EVALUATING MOBILE INFORMATION DISPLAY SYSTEM IN TRANSFER OF CARE

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Industrial and Human Factors Engineering

By

KATELYN BERBERICH
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Wright State University
I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Katelyn Berberich ENTITLED Evaluating Mobile Information Display System in Transfer of Care BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Industrial and Human Factors Engineering.

Subhashini Ganapathy, Ph.D.
Thesis Director

Jaime E. Ramirez-Vick, Ph.D.
Chair, Department of Biomedical, Industrial and Human Factors Engineering

Committee on Final Examination

Subhashini Ganapathy, Ph.D.

Mary E. Fendley, Ph.D.

Aerial N. Kreiner, Ph.D.

Robert E. W. Fyffe, Ph.D.
Vice President for Research and Dean of the Graduate School
ABSTRACT
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Transfer of care continuum is highly dynamic in nature and there are multiple complexities associated with man-man interaction and man-machine interaction. During transfer of patient care, which occurs from an emergency medical team (EMT) to an emergency department, adequate information related to the patient must be communicated very quickly and precisely. Challenges EMTs and emergency department personnel face are communicating and obtaining all the essential information to ensure the patient receives the best care. Providing the receiving emergency department with patient vitals and pre-hospital procedures that occurred en route could allow for enhanced preparation and improved communication during the transfer process thereby being beneficial to the patient’s health. This research focuses on designing and evaluating the usability of information presentation for a tablet device and the use of such device to improve efficiency during the transfer of care process. This could potentially help emergency department workers better prepare for the incoming patient, reduce the amount of information needed to be quickly communicated in a short time, and provide appropriate medical care. Results indicated that on mobile devices in a transfer of care the use of basic information displays provides faster preparation response times in one and three patient-simulated scenarios.
# TABLE OF CONTENTS

1. **INTRODUCTION** .................................................................................................................. 1  
   1.1 Complex Adaptive System ............................................................................................. 2  
   1.1.1 Transfer of Care ........................................................................................................ 5  
   1.2 Human Machine Team ................................................................................................... 8  
   1.3 Mobile Technologies .................................................................................................... 10  
   1.4 Usability ........................................................................................................................ 12  
   1.4.1 Information Presentation ........................................................................................... 13  

2. **RESEARCH OBJECTIVES** ................................................................................................. 15  
   2.1 Research Question and Hypothesis .............................................................................. 15  
   2.2 Research Approach ...................................................................................................... 17  

3. **METHODOLOGY** ............................................................................................................. 19  
   3.1 Design of Experiment .................................................................................................. 19  
   3.2 Mobile Application Design ......................................................................................... 20  
   3.3 Testing Procedures ....................................................................................................... 21  
   3.4 Measurements ............................................................................................................. 25  

4. **RESULTS** ......................................................................................................................... 27  

5. **DISCUSSION** .................................................................................................................. 32  
   5.1 Discussion .................................................................................................................... 32  
   5.2 Future Work ................................................................................................................ 35  

6. **IMPLICATIONS** .............................................................................................................. 36  

7. **REFERENCES** .................................................................................................................. 38  

   **Appendix I** - Questionnaire ............................................................................................ 46  
   **Appendix II** - System Usability Scale ............................................................................ 47  
   **Appendix III** - Scenarios ............................................................................................... 48  
   **Appendix IV** - Triage Indices ......................................................................................... 50  
   **Appendix V** - Action Plan Examples .............................................................................. 51
LIST OF FIGURES

Figure 1: Patient Vital System Model........................................................................... 7
Figure 2: Research Framework ...................................................................................... 17
Figure 3: Mock Participant Using Tablet....................................................................... 20
Figure 4: Example 1 Training Screen........................................................................... 22
Figure 5: Example 2 Training Screen........................................................................... 22
Figure 6: Scenario Navigation ...................................................................................... 24
Figure 7: Situation Display A....................................................................................... 25
Figure 8: Situation Display B....................................................................................... 25
Figure 9: Situation Display C....................................................................................... 25
Figure 10: Situation Display D...................................................................................... 25
Figure 11: Average Response with Respect to Scenario Type ...................................... 27
Figure 12: Average Response with Respect to Display Type......................................... 28
Figure 13: Average Response with Respect to Each Situation...................................... 29
Figure 14: Average SUS Score by Situation.................................................................. 30
Figure 15: Scatterplot Correlation of SUS Scores and Response Times....................... 31
LIST OF TABLES

Table 1: Hypothesis Related to Research Questions ...................................................... 15

Table 2: Four Types of Situations .................................................................................. 23
1. INTRODUCTION

Transfer of patient care are situations in which the overall responsibility for the patient is handed over from one healthcare personnel to another (Jensen, Lippert, Østergaard, 2013). Handover communications are a type of face-to-face communication that pertains to the patient’s current condition, recent changes in condition, and treatments that have been given. At present time, this type of communication is commonly utilized in transfer of care. As each handover relies on the discretion of individual healthcare workers and their experience level, the chance for miscommunication of verbal information or underreporting of information increases with each occurrence. In fast-paced environments like ones that occur during a transfer of care, time is critical and delays can result in negative outcomes (Jensen et al., 2013). With an increase in amount of information presented to healthcare providers, there is an increase in the need to utilize information management technology (Johnson, Johnson, Zhang, 2005). To aid in problems of miscommunication or information loss regarding transfer of care, new technology is being developed which can give the receiving members of the hospital information about the patient as they are in route (Gao, Greenspan, Welsh, Juang, Alm, 2006). These new technologies implement wearable sensor devices which monitor and record the patient information similar to telemedicine systems. Patient vitals are important pieces of information to capture during emergency medical situations. For
example, ICU nurses constantly monitor patient vitals to ensure the patient is stable (Drews, 2008). Previous research indicates that poor information displays can lead to inefficient patient care (Johnson et al., 2005). Providing receiving emergency department doctors and nurses with patient vitals and pre-hospital procedures could enhance the transfer of care and patient outcomes. However, little research has been done on displays and tools that present the information in a meaningful manner that can potentially improve transfer of care communication and aid in decision making. The key focus of this research project is to study the effects of technology integration for improved transfer of care.

This chapter will present a review of complex adaptive systems and their relationship to healthcare systems, transfer of care, human machine teaming, mobile technologies, and finally usability principles and information presentation. The following chapter will address the research objectives including the research questions and hypotheses and research approach. The third chapter will be the methodology: design of experiment, the mobile application design, testing procedures, and measurements taken. The fourth chapter will report the results with chapters on the discussion and implications to follow.

1.1 Complex Adaptive Systems

The uncertainty and difficulty in prediction, need for multiple providers, and ubiquity of information all contribute to the association of healthcare to a complex adaptive system (Clancy, Effken, Pesut, 2008). Transfer of care scenarios specifically, have a high degree of ambiguity along with the need for quick responses and can be correlated with complex adaptive systems. Complex adaptive systems (CAS) are defined
by Plsek & Greenhalgh (2001) as a “collection of individual agents with freedom to act in ways that are not always totally predictable, and whose actions are interconnected so that one agent’s actions change the context for other agents.” Tan, Wen, and Awad (2005) expand the definition of a complex adaptive system to include the agents actions seek to maximize some measure of goodness, or fit, by evolving over time. CAS can be found in many aspects of nature and society. Examples of CAS are ecosystems, supply chains, social networks formed by people, and the human body (North, 2014). CAS systems have many components (agents), which interact, adapt, and learn with each other (Holland, 2006). Despite the fact complex adaptive systems can be seen in many different areas, they all share four major features: Parallelism- CAS contains large numbers of agents that all send and receive signals, Conditional action- actions of agents depend on signals they receive, Modularity- agents have groups of rules that act as subroutines, and Adaptation and evolution- agents in CAS change over time (Holland, 2006). Since complex adaptive systems can be very large with several interacting parts they can be difficult to predict and understand.

Further understanding of complex systems can come from comparing them to simple linear systems. Perrow (1999) lays out several key differences between complex and linear systems. As the name implies, the simple system works in a linear fashion and permits easier detection of failed components while also allowing equipment to be spread out. A downfall to a simple linear system is the lack in the ability for potential interactions and the fact they often have rigid, segregated production steps (Perrow, 1999). Although both simple and complex systems have advantages and disadvantages, complex systems have less underutilized space, less tolerance of low-quality
performance, and more multifunctional components (Perrow, 1999). All these advantages can be seen when looking at healthcare as a complex system.

In recent years, there has been more attention on CAS in social networks, specifically the healthcare sector. Researchers in the healthcare field use complexity science, or the study of multilevel CAS, to improve management, organization, and communications in hospital settings (Benham-Hutchins & Clancy, 2010). Healthcare organizations have several interconnected networks from departments, teams, and units to the patients and providers; all of which act as complex adaptive systems. Transfer of patient care involves a collection of workers who share a network of knowledge that aids in the coordination of the task (Benham-Hutchins & Clancy, 2010).

By investigating areas in healthcare as CAS, a better understanding can begin to form along with news ways of analyzing the system. Transfer of care scenarios contain parallelism, conditional action, modularity, and adaption and evolution- the four key features of CAS systems. Parallelism is seen with many healthcare personnel that participate throughout the transfer process. Conditional action in a transfer of care can be described by the healthcare personnel’s actions depending on the patient information they receive from the EMT’s, and then acting based upon said data. Modularity is exhibited by subroutines being commonly used in transfer of cares due to the variations that occur. Adaption and evolution shows how there is change is the CAS over time, this is seen in transfers due to changes in rules and regulations and the addition of new technology and treatments. A common difficulty expressed in CAS are the agents are constantly having to revise and update their information and adjust their actions accordingly (Holland, 2006). Specifically addressing conditional action by providing an information display
system prior to patient arrival could be beneficial for the overall transfer process. In addition, using complex system principles with computer simulation can help improve training for the agents within the complex adaptive systems (Clancy et al. 2008). Providing patient information and understanding how it should be presented on a display will help in designing CAS type of simulation system for transfer of care that can be used for studying organization of systems, training personnel, conducting what if analysis, and so on.

1.1.1 Transfer of Care

Transfer of care scenarios, or sometimes called patient handoffs, can be defined as “situations in which responsibility for a patient’s diagnosis, treatment and care is handed over- completely or partly, temporarily or permanently- from one health care professional to another” (Jensen et al., 2013). Transfer of care scenarios can be considered as a subset of complex adaptive system; they are fast paced, unpredictable, and negative outcomes often directly affect the patient (Carter, Davis, Evans, Cone, 2009; Evans, Murray, Patrick, Fitzgerald, Smith, Andrianopoulos, Cameron, 2010). Similar to complex adaptive systems, ambulance workers and emergency department personnel are working as agents that respond to signals and alter their behavior based on other agents’ actions and behaviors (Tan et al., 2005). A key component of CAS is that the agents within adapt and change based on the situation and this can easily be seen during transfer of care scenarios.

Due to the complexity and irregularity of transfer of care scenarios, it is very difficult to predict behaviors or outcomes. Transfer of care scenarios, or patient handoffs, rely heavily on information transfer and a well-studied component is the communication
aspect (Apker, Mallak, Gibson, 2007). In a review article on handovers to emergency departments, Jensen et al. identified information gaps and cultural/organizational aspects as two major challenges faced in transfer of care. Most of the information transferred from emergency medical personnel to emergency department personnel is in verbal or written form (Jensen et al. 2013). The communication between ambulance workers and emergency department personnel is critical but often brief and incomplete (Scott, Brice, Baker, Shen, 2003; Bost, Crilly, Patterson, Chaboyer, 2012; Alfes, Reimer, 2016). Carter et al. (2009) found that EMS personnel can miss almost 30% of key pre-hospital data points during transfer of cares. The root causes as to why key information is missed cannot be pinpointed exactly due to the variation in each scenario, but studies have made some suggestions. Owen, Hemmings, and Brown (2009) investigated perceptions of paramedics and hospital staff about patient handoffs and found common difficulties were creating a shared cognitive picture, tensions between ‘doing’ and ‘listening’, and fragmented communication. Communication handoffs lack standardization, and mistakes have been shown to be a significant cause of medical errors (Cohen, Hilligoss, Amaral, 2012). Working in an interdisciplinary team can also be a challenge during the transfer of care process. Bost, Crilly, Patterson, Chaboyer (2012) identified a lack of active listening and access to written information as issues in the handover process and note that shared training programs could aid in structuring communications between teams with different background. Work has started for designing a set of core information that must be communicated to improve handoffs (Alfes & Reimer, 2016) but there is still much research to be done to ensure effectiveness and efficiency. Providing training is a common way to improve teamwork and duties. One study investigated improving
communication during simulated traumas by implementing leadership and team behavior training and while communication behaviors did improve, there was some retention loss (Roberts, et al., 2014). Training alone is not enough to improve communications during transfer of cares. Providing an information display system to relay critical information, such as patient vitals, condition, and pre-hospital procedures, to the emergency department before patient arrival could improve the communication between the inter-disciplinary teams and assist the emergency department team to be better prepared. Figure 1 depicts a system model where personnel at the hospital would receive patient data prior to their arrival to improve the transfer of care process.

Figure 1: Patient Vital System Model

The use of any systems during a transfer of care requires an understanding of the human machine team. The complex, fast paced environment that is transfer of care could greatly benefit from a real-time information display system but only if there is a suitable human machine team established and proper implementation of the system.
1.2 Human Machine Team

An understanding of human machine teaming is necessary for a system to be properly designed. In healthcare, there is an abundance of technology being used to aid the human users. A commonly used tool that would be applicable to address issues faced during a transfer of care scenario is an information display or decision support system (Hajioff 1998). These systems support the human user in making effective decisions by providing information and thereby work together as a team. Decision support systems in healthcare can be designed for the patient or for the healthcare professional and can result in reduced time for decisions and decrease mental workload (Vahidov & Fazlollahi, 2004). A common system used throughout healthcare currently are electronic healthcare records (EHR). This system is used to collect comprehensive, cross-institutional, and longitudinal data of a patient’s healthcare (Hoerbst & Ammenwerth, 2010) and is a good example of a human machine team in healthcare. This system aids the human users by reducing mental workload and providing an organized, digital way of containing patient healthcare records. Similar technology can be designed and used to provide real-time patient data to emergency departments.

Designs of information systems to be used in the human machine team must be created with end users, the humans, in mind. Previous issues regarding the design and implantation of information systems centered around the lack of understanding about the human machine team in addition to a lack of consideration for the human users’ cognitive needs (Tang & Patel, 1994). In the high mental work environment of transfer of cares, understanding the cognitive needs of the workers and designing an information display from those needs could reduce the mental workload and improve performance. Literature
states the importance of involving end users of the system in the design of the machine and understanding the capabilities and limitations of both the user and machine (Nielsen, 1993). Understanding the abilities and restraints of the human results in an appropriate design of the machine counterpart.

For any human machine team to work in harmony, the system must be useful, working properly, and be efficient. An information display system would serve as a decision support system to the emergency department personnel, allowing the users to see patients’ incoming vitals, pre-hospital procedures and injury information before the patient arrives. Providing a decision support system which delivers patient vital signs has been shown to reduce mortality rates (Schmidt et al., 2015) and constant monitoring of patient vitals performed by a system allows a human to be freed up to perform other healthcare tasks on the patient. In addition, increased access to information results in the ability to make better informed decisions in a more rapid manner (Schmidt et al., 2015).

During the transfer of care process there is a great deal of teamwork being accomplished between multi-disciplinary teams. Understanding the capabilities of the machine and how it can be utilized to support the healthcare professionals is key in building a working human machine team for transfer of care.

Implementation of an information display system as a decision support tool in the highly unstable environment of transfers will require an iterative design process of the system to lead to a proper human machine team. Information display systems are becoming increasingly popular on mobile technologies such as smartphones and tablets. Areas of healthcare are rapidly beginning to use mobile technologies for information displays prompting further research.
1.3 Mobile Technologies

The concept of mobile health (mHealth) is expanding and growing at a rapid rate. Mobile health is a term used to describe the use of mobile devices to communicate healthcare data in support of wellness (Steinhubl, Muse, Topol, 2013). The use of mobile technologies in healthcare can range from patients’ monitoring their own health in the comfort of home to hand-held devices used in hospitals by doctors and nurses. An example of a mobile device used for at home healthcare is a computerized decision support system used to aid patients in tracking their medication schedules (Mazzaglia et al., 2016). The smart phone has become pivotal in mHealth by providing mobile health apps, giving providers quick access to medical information, and allowing patients to become more active in managing their health (Ramirez et al., 2016). The constant need for accurate and quickly updated information has led to the use of mobile devices inside the hospitals. The expanding practice of using mobile technologies is mainly due to their capabilities of information sharing, improving communications, and providing educational materials all at a moment’s notice for the user (Braekkan-Payne, Wharrad, Watts, 2012). Examples of mobile devices used within hospital settings are personal digital assistants (PDA) and handheld tablets (Braekkan et al., 2012). The PDA system gives healthcare workers the ability to access updated information at any moment (Lindquist, Johansson, Petersson, Saveman, Nilsson, 2008). Mobile devices give the healthcare professionals ways to improve the efficiency and effectiveness of patient care delivery (Lu, Xiao, Sears, Jacko, 2005). Ensuring patients receive the best care requires the healthcare field to remain up to date with emerging technologies.
In the transfer of care, time and information are two critical factors that play into the outcome of the patient. Presently, hospitals receive any information about the patient via phone call before the patient arrives and at the moment the patient is handed over. Providing receiving emergency departments with tablets that receive live updates of patient vitals and EMT procedures could enhance the transfer process itself and reduce errors. Currently, there is no real-time implementation for devices to receive live patient vitals from EMTs in use, but these capabilities are being actively researched (Gao et al., 2005). The use of hand held devices in the medical field continues to expand (Bonato, 2010) but there is a need for further research in information displays of patient care data.

The average transport time can be anywhere from 10-17 minutes based on the location (Carr, Caplan, Pryor, Branas, 2006). During the ride to the hospitals EMT’s are busy at work monitoring patient vitals and undertaking critical procedures. Upon arrival at the receiving emergency department, updates such as a brief summary, vital signs, changes in vital signs and other information, are given verbally via the first responder. The use of wearable sensors to monitor patients’ vitals can address the need to reduce response time (Carr, Caplan, Pryor, Branas, 2006), assist the EMT, as well as help the receiving hospital get a better overall picture of the patient’s condition upon arrival. When wearable sensors are utilized in this setting, knowing the best way to present the incoming data to the receiving emergency department becomes significant. Utilizing advanced technologies such as patient monitoring sensors allows for improved patient care, decreased mental workload, increased organization, and better communication.
The current study aims at operating on the idea of EMTs attaching wearable sensors onto the patient immediately upon arrival and the wireless transmission of the incoming data to a handheld tablet at the receiving emergency department.

1.4 Usability

As the technology advances in wearable sensors and their use becomes prevalent in wireless transferring of patient data, usability of user interfaces on computers and handheld tablets in healthcare will become a critical component to study. Usability can also be defined as the ability of a system to permit users to carry out tasks safely, effectively, efficiently, and enjoyably (Patel & Kuskniruk, 1998). Nielsen, in his book titled Usability Engineering, states that usability has multiple components and has five traditional attributes which can be measured: Learnability, Efficiency, Memorability, Errors, and Satisfaction (1993). Throughout the iterative design of an information display, usability testing is a key method for conducting evaluations (Kushniruk, 2002).

Literature on healthcare information systems states that the ultimate rejection or acceptance of a system will largely depend on the degree of usability (Peute, Spithoven, Bakker, Jaspers, 2008). Transfer of care scenarios deal with a vast amount of information in a short amount of time, proposing a need for an information display of incoming data. Before deployment of an information display in such a high stakes environment usability evaluations are essential. While earlier methods of evaluating systems involved a well-completed system, current methods focus on evaluation occurring during the development and design process (Kushniruk, 2002). A large component of correctly evaluating the system during the design process involve gathering information on the actual process of using the system (Kushniruk & Patel, 2004). Due to the highly complex
and variable environment in a transfer of care, creating a complete design of an information display without performing usability testing throughout the process will result in almost sure failure. Usability testing refers to evaluating systems by using participants who represent the target user population (Nielsen, 1993). In transfer of cares, trauma teams consist of nurses and physicians who aid in the process and therefore would be the target population for evaluation. A healthcare information display system that has high usability throughout the iterative design will increase overall acceptance rates and can improve efficiency of the task. Developing guidelines and evaluating the usability for information displays in transfer of care scenarios will aid in the development of the final system design.

1.4.1 Information Presentation

To increase efficiency, usability and improve decision-making performances, information presentation is utilized (Card, Mackinlay, Shneiderman, 1999; Chen 1999; Ware, 2000). The way, type, and amount of information presented as well as and the environment in which the user is operating all play a role in any decision made (Caplin, Dean, 2011; Speier, 2006). Gathering patient information, such as vitals, during an EMT transport to an emergency department will require adequate presentation for the receiving personnel.

Patient vital displays typically have a display system which integrates both numeric and graphical data. Numeric data alone can result in disorganized approaches to data interpretation (Drews & Westenskow, 2006) whereas graphical data offers a more enhanced interface for the user (Drews, & Doig, 2014). While the additional of colors does not always aid in response times (Tullis, 1981), the use of triage colors helps to
organize and prioritize injuries in multi-patient and disaster scenarios (Mackway-Jones, Marsden, Windle, 2006). While it might seem wise to provide receiving personnel with all data collected, research has shown having more information accessible does not always suggest the best choice is made (Marshall, Shekelle, Leatherman, Brook, 2000).

Since there is a relationship between how the information is shown and the complexity of the task (Speier, 2006), research needs to be conducted on understanding the type of information display for the transfer of care environment. Providing trauma teams with information, in this case injuries sustained, vitals, and pre-hospital procedures, could provide better overall care for the patient. Information, especially in the text format, must be given at the correct time and place to be most beneficial (Abhyankar et al., 2013; Ganapathy, Anderson, Kozintsev, 2011). Providing time for the team to prepare the necessary treatment based from the information given can improve overall outcome.
2. RESEARCH OBJECTIVES

2.1 Research Question and Hypothesis

The primary goal of this research is to lay groundwork for developing guidelines for information displays of patient information in transfer of care scenarios on a handheld device to improve communication and medical care. Table 1, below lists the research questions and associated hypotheses.

Table 1: Hypothesis Related to Research Questions

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Hypotheses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does information presentation such as amount of patient vital trends, triage colors, patient details, and pre-hospital procedures influence response time in a transfer of care scenario?</td>
<td>Response time for creating an action plan will differ between simple and complex scenarios</td>
</tr>
<tr>
<td></td>
<td>$H_0$: $U_{Simple} = U_{Complex}$</td>
</tr>
<tr>
<td></td>
<td>$H_1$: $U_{Simple} \neq U_{Complex}$</td>
</tr>
<tr>
<td></td>
<td>Response time for creating an action plan will differ between basic and advanced information displays</td>
</tr>
<tr>
<td></td>
<td>$H_0$: $U_{Basic} = U_{Advanced}$</td>
</tr>
<tr>
<td></td>
<td>$H_1$: $U_{Basic} \neq U_{Advanced}$</td>
</tr>
</tbody>
</table>
### Response Time for Creating an Action Plan

Response time for creating an action plan will differ between type of medical personnel.

- $H_0$: $U_{\text{Nursing}} = U_{\text{Medical}}$
- $H_1$: $U_{\text{Nursing}} \neq U_{\text{Medical}}$

### Usability Scores for Information Presentation

Does information presentation such as amount of patient vital trends, triage colors, patient details, and pre-hospital procedures influence usability of a mobile device in transfer of care scenarios?

Usability Scores will differ between simple and complex scenarios.

- $H_0$: $U_{\text{Simple}} = U_{\text{Complex}}$
- $H_1$: $U_{\text{Simple}} \neq U_{\text{Complex}}$

Usability Scores will differ between basic and advanced information displays.

- $H_0$: $U_{\text{Basic}} = U_{\text{Advanced}}$
- $H_1$: $U_{\text{Basic}} \neq U_{\text{Advanced}}$

Usability Scores will differ between nursing students and medical students.

- $H_0$: $U_{\text{Nursing}} = U_{\text{Medical}}$
- $H_1$: $U_{\text{Nursing}} \neq U_{\text{Medical}}$

### The Next Section

The next section provides an overview of the research approach that was used to investigate the research questions and provide empirical data to support the hypotheses.
2.2 Research Approach

Figure 2 Research framework

To adequately address the research questions, the research was conducted in three phases as shown in Figure 2. Phase I involved data collection related to information display technology used in the emergency medicine domain and understanding the need for improvements in communication during the transfer of care scenarios. In phase I of the study, extensive research was done in the area of complex adaptive systems transfer of care scenarios, and human machine teaming. Also, research in mobile technologies, usability and information presentation in healthcare was conducted to complement the area of focus for the study. Finally, contextual interview with subject matter experts were completed to collect information about current transfer of care, information displays, and to validate patient vital data created for testing. Phase II included creation of the application which would be used for testing during the experiment. First, the wireframe was developed, based on the requirements gathered from phase I, which was followed by the design and development of the application. The patient vital data that was created and validated during phase I was utilized by inputting the data into the application. Phase III consisted of testing the application and analyzing the data to address the research questions. Here, the application that was created in previous phases was used in
experimental testing on nursing and medical students. The data collected was statistically
analyzed and the results were used to answer the research questions. This phase
concluded with discussion for future directions and areas that need to be further explored
based on what this study yielded.
3. METHODOLOGY

3.1 Design of Experiment

Research questions to be addressed are: 1) what type of information display will help improve response time and show the greatest usability for the transfer of care scenarios 2) does the type of scenario influence usability of the system and 3) are there differences in response time and usability between types of healthcare professionals?

An empirical study was conducted to determine the effects of information displays of patient vitals, during transfer-of-care, on a handheld tablet for improved patient transfer of care. An observation of a transfer of care was conducted to see the communication aspect as well as study experts during the process. The experiment was designed to be conducted on a 7-inch Samsung tablet. The pool of participants was 16 Wright State Nursing or Medical Students (8 nursing students and 8 medical student). Participants had a brief training period before running through the four different experimental scenarios.

The training period was intended to familiarize the participant with the display screens they would be seeing during the experimental scenarios. Two display screen examples were shown during the training period. Participants were allowed as much time as they needed during the training period and could ask any questions regarding the displays during that time.
During the experimental phase, participants were asked to navigate through 4 different simulated transfer of care scenarios using a 7-inch Samsung tablet. Figure 3 shows the simulated participant observing the patient vital data.

![Mock participant using tablet](image)

**Figure 3: Mock participant using tablet**

### 3.2 Mobile Application Design

The mobile application design was created by observing and assessing various types of patient monitoring tools. Numeric and graphical data were chosen since they are commonly used in current patient monitoring systems and help avoid disorganized approaches to data interpretation (Drews & Westenskow, 2006). In addition, the design of the application centered around providing the users with relevant patient data to allow them time to prepare. To ensure consensus, three subject matter experts (SMEs) with extensive emergency response knowledge were interviewed throughout the iterative application design process. Questions asked to the SMEs concentrated on the primary focus of the study. Relevant patient data was determined by the SMEs to be the 5 patient vitals (Blood pressure, Pulse, Respiration Rate, PaO2, and Temperature), patient age and injury, and EMT pre-hospital procedures. In addition to providing input on the information displays, SMEs also validated scenarios and data used in the application. By including this information, the design aimed to improve the CAS environment of the
transfer of care scenario. Since agents within a complex adaptive system react based upon the input of another agent, providing patient information as input prior to arrival allows for the emergency department personnel to prepare and therefore improve organization of the CAS. Furthermore, designing this application to be used on a 7-inch tablet does not take up much space in an emergency department and fulfills the need of a CAS to have limited underutilized space. For this study, an Android application was created and utilized on a Samsung tablet. The development environment the application was designed within was Android Studio. Within Android Studio programming languages XML and Java were used to design and set behaviors for components inside the application.

3.3 Testing Procedures

Prior to beginning the test, participants were informed of the simulated set up- an EMT is arriving at an accident, placing wearable sensors that accurately and immediately starts to record patients’ blood pressure, respiration rate, PaO2, and body temperature. Four simulated scenarios were used throughout the testing. Scenarios involved either 1 or 3 patients, their ages either middle aged or elderly, and accidents were either an automobile accident or a type of kitchen fire/explosion. Participants were introduced to the tablet and the example screens during the training portion. Two example display screens were used during the training. Example one displayed what the ‘Initial Patient Vitals’ screen would look like and showing the graph was static while example two showed an advanced display screen, showing the graph had a dynamic scrolling feature while also showing the participant how to toggle between multiple patients. Figures 4 and
show examples one and two, respectively. Participants could examine, touch, and ask questions while going through the two display screens.

The experimental phase was a 2 X 2 factorial within-participant design. The independent variables were: Scenario (Simple or Complex), Information Display (Basic or Advanced) and an attribute variable, Type of Personnel (Nursing or Medical). The experiment was counterbalanced using Latin Square with respect to scenario and information display. Each participant would go through 4 different situations which consisted of different scenarios and information displays. A simple scenario contained only one patient whereas a complex contained three patients. A basic information display contained graphs which were static, lacked the use of triage colors, and lacked time stamps with the EMT procedures, whereas an advanced display had dynamic scrolling.
graphs, contained the use of triage colors in numeric vitals and patient toggle boxes, and contained time stamps with EMT procedures.

Table 2: Four types of Situations

<table>
<thead>
<tr>
<th>Situation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation A</td>
<td>Simple Scenario, Basic Information Display</td>
</tr>
<tr>
<td>Situation B</td>
<td>Simple Scenario, Advanced Information Display</td>
</tr>
<tr>
<td>Situation C</td>
<td>Complex Scenario, Basic Information Display</td>
</tr>
<tr>
<td>Situation D</td>
<td>Complex Scenario, Advanced Information Display</td>
</tr>
</tbody>
</table>

All situations had the participant use the patient vitals and additional information given to create an action plan for the patient upon arrival. Participants were asked to view initial patient vital data (first 60 seconds), play a short distraction game to simulate commotion in the ED, and then view updated patient vitals. After viewing the updated vitals participants were asked to create an action plan based on the scenario and data presented. The action plan was to be what the participant would do when the patient arrives at the emergency department. The navigation of the scenarios during the experiment is shown in Figure 6.
The ‘Updated Vital Screen’ varied between four interface displays showing basic or advanced displays with simple (one patient) or complex (three patient) scenarios. Basic displays only showed the last five minutes of patient vitals recorded in a static graph, did not include the use of triage colors and did not include what minutes EMT procedures were performed whereas the advanced display had all patient vitals recorded in a dynamic graph, included the use of triage colors, and indicated at what minute EMT procedures were performed. Figures 7-10 show the four different user interfaces.
3.4 Measurements

Time latency, System Usability Scale, and open-ended questionnaires were used for evaluation. Time taken in making an action plan was recorded for each participant during all four scenarios. Participants were measured on how long they looked at the

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**Figure 7**: Situation A Display

**Figure 8**: Situation B Display

**Figure 9**: Situation C Display

**Figure 10**: Situation D Display
patient vital data until they decided to ‘create an action plan’. Time measurements were recorded using a standard timer. Time started when the participant finished reading the scenario information and started to view the updated vital screen and the timer was stopped when the participant pressed the ‘Create Action Plan’ button. Usability of the information displays was measured using the System Usability Scale (SUS) score citation. Developed by Brooke, 1996, SUS provides a quick and reliable way to measure usability. The survey consists of 10 statements for the user to answer using a 5-point scale ranging from strongly disagree to strongly agree. The final score ranged from 0-100 with higher scores showing a more reliable and usable system. Analyzing the scores are as followed: scores above 90 can be considered superior systems, less than 70 may be considered for further scrutiny and improvement and less than 50 may require serious improvement (Brooke, 1996).

Before the experiment concluded a general open-ended questionnaire was administered by the experimenter. The questionnaire was used to evaluate the overall system, gain insight into impressions of the system, identify what elements were liked, disliked, and what improvements, if any, could be made for the system.
4. RESULTS

Oneway analysis of variances with alpha level of 0.05 were conducted on the data collected. Results indicate that there were significant differences in response times for simple and complex scenarios ($F (1,62) = 46.60, p < 0.0001, \eta^2_p = 0.439$) and for basic and advanced information displays ($F (1,62) = 4.09, p = 0.0474, \eta^2_p = 0.062$). Figures 11 and 12 show the average response times in respect to type of scenario and display type respectively.

![Figure 11: Average response with respect to scenario type](image)

Figure 11: Average response with respect to scenario type
Figure 12: Average response time with respect to display type

An analysis of variance indicated there was a significant difference in the response time by situation ($F(3,60) = 19.66, p<0.0001$, $\eta^2_p = 0.496$). Response time for situation D had the slowest response time to create an action plan ($M=91.19$, $SD=38.06$), followed by situation C, ($M=71.63$, $SD=18.51$). The fastest response time was situation A ($M=32.50$, $SD=13.90$) with situation B slightly slower ($M=44.63$, $SD=17.16$). Figure 13 displays the difference in response time for each of the four situations.
Further investigating into the interactions resulted in a significant difference between simple scenario with basic display (Situation A) and simple scenario with advanced display (Situation B) \((F (1,30) =5.36, p=0.0276, \eta_p^2 = 0.1517)\). There was also a significant difference in response times between complex scenario with basic display (Situation C) and complex scenario with advanced display (Situation D) \((t(30)=1.849, p=0.0372)\). Comparison between simple scenario with basic display (Situation A) and complex scenario with basic display (Situation C) yielded a significant difference in response time \((F (1,30) =45.70, p< 0.0001, \eta_p^2 = 0.979)\). Significant difference was also observed between simple scenario with advanced display (Situation B) and complex scenario with advanced display (Situation D) \((F (1,30) =19.40, p< 0.0001, \eta_p^2 = 0.951)\).

There was no significant difference in response time for the different student types. There was a significant difference in response time for nursing students for situations A and B \((F (1,14) =9.34, p=0.0086, \eta_p^2 = 0.400)\). The mean response time for nursing students
during situation A was 45.3 seconds with a standard deviation of 15.1 seconds and for
situation B a mean of 71.1 seconds with a standard deviation of 18.6 seconds. There also
was a significant difference in response time for medical students between situations C
and D (F (1,14) =7.60, p=0.0154, ηp² = 0.352). The mean response time for medical
students during situation C was 72.1 seconds with a standard deviation of 19.7 seconds,
and for situation D a mean of 113.6 seconds and a standard deviation of 37.7 seconds.

The System Usability Scale (SUS) results showed that there was no significant
difference between the scenarios, display types, or type of medical personnel. The overall
average SUS score was 85.28 with a standard deviation of 11.53 and range of 55-100.
Situation A had an average score of 86.88 with a standard deviation of 11.95. Situation
B’s average score was 86.04, standard deviation of 10.95. Situation C had an average
score of 86.43, standard deviation 11.54. Situation D had an average score of 81.41,
standard deviation 11.87. Figure 14 shows the average SUS scores of each situation in a
bar graph.

![Mean(SUS Score) vs. Situation](image)

**Figure 14: Average SUS scores by situation**
A Pearson product-moment correlation coefficient was computed to assess the relationship between the SUS scores and response time. There was a weak, negative correlation between the two variables, $r = -0.297$, $n = 64$, $p = 0.0173$. A scatterplot summarizes the results in Figure 15.

![Figure 15: Scatterplot correlation of SUS Scores and Response times](image)
5. DISCUSSION

5.1 Discussion

Investigating the response times to create an action plan and SUS scores for display type, scenario, and type of medical personnel helped to identify the best information display design for patient vitals in a transfer of care. The significant difference in response time for simple and complex scenarios indicate that when more patients require care, there will be an increase in time spent analyzing patient vitals and data. The results indicating there is a significant difference between response times for display type suggest the advanced display screen resulted in an increased response time. These results could indicate the addition of either triage colors, scrolling dynamic patient vital graphs, summary table, or additional EMT pre-hospital procedure data could influence the user’s response time. Although the result was significant, the low partial eta squared value ($\eta_p^2 = 0.062$) indicates that the display type accounted for only about 6% of the total variability in response time. The significant results for response time by situation shown in Figure 13 indicated that in both simple and complex scenarios the advanced display screens resulted in an increase response time. The interaction effect results helped further identify that basic information display tended to result in quicker response times, suggesting future displays to focus on a more basic display. Investigation into how detailed the action plans were showed that when there is a multi-patient situation, the action plans tended to become less detailed compared to the single patient situations. The action plans for the advanced display tended to have more prioritization perhaps due to
the inclusion of triage colors. While overall there was no significant result in response time for medical personnel type, there were some interesting results found within each personnel type. During the simple scenarios, nursing student had quicker responses when using the basic information display (M=31.5) compared to the advanced (M=45.25) and the same was observed for the medical students during the complex Scenario (Basic display M=33.5; Advanced display M=45.25). These results may suggest the use of basic information displays as being beneficial for nursing students during a simple one patient scenario whereas medical students, perhaps having more knowledge and experience, can use the basic information display to quickly respond in a multi-patient environment. Although the SUS scores yielded no significant results, the majority of the scores fall into the third quantile and were above a 75. Investigation into if the SUS scores and response times had any correlation resulted in a weak negative correlation suggesting a quicker response time tended to lead to a high SUS score. Figure 15 shows high dispersion of the data points for this correlation.

The open-ended questionnaire conducted at the end of the experiment aimed to identify overall usability of the system and display screens. Questions asked addressed if the user thought the application aided in the action plan creation, likes/dislikes of each display, the future of the system, and suggestions for improvement. All the participants agreed that the application aided in their creation of an action plan by providing critical and key information to them. The key findings from the open-ended questionnaire indicate:

- Participants found the application to be helpful for early analysis of the patient status and for preparing a plan of action.
Aspects of the displays participants found most useful were the graph showing the full trends and the EMT pre-hospital procedures.

No consensus was determined for what aspects of the displays were least useful to the participants. Some examples of least useful features mentioned were: use of triage color and patient summary box for multiple patient scenario- found to be distracting to medical students.

All the participants stated they could see a future use for this application in an emergency department setting for transfer of cares.

Improvement suggestions varied. Examples of suggestions were: more/less use of triage colors in vitals/graphs, more detailed EMT pre-hospital procedures, and larger graphs.

From this work, a set of guidelines for developing future displays for transfers to emergency department have been developed. Simple displays such as the ones pictured in Figures 7 and 9 were shown to have faster response times and high usability scores and therefore would be ideal examples for future display designs. Although previous research did not find a response time difference between the use of color and no color (Tullis, 1981) this research study may indicate the use of colors to be distracting and increase in response times.

5.2 Future Work

Future work in this area could be accomplished by increasing and specifying the sample size. A potential study could also work on fine tuning the information displays to further target the specific qualities that will lead to decreases response time, high usability scores, and low mental workload. Prospective work could take updated
iterations of the information displays and test their usability in a simulated emergency
department with the patient vitals being livestreamed to more closely imitate a real
transfer of care. Once wearable sensor technology and wireless transfer of data become
more widely utilized in the EMT field, future work can address the integration of the
application.
6. IMPLICATIONS

There is much need for additional research regarding wireless transfer of patient data and resulting information display. The fast paced, highly unpredictable environment of transfer of care results in critical information being condensed down to be verbally conveyed as quickly as possible. Reducing patient information can result in errors, miscommunications, and even negative outcomes for the patient. This study analyzed response time and usability in information displays for transfer of care scenarios. The research implications of this study showed some potential for advancing uses of information displays on mobile devices into emergency departments for transfer of cares and thereby improving the complex adaptive system that is a transfer of care. Investigating the best information display resulted in the simpler displays having a faster response times compared to the advanced. The research also showed that the higher the SUS score the quicker the response time suggesting future studies focus on high usability. The use of an information display such as the one in this study could potentially help with the creation of simulation systems for transfer of care training. With advanced simulated scenarios researchers can learn further about the uses and benefits of information displays during transfer of cares. An iterative design process will yield an information display with a high usability as well as specific design guidelines for using such tool. With this gained knowledge, research in improving communications during time critical patient
handoffs and overall patient outcomes can better be attained in emergency departments.
7. REFERENCES


_Prehospital Emergency Care, 7_(2), 247-251.


Appendix I - Questionnaire

SUBJECT ID________________

Type of student: Nursing Medical

Resident

Years of study ______________

1) Did the application help you in creating the action plan? Yes, no? Why/why not?

2) What did you find most useful in the application? What was least useful?

3) Could you see a future use for this application in an emergency department setting? If yes- why? no- explain (note: ask about how this would fit with ED electronic records)

4) If you could make any improvements or suggestions to this application, what would they be?

5) Any additional comments?
# Appendix II – System Usability Scale

## System Usability Scale

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

Scenario 1
Simple 1
Initial information given: 1 patient coming in from an automobile accident. ETA: 15 minutes

Additional information/Scenario:
You’ve received further information on the accident and status of your patient via the EMTs.
The patient was the driver of the vehicle and is a 35 y/o male. The patient suffered a head injury after rear ending another car and suffered a broken forearm. There are bruises and discoloration on his temporal area and he had a two, minute loss of consciousness (LOC) during transport. Vital signs over the last 5 minutes have been arriving in addition to a record of procedures performed by EMTs.

Scenario 2
Simple 2
Initial information given: 1 patient coming in from an automobile accident. ETA: 15 minutes

Additional information/Scenario:
You’ve received further information on the accident and status of your patient via the EMTs.
The patient is a 75 y/o male. The car slid off road into a nearby tree. He was found unconscious but is awake once brought into ambulance. The patient suffered minor head and neck injuries due to the slow speed during the accident. The patient has a fractured foot and is complaining of neck pains and has bruises and discoloration on his forehead and has cuts and bruises on his head. Vital signs over the last 5 minutes have been arriving in addition to a record of procedures performed by EMTs.

Scenario 3
Complex 1
Initial information given: 3 patients injured in an explosion at a local restaurant. ETA: 15 minutes

Additional information/Scenario:
You’ve received further information on the status of your patients via the EMTs. The explosion was in the kitchen of a restaurant; 3 workers were near the explosion. Patient 1, male 18 y/o, was closest to the explosion and has multiple 2nd degree burns and some 3rd degree burns on his arms and torso. Patient 2, female 22 y/o, was near glass that was caught in the explosion and has multiple cuts on her face and a piece of glass in her eye, her face is bleeding continuously from the cuts. Patient 3, male 19 y/o, inhaled too much smoke, has shortness of breath (SOB) and had a loss of consciousness (LOC). EMTs
picked him up in an unconscious state. Vital signs during entire transport have been arriving in addition to a record of procedures by the EMTs.

**Scenario 4**

*Complex 2*

Initial information given: 3 patients injured in an explosion at a nursing home: ETA: 15 minutes

Additional information/Scenario:

You’ve received further information on the status of your patients via the EMTs. The explosion was in the kitchen of a nursing home; 3 elder patients who live at the nursing home were injured. All patients are over 70. Patient 1 is an elderly patient who was near the kitchen to get food and suffered a hip fracture from falling down due to the blast. Patient 2 and 3 are having shortness of breath (SOB) from inhaling too much smoke from the explosion/fire. Patient 3 had a loss of consciousness (LOC) during transport. Vital signs during entire transport have been arriving in addition to a record of procedures by the EMTs.
Appendix IV – Triage Indices

Triage indices:

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Intermediate</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure (Systolic)</td>
<td>111-120</td>
<td>90-110</td>
<td>&lt;90 or &gt;160</td>
</tr>
<tr>
<td></td>
<td>121-160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse</td>
<td>60-100</td>
<td>50-60</td>
<td>&lt;50 or &gt;120</td>
</tr>
<tr>
<td></td>
<td>101-120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory Rate</td>
<td>12-20</td>
<td>8-11</td>
<td>&lt;8 or &gt;25</td>
</tr>
<tr>
<td></td>
<td>21-25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PaO2</td>
<td>95-100</td>
<td>88-95</td>
<td>&lt;88</td>
</tr>
<tr>
<td>Temperature (F)</td>
<td>98.2-100.2</td>
<td>95.0-98.1</td>
<td>&lt;95 or &gt;102</td>
</tr>
<tr>
<td></td>
<td>100.3-102</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix V – Action Plan Examples

Nursing Student Example Actions Plans:

Situation A Action Plan

Write down your action plan here:

Pt. 1: Assess head-to-toe, reevaluate vital signs, redo Glasgow coma scale, call for neuro- consult, consult ortho for bone-injury case, asks pt what happened, medications be on, allergies, instruct pain medicine, notify family. Keep in ED until consults are finished or further instruction is given.

Situation B Action Plan

Write down your action plan here:

Pt. 1 - Assess head-to-toe, redo Glasgow coma scale, ask the man what happened, pain level, feeling in extremities. Call X-ray to look at fractured foot, maintain bedrest, add precautions, get a list of medications he is on, allergies, transfer to ortho.

Situation C Action Plan

Write down your action plan here:

Patient 1: Assess burns, remove debris from burns, clean them, prepare before closing with pain medication, if able, transfer to burn ICU, monitor vital signs continuously.

Patient 2: Assess cuts on face and call plastic surgeon liquids at the eye, monitor vital signs continuously, prep for surgery, give pain meds if applicable, transfer to Pre-op.

Patients: Assess resp. status, get an order/protocol for intubation to maintain patent airway, monitor vitals continuously, pain management, correct mechanical ventilation.
Situation D Action Plan

Write down your action plan here:

Pt. 1: Monitor vital signs, call x-ray tech to look at her hip, possible prep for surgery STAT, DVT prophylaxis implementation.

Pt. 2: Monitor vital signs, assess thorax, possible identification, transfer to trauma.

Pt. 3: Monitor vital signs, maintain patient airway with ET tube, assess for trauma, transfer to ICU.

Medical Student Example Actions Plans:

Situation A Action Plan

Write down your action plan here:

1. 1st Assessment: "ABCDE" GCS
2. Exam w/ focus on neuro + GCS in ED (as compared to field), r/o x3 assessment
3. Exam for arm + head inj.; IV access x 2
4. X-ray of forearm, CT scan of head
5. EKG, level, V/Q

Situation B Action Plan

Write down your action plan here:

1. 1st Assessment: "ABCDE" GCS
2. IV access x 2
3. Assess r/o x3/GCS
4. Exam: lungs/heart, head, abdomen, feet, chest
5. CT of head/chest/abdomen
6. XR of foot
7. Type & cross, ABG, CBC
8. Portable CXR
Situation C Action Plan

Write down your action plan here:

1st
- **Assessment:** "ABDE"
  - GCS, Pulse, SpO2, BP, HTN
  - Start IV
  - Keep warm

2nd
- Same
  - EX IV access
  - Assess Active Bleeding/Stop Bleeding
  - Assess Eye Vision/Damage
  - LT Head: Assess Gouging Injury
  - Left Eye/Pupil

3rd
- Same
  - Keep O2/iv/warm
  - ABG + CXR
  - Keep warm
  - IV access x2

Situation D Action Plan

Write down your action plan here:

**Pt #1**

- General Assessment: Exam of skin, appearance, GCS, pulse, ABD (Hemorrhagic/hypovolemic)
- Lung/hem
- Focused Assessment of H&P
- X-ray of hip
- Motor/VS
- Appropriate pain management

**Pt #2**

- Same
- Assess work of breathing, airway patency, sputum/watery
- Keep supplemental O2 on mask, get CXR + ABG
- Monitor VS + Resuscitate status
- IVF after IV access x2
- Have intubation ready

**Pt #3**

- Same
- IV access x2, start IV, start warming gel
- Keep intubation + warming gel
- ABG, CXR, LT head
- Look for other injuries