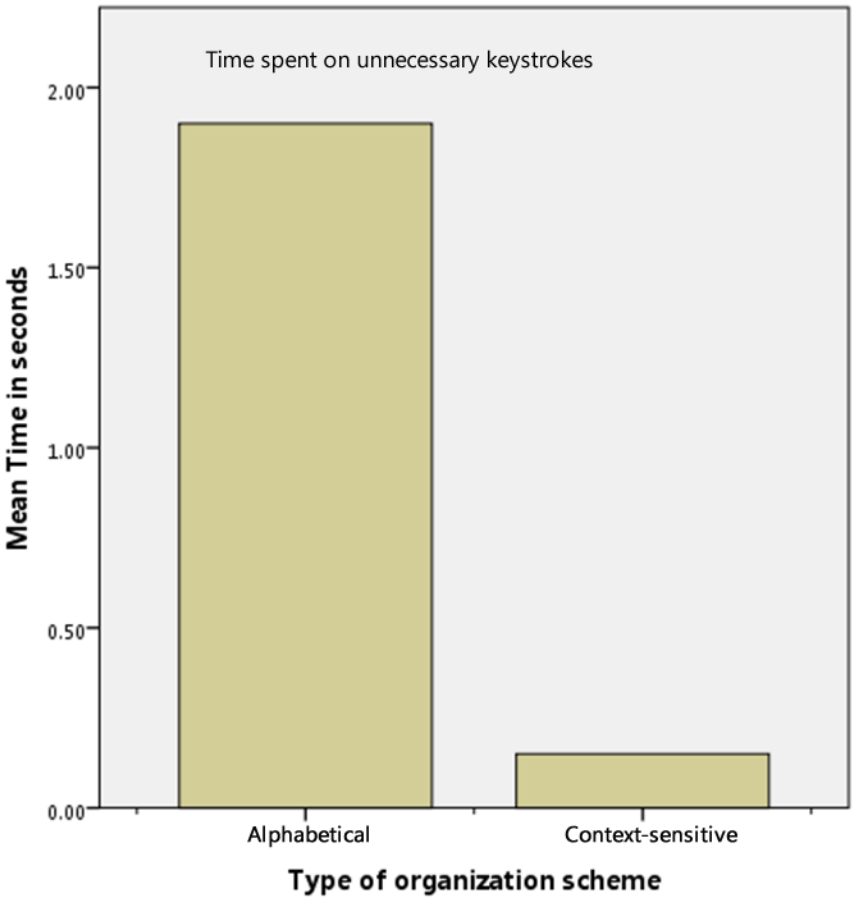

Figure 6.5 Mean time spent on unnecessary keystrokes

Number of deviations from the recommended treatment steps

Methodology:

The number of deviations from the recommended treatment steps administered upon identification of a final reversible cause within 2 CPR cycles (4 minutes) was calculated by counting the un-recommended treatment steps every time the participant identified and confirmed a reversible cause in the Rapid Rescue application. These data were recorded by the app and saved to a database from which they were later retrieved. The nine recommended treatment steps for hypovolemia and the eleven recommended for hyperkalemia listed in Appendix D were created and validated by experts at the medical university.

The number of steps deviating from the recommended steps was also categorized as commissions and omissions for further analysis.

- Commissions

  One participant performed an omission error for hyperkalemia, where he performed an additional electro-cardiogram (ECG) in both schemes, a deviation from the recommended steps. For the alphabetical scheme, two participants performed an additional central venous line (CVL) and ultrasound for hypovolemia, both of which are not recommended, and one participant performed an optimization of CPR, also not recommended. Thus, the total numbers of commissions were 4 for the alphabetical scheme and 1 for the context-sensitive scheme.

- Omissions

  One participant in the alphabetical scheme omitted 2 steps, leaving out both insulin and furosemide administration. Thus, the total numbers of omissions were 2 for the mnemonic scheme and 0 for the context-sensitive scheme.

The data from the two scenarios were combined, and the analysis was conducted only with respect to the schemes. The data for the number of deviations from the recommended steps were not normal. Thus, a non-parametric test was used.

The analysis of the results for the number of deviations from the recommended steps:

A Wilcoxon's signed rank test revealed that the median differences between the number of deviations from recommended steps in the context-sensitive scheme vs. the alphabetical scheme was significantly greater than 0 (Z=-2.070, *p*=.038). The descriptive statistics for the number of deviations from the recommended steps are given in Table 6.8, and the results from the Wilcoxon's test are given in Table 6.9, while a graph displaying the mean number of deviations across all conditions is presented in Figure 6.6.

Table 6.8

Descriptive statistics for the Wilcoxon's signed rank test for the deviations from the recommended steps

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
						25th	50th (Median)	75th
Deviations using alphabetical scheme	20	.4000	.75394	.00	2.00	.0000	.0000	.7500
Deviations using context-sensitive scheme	20	.0000	.00000	.00	.00	.0000	.0000	.0000

Table 6.9

Wilcoxon's signed rank test results for the deviations from the recommended steps

Test Statistics[b]

	Context_Sensitive_Deviations_Hyper - alphabetical _Deviations_Hyper
Z	-2.070[a]
Asymp. Sig. (2-tailed)	.038

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

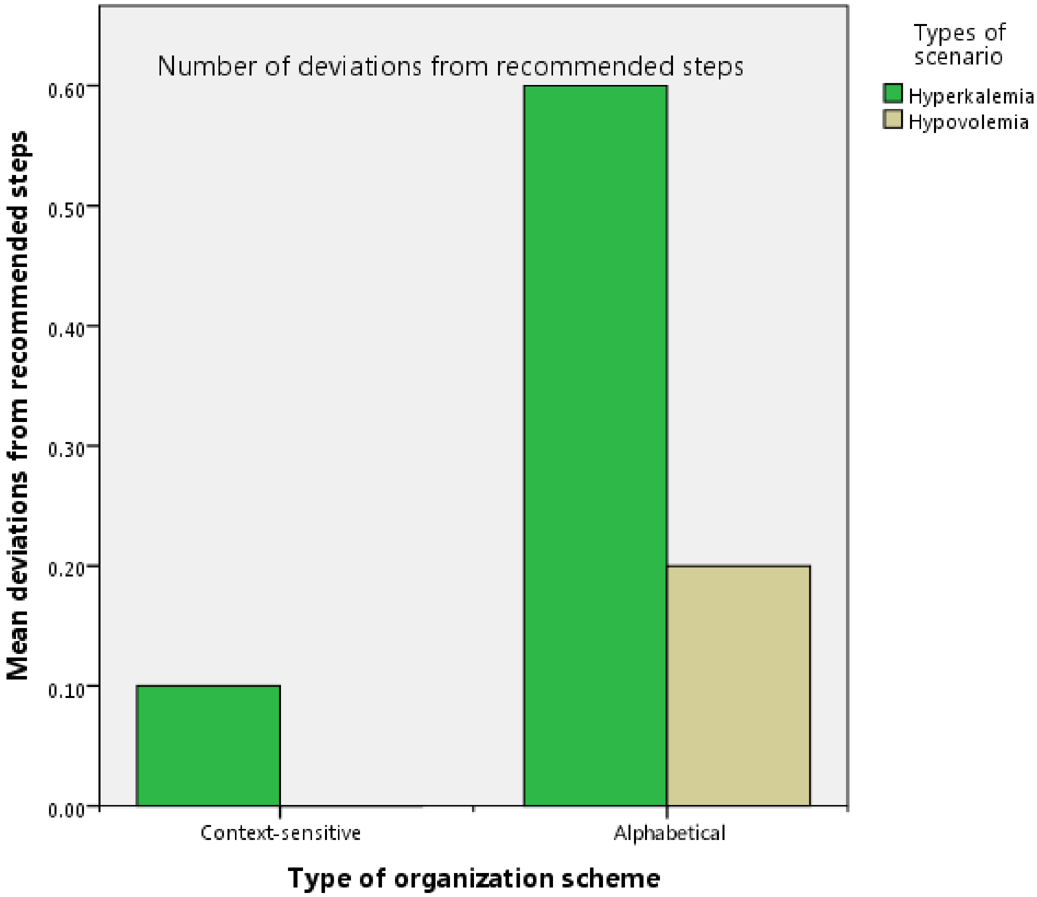

Figure 6.6 Mean number of deviations from the recommended steps

Perceived workload indices

Methodology:

The perceived workload was measured using the NASA-Task Load Index (NASA-TLX) as seen in Appendix F (Hart, S.G., & Staveland, L.E., 1988). The questions were ranked on a 7-point Likert scale, with the responses to Question 5 (performance) reverse coded because it was worded differently from the rest. The scores on all the items including mental demand, physical demand, performance, effort and frustration were then used to calculate the overall workload. All the data were distributed normally, and the Levene's statistic for the homogeneity of variances indicated that this assumption was satisfied.

The analysis of the results for the perceived workload indices:

A one-way repeated measures ANOVA indicated that effort was significantly higher for the context-sensitive scheme (*M* = 3.4, *SD* = .84) than for the alphabetical scheme (*M* = 2.2, *SD* = 0.91), *F* (1, 18) = 8.450, *p* =.033. Temporal demand was also higher for the context-sensitive scheme (*M* = 4.2, *SD* = 1.13) than for the alphabetical scheme (*M* = 2.9, *SD* = 1.37), *F* (1, 18) = 9.257, *p* = .007. The descriptive statistics and the results of the statistical tests for all workload indices are provided in Table 6.10, while the one way ANOVA results for the perceived workload are given in Table 6.11. A graph showing the mean scores across all conditions is displayed in Figure 6.7.

Table 6.10

Descriptive statistics for the NASA-TLX scores

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Mental Demand	Alphabetical	10	2.6000	1.34990	.42687	1.6343	3.5657	1.00	5.00
	Context-Sensitive	10	3.8000	1.39841	.44222	2.7996	4.8004	1.00	6.00
Physical Demand	Alphabetical	10	2.2000	1.13529	.35901	1.3879	3.0121	1.00	4.00
	Context-Sensitive	10	2.5000	1.43372	.45338	1.4744	3.5256	1.00	4.00
Temporal Demand	Alphabetical	10	2.9000	1.37032	.43333	1.9197	3.8803	1.00	5.00
	Context-Sensitive	10	4.2000	1.13529	.35901	3.3879	5.0121	2.00	6.00
Effort	Alphabetical	10	2.2000	.91894	.29059	1.5426	2.8574	1.00	4.00
	Context-Sensitive	10	3.4000	.84327	.26667	2.7968	4.0032	2.00	4.00
Frustration	Alphabetical	10	2.4000	1.42984	.45216	1.3772	3.4228	1.00	5.00
	Context-Sensitive	10	3.0000	1.05409	.33333	2.2459	3.7541	1.00	4.00

Table 6.11

One-way ANOVA results for NASA-TLX

		Sum of Squares	df	Mean Square	F	Sig.
Mental Demand	Between Groups	7.200	1	7.200	3.812	.067
	Within Groups	34.000	18	1.889		
	Total	41.200	19			
Physical Demand	Between Groups	.450	1	.450	.269	.610
	Within Groups	30.100	18	1.672		
	Total	30.550	19			
Temporal Demand	Between Groups	8.450	1	8.450	5.337	.033
	Within Groups	28.500	18	1.583		
	Total	36.950	19			
Effort	Between Groups	7.200	1	7.200	9.257	.007
	Within Groups	14.000	18	.778		
	Total	21.200	19			
Frustration	Between Groups	1.800	1	1.800	1.141	.300
	Within Groups	28.400	18	1.578		
	Total	30.200	19			

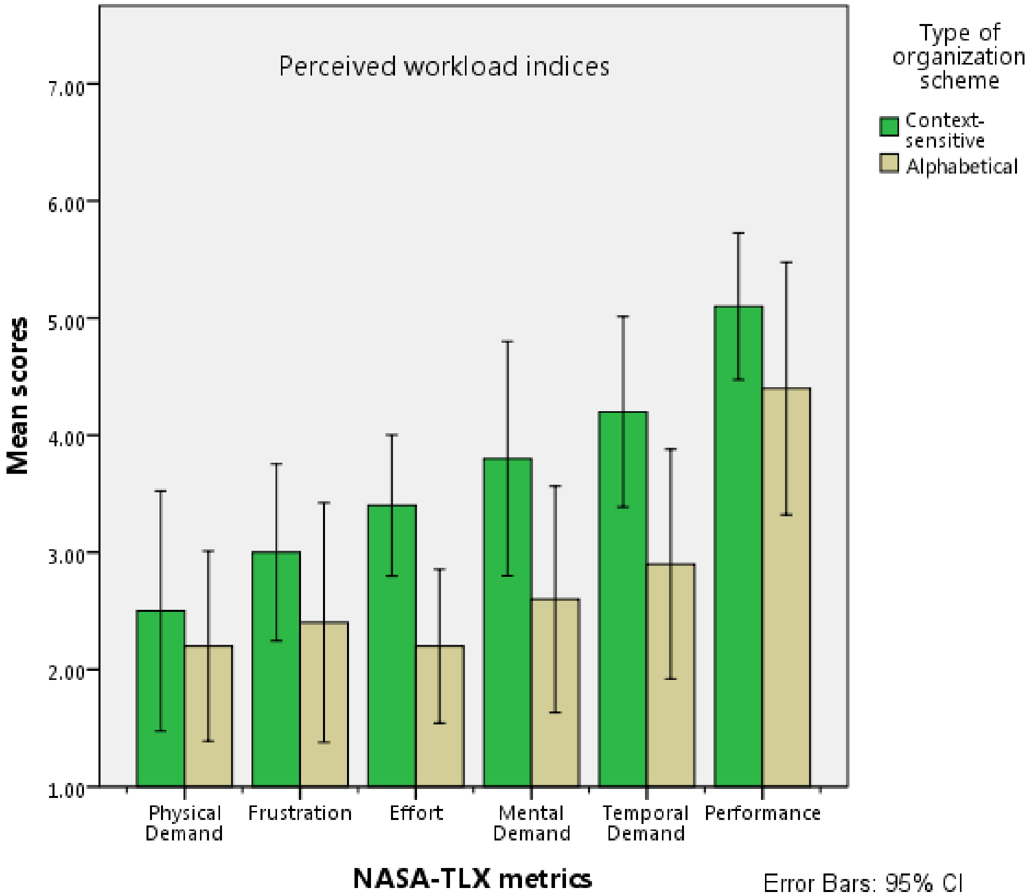

Figure 6.7 Mean NASA-TLX scores

Perceived system usability

Methodology:

The perceived usability of each organization scheme was measured using the System Usability Scale (SUS) questionnaire (Brooke, 1996). This standardized questionnaire contains 10-items, with the answers varying across a 5-point Likert scale (Appendix E). The scores on these 10 items were used to calculate the overall usability score of the scheme. The questionnaire consisted of 5 positively worded (questions 1, 3, 5, 7 and 9) and 5 negatively worded ones, the responses to the latter (questions 2, 4, 6, 8 and10) being reverse coded. The SUS questionnaire was administered after each participant completed both scenarios with the assigned organizational scheme. Responses to all 10 questions were averaged, and a single usability score for each participant was computed. The results indicated that the system usability scale scores were normally distributed. A one-way ANOVA was conducted to compare the perceived usability of the two schemes.

The analysis of the results for the System Usability Scale scores:

One-way ANOVA results for the perceived system usability indicated no significant differences between the context-sensitive scheme and the alphabetical scheme, F (1, 8) = 1.009, p =.328. The descriptive statistics and the results from the statistical tests are provided in Tables 6.12 and 6.13, respectively. A graph showing the mean scores for the two schemes is displayed in Figure 6.8.

Table 6.12

Descriptive statistics for the SUS scores

	N	Mean(Scores)	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Alphabetical scheme	10	70.0000	15.27525	4.83046	59.0727	80.9273	52.50	97.50
Context-sensitive scheme	10	63.2500	14.76906	4.67039	52.6849	73.8151	32.50	82.50

Table 6.13

One-way ANOVA results for the SUS scores

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	227.813	1	227.813	1.009	.328
Within Groups	4063.125	18	225.729		
Total	4290.938	19			

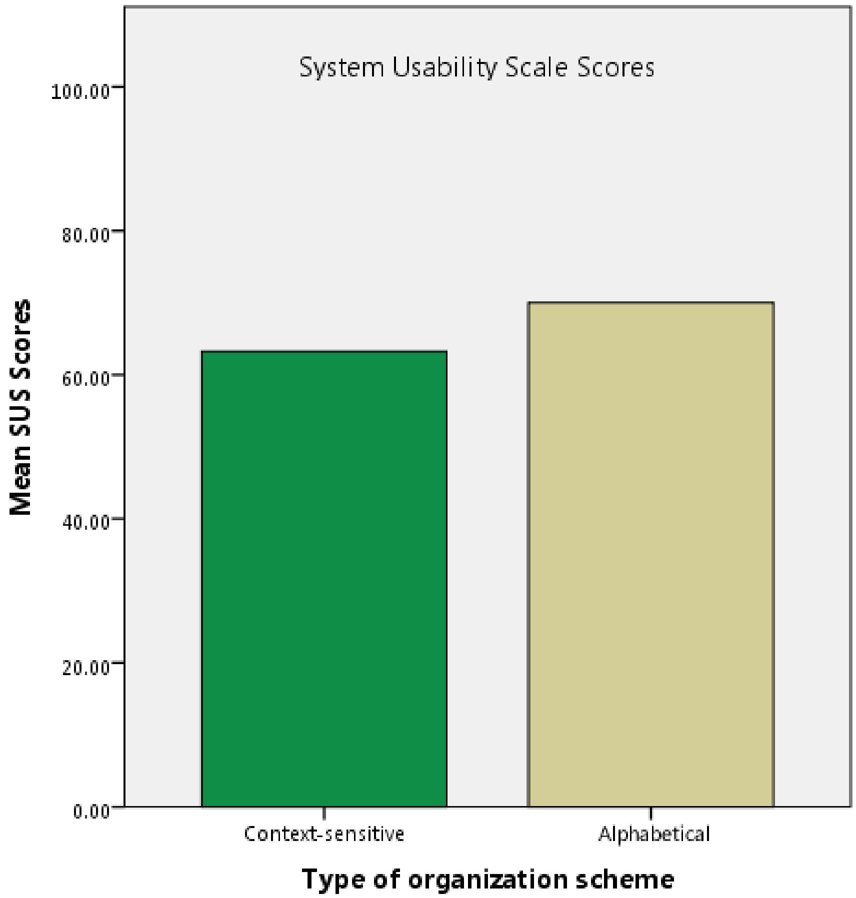

Figure 6.8 Mean SUS scores

Preference ranking

Methodology:

The preference ranking of the organization schemes was measured using the questionnaire in Appendix G. The data were not normally distributed; thus, a Wilcoxon's signed rank test was used.

The analysis of the results of the preference ranking:

A Wilcoxon's signed-rank test indicated that the results approached significance, $Z(1) = 1.897$, $p = .058$. Three of the ten participants preferred the context-sensitive scheme whereas seven preferred the alphabetical based scheme. The results of Wilcoxon's signed-rank test are given in Table 6.14.

Table 6.14

Analysis of results for the preference ranking scores

Test Statistics[b]

	Pref_Ranking_ScreenB - preference_ranking_Screen_[a]
Z	-1.897[a]
Asymp. Sig. (2-tailed)	.058

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

CHAPTER VIII

DISCUSSION

The goal of this research was to identify an efficient, effective and usable methodology for organizing the reversible causes of pulseless cardiac arrest using a digital cognitive aid. The results from this study supported two of the five proposed hypotheses, specifically, those addressing the number of unnecessary keystrokes and the number of deviations from the recommended treatment steps. The three remaining hypotheses (addressing the time taken to identify a reversible cause, the number of keystrokes and perceived workload), though not supported, produced interesting results in the context of the study as a whole. These results and the implications of this study are discussed in this chapter.

Time taken to identify a reversible cause:

It was hypothesized that the time taken to identify a reversible cause using the alphabetical scheme would be longer than for the context-sensitive scheme. However, it was observed that the participants took 56% less time using the alphabetical scheme (*Mean*=24.4s) than the context-sensitive scheme (*Mean*=43.4s). Possible explanations for this result include:

- Learning effects
    - Participants were already highly trained in the mnemonic-based alphabetical scheme

  - The context-sensitive scheme presented new cues to the user that they needed to process

- The context-sensitive scheme, by design, involved more keystrokes because it contained a list of 31 items the participants had to read before coming to the rank-ordered list of reversible causes.
- The scenarios were simple and the causes and treatments were easy to identify without a cognitive aid.

In retrospect, the long list in the context-sensitive scheme, in conjunction with a previously familiar methodology and a simple set of scenarios to diagnose may have contributed to the participants performing better using the alphabetical scheme.

Performance measures—Efficiency measures:

The number of keystrokes or key presses is one of the efficiency measures commonly used in evaluating the success of an electronic decision support tool (Belden et al., 2009). The number of keystrokes recorded for the study reported here was significantly larger for the context-sensitive scheme than for the alphabetical. This finding is consistent with the expectations of this study because navigating through the list of cues in the context-sensitive scheme naturally increased the number of keystrokes.

Unnecessary keystrokes, a subset of the total number of keystrokes were also counted. This resulted in a significant finding that potentially impacts both system design and, more importantly, patient outcome. In total, seven out of the ten participants performed unnecessary steps. These unnecessary keystrokes took several forms. Two participants selected irrelevant causes and their treatment steps in addition to selecting the correct reversible cause for the scenario. Two of these unnecessary, irrelevant steps, i.e, keystrokes, could be termed close calls, which as defined by the FDA, are " instances in which a user (here, the participant team leader) experiences confusion, misinterpretation, difficulty, or error that would result in mistreatment or harm, but the user 'recovers' and no actual performance failure occurs" (Kaye et al., 2011). Three other participants committed unnecessary keystrokes that could potentially distract them from the preferred treatment procedures. Two participants committed unnecessary keystrokes that were not directly related to the patient outcome, but might have an impact on task completion time. Thus, 70% of the participants committed unnecessary steps in one form or another.

The context-sensitive scheme, though an unfamiliar system that required additional learning, resulted in significantly fewer of these unnecessary keystrokes than the alphabetical. Possible reasons for this result might be found in cognitive psychology, which defines attention in two forms

- Focused attention (processing of a single input)
- Divided attention (simultaneous processing of multiple signals)

Perhaps the alphabetical scheme requires that attention be divided to evaluate all the likely causes simultaneously, increasing the need to temporarily store information elements in memory as chunks related to each cause. The unnecessary keystrokes may have occurred during the retrieval of these information elements from memory during the process of evaluating the likely reversible causes. However, the context-sensitive scheme may have helped focus attention by providing a list of cues related to the patient, avoiding the need to store these elements temporarily in memory. This result is consistent with the research conducted by Devolder et al., (2009), who found that groups of cognitive elements amalgamated together (here cues related to the patient) aids in focused attention, thus reducing cognitive load. Another explanation for the reduction in the number of unnecessary keystrokes for the context-sensitive scheme could be the method of presentation of the causes: they were provided in a ranked order of their likelihood with color coding distinguishing between the ranks.

The number of deviations from the recommended treatment steps for a reversible cause was also smaller for the context-sensitive method. Though both schemes were displayed using an iPad application that listed the same treatment steps, participants committed more commission deviations using the alphabetical scheme. Five participants deviated from the necessary steps in the alphabetical scheme while only one did so using the context-sensitive scheme. The most frequent commission deviation was the administration of a Central Venous Line (CVL). One possible reason for adding more steps than required could be distractions resulting from previous steps, for example, having to evaluate multiple reversible causes. Table 8.1 below provides a list of the deviations for the two schemes.

Table 8.1

Deviations in the two schemes

Type of deviation	Details	Type of scheme	Type of scenario	Number of participants
Commission	Administration of CVL and Ultrasound	Alphabetical	Hypovolemia	2
Omission	Administration of Furosemide and Insulin	Alphabetical	Hyperkalemia	1
Omission	Administration of ECG	Context-sensitive	Hyperkalemia	1
Commission	Administration of ECG	Alphabetical	Hyperkalemia	1
Commission	Optimization of CPR (Toxin management)	Alphabetical	Hyperkalemia	1

Subjective measures:

The analysis of the system usability scale scores indicated no significant differences between the schemes in terms of perceived usability. However, the mean score for the alphabetical scheme was higher than that of the context-sensitive scheme, perhaps because the participants were more familiar with it as it was a representation of what they had used previously (an ACLS code sheet). The usability scores for both systems fell in the marginally acceptable range (Bangor, Kortum and Miller, 2008).

There were no significant differences perceived in the workload between the two systems except in temporal demand and effort, both of which were perceived to be higher for the context-sensitive scheme. According to Devolder et al., (2009), “a high working memory load may result from the kind and amount of new information (extraneous cognitive load) and the complexity of information (intrinsic cognitive load)”. Hence, the temporal demand may have been higher for the context-sensitive scheme because of the amount of new information required to be processed within a short period of time. As for higher perceived effort observed using this scheme, a possible explanation is that users had to navigate through information across 2 screens as well as ask the nurse respondents and other participants in the room about patient-related cues. However, in retrospect, this could possibly improve team-building. The perceived effort exerted in the context-sensitive scheme could perhaps be reduced if it were possible to pre-select the cues related to a patient by linking the mobile device application with the patient’s Electronic Health Record.

When asked to rank the two schemes, only 3 of the 10 participants preferred the context-sensitive scheme. However, almost all participants felt that they would utilize it during complex scenarios, and 2 suggested providing a combination of the two schemes. However, when asked to choose one, they picked the alphabetical scheme, perhaps because of the relative simplicity of the scenarios.

CHAPTER VIII

CONCLUSION AND FUTURE WORK

An analysis of the final comments of the participants indicates that the participants found both of the schemes useful. They said they would have found the context-sensitive scheme to be more useful for more complex scenarios involving less common reversible causes. Thus, a design incorporating the needs of the participants and allowing them to choose between both the schemes is suggested. The design could also be refined to display only those causes having the highest association scores and the second highest association scores, leaving out the ones with very low scores.

An example of such a system is shown in Figure 8.1.

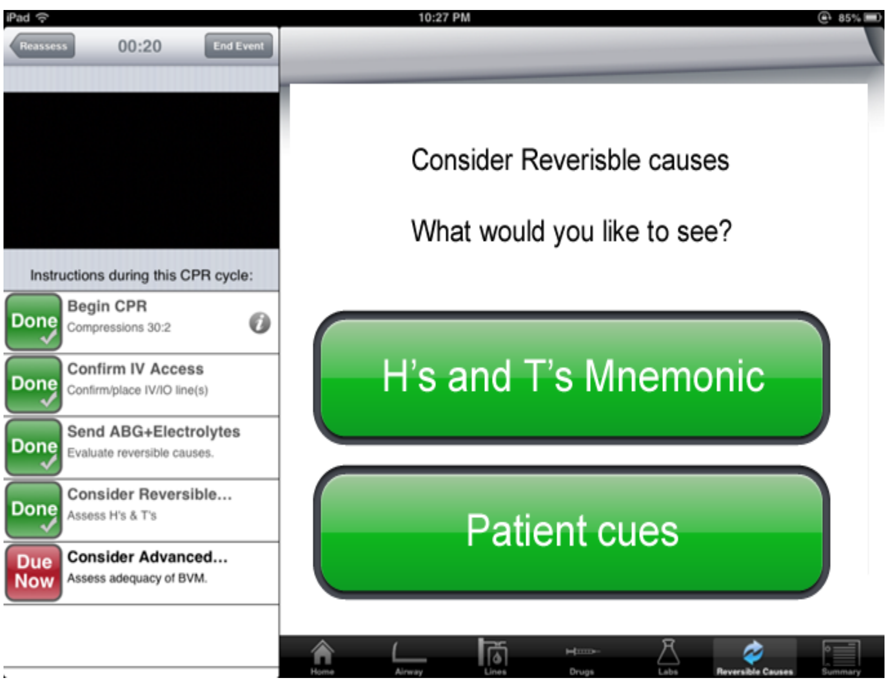

Figure 8.1 Mock-up showing representations of both schemes

Below is a list of recommendations and suggestions for future studies:

1. A combination of the two methods as suggested in this figure could be implemented in ensuing studies and tested based on efficiency and effectiveness measures. The context-sensitive scheme could be pre-populated with known cues based on connection to patient's health record.
2. The current study evaluated the performance and usability of the participants using only 2 scenarios—hyperkalemia and hypovolemia, both very common. It is recommended that performance in other scenarios involving rare occurrences and diagnostic complexity be investigated. Ideally, one scenario from each of the following groups: easy to diagnose (hypovolemia or hypoxia), moderately easy to diagnose (hyperkalemia or hypothermia), moderately difficult to diagnose (acidosis or toxins), and difficult to diagnose (cardiac tamponade or tension pneumothorax) could be used.
3. The sample size for the study (N=11) was small. It is recommended that a further study be conducted with at least 15 participants to improve the validity, reliability and generalizability of the results.
4. Some measures, including trust and confidence in the cognitive aid, were not specifically tested. Questionnaire items addressing these issues might provide insights on the human factors related to trust and confidence in the two organization schemes.

5. To further account for effects caused by previous training with the alphabetical scheme, a comparative study with population unfamiliar with either of the schemes is recommended.

APPENDICES

APPENDIX A

INFORMED CONSENT FORM FOR THE PARTICIPANT

Medical University of South Carolina
Organization of information for reversible causes of pulseless in-hospital cardiac arrest: a randomized control trial using a cognitive aid

A. PURPOSE AND BACKGROUND

You are being asked to volunteer to participate in a research study. The study investigates the effectiveness and usability of two different schemes of organizing reversible causes of cardiac arrest in simulated cardiac arrest scenarios using an electronic decision support tool. Electronic decision-aid tools (such as an iPad app) may aid in increasing adherence to guidelines during cardiac arrests. Accurate and effective information organization and presentation is important while designing such tools. This study will seek to identify the most effective organization scheme that results in the quickest and easiest means of identifying reversible causes associated with an arrest. The future aim of this research is to have the best scheme that results from this study implemented in the decision support tool known as Rapid Rescue for actual use. This study will be conducted at the Simulation Center at the Medical University of South Carolina in a simulation laboratory and will involve up to 20 participants total.

The Principal Investigator of this study at MUSC is Matthew D. McEvoy, MD (Department of Anesthesia and Perioperative Medicine).

B. PROCEDURES:

If you agree to participate in this study, the following will happen:

1. You will participate as a part of this study in two sessions, a week apart. You will come in approximately a week later for the second session. Both sessions will take place in the MUSC Simulation Center.

2. On the day of the study during the first session, you will arrive at the Simulation Center location, sign informed consent, and then be given a 5-minute orientation to using an iPad, using the application, and to the simulation setting. You will then complete a pre-test questionnaire consisting of 9 questions.

3. You will manage 4 emergency simulation scenarios, each about 4-minutes in length. These four scenarios will be managed with a two-person team involving you and a ‘Reader’ (a graduate student researcher who is trained to help with use of the app). You will be the team leader in all sessions. Your goal will be to identify the reversible

medical/physiologic cause associated with each scenario within 4 minutes (2 CPR cycles). The reader will read each scenario to you from the iPad and will hand the iPad to you when he/she gets to "reversible causes" screen. You will determine the reversible cause and continue with the treatment steps using the iPad until the end of the 4-minute period. Another graduate student researcher will be present during each scenario to assist you to perform simulated chest compressions in the scenario. You will complete a pre-session survey and 2 post-session surveys after a set of 2 scenarios. Participation can be discontinued at any time at your request. Total time of participation from orientation to completion of the survey should be roughly 30 minutes for each session.

4. You will come in approximately a week later. A similar procedure will be followed for the second session, (managing 4 simulated cardiac arrest scenarios to find reversible cause associated with each scenario and answering questionnaires) except without the orientation and the consent form.

5. The team will collect performance data (time taken to complete the tasks, number of errors and number of keystrokes to complete the task, etc.) and survey data. Your sessions will not be recorded in any form that is personally identifiable (video/audio recordings).

C. DURATION

The study period begins when the consent form is signed and continues throughout the simulation scenarios for 30 minutes. The study lasts approximately an hour total spread across 2 weeks.

D. RISKS/DISCOMFORTS

There are few risks associated with participation in this research study. There is the theoretical possibility of loss of confidentiality due to compromise of the security of the secure servers on which the study data will be stored. However, this is very unlikely. Please note that data security is a priority for the MUSC Simulation Center, and the data collected are actually embedded in a password-protected system, and very difficult to view without authorization or to copy. There is also the possible discomfort of performance anxiety in managing high-stakes clinical events. If you feel anxious and desire to stop the session, you can do so and discontinue at any time.

E. BENEFITS

A direct benefit to you as a participant cannot be guaranteed. However, the study will help establish an efficient, effective and usable scheme of organization of reversible causes of cardiac arrest. It will also serve as an input for the design of an electronic decision support tool. The findings from this study may help future patients to receive improved care during an in-hospital cardiac arrest.

F. COST

You will incur no additional costs as a consequence of your participation in this study.

G. PAYMENT TO PARTICIPANTS

You will not be paid for participating in this study.

H. ALTERNATIVES

You may refuse to participate in or dis-enroll from the study at any time.

I. STUDENT PARTICIPATION

Your participation, non-participation, or discontinuance will not constitute an element of your academic performance, nor will it be a part of your academic record at this institution.

J. EMPLOYEE PARTICIPATION

Your participation or discontinuance will not constitute an element of your job performance or evaluation, nor will it affect your professional standing in any way.

Results of this research will be used for the purposes described in this study. This information may be published, but you will not be identified. Information that is obtained concerning this research that can be identified with you will remain confidential to the extent possible within State and Federal law. The investigators associated with this study, the sponsor, and the MUSC Institutional Review Board for Human Research will have access to identifying information. All records in South Carolina are subject to subpoena by a court of law.

In the event of a study related injury, you should immediately go to the emergency room of the Medical University Hospital if you are on the MUSC campus, or in case of an injury or emergency off-campus, you should go to the nearest hospital. Dr. McEvoy or one of the Co-Investigators present at the time of an injury or emergency will direct your care until it is transferred to appropriate personnel in an emergency room. If your insurance company denies coverage or insurance is not available, you will be responsible for payment for all services rendered to you.

Your participation in this study is voluntary. You may refuse to take part in or stop taking part in this study at any time. You should call the investigator in charge of this study if you decide to do this. Your decision not to take part in the study will not affect your current or future medical care or any benefits to which you are entitled.

The investigators and/or the sponsor may stop your participation in this study at any time if they decide it is in your best interest. They may also do this if you do not follow the investigator's instructions.

Volunteer's Statement

I have been given a chance to ask questions about this research study. These questions have been answered to my satisfaction. If I have any more questions about my participation in this study or study related injury, I may contact Dr. Matt McEvoy at 843-792-2322. I may contact the Medical University of SC Hospital Medical Director (843) 792-9537 concerning medical treatment.

If I have any questions, problems, or concerns, desire further information or wish to offer input, I may contact the Medical University of SC Institutional Review Board for Human Research IRB Manager or the Office of Research Integrity Director at (843) 792-4148. This includes any questions about my rights as a research subject in this study.

I agree to participate in this study. I have been given a copy of this form for my own records.

If you wish to participate, you should sign below.

____________________________________ ____________________________________

Signature of Person Obtaining Consent Date Signature of Participant Date

APPENDIX B

PRE-TEST QUESTIONNAIRE

GENERAL

Participant: ___________________ (*This will be filled out by the test administrator.*)

Age: _____________________

Gender: Male ☐ Female ☐

EDUCATION

1. Please select your occupation at MUSC:

Nurse ☐
Doctor ☐
ACLS Instructor ☐
Other ☐
(Please specify: ____)

CODE EVENT EXPERIENCE

2. How long have you been a participant in a code event?

< 1 year ☐ 1-2 years ☐ 3-5 years ☐ > 5 years (Please specify) ☐

3. Have you used a smart phone e.g. Android/ iPad/ iPhone before? If yes, for long have you used iPad?

< 1 year ☐ 1-2 years ☐ 3-5 years ☐ > 5 years (Please specify) ☐

APPENDIX C

SCENARIOS

Scenario 1 (Hyperkalemia-1)

You are called to Preop/Holding emergently. When you arrive to the patient bay, CPR is in progress

The following information can be given:

Patient is a 74 year old African American male with a history of end-stage renal disease. He was brought into the hospital for kidney transplant. He did not have his normal dialysis today. Patient was on 2L NC oxygen to help with sats of 93% and reported feeling "funny feeling in chest" and "fluttering in chest" for about 10 minutes.

Past Medical History:

I. End-stage renal disease – on hemodialysis MWF.
II. Diabetes – insulin-dependent
III. Hypertension – moderately controlled.
IV. Coronary artery disease

Meds:

- Metoprolol 50mg PO BID
- Novolog 20u BID and SSI QAC (with meals).

PE: Patient was noted to have crackles in lungs bilaterally on admission.

Labs:

I. Chem 10 – pending from admission
II. ECG on admission – NSR, LVH, few PVCs
III. ABG – see printout out – ABG1HYPERK135

Scenario 2 (Hyperkalemia-2)

You are called to **see a trauma patient in the ER** who sustained multiple orthopedic crush injuries in an MVC and needs to be brought to the OR to rule out abdominal injury and for ORIF of fractures. When you arrive to the patient bay, CPR has just begun. [Resident to be given this stem]

The following information can be given:

Patient is a 34 year old White male s/p MVC with multiple long bone fractures and crush injuries. He was initially unstable on arrival, but was stabilized with 6u PRBC, 6u FFP, and 2L 0.9% NaCl. He then developed a dysrhythmia and became pulseless.

Past Medical History: None known

Meds: None known

PE: intubated with normal breath sounds bilaterally.

Labs:

I. Chem 10 – pending from admission
II. CBC – H/H 5.1/15.2 on admission; now 10.5/28.9
III. ECG on admission – Sinus tachy, otherwise normal
IV. ABG – see printout out – ABG1HYPERK135

Scenario 3 (Hypovolemia -1)

You are called emergently to the PACU. When you arrive to the patient bay, CPR is in progress.

<u>The following information can be given:</u>

Patient is a 58 year old White female s/p TAH/BSO and peri-aortic node dissection. Surgery and anesthesia was fairly uneventful. She has a T7-8 epidural in place that is running at 7 cc/hr. The patient has been in the PACU for about 2 hours and was waiting on a floor bed to become available.

The nurse noted that the patient became agitated and "pale," and also noted that the JP suction bulbs were both full of blood. She called you to come assess the patient and the patient then became unresponsive.

Past Medical History: No known history except for advanced uterine cancer.

Meds: Multi-vitamin

PE: no abnormalities noted on preop physical exam.

Labs: ABG – see printout out – ABG1HYPOVOL135

UOP: was recorded as ~150 cc/hr in the OR, but has been minimal over the past hour.

Scenario 4 (Hypovolemia -2)

You are called emergently to the PACU. When you arrive to the patient bay, CPR is in progress.

<u>The following information can be given:</u>

Patient is a 63 year old White female s/p right total liver lobectomy for hepatocellular carcinoma (HCC). Surgery and anesthesia was fairly uneventful. She has a T6-7 epidural in place that is running at 6 cc/hr. The patient has been in the PACU for about 2 hours and was waiting on a floor bed to become available. Pain has been well-controlled with minimal narcotics.

The nurse noted that the patient became agitated and "pale" and complained of not being able to breathe. She also noted that the JP suction bulbs were both full of blood and called you to come assess the patient and the patient then became unresponsive.

Past Medical History: No known history except for advanced HCC.

Meds: None

PE: no abnormalities noted on preop physical exam.

Labs: ABG – see printout out – ABG1HYPOVOL135

UOP: was recorded as ~150 cc/hr in the OR, but has been minimal over the past hour

APPENDIX D

LAB REPORTS

LAB REPORT
SCENARIO 1 (HYPERKALEMIA -1)
RADIOMETER ABL800 FLEX

ABG1HYPEK135 1 : __/__/__
PATIENT REPORT LONG Syringe – S Sample # 77777
195uL

Identifications

T	37.0° C
Accession No,	188777777A

Blood Gas Values					
pH	7.25		[	-	]
pCO2	39	mmHg	[	-	]
pO2	111	mmHg	[	-	]
Temperature Corrected Values					
pH(T)c	____		[	-	]
pCO2(T)c	____	mmHg	[	-	]
pO2(T)c	____	mmHg	[	-	]
Electrolyte Values					
cNa+	132	mmol/L	[	-	]
cK+	7.5	mmol/L	[	-	]
cCa+	0.9	mmol/L	[	-	]
Acid Base Status					
cHCO3-(P)c	18	mmol/L	[	-	]
ctCO2(P)c	____	mmol/L	[	-	]
cBase(B)c	____	mmol/L	[	-	]
Oximetry Values					
sO2	____	%	[	-	]
Hctc	33.4	%	[	-	]
ctHb	11.1	g/dL	[	-	]
Metabolite Values					
cGlu	153	mg/dL	[	-	]
cCl-	114	mmol/L	[	-	]

....

Notes

c Calculated value(s)

Printed : __/__/__

LAB REPORT
SCENARIO 2 (HYPERKALEMIA-2)
RADIOMETER ABL800 FLEX

ABG2HYPEK135 2 : __/__/__
PATIENT REPORT LONG Syringe – S Sample # 77777
195uL

Identifications

T	37.0° C
Accession No,	188777777A

Blood Gas Values					
pH	7.25		[	-	]
pCO2	39	mmHg	[	-	]
pO2	111	mmHg	[	-	]
Temperature Corrected Values					
pH(T)c	____		[	-	]
pCO2(T)c ____	mmHg		[	-	]
pO2(T)c	____	mmHg	[	-	]
Electrolyte Values					
cNa+	132	mmol/L	[	-	]
cK+	7.5	mmol/L	[	-	]
cCa+	0.9	mmol/L	[	-	]
Acid Base Status					
cHCO3-(P)c	18	mmol/L	[	-	]
ctCO2(P)c	____	mmol/L	[	-	]
cBase(B)c	____	mmol/L	[	-	]
Oximetry Values					
sO2	____	%	[	-	]
Hctc	30.4	%	[	-	]
ctHb	10.1	g/dL	[	-	]
Metabolite Values					
cGlu	153	mg/dL	[	-	]
cCl-	113	mmol/L	[	-	]

Notes

Calculated value(s)

Printed : __/__/__

LAB REPORT
SCENARIO 3 (HYPOVOLEMIA-1)
RADIOMETER ABL800 FLEX

ABG1HYPOVOL135 1 : __/__/__
PATIENT REPORT LONG Syringe – S Sample # 77777
195uL

Identifications

T	37.0° C		
Accession No,	188777777A		

Blood Gas Values

pH	7.34		[-]
pCO2	34	mmHg	[-]
pO2	91	mmHg	[-]

Temperature Corrected Values

pH(T)c	____		[-]
pCO2(T)c____	mmHg	[-]	
pO2(T)c	____	mmHg	[-]

Electrolyte Values

cNa+	134	mmol/L	[-]
cK+	4.5	mmol/L	[-]
cCa+	1.1	mmol/L	[-]

Acid Base Status

cHCO3-(P)c	18.5	mmol/L	[-]
ctCO2(P)c	____	mmol/L	[-]
cBase(B)c	____	mmol/L	[-]

Oximetry Values

sO2	____	%	[-]
Hctc	16.4	%	[-]
ctHb	5.2	g/dL	[-]

Metabolite Values

cGlu	107	mg/dL	[-]
cCl-	110	mmol/L	[-]

....

Notes

c Calculated value(s)

Printed : __/__/__

LAB REPORT
SCENARIO 4 (HYPOVOLEMIA-2)
RADIOMETER ABL800 FLEX

ABG2HYPOVOL135 2 : __/__/__
PATIENT REPORT LONG Syringe – S Sample # 77777
195uL

Identifications

T	37.0° C
Accession No,	188777777A

Blood Gas Values

pH	7.34		[	-	]
pCO2	34	mmHg	[	-	]
pO2	91	mmHg	[	-	]

Temperature Corrected Values

pH(T)c	____		[	-	]
pCO2(T)c____	mmHg	[	-	]	
pO2(T)c	____	mmHg	[	-	]

Electrolyte Values

cNa+	134	mmol/L	[	-	]
cK+	4.7	mmol/L	[	-	]
cCa+	0.9	mmol/L	[	-	]

Acid Base Status

cHCO3-(P)c	18.1	mmol/L	[	-	]
ctCO2(P)c	____	mmol/L	[	-	]
cBase(B)c	____	mmol/L	[	-	]

Oximetry Values

sO2	____	%	[	-	]
Hctc	15.9	%	[	-	]
ctHb	5.4	g/dL	[	-	]

Metabolite Values

cGlu	107	mg/dL	[	-	]
cCl-	110	mmol/L	[	-	]

....

Notes

c Calculated value(s)

Printed : / /

APPENDIX E
RECOMMENDED TREATMENT STEPS

Hyperkalemia

1. Continue CPR
2. Assess adequacy of BVM/Consider intubation
3. Follow pulseless arrest algorithm for rhythm for medication and shocks, if appropriate
4. Give CaCl 1-2 GM IV bolus
5. Give Sodium Bicarb 2-4 mEq/kg after return of circulation
6. Give IV Fluid bolus (>1 L)
7. Hyperventilate after return of circulation
8. Consider insulin 10U IV bolus with Dextrose
9. Consider furosemide 20-40mg IV bolus
10. Consider emergency dialysis after return of circulation, call ICU and prep for dialysis
11. Re-assess ABG after initial therapies completed

Hypovolemia

1. Continue CPR
2. Notify the surgical team
3. Reintubate ASAP
4. Prep OR for immediate return
5. Follow pulseless arrest algorithm for rhythm for medication and shocks, if appropriate
6. Consider IV Fluid bolus
7. Consider vasopressor on ROSC
8. Obtain additional IV access
9. Re-assess ABG after initial therapies completed

APPENDIX F

<u>SYSTEM USABILITY SCALE QUESTIONNAIRE:*</u>

*Source: Brooke, J. (1996). Usability Evaluation in Industry. Niagara Falls, NY: CRC Press

System Usability Scale

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think that I would need the support of a technical person to be able to use this system					
5. I found the various functions in this system were well integrated					
6. I thought there was too much inconsistency in this system					
7. I would imagine that most people would learn to use this system very quickly					
8. I found the system very cumbersome to use					
9. I felt very confident using the system					
10. I needed to learn a lot of things before I could get going with this system					

APPENDIX G

NASA-TLX SUBJECTIVE QUESTIONNAIRE*

*Source: Hart, S.G., and Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. Advances in Psychology, 52, 139-183.

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

APPENDIX H

PREFERENCE RANKING QUESTIONNAIRE

Rank the scheme that you prefer as # 1 and the other scheme as # 2

1. Scheme – alphabetical

   Rank # ________

2. Scheme –Context-sensitive

   Rank # ________

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