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Human Factors Considerations in a Telemedicine-Integrated Ambulance-Based Caregiving Environment for Stroke Care

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HUMAN FACTORS CONSIDERATIONS IN A TELEMEDICINE-INTEGRATED AMBULANCE-BASED CAREGIVING ENVIRONMENT FOR STROKE CARE

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by
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ABSTRACT

Telemedicine, the use of communications technology to connect patients to medical professionals remotely, can be applied to a variety of settings, for example connecting older adults with their physicians from home, specialists to rural county hospitals or patients to physicians for emergency care. This dissertation focuses on the use of telemedicine for ambulance-based care for stroke patients, including how the design of this system impacts caregivers.

The initial study investigated both the usability of a telemedicine system implemented in ambulances for stroke care as well as the possibility of human error when using it. The heuristic evaluation of usability violations found several issues that needed to be addressed, including the lack of clarity in the tab structure and the lack of suggestions for correct data inputs. Similarly, the analysis of possible errors also determined several issues with this system, with the two most common being miscommunication and difficulty in locating data input or selecting an incorrect option. Several remediations strategies were recommended based on this study: improvement of the labelling of the tab structure, consistent formatting, rigid or suggested formatting for data input, automation of task structure and camera movement, and audio/visual improvements to support communication.

The second study investigated the experience of caregivers with the ambulance-based stroke telemedicine system, focusing on the support of the distributed cognition of the caregiving teams. Teams comprised of a neurologist, nurse, and paramedic were

observed conducting 13 simulated stroke consults, after which each caregiver completed a survey on the perceived workload, usability, and teamwork during the session and an interview about their experience with the telemedicine system. In total, thirty-nine caregivers were interviewed, and the data collected were analyzed for themes. The themes that emerged identified such barriers to and facilitators for using telemedicine for ambulance-based stroke caregiving as training and experience, technical difficulty barriers, and patient care and efficiency improvement facilitators. The findings from this study resulted in design recommendations for supporting healthcare professionals during caregiving, especially ones that support their distributed cognition when using ambulance-based telemedicine for stroke care.

The final study evaluated the effect of design recommendations implemented in a new telemedicine system on the neurologist's workload, situation awareness, and task performance in addition to evaluating the perceived usability of this new design and its support of distributed cognition. For this study based on a within-subjects experimental design, 20 neurologists completed simulated stroke assessments using both the new design and the design investigated in the two previous studies and evaluated each system. Overall, the results found that the neurologists experienced a lower workload, performed better in their task, exhibited higher situation awareness, and rated usability highly in the new design. In addition, most participants thought that the new design better supported distributed cognition principles and preferred the new system for ambulance-based stroke consults.

DEDICATION

This work is dedicated to my family, my mom Stephanie, my dad Steve, and my sisters Kaitlyn and Meaghan who never gave up on me, never let me give up on myself and saw the light at the end of the tunnel even before I did. Your love and support kept me through and I am forever grateful.

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CHAPTER ONE

INTRODUCTION

Emergency Medical Services (EMS) stabilize and care for a variety of people and sometimes complex conditions. The nature of the work creates a fast-paced, high-stress environment with shifts longer than 8 hours for most Emergency Medical Technicians (EMTs). These factors, in addition to the types of conditions seen and their work environment, can create a high incidence of errors in both equipment and organization, but more importantly in human action or inaction. Errors in these cases are likely more frequent than in a normal health care setting because of high decision density, high severity conditions, and a small work area (Hobgood, Xie, Weiner, & Hooker, 2004; Patterson et al., 2012). These cases are also, by nature of being in an ambulance, emergencies which mean errors could quickly turn serious or fatal. It is for these reasons that patient safety in the pre-hospital setting is so vital to understand through research, specifically how humans make errors in this setting. However, the use of ambulances as not just transport, but vital stabilization and treatment facilities improves patient outcomes and time to treatment (Band et al., 2011; Bernard et al., 2010; Gardtman, Waagstein, Karlsson, & Herlitz, 2000; Jurriën et al., 2010). Specifically in the transport of cardiac and stroke patients, ambulance care can improve triage, decrease time to treatment, and increase use of time-limited lifesaving treatments such as tissue plasminogen activators (t-PA) (Kunisawa et al., 2014; Kwan, Hand, & Sandercock, 2004; Mosley et al., 2007; Quain et al., 2008; Wendt et al., 2015).

PROBLEM STATEMENT

Telemedicine, the use of telecommunications technology to provide access to healthcare when geographical barriers make face-to-face consultation impractical (Board on Health Care Services & Institute of Medicine, 2012; Kobb, Hoffman, Lodge, & Kline, 2003; National Academy of Sciences, 2014), is being integrated into such wide-ranging aspects of patient care as home health monitoring (Koch, 2006), out-of-office hospital consultation (Agnisarman et al., 2017), and ambulances (LaMonte et al., 2004). This growing field began in the 1960s when telephone communications and microwave signals were first introduced for transporting data (Field, 1996), followed by the second generation in the 1990s with the creation of the Internet and the World Wide Web, both of which relaxed the constraints of time and geography (Institute of Medicine, 2012). The third and current generation focuses on the use of mobile networks to transfer data, including video and voice communication, across vast distances (Yperzeele et al., 2014). Feasibility, pilot, and clinical studies using this third generation have explored both the benefits and limitations of this growing field (Barrett et al., 2016; Bergrath et al., 2011; Charash et al., 2011; Cho, Kwon, & Jeong, 2015; Czaplik et al., 2014; Felzen et al., 2016; Hadeed & Hadeed, 2011; Kwak et al., 2009; LaMonte et al., 2004; Liman et al., 2012; Lippman et al., 2016; Mandellos et al., 2004; Sibert et al., 2008; Takeuchi et al., 2015; Terkelsen et al., 2002; Valenzuela Espinoza et al., 2016; Walter et al., 2012; Xiao et al., 2000; Yperzeele et al., 2014), finding that these systems require low interference and a high level of functionality and usability to facilitate seamless interaction.

Emergency care, specifically that given in ambulances, is one area where telemedicine has the potential to play a critical role. Past research (LaMonte et al., 2004; Mandellos et al., 2004; Papai et al., 2014; Terkelsen et al., 2002; Valenzuela Espinoza et al., 2016; Walter et al., 2012; Yperzeele et al., 2014), found that its use can decrease treatment time by completing diagnosis steps in pre-hospital transport with a high level of diagnosis accuracy. For example, several studies (Barrett et al., 2016; Liman et al., 2012; Rörtgen et al., 2013; Walter et al., 2012) have found that stroke evaluation completed by teleconsultation in conjunction with EMS personnel can improve the level of care given before admittance to the hospital; this is especially important because according to a recent review (Schwamm et al., 2009), 74% of stroke cases died outside of the hospital (Norris, 1998). A recombinant tissue plasminogen activator (rt-PA) treatment, the gold standard for stroke care, can dissolve a clot that causes an ischemic stroke intravenously. However, 99.1% of hospitals in the U.S. alone have a rt-PA treatment rate of 10% or less (Kleindorfer et al., 2009). In most instances this is caused by the time to treatment being longer than the 3 hour window from symptom onset (LaMonte et al., 2004; Valenzuela Espinoza et al., 2016). Reducing transport time using telemedicine holds a large potential for increasing stroke survival rate (Saler, Switzer, & Hess, 2011). Integrating telemedicine systems in ambulances may reduce fatalities from not only strokes, but also other cardiovascular diseases.

With an abundance of research on the benefits and costs of using telemedicine systems in ambulances, there is a lack of research found in the literature that provides an understanding of how these systems influence EMTs or paramedics workflow or the demands placed on them in this work system. Limited research is also conducted on the demands placed on the nurses and emergency physicians that support the EMTs and paramedics through the telemedicine system.

THEORETICAL FRAMEWORK

SEIPS 2.0

The Systems Engineering for Patient Safety or SEIPS 2.0 model will be used in this research to understand the ambulance work system and how the addition of a telemedicine system changes that work system. This model takes a system approach to looking at health care and how work systems ultimately shape outcomes (Holden et al., 2013). This model has sought to improve healthcare using human factors principles and a focus on human system integration. The model is graphically represented in Figure 1.1. Here the work system is depicted as containing 6 interacting components: Tools & Technology, Organization, Tasks, Internal Environment, External Environment and Person(s). These components create processes that can be specified as being Professional work, Collaborative Professional - Patient work, and Patient work. These processes are also referred to as workflow in healthcare. These processes create outcomes that can be classified as Patient, Professional or Organizational and can be desirable or undesirable and proximal, the direct result of a work process, or distal, a result of causal actions and observed over time. Through all stages of this model, feedback or adaptation is present, outcomes are observed, and changes are made to work processes or the work system.

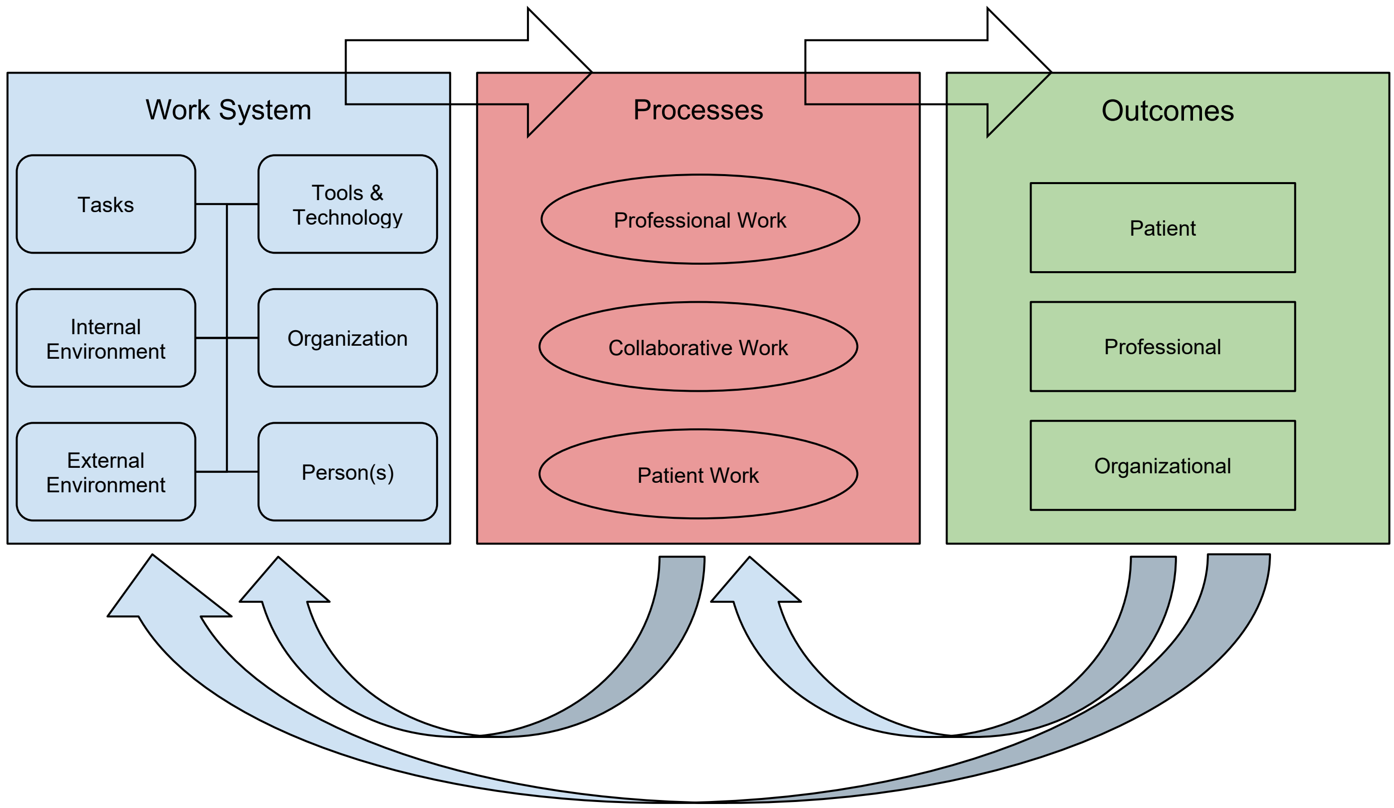

Figure 1.1: The SEIPS 2.0 model adapted from (Holden et al., 2013)

This research will investigate how telemedicine in an internal environment of an ambulance will interact with organization, task, external environment, and the people (EMTs or paramedics, nurses, and emergency physicians) components of a work system. This will be observed through the workflow or work processes identified in this model. Assessing patient condition, communication of symptoms, and development of diagnosis and treatment plan is classified by this model as Collaborative Professional - Patient work, with the assumption that the patient is conscious or is accompanied by a family member or caretaker. Interviews will improve understanding of the interaction of the components in this work system and how the interaction creates the current workflow as well as perceptions of how that workflow impacts outcomes. This research will also consider how changes to the work system affect professional outcomes through system testing and provide feedback for future development of these work systems.

Distributed Cognition

By its nature, the placement of people and components in a telemedicine consultation are distributed by physical distance. There is also a separation of the mental models of all providers in a telemedicine consultation that needs to be considered. Specialists, emergency physicians, or nurses have a knowledge of diagnoses and treatments that they must relay to the patient or pre-hospital provider and likewise the patient or pre-hospital provider must communicate vital signs and symptoms. Distributed Cognition considers the information processing in a system when people are physically or mentally separated (Hollan, Hutchins, & Kirsh, 2000). Previous studies have approached areas such as medical informatics (Hazlehurst, Gorman, & McMullen, 2008), patient records (Bång & Timpka, 2003), and clinical research forms for data collection (Nahm, Nguyen, Razzouk, Zhu, & Zhang, 2010), using distributed cognition as a framework. Furniss and Blandford developed a method of modeling distributed cognition in teamwork through understanding the information flow, physical layout, and artifacts of the system called Distributed Cognition for Teamwork or DiCoT (Furniss & Blandford, 2006). This method of modeling has been used to improve mobile healthcare (McKnight & Doherty, 2008) and infusion administration in the Intensive Care Unit (ICU) (Rajkomar & Blandford, 2012). Understanding the information flow and the physical layout of the stroke telemedicine consultation, specifically completing communication analysis, is paramount to supporting distributed cognition and ultimately effective teleconsultation. This research will use the principles outlined in the DiCoT model to understand the telemedicine system and to develop interventions to enhance distributed cognition and improve workflow and usability of a telemedicine system for ambulatory stroke care.

RESEARCH OBJECTIVES

The primary objective of this dissertation is to understand how telemedicine systems can be used to support general patient care and specifically stroke care in ambulances. More specifically this dissertation explores the following research topics:

1. Understanding how telemedicine systems have been implemented in ambulances worldwide.
    a) To understand the improvements and challenges found in implementation
    b) To understand what human factors considerations have been made in implementation
2. Understanding the errors made by EMTs or paramedics in pre-hospital or ambulatory care of patients and how technology could mitigate the causes of errors.
3. Evaluate a telemedicine integrated ambulance-based system for stroke care and how that system affects workflow, information flow, and patient and professional outcomes.
4. Develop interventions for a telemedicine integrated ambulance-based system for stroke care to enhance distributed cognition among geographically dispersed caregivers.

Research Questions

The overall research questions this dissertation aims to answer are listed below:

1. How are telemedicine systems being used or evaluated currently and what are the barriers to their use?
2. What human error occurrences impact ambulance-based emergency care?
3. What are the issues concerning usability and human error in a current ambulance-based telemedicine for stroke caregiving?
4. What are the cognitive demands and workload of geographically distributed caregivers in a current ambulance-based telemedicine for stroke caregiving?
5. What design interventions can be used to improve the work system, workflow, outcomes, and distributed cognition when using a telemedicine-equipped ambulance?

DISSERTATION ORGANIZATION

This dissertation is organized as follows: Chapter Two details a systematic review of the literature on the challenges and benefits of implementing telemedicine systems in ambulances. Chapter Three summarizes the types and rates of human error of paramedics and EMTs in ambulances found in the literature. Chapter Four evaluates the usability and human error possibilities of the current telemedicine system integrated in ambulances in a South Carolina county used for stroke care. Chapter Five evaluates demands placed on EMTs, nurses, and physicians when stroke care is provided through telemedicine-equipped ambulances. Chapter Six explores the generation and testing of interface design interventions to enhance distributed cognition among caregivers for ambulatory stroke care. Chapter Seven summarizes findings of this dissertation, discusses impact of the findings, and provides future research recommendations.

CHAPTER TWO

A SYSTEMATIC REVIEW OF THE IMPLEMENTATION CHALLENGES OF TELEMEDICINE SYSTEMS IN AMBULANCES

INTRODUCTION

The use of telemedicine represents one of the benefits to society from advancements in information technology. The ability to send packets of data and communicate lifesaving information from almost anywhere represents possibilities to vastly improve patient care and quality of life. Whether for use in the home (Agnisarman et al., 2017; Newlin, McCall, Ottmar, Welch, & Khairat, 2018) or in emergency transport (Curry & Harrop, 1998; Kyriacou et al., 2003), telemedicine is being tested for benefits and barriers. The costs of the technology are apparent, but other obstacles such as usability or time investment need to be assessed as well. Improvements to patient care and health outcomes need to be understood in tandem.

This systematic review of the literature focuses on answering the following research questions:

1. What are the benefits of implementing telemedicine in ambulances?
2. What are the challenges or barriers associated with the implementation of telemedicine systems in ambulances?
3. On a larger scale, what are the implications of using telemedicine in ambulances?

Furthermore, this review summarizes the results from the research reviewed and identifies the challenges, best practices, and opportunities for further research.

MATERIALS AND METHODS

Institutional Review and Human Subject Determination

This study was exempted from approval by Clemson University's Institutional Review Board, as it did not involve active human subject research. No individual patient participated in this study.

Data Sources

Web of Science and PubMed were searched for articles published between the years 2000 and 2016. Duplicates were identified using Endnote and searching manually. An additional search was made through citations of articles selected for review for relevant studies published within the same time frame, but none were found to be useful for review.

Search Terms

The databases were searched using keywords ‘‘Telemedicine AND Ambulance’’ (retrieved 134 articles from PubMed; retrieved 140 articles from Web of Science), ‘‘Telemedicine AND emergency healthcare’’ (retrieved 8 articles from PubMed; retrieved 14 articles from Web of Science), ‘‘Emergency Telemedicine’’ (retrieved 57 articles from PubMed; retrieved 55 articles from Web of Science), and ‘‘Telemedicine AND Emergency Medical Services’’ (retrieved 396 articles from PubMed; retrieved 72 articles from Web of Science), and selected titles and abstracts that incorporated telemedicine systems into ambulances, testing the system's feasibility in any patient category.

Inclusion and Exclusion Criteria

Domain

Articles were included from any domain as long as they focused on the implementation of telemedicine systems in ambulances.

Article Format

Extended abstracts and posters were not included in this review, and studies were excluded if they did not contain at least a pilot study with simulated or real patients.

Language

Only articles published in English were included in this review.

Publication Year

Articles were only chosen if they were published between 2000 and 2016. This time-period was chosen not only to keep studies relevant but also to document the beginning and development of the third generation of telemedicine, which is defined by the revolution of communication over mobile networks.

Article Selection

The research team reviewed titles and abstracts of all articles found in initial search (864) to determine which could be included for full-text screening. Abstracts were not considered for full text review if they did not include any experimental results. With this screening process, 102 articles were chosen for full text analysis. Articles were excluded if they did not test telemedicine system capabilities in some way to show feasibility or implementation benefits and challenges. As a result, 23 studies were selected for review;

any conflicts in selection decisions were resolved through discussion between readers. Figure 2.1 describes the article search, screening, and selection in more detail.

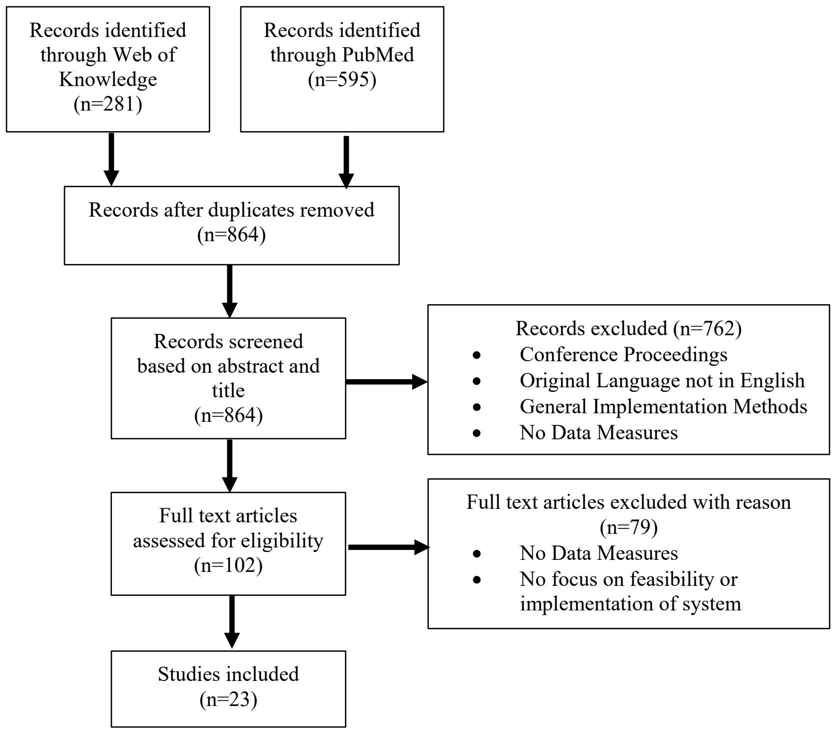

Figure 2.1: Selection flowchart

Data Abstraction

Data were taken from each article and placed into a table to organize results and details about each article. Method, sample size, objectives, technology, application, key findings, and limitations were identified in each article.

RESULTS

Analysis of these 23 studies suggested three major domains of research: General Care, Stroke Care, and ST- Elevated Myocardial Infarction (STEMI) Care, with each study including the application, the technology explored, the data collection methods used, and an analysis of the data collected and the results found.

Table 2.1: Application of selected studies

	Application		
Author	General Care	Stroke	STEMI
Tang et al., 2006	•		
Yperzeele et al., 2014	•		
Bergrath et al., 2013	•		
Cho et al., 2015	•		
Xiao et al., 2000	•		
Espinoza et al., 2016		•	
Mandellos et al., 2004	•		
Takeuchi et al., 2015			•
Papai et al., 2014			•
Terkelsen et al., 2002			•
Sibert et al., 2008	•		
Bergrath et al., 2011	•		
Barrett et al., 2016		•	
Felzen et al., 2016	•		
La Monte et al., 2004		•	

Rörtgen et al., 2013	•	
Charash et al., 2011	•	
Liman et al., 2012		•

Application Overview

An analysis of the 23 articles found they represented three application categories. Most studies (61%) involved general emergency care, with the remaining 39% focusing on one type of emergency patient. More specifically, six studies focused on stroke pre-hospital care and three on STEMI care. Table 2.1 categorizes the studies based on application domain.

Origin Overview

Thirty-five percent of studies were conducted in the United States, another 30% were conducted in Germany, and the remaining countries of origin have no more than two studies. Specifically, two studies were conducted in each of the following countries: Greece, South Korea, and Belgium, and one study was conducted in each of the following countries: Japan and Denmark.

Technology

The technology used most frequently in the studies reviewed was for the transmission of vitals or testing results over a network, a use case seen in all but six of the studies (Bergrath et al., 2013, 2011; Charash et al., 2011; Cho et al., 2015; Czaplik et al., 2014; Felzen et al., 2016; Hadeed & Hadeed, 2011; Lippman et al., 2016; Papai et al., 2014;

Rörtgen et al., 2013; Sibert et al., 2008; Takeuchi et al., 2015; Tang, Johnson, Tindall, & Zhang, 2006; Terkelsen et al., 2002; Valenzuela Espinoza et al., 2016; Walter et al., 2012; Xiao et al., 2000; Yperzeele et al., 2014). Such vital signs as blood pressure, blood sugar, body temperature, and electrocardiogram (ECG) were transmitted over various network types, with six studies using a Global System for Mobile communications (GSM) (Bergrath et al., 2011; Czaplik et al., 2014; Felzen et al., 2016; Mandellos et al., 2004; Terkelsen et al., 2002; Xiao et al., 2000), nine using 4th Generation Long Term Evolution (4G LTE)/ 3rd Generation (3G) networks (Barrett et al., 2016; Charash et al., 2011; Czaplik et al., 2014; LaMonte et al., 2004; Lippman et al., 2016; Sibert et al., 2008; Takeuchi et al., 2015; Valenzuela Espinoza et al., 2016; Yperzeele et al., 2014), and two using a High-Speed Downlink Packet Access (HSDPA) technology (Cho et al., 2015; Liman et al., 2012). The remaining studies either used radio links (Bergrath et al., 2013; Papai et al., 2014), Wireless Broadband Internet (Hadeed & Hadeed, 2011; Kwak et al., 2009), or did not specify the network (Rörtgen et al., 2013; Tang et al., 2006; Walter et al., 2012). In addition to the transmission of vital data, all but 2 (9%) used some form of communication from the ambulances to either a hospital or an out-of-office location (Mandellos et al., 2004; Tang et al., 2006). Sixty-seven percent of the studies used a cell phone system with a video feed or still images for communication with the hospital unit (Bergrath et al., 2013, 2011; Charash et al., 2011; Czaplik et al., 2014; Felzen et al., 2016; Kwak et al., 2009; LaMonte et al., 2004; Papai et al., 2014; Rörtgen et al., 2013; Sibert et al., 2008; Takeuchi et al., 2015; Terkelsen et al., 2002; Walter et al., 2012; Xiao et al., 2000), while the remaining 33% used a bi-directional video and audio system (Barrett et al., 2016; Cho et al., 2015;

Hadeed & Hadeed, 2011; Liman et al., 2012; Lippman et al., 2016; Valenzuela Espinoza et al., 2016; Yperzeele et al., 2014). Table 2.2 shows the technologies and networks used in each study.

Table 2.2: Technology and Network of Selected Studies

	Transmission Content			Transmission Method				
Author	Vitals	Voice	Bi-directional Video	GSM	HSDPA	4G/3G	Radio	Not specified
Tang et al., 2006	•							•
Yperzeele et al., 2014	•		•			•		
Bergrath et al., 2013	•	•					•	
Cho et al., 2015	•		•		•			
Xiao et al., 2000	•	•		•				
Espinoza et al., 2016	•		•			•		
Mandellos et al., 2004				•				
Takeuchi et al., 2015	•	•				•		
Papai et al., 2014	•	•					•	
Terkelsen et al., 2002	•	•		•				

Sibert et al., 2008		•			•	
Bergrath et al., 2011	•	•		•		
Barrett et al., 2016			•		•	
Felzen et al., 2016	•	•		•		
La Monte et al., 2004		•			•	
Rörtgen et al., 2013	•	•				•
Charash et al., 2011	•	•			•	
Liman et al., 2012			•		•	

Data Collection and Analysis Methods

Of the studies reviewed, 61% included some form of user evaluation (Barrett et al., 2016; Bergrath et al., 2013, 2011; Cho et al., 2015; Czaplik et al., 2014; Felzen et al., 2016; Hadeed & Hadeed, 2011; Kwak et al., 2009; Liman et al., 2012; Lippman et al., 2016; Sibert et al., 2008; Terkelsen et al., 2002; Xiao et al., 2000; Yperzeele et al., 2014) to collect the data from the participants. This evaluation focused on usability of the telemedicine system (Barrett et al., 2016; Kwak et al., 2009; Sibert et al., 2008; Xiao et al., 2000; Yperzeele et al., 2014), the clinical value of the telemedicine equipment and its results (Felzen et al., 2016; Kwak et al., 2009), the acceptance rate of the telemedicine system

(Bergrath et al., 2013; Yperzeele et al., 2014), and/or the technical quality of the telemedicine transmissions (Bergrath et al., 2011; Cho et al., 2015; Czaplik et al., 2014; Felzen et al., 2016; Hadeed & Hadeed, 2011; Liman et al., 2012; Lippman et al., 2016; Terkelsen et al., 2002). In addition, network signal strength and data transfer speeds were used for data collection, with 4 of the 23 studies using this evaluation method (Czaplik et al., 2014; Valenzuela Espinoza et al., 2016; Xiao et al., 2000; Yperzeele et al., 2014). Another two studies focused on comparing the tasks completed in a regular ambulance to those completed in a telemedicine-equipped ambulance (Charash et al., 2011; Rörtgen et al., 2013). Stroke care studies reviewed involved evaluating the possibility and reliability of stroke assessment (Barrett et al., 2016; LaMonte et al., 2004; Liman et al., 2012; Walter et al., 2012) and measured the time to evaluate a patient with National Institutes of Health Stroke Scale (NIHSS) to validate the system's feasibility (Barrett et al., 2016; Lippman et al., 2016). Time-to-treatment was a method used largely in Stroke and STEMI care studies (LaMonte et al., 2004; Papai et al., 2014; Takeuchi et al., 2015; Terkelsen et al., 2002; Walter et al., 2012), with one general care study using this method (Mandellos et al., 2004). Furthermore, diagnosis accuracy, the comparison of pre-hospital and final diagnosis, was used in three studies (Terkelsen et al., 2002; Valenzuela Espinoza et al., 2016; Yperzeele et al., 2014), while one study used a heuristic methodology to evaluate a telemedicine system, with evaluators and EMS users analyzing the prototype iterations based on their usability characteristics (Tang et al., 2006).

Reported Results

The system user evaluations varied, with four studies measuring system usability (Kwak et al., 2009; Sibert et al., 2008; Xiao et al., 2000; Yperzeele et al., 2014) and five measuring the technical quality of the system (Bergrath et al., 2011; Cho et al., 2015; Czaplik et al., 2014; Felzen et al., 2016; Hadeed & Hadeed, 2011). A study measuring usability through a survey of users, asking them to rate their level of agreement with certain statements found high agreement with the statements, ‘‘the telemedicine system was easy to operate,’’ ‘‘the telemedicine system was easy to learn,’’ and ‘‘delays in sending videos posed few problems.’’(Xiao et al., 2000) Another study found that a new system has low usability and maintenance ratings, but had high clinical value (Kwak et al., 2009). In two studies, the quality of still images was rated as excellent to good in 73% (Bergrath et al., 2011) and 93% (Felzen et al., 2016) of cases and video streaming was rated as excellent to good in 89% (Bergrath et al., 2011) and 92% (Felzen et al., 2016) of the cases. Acceptance of the telemedicine system was assessed in two studies through user evaluation, with one study concluding high acceptance based on a 0% patient refusal rate (Bergrath et al., 2013). In addition, three studies (Felzen et al., 2016; Kwak et al., 2009; Yperzeele et al., 2014) measured the clinical value of telemedicine with the clinical value of images and video rated very helpful and helpful in routine use by 94% and 87% of the users, respectively, in one study (Felzen et al., 2016).

Because of the limitations in bandwidth and signal at various locations, the user evaluation of the audio and/or visual quality of transmissions varied, with three studies (Czaplik et al., 2014; Xiao et al., 2000; Yperzeele et al., 2014) measuring signal strength and speed. One study determined median upload and download speeds of out-of-office hours at ~200 kilobits per second (kbps) and 100 kbps and of in-office hours at ~750 and 75 kbps with a transmission success rate of 73.2% (Yperzeele et al., 2014).

Comparing traditional ambulance care to telemedicine ambulance care and survival rates, the studies reviewed here found that not only did EMTs in the latter complete more positive tasks in a simulation study but were also able to complete procedures, for which they had no previous training, successfully with the instruction of doctors through telemedicine using simulated patients; in addition, the telemedicine-equipped ambulance (Charash et al., 2011; Rörtgen et al., 2013) had a higher survival rate. Pre-hospital diagnosis and final diagnosis agreement rates in studies comparing the two were high, with a K statistic of 0.98 and 0.92 for neurological and non-neurological disease, respectively, and 100% for stroke cases using the ambulance (Yperzeele et al., 2014).

Heuristic evaluation decreased usability and heuristic violations by 42% and 50%, respectively, after one round of evaluation in one study. However, heuristic evaluation did not find all issues in the system during the four iterations of the design tested. An ethnographic test in this study revealed 48 usability problems, 21 being potentially catastrophic, with 6 of these 21 being verified in the heuristic evaluation (Tang et al., 2006).

For the NIHSS evaluation, agreement rates were measured by comparing different trained evaluator's ratings of a patient completed through teleconsultation and/or by comparing standard training video ratings, or in ambulance ratings to telemedicine system ratings; both of these studies revealed similar results (LaMonte et al., 2004; Liman et al., 2012). In a study with three raters, the overall interrater reliability K statistic in the 12 scenarios tested were 0.78 in the telestroke group and 0.69 in the control (Liman et al., 2012). In a different study evaluating the success rate in telemedicine NIHSS evaluations, the assessments were successfully completed in 10 of 11 real patient cases and 5 of 5 simulated patients, with the mean time taken to complete the assessment being 7.6 min (Barrett et al., 2016).

Table 2.3: Key Findings of Selected Studies

Authors	Data Collection Method	Reported Results
Tang et al., 2006	• Heuristic Evaluation	• Heuristic evaluation decreased usability and heuristic violations by 42% and 50% respectively after one round of evaluation.
		• Ethnographic study revealed 48 usability problems, 21 being potentially catastrophic problems, only 6 of the 21 problems were verified in heuristic evaluation
Yperzeele et al., 2014	• Diagnosis Accuracy	• A K statistic of .98 and .92 for neurological and non-neurological disease respectively and 100% of cases with stroke were diagnosed in the ambulance
	• User Evaluation	• 75.4% system activation (high acceptability of the system) and usability was rated as 'Good" (median=4 from Likert scale)
	• Signal Strength and Speed	• Median upload and download speeds out of office hours at about 200 Kb/s and 100 Kb/s. Median upload and download speeds in office hours at about 750 Kb/s and 75 Kb/s. Transmission success rate of 73.2%
Bergrath et al., 2013	• User Evaluation	• 0% patient refusal rate
Cho et al., 2015	• User Evaluation	• Video transmission and Biosignal transmission quality received a satisfaction score of 4 by EMS personnel as well as physicians
Xiao et al., 2000	• User Evaluation	• Users agreed, in some cases strongly, that the telemedicine system was easy to operate, easy to learn and that delays in sending videos posed few problems

	• Signal Strength and Speed	• over 70% of pictures transferring at speeds from 1 to 10 frames per second
Espinoza et al., 2016	• Diagnosis Accuracy	• 100% of stroke cases were diagnosed and 83% of stroke pre-hospital diagnoses were confirmed
	• Signal Strength and Speed	• The average upload speeds (from the teleconsultant to the ambulance) was 40 kB/s The average download speeds (from the ambulance to the teleconsultant) was 127 kB/s
Mandellos et al., 2004	• Treatment and Transport Time	• Pre-hospital diagnosis could be made 4 minutes and 20 seconds before patient arrival to the hospital
Takeuchi et al., 2015	• Treatment and Transport Time	• The door-to-balloon time in the telemedicine group was 56.1 ± 13.7 minutes and 74.0 ± 14.1 minutes in the control group
Papai et al., 2014	• Treatment and Transport Time	• Door-to-balloon time (min) of the telemedicine group was 60.31 ± 19.50 and 63.73 ± 21.13 for the control group
		• Transport time (min) of telemedicine group was 53.75 ± 32.97 and 40.78 ± 21.30 in the control group
Terkelsen et al., 2002	• User Evaluation	• Technical quality of the ECGs transmitted were classified as 'good' in 78% of cases and technical quality of communications were classified as 'good' in 73% of cases
	• Diagnosis Accuracy	• Positive Predictive value of 56%
	• Treatment and Transport Time	• Transport time to local hospital in control group was 22 minutes, in telemedicine ambulances where diagnosis was not attempted 10 minutes, in telemedicine ambulances where diagnosis was attempted 14 minutes. Door-to-needle time in control group was 81 minutes, and in telemedicine ambulances 38 minutes
Sibert et al., 2008	• User Evaluation	• Ratings from 1-9 in usability and technical quality characteristics: Ultrasound = 5.1 ± 1.6, Laryngoscope = 7.2.
Bergrath et al., 2011	• User Evaluation	• Quality of still images: 73% 'excellent'-'good', quality of video streaming 89% 'excellent'-'good'
Barrett et	• User Evaluation	• Satisfaction rated at "satisfied" to "very satisfied" in 83% of cases

al., 2016	• Stroke Evaluation	• NIHSS evaluations successfully completed in 10 of 11 real patient cases and 5 of 5 simulated patients and mean time to complete the assessment was 7.6 minutes
Felzen et al., 2016	• User Evaluation	• Clinical value of images and video were rated very helpful to helpful in routine use in 2014 by 94% of users and 87% of users respectively, Quality was rated at Excellent to good for 93% of users for pictures and 92% of users for video
La Monte et al., 2004	• Stroke Evaluation	• Data showed no variability between patients on scores for NIHSS questions including level of consciousness, level of consciousness commands, best gaze, visual fields, and right motor arm testing
	• Treatment and Transport Time	• The mean time to treatment for historic control patients was 33 ± 17 minutes and that for patients with TeleBAT transport was 17.4 ± 3.6 minutes.
Rörtgen et al., 2013	• Task Evaluation and Comparison	• Based on the predefined checklist of sample care activities the telemedicine group's care was comparable to the control with some positive tasks being performed at a higher percentage than the control (obtaining allergies, and medications)
Charash et al., 2011	• Task Evaluation and Comparison	• 24 tests with the telemedicine groups only 2 patients expired, compared to the control where 16 of 16 simulated patients died. Other measures such as the interventions, signs and patients, the telemedicine groups % correct identification was much higher (92%, 96%, 98%) than the control (49%, 79%, 75%). and in the simulations that were outside of the EMTs scope of practice only the telemedicine group was able to complete procedures.
Liman et al., 2012	• User Evaluation	• mean audio signal quality ratings at 2 out of 6 and video signal quality ratings between 2 and 4 out of 6
	• Stroke Evaluation	• Interrater reliability K statistic in the 12 scenarios tested and the 3 raters was .78 in the telestroke group and .69 in the control

When evaluating time to treatment in stroke application, one study found the mean time to be 33 min in the control group and 17 min in the telemedicine group (LaMonte et al., 2004). The results from STEMI studies vary in the improvement in door-to-balloon time, but one study (Terkelsen et al., 2002) found the mean door-to-needle time was 38 min faster than the control group. This study also found a mean transport time that was faster in the telemedicine group by 8 to 12 min depending on if a diagnosis was attempted (Table 2.3).

DISCUSSION

This review was executed to understand the current state of research and detail benefits and challenges faced in studies implementing or testing telemedicine systems in ambulances. Limitations of these studies were documented and are discussed in this section to gain insight on what further study needs to be completed to eliminate these limitations.

Growing concerns in healthcare information technology include the feasibility of using technology to assist in patient care (Chalil Madathil et al., 2013; Madathil, Rivera-Rodriguez, Greenstein, & Gramopadhye, 2015), especially in emergency situations. Of particular interest is how to ensure that this technology works seamlessly with healthcare professionals to limit interference with patient care (Board on Health Care Services & Institute of Medicine, 2012; Koikkara, Greenstein, & Madathil, 2015). Usability testing and user evaluations were represented as a methodology used in more than half of the studies reviewed in this article, with one study devoted entirely to heuristic evaluation and ethnography (Tang et al., 2006); however, four studies reported low usability (Felzen et al., 2016; Kwak et al., 2009; Sibert et al., 2008) or low transmission quality (Liman et al., 2012; Sibert et al., 2008), and one study concluded that the transportation of the telemedicine unit was not feasible in situations where transport on scene to treat a patient outside of the ambulance was needed given the size and weight of the unit (Cho et al., 2015). Given the importance of implementing a highly functional system in a time-dependent process, stakeholders such as EMTs, patients, and doctors should be at the heart of the design process. The timing, efficiency, and level of care are paramount in EMS, and design of the telemedicine systems has to be designed with them in mind to be integrated successfully.

One concern in human-centered design is the cognitive and physical stressors put on the stakeholders by the system (Narasimha, Agnisarman, et al., 2016; Narasimha, Chalil Madathil, et al., 2016; Sanderson et al., 2013; Valdez et al., 2016). Research developing possible stressors, how they affect work in ambulances and with a teleconsultant, and how to eliminate these stressors is needed specifically with telemedicine to be a viable tool for use in ambulances. Another consideration in design is the patient's level of perceived privacy, which has been addressed in one study included in this review. The study cited that patients did not feel that telecommunications intruded on their privacy and felt comfortable in the use of the system, but more studies should include an emphasis on this viewpoint in the patient experience (Xiao et al., 2000). Another aspect necessary to creating effective care when using telemedicine systems is designing those systems in an integrated environment (Madathil, Greenstein, Juang, Neyens, & Gramopadhye, 2013; Narasimha, Chalil Madathil, et al., 2016; Valdez et al., 2016). This method limits training needed to effectively use the system and reduces probability of errors given that the system is similar to other technologies and systems in the environment that users are familiar with (Valdez et al., 2016).

Simulated Studies

Six of the 23 articles reviewed used a simulation study as their sole method of system testing (Charash et al., 2011; LaMonte et al., 2004; Liman et al., 2012; Lippman et al., 2016; Rörtgen et al., 2013; Sibert et al., 2008), a situation that limited the procedures tested because they used medical dummies. For example, the study evaluating the feasibility of completing ultrasounds and intubation procedures in an ambulance through teleconsultation, used a medical dummy to test intubation with a video laryngoscopy and 1 patient to test the ultrasound process, simplifying the investigation to a still, nonresponsive patient or a healthy participant (Sibert et al., 2008). A second study used an METI Human Patient Simulator; however, it simulated patient responses using only a limited number of noninvasive procedures to test the system, thus limiting the testing capacity of the study (Charash et al., 2011).

Another 9% of the studies used actors to simulate patients, specifically in the NIHSS evaluation. One study generated 12 scenario scripts that actors and clinical care transport staff completed, while three evaluators observed either by TV/VCR recording or through a TeleBAT system on a desktop computer, comparing the results to historic patients (LaMonte et al., 2004), while another study used actors trained in simulating right and left middle cerebral artery stroke syndromes with differing severity (Liman et al., 2012). These studies may introduce a bias in the simple NIHSS evaluation because of the previous experience of the actors in simulating strokes as well as limitations in evaluating clinical value of vital transmission as these studies used healthy patients. Two studies reviewed completed an onboard trial with a simulated patient to test the feasibility of the system and orient the medical staff with the equipment before a live trial to both test system capabilities in real situations and validate the feasibility results (Barrett et al., 2016; Xiao et al., 2000).

Sample Size and System Testing

A common limitation cited in the studies reviewed was the sample size of the patient trials or simulation runs. Studies cited small sample sizes as they tested the system, using 4 to 12 participants. Similarly, the sample sizes of simulation tests were also small (n = 7) as were simulation scenarios which ranged from a sample size of 3 to 12; however, the number of runs of these scenarios ranged from 24 to 30. Four of the eight studies citing small sample sizes were feasibility or pilot studies, although further studies with larger sample sizes have been conducted in other studies included in this review. Limitations in system use were cited in 4 of the 23 studies reviewed; however, this issue was of particular importance in simulated patient studies. Two such studies only tested specific functions of a system (LaMonte et al., 2004; Sibert et al., 2008) rather than running tests in the field. An additional four studies investigated system functionality using simulated patients (Charash et al., 2011; Liman et al., 2012; Lippman et al., 2016; Rörtgen et al., 2013). Field test studies addressed this limitation by running tests for long periods of time with no dispatch routing rules and large sample sizes of patients, thus requiring a range of system functions to be used.

Bandwidth and Connection Limitations

A common challenge discussed in these studies was the technical issues faced when using public networks. More specifically, 13 studies which cited this technical challenge or limitation used this method because of its widespread application and low cost.

However, this method created a trade-off in data transfer size and speed. In addition, using public networks in rural areas resulted in signal loss. In one study, the system addressed this issue by allowing users to select the frame rate or picture quality for the telemedicine transmissions (Sibert et al., 2008).

EMT Considerations

Interactions among the stakeholders, including patient and EMT personnel, patient and doctor (in a remote facility), and EMT and doctor (remote facility), should be considered when designing a telemedicine-mediated healthcare environment. When designing telemedicine systems, from a human-system integration perspective, consideration should be given for the current tasks completed by EMTs and doctors in a technology-mediated environment. Integrating technology such as a telemedicine-mediated environment into an ambulance setting can change the job requirements of EMTs and could change the methods that have proven to be successful for maintaining their situation awareness. It could create more work because now the telemedicine equipment, as well as the system itself, must be monitored.

In this development of communication systems, EMTs can do much more than just stabilize a patient; they could begin testing, create a tentative diagnosis, or even administer treatment, if authorized. This situation is tested in studies in this review, specifically those measuring diagnosis accuracy (Terkelsen et al., 2002; Valenzuela Espinoza et al., 2016; Yperzeele et al., 2014). Additional studies mentioned a pre-hospital diagnosis being performed, but did not measure the accuracy of those diagnoses to the final hospital diagnosis (Bergrath et al., 2011; Felzen et al., 2016). In the studies measuring diagnosis accuracy, the accuracy was found to be high, reflecting clinical value of EMTs diagnosing patients in ambulance or on the scene not just for simplicity of treatment post-transport, but also because this ability to diagnose pre-hospitally could shorten transport time and treatment time.

Financial Implications

Thirteen studies mentioned the limitations of using public networks for cost-effectiveness and common, inexpensive materials to outfit ambulances as teleambulances when available; however, the cost of this initiative remains a concern. One study identified in the literature screening process for this review investigated the cost of using telemedicine to increase the use of rt-PA treatments in eligible patients. The study also evaluated the benefit-to-cost ratio of the system using different configurations of personnel at varying operating distances, and even the highest cost configuration of personnel achieved a benefit ratio greater than 1 at an operating distance of 20 km (Dietrich et al., 2014).

Another study investigated the benefit to cost comparison of congenital heart disease patients using an ambulance equipped with an ECG, a camera, an iPod touch and a laptop connected to a central server. The results of this study found cost savings between 33,586 € and 35,740 € within 1 year (Frexia et al., 2014). While these studies only represent care for a specific condition rather than general care, they show that it is feasible and cost-effective to implement a telemedicine system. Future study could include the possibility of using private networks with higher bandwidth capabilities and a cost analysis of applying a telemedicine system for general emergency care.

Limitations

This review has limitations. Only peer-reviewed journal articles written in English were included in this review. Defining the search keywords was difficult, and it was learned that not all studies that should have been identified were found in the search.

Future Research Questions

This review suggests a paucity of published studies describing scientifically valid and reproducible evaluations at various stages of telemedicine implementation in ambulances. The common limitations and unique testing challenges found in the studies reviewed here led to the formulation of several recommendations for future studies or for generating a focus for a study to further test the feasibility of telemedicine systems in improving patient care.

A system of systems is where a collection of different systems, originally designed for a specific purpose, are combined and/or coordinated to produce a more capable system. Inherently, such a system poses new challenges (National Research Council, Division of Behavioral and Social Sciences and Education, Committee on Human Factors, & Committee on Human-System Design Support for Changing Technology, 2007; Sanderson et al., 2013). A telemedicine-integrated ambulance is an example of a system of systems. Human capabilities and limitations must be considered while implementing such a system. A technology-mediated caregiving environment is operated by a team consisting of EMTs and doctors whose interactions must be considered while implementing a telemedicine system in an ambulance. System designers need to ensure that in such a remote caregiving process, considering the operational aspects of just the telemedicine system may not be enough. The key stakeholders involved in this process are required to operate multiple systems, including Electronic Health Records (EHRs) telemedicine systems, adding to the complexity of the caregiving process. Extreme cognitive, physical and temporal demands are placed on the caregivers when operating such a system of systems. Further studies need to be conducted to understand the sensemaking process and situation awareness of caregivers while providing care in such technology-mediated, high-stress environment.

Four studies reviewed discussed the impact of developing studies in a variety of areas, as the location determines such variables as response and transport times, signal availability, patient acceptance, and population statistics. One simulation study in this review determined that transportation time in rural areas could be as long as 40 to 50 min, thus creating simulations in which a patient would go critical within 40 min to test the capacity of EMTs to perform lifesaving measures over long transport times. The range of transport times, among other factors, suggests the need for future research exploring the implications in patient care and survival rates of implementing a telemedicine system in an urban area versus a rural area.

One future application of telemedicine that could improve emergency department function would be to use teleconsultation to triage emergency patients. The American College of Surgeons suggests an acceptable percentage of over-triaging is 25% to 35% (Sasser et al., 2012); however, even in that range, there is a cost associated with this practice. The Center for Disease Control and Prevention (CDC) cites a study comparing triaging guidelines from 1991 to 2006, identifying a potential $568 million cost savings (Sasser et al., 2012). Telemedicine may be a useful tool for addressing this situation, if pre-hospital diagnosis could be utilized for triaging patients and preparing the hospital for their arrival. Future research needs to validate using remote triaging through teleconsultation to reduce over-triage rates and improve patient transfer.

CONCLUSION

This article reviewed the literature conducted on telemedicine systems in ambulances for emergency care. According to these studies, the usability ratings of the systems tested are high, and the effects of implementation are significant and positive. However, limitations in usability testing, simulation studies, public network bandwidth, sample size, and cost suggest the need for additional research. Thus, future work should focus on enhanced human-system integration, developing a high fidelity, usable system at a low cost and testing this system using live patients suffering from a variety of conditions and injuries to fully explore the use of telemedicine in ambulances. Such research studies could further support the use of telemedicine in ambulances as a viable way to treat emergency patients quickly and efficiently, thus improving the healthcare delivery system for this population.

CHAPTER THREE

A SYSTEMATIC REVIEW OF HUMAN ERROR IN EMERGENCY AMBULANCE-BASED CARE

INTRODUCTION

Emergency Medical Services

Emergency medical services (EMS) stabilize and care for a variety of people, frequently involving complex health conditions, in a fast-paced, high-stress environment, with these prehospital providers working in shifts longer than 8 hours at a time. EMS responders, Emergency Medical Technicians (EMTs) or paramedics respond to 911 calls to assess the patient, stabilize their condition, conduct what tests they can, and in many cases transport the patient to a hospital. Depending on the severity and location of the patient emergency responders will transport the patient via an ambulance or helicopter. These emergency responders can be called out for a variety of symptoms, most commonly found in this review were difficulty breathing, anaphylaxis, stroke symptoms, or cardiac arrest symptoms. Some cases can be straightforward, clear and present symptoms of a heart attack for which EMS has protocols in place to treat and transport the patient. Other more complex situations such as unresponsive patients, or patients with multiple competing trauma injuries require more effort to stabilize or difficult procedures such as intubation. Protocols and treatments can be standardized across countries, states, or nations; however each EMS is different. Some EMS use volunteers to operate, or others use employed staffing, the number and training of individuals in the ambulance can also vary. When more individuals (EMTs or paramedics) are available to treat and transport the patient, tasks may be more manageable as they are distributed across the caregivers (collecting blood pressure, establishing an IV line, gathering blood samples). However, having multiple caregivers in this environment creates the need for coordination of tasks and communication which in addition to the fast pace and urgency in these tasks creates a complex sociotechnical system. These factors can create a high incidence of error in both equipment and organization, but more importantly, in human action or inaction. In fact, errors in this environment potentially occur more frequently than in other health care settings because of the high decision density, the severity of the health conditions being treated, and the small work area (Hobgood et al., 2004; Patterson et al., 2012). These cases are also, by nature of being in an ambulance, emergencies, meaning errors could quickly become serious or fatal. A common practice in healthcare is to measure adverse events, injury caused by medical management rather than disease or condition of the patient (Brennan et al., 1991). Research abounds in healthcare on the topic of adverse events, their occurrence in different fields or geographic locations (Davis et al., 2001; Kable et al., 2002; Rigby et al., 1999; E. J. Thomas & Brennan, 2000), methods of measurement (Leape, 2002; Thomas & Petersen, 2003; Walshe, 2000; Woloshynowych et al., 2005), effects on patient safety (Mardon et al., 2010; Rivard et al., 2008; X. Wang et al., 2014), and mitigation strategies (Pettker et al., 2009; Rafter et al., 2015). However, an important distinction is that not all adverse events are errors, preventable adverse events are events created by error. For these reasons, research on patient safety in the prehospital setting is critical, especially that of human errors in this setting.

Human Error Taxonomies

James Reason in his seminal book, Human Error, describes the process of identifying error as a series of 3 yes or no questions: were the actions directed by some prior intention, did the actions proceed as planned, and did they achieve their desired end (Reason, 1990). Reason describes human error in this way to identify where in the mental process errors are made in a similar fashion to the skill-rule-knowledge (SRK) framework developed by Rassmusen 10 years prior (Rasmussen, 1983). James Reason furthermore created the Swiss Cheese model, which describes how hazards can travel through layers in a system and when holes in these layers align it allows for "a trajectory of accident opportunity" (Reason, 1990). This model identifies four layers of the cheese model, which allow for accidents to occur: organizational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts. This model was the foundation for the error taxonomy called Human Factors Analysis and Classification System (HFACS) created by Doug Wiegmann and Scott Shappell shown in Figure 3.1 (Shappell & Wiegmann 2000). This error taxonomy focuses on errors as a result of system failures rather than only the result of the actions of an individual. Unsafe acts are the actions which are made in the system that can be further classified as errors or violations. Errors in this case are acts that are not purposefully incorrect. Errors in this model are described by 3 categories: Decision Errors, Skill-based Errors and Perceptual Errors. These three categories are modeled after the SRK framework. Decision Errors are made by applying an incorrect rule or choice to a situation which is similar to rule-based errors in SRK. Skill-based Errors are typically due to mis-attention or failure of memory or technique, which is the same in SRK. Perceptual Errors are made when a situation is misjudged or not perceived correctly, this type of error correlates to the knowledge-based errors in SRK. It is the classification level of unsafe acts that adds to the concept of violations which are unsafe acts or errors, in terms of how the system was designed, that are done purposefully. These violations occur in two ways; a routine violation would occur for example, when an assembly worker installs items based on experience, rather than the policy, to speed up the installations, also known as a workaround. Violations can also occur as an exception, an isolated departure from authority.

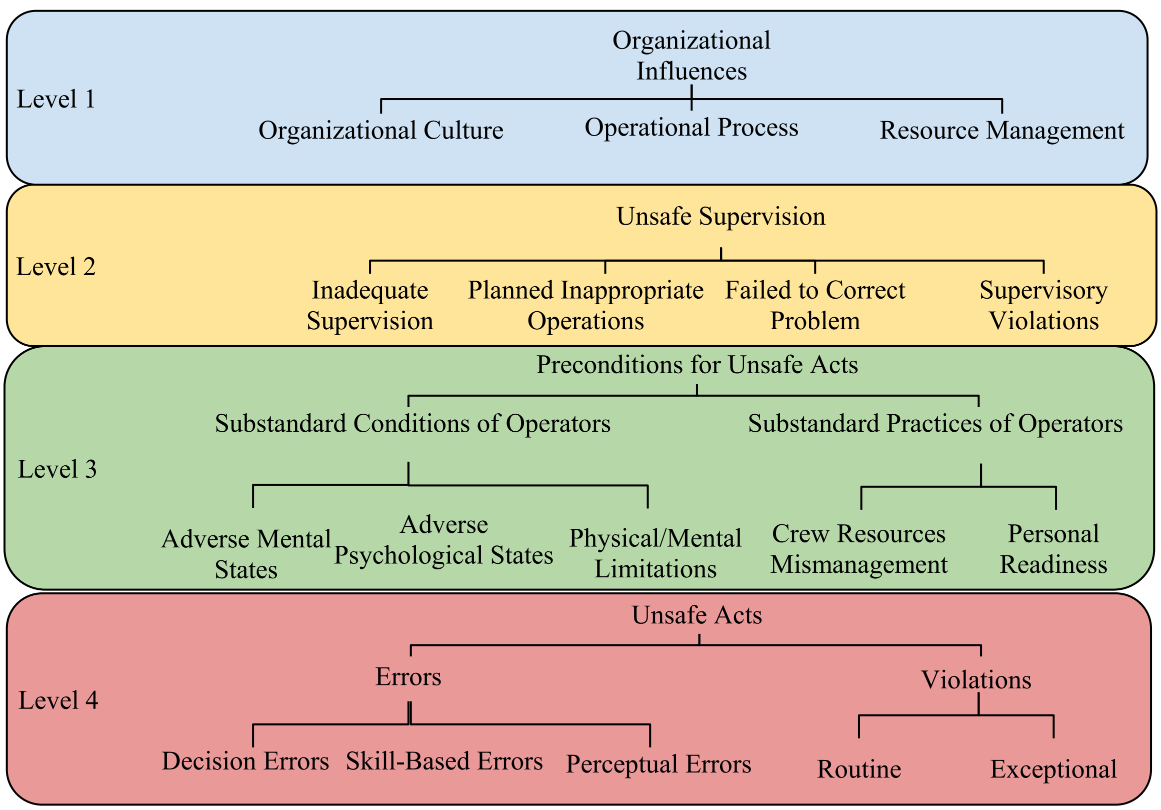

Figure 3.1: HFACS model Adapted from (Shappell & Wiegmann, 2000)

James Reason states that there is no “universally agreed classification of human error … and no single scheme is likely to satisfy all needs.” (Reason, 1990). However, these classifications support understanding how errors are made and provide avenues for interventions that minimize occurrences of error. The knowledge of what errors are or what mental processes cause them can identify solutions for minimizing errors in a systematic fashion.

Human Factors Approach to Human Error

To Err Is Human asserts that the problem is not bad people in healthcare--it is that good people are working in bad systems that need to be made safer (Institute of Medicine (US) Committee on Quality of Health Care in America, 2014). Human Factors concepts provide frameworks or theory to understand error as a function of cognition and work systems. One such framework is the Systems Engineering Initiative for Patient Safety (SEIPS) model. The SEIPS model offers more specific human factors concepts to organize human error within healthcare than the generalized error frameworks described above. The updated SEIPS 2.0 model describes the healthcare socio-technical system and how that system affects the work and outcomes of work of professionals and non-professionals. The factors of the system are described in the figure, these factors impact the work processes which in turn creates outcomes of different kinds. Outcomes can further be described as desirable or undesirable and proximal (immediate result) or distal (result further removed from work process). Adaptation is also considered in this model, feedback from outcomes impact how work processes are conducted and the work system as a whole. SEIPS can provide insight and interventions for error by organizing the root cause of error by work system factors. By understanding the work system factors that impacted the processes creating errors, or undesirable outcomes, interventions can be focused on improving those work system factors.

Research Purpose and Questions

Past studies have focused on understanding the prehospital setting (Brice et al., 2000; Callaham, 1997; Cohen & Patel, 2014). A prior review has also systematically reviewed patient safety in emergency medicine, however their inclusion for review was based generally on events in EMS that cause patient harm with no further qualification of how that event was committed (human, equipment, management) (Bigham et al., 2012). Currently, no attempts have been made to systematically review the types and occurrences of human error in ambulance based care. An understanding of human errors in this setting is critical for developing interventions to mediate error and improve patient safety. As a first step, this review summarizes the limited literature found to quantify the occurrences and causes of human error in prehospital care. Specifically, it addresses the following research questions:

1. What types of errors are made by prehospital providers during emergency care?
2. How often does human error occur in the prehospital setting?
3. What are some of the causes of the errors made by prehospital providers in emergency care?

METHODOLOGY

Search Strategy

Eleven databases: Web of Science, PubMed, Science Direct, AgeLine, and Alt Health Watch, Applied Science and Technology, PsychINFO, ACM Digital Library, Health Reference Academic, BioOne, and Academic OneFile, were searched between January 18-23, 2019 for articles to better understand the errors made by emergency response personnel in ambulances. These databases were searched for articles published between 1988 and 2019 with titles or abstracts containing terms emergency medical services and errors along with two term combinations of synonyms for each term. Table 3.1 lists all terms used. An example of the search strategy used for the BioOne database is ((ABSTRACT:(prehospital) OR ABSTRACT:(Emergency Medical) OR ABSTRACT:(Emergency Care) OR ABSTRACT:(Ambulance) OR ABSTRACT:(paramedic)) AND (ABSTRACT:(error) OR ABSTRACT:(incident) OR ABSTRACT:(mistake) OR ABSTRACT:(failure) OR ABSTRACT:(adverse event)). The search strategy for each database varied based on the selection of terms available or the coding structure required. The complete search strategy for each database, and search results can be found in Appendices A and B. Additional articles were found by hand searching the references in the studies selected after full text review to exhaust all options of search. The number of citations and the filtering process are outlined in Figure 3.2

Data Selection

After completing the database search the articles were reviewed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Table 3.1: Two Term Search List

Emergency Medicine Terms	Error Terms
emergency medical services or EMS	error
prehospital, pre hospital, or pre-hospital	incident reporting or incident
emergency medical technician or EMT	mistake
ambulance	adverse event
emergency care	safety event
paramedic	mistake
	failure

Articles were first reviewed by title to eliminate those that may have contained the search term *error* in the title but did not focus on the errors made in the prehospital setting. Then abstracts were reviewed first by finding the context of the study, followed by the methods for recording or determining errors, and finally identifying the type of errors. The inclusion criteria for this review were that the study measured the number of errors or error occurrences in some way, the errors were defined (for example as medication error, deviations from regulation procedure, failure of a procedure, diagnosis accuracy, or generally as adverse or safety events), and the study measured these errors only in an emergency setting and within the prehospital arena of patient care (ambulance treatment and transport). Non- English, abstract only, and commentary papers were excluded. Then the full text of the articles were reviewed using the same inclusion criteria.

Each of these stages of review were completed by two independent reviewers (Hunter Rogers and Mackenzie Wilson), then consensus coded after assessing Inter-Rater

Reliability (IRR), which was calculated using prevalence-adjusted bias-adjusted kappa to adjust for the large number of papers removed at each stage (Chaturvedi & Shweta, 2015). IRR for the title review was 0.98, for the abstract review 0.73, and for the full text review was 0.72. Additionally, the quality of each study was assessed before inclusion in the review.

Quality Assessment

Determining the quality of studies selected in a systematic review is generally good practice, but it is important to limit the studies reported to only high quality research to ensure that standards of reporting and measuring these errors were maintained in the studies. It is also important to assess researcher biases in selection by using a rigid method of quantifying quality. For these reasons a quality checklist was used to review all studies that remained after reviewing full text articles for inclusion criteria. Given the variety of the studies found and the number studies lacking an intervention, the Strengthening The Reporting of OBservational Studies in Epidemiology (STROBE) Checklist was used (von Elm et al., 2007). The checklist is structured by sections of an article selected for review, certain items are required in the introduction, methods, results, or discussion and conclusion. Checklist items were elements of the study or analysis that must be reported in the article. For example, describing limitations of the study, reporting demographic characteristics of sample size, or stating study objectives or hypotheses. This checklist allows for the most variability in study design, but as it does not have a quality structure, one was created. If a study had 80% or more of the checklist items completed, it was considered good quality, between 80% and 60%, fair quality, and less than 60%, poor quality and was not included in the review. Five studies were removed for low quality, with two items common among all that were removed: explaining how sample size was determined and describing the generalizability of the results. The quality assessment, with rows in red indicating the study was of poor quality, of each study can be found in Appendices C and D.

Data Extraction

Articles were reviewed, and data items were iteratively added to the extraction list by one researcher. A table was used to list the data from each paper: when and where the study was conducted, what procedures were considered for analysis, if a population was specified for the study, if a condition was used to limit the scope of the study, what types of errors were documented, possible causes of these errors, and methods used in conducting the study. The primary outcomes extracted from each study were the error occurrence studied and the possible causes for error. These findings were subsequently used to develop themes found in the literature and to systematically analyze the errors found in these studies.

RESULTS

The initial search returned 28,773 articles, 21,929 after removing the duplicates; using the process seen in Figure 1, another 21,781 were removed, meaning 148 remained for full article review. The inclusion criteria were applied to an additional search that was conducted as described in the Methods, resulting in 69 articles to be included in this review.

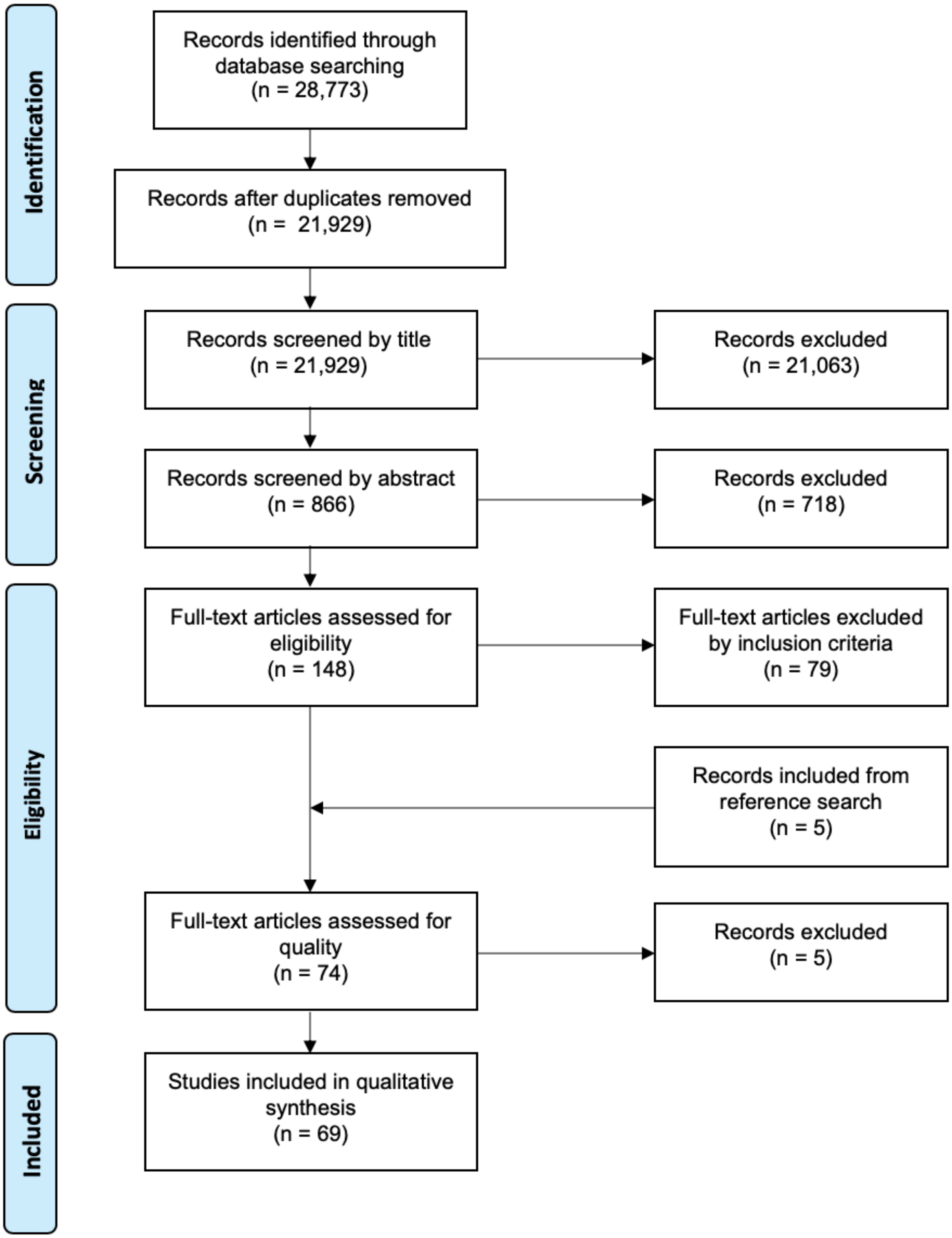

Figure 3.2: Citation search and review process

Five distinct themes based on the types of errors seen in emergency medical services emerged in these studies: procedure errors (Table 3.2), protocol deviations (Table 3.3), medication errors (Table 3.4), diagnosis accuracy (Table 3.5), and adverse or safety events (Table 3.6). Data for each including population, condition, procedure, method, error occurrence, and possible causes were extracted as can be seen in Tables 3.2-6. However, the variety of methods and procedures used did not allow for meta-analysis.

Location

Studies included in this review were conducted in many countries, a majority (60%) being from the United States, with most being conducted by a state or local EMS. Although some studies were conducted nationally (10%), the rest were conducted in state communities. Of the studies reviewed, 40% were conducted internationally: 8 in Australia (17%); 5 in Germany or German-speaking countries (7%); 4 in Canada (6%); 2 in Israel (3%); 2 in the United Kingdom; and 1 in each of the following: Finland, Iran, New Zealand, South Africa, Sweden, and Switzerland. The US has 28% studies in pediatric care, the only other country to identify a specific population is Sweden, their only study in this review, which was also a study of pediatric care. Almost all locations in this review isolated certain conditions, the US (40% of studies), Canada (50%), Australia (50%) were the most frequent outside of the UK, Finland, New Zealand, Switzerland, and German-speaking countries for which each of the single studies isolated a condition. Cardiac conditions were the most common, but the relative percentage of studies conducted was similar across countries who isolated any conditions. However, stroke research was only conducted in the

Table 3.2: Procedure Errors

Citation	Population	Condition	Procedure	Method	Error Occurrence	Possible Causes
Eberle et al. 1996*	None Specified	None Specified	Pulse Check	Simulation	83.5% were not able to reach the diagnosis within the guideline time limit	• Lack of intensive training specifically for pulselessness
Ruppert et al. 1999*	None Specified	None Specified	Breathing Check	Simulation with mannequin	44.4% of the time incorrect technique was used	• Lack of training for participants except EMS
MacDonald et al. 2001	None Specified	None Specified	AED use	Retrospective Record Search	Almost 4% of all rhythms had errors and 54% of those were operator errors	• Patient movement during AED analysis due to CPR • Unable to recognize when the AED is analyzing a cardiac rhythm
Barnes et al. 2003	None Specified	None Specified	Blind Tracheal Intubation	Simulation	79% were not successful in blindly placing an endotracheal tube in the 60 second window	• None Specified
Jemmett et al. 2003	None Specified	None Specified	ET Intubation	Observation	12% of all EMS recorded cases were misplaced	• No protocol in place for checking tube placement with end-tidal CO2 monitors or esophageal detector devices
Jones et al. 2004	None Specified	None Specified	ET Intubation	Observation	Unrecognized, misplaced ET Tubes inserted in the out-of-hospital setting byground paramedics happened in 5.8% of cases	• Limited training or tools • No uniform application of verification techniques
McDermott et al. 2005	None Specified	Traffic Fatalities	None Specified	Retrospective Record Search	77% of fatalities had prehospital errors that contributed to death, of the errors found, 11% were human error	• Failure to establish IV access • Low GCS score for intubation patients
Wang et al. 2006	None Specified	None Specified	ET Intubation	Retrospective Record Search	23% of patients had an ET intubation error occur	• Semiconscious and head-injured patients protective reflexes that impede access to airway • Limited practice of procedure in clinical field

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Hein et al. 2008	None Specified	None Specified	Laryngeal mask airway	Retrospective Record Search	Failure due to technique was found in 9 of 285 attempts 0.03%	• Difficulty determining successful insertion • Inappropriate size selection
Brice et al. 2008	None Specified	Chest Pain	Demographic reporting	Retrospective Record Search	Overall error rate (name, DOB, SSN, etc.) was 73.9%	• Patient distress • EMT more focused on patient care than recording • Poor handwriting skills
Williams et al. 2008	None Specified	None Specified	ECG interpretation	Simulation	90% of paramedic students did not correctly identify the ST-segment at least once and 89% incorrectly identified the J-point at least once	• Level of education and mode of learning environment
Kaserer et al. 2017	None Specified	Trauma	Resuscitation	Retrospective Record Search	17% failure rate with TT, 82% failure with NT	• Limited experience and difficulty determining tension pneumothorax in the field • Inadequate catheter length
Alenyo et al. 2018	None Specified	None Specified	Triage	Survey	Over-triage was 31.4% (95% CI, 29.66 to 33.2), and under-triage was 13.8% (95% CI, 12.55 to 12.22)	• Limited training in triage
Ghiyasvandian et al. 2018	None Specified	None Specified	Ventilation and Intubation	Simulation	The total failure rate in the three stages of ventilation, intubation and airway back-up were 49.4%, 46.7%, and 50%, respectively	• Inappropriate depth of intubation tube • Lack of experience with BVM

* Also addressed diagnosis errors. AED: Automated External Defibrillator, BVM: Bag Valve Mask, DOB: Date of Birth, EMT: Emergency Medical Technician, ET: Endotracheal, GCS: Glasgow Coma Scale, IO: Intraosseous, IV: Intravenous, NT: Needle Thoracentesis, SSN: Social Security Number, TT: Chest Tube Thoracostomy

Table 3.3: Protocol Deviations

Citation	Population	Condition	Procedure	Method	Error Occurrence	Possible Causes
Salerno et al. 1991	None Specified	None Specified	None Specified	Retrospective Record Search	16% of ambulance runs were found to contain procedure deviations, 45% were serious or very serious	• In 69% of cases with procedure deviations a physician was not contacted for advice • Lack of understanding of IV solution or flow rates needed
Liberman et al. 1999	None Specified	None Specified	CPR	Simulation with mannequin	74.2% of compression depths were outside of guidelines, 35.9% were in the wrong position, 60.6% ventilations were incorrect	• Insufficient practice of correct compression depth • Unable to complete landmarking to find proper position
Kirves et al. 2007	None Specified	Cardiac arrest	Resuscitation	Retrospective Record Search	60% of cases did not meet care guidelines	• Patients with neurological diseases and females had were more frequently associated with care not within care guidelines • Overuse of adrenaline during care • Lack of sedative use
Boyle 2009	None Specified	Vehicular trauma	None Specified	Retrospective Record Search	Errors per patient in the prehospital were up to 3.20 with 2.12 of those errors contributing to death in the 2003 report	• Constant change and introduction of new procedures and drugs • Training to support these changes
Lammers et al. 2009	Pediatric	Cardiac Arrest, Asthma, and Sepsis	None Specified	Simulation in Static Ambulance	The average amount of procedure stepped missed by scenario were 54.7% for cardiac arrest, 48.4% for asthma, 52.9% for sepsis	• Overconfidence in intubation ability • Lack of supporting checklist
Cienki and DeLuca 2012	None Specified	None Specified	Blood Pressure Measure	Ride Along Observation	Lowest rates of adherence to standards were found in palpitating the brachial artery and placing the pressure cuff at 6%	• Paramedics are unaware of problems with their technique
Lammers et al. 2012	Pediatric	Shaken Baby Syndrome	None Specified	Simulation in prepared room	Participants did not complete 38% of procedure steps identified by researchers	• Did not use proper equipment for oxygen delivery
Lammers et al. 2014	Pediatric	Cardiac Arrest	None Specified	Simulation in prepared room	Participants did not complete 33% of procedure steps identified by researchers	• Lack of proper respiration equipment knowledge • Poor CPR compressions • Inability to place IO line • Inaccurate weight estimates and dosing calculations

CPR: Cardiopulmonary Resuscitation, IO: Intraosseous, IV: Intravenous

Table 3.4: Medication Errors

Citation	Population	Condition	Procedure	Method	Error Occurrence	Possible Causes
Hubble et al. 2000	None Specified	None Specified	Medication Dosing	Simulation	The mean score was 51.4%	• Skill decay from drug calculations infrequently performed • Lack of calculation aids in field and continued competency training
Goebel et al. 2004	None Specified	Tachycardia	Adenosine Use	Retrospective Record Search	20% of patients had inappropriate use of adenosine due to rhythm misidentification	• Lack of practice identifying rhythms • Limited use of 12-lead electrocardiogram
Kaji et al. 2006	Pediatrics	Cardiopulm-onary Arrest	Epinephrine Dosing	Retrospective Record Search	In the most recent 2003-2004 cohort 45% of doses were not within 20% of correct dose, as compared to the 1994-97 cohort which had a rate of 66%	• Difficulty of remembering dosing and concentration with different administration routes • Higher error rate when Broselow tape was not used to estimate weight
Vilke et al. 2007	None Specified	None Specified	Drug Administration	Survey	Of responding paramedics 9.1% reported an error made in the last year, 67% were medication related, with the most common being Atropine and epinephrine	• Failure to triple check • Infrequent use of medication • Dosing calculation
Hoyle et al. 2012	Pediatrics	None Specified	Drug Administration	Retrospective Record Search	Dosing errors occurred in 34.7% of doses administered during the study period, with epinephrine having the highest incorrect dosage rate	• Lack of pediatric clinical experience • Calculation error • Low utilization of dosing aids
Lifshitz et al. 2012	None Specified	None Specified	Drug Administration	Retrospective Record Search	12.7% of patient had a drug error occur in care and 25.8% were described as significant	• Longer evacuation time had higher risk for error • 32.6% of these errors were due to a drug administer that was not indicated for the patient • 38.7% were dosing errors

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Eastwood, et al. 2012	None Specified	None Specified	Medication Dosing	Simulation	Undergraduate paramedics achieved an overall mean score of 39.5%	• Poor basic math skills • Knowledge decay with lack of practice
Lim et al. 2013	None Specified	Tachycardia	Adenosine use	Retrospective Record Search	20% of patients had inappropriate use of adenosine due to rhythm misidentification	• Lack of practice identifying rhythms • Limited use of 12-lead electrocardiogram
Lammers et al. 2014	Pediatric	Anaphylaxis	Medication dosing	Simulation	Of the 95% of teams that chose epinephrine, 54% used incorrect dosing or method, other medications used were outside of correct dosing 99% of the time.	• Weight estimation error • Faulty reasoning or communication error
Stevens et al. 2015	Pediatric	Cardiac Arrest	Epinephrine and Atropine dosing	Simulation	53% of cases of incorrect doses were errors and 27% of those were critical errors	• Calculation of dosing required • Lack of regularity and practice with pediatric dosing
Coppler et al. 2016	None Specified	None Specified	IV fluid measurement	Observation	The absolute error comparing self-reported to mass-derived fluid volume was median 109 mL [IQR: 41–205 mL], and was less than 250 mL in more than 80% of subjects, which is small	• Short transport times • Low acuity transports

IQR: Interquartile Range, IV: Intravenous

Table 3.5: Diagnosis Accuracy

Citation	Population	Condition	Procedure	Method	Error Occurrence	Possible Causes
Kothari et al. 1995	None Specified	Stroke	Diagnosis	Retrospective Record Search	28% of diagnoses made by EMTs were unconfirmed by Emergency Department physicians	• Short interactions with patients • Lack of knowledge of the symptoms of a stroke
Hollander et al. 1995	None Specified	None Specified	ECG Interpretation	Retrospective Record Search	10% of ECGs were interpreted incorrectly, 6% of those cases were determined to be clinically important errors	• Inability to identify atrial fibrillation or flutter and supraventricular tachycardias accounted for the majority of misinterpreted rhythms
*Eberle et al. 1996	None Specified	None Specified	Pulse Check	Simulation	35% of cases were misidentified	• Lack of intensive training specifically for pulselessness
Linn et al. 1997	None Specified	None Specified	Air Evac Diagnosis	Retrospective Record Search	23% of diagnoses were missed by flight physicians and 74.5% of those could have been made by the flight physician	• Sever injuries and stabilizing the patient may distract from determining all diagnoses • Missed measuring blood pressure or temperature • Head or spine injuries can mask others
Smith et al. 1998	None Specified	Stroke	Diagnosis	Retrospective Record Search	Paramedics identified a stroke/TIA that was incorrect 23% of diagnoses and did not diagnose 39.5% of patients later diagnosed with stroke/TIA	• Documentation deficiencies • Lack of training in identifying stroke symptoms
Haynes and Pritting 1999	None Specified	None Specified	None Specified	Retrospective Record Search	25% disagreement	• Limited accuracy in treating respiratory distress • Low utilization of intravenous line
*Ruppert et al. 1999	None Specified	None Specified	Breath Check	Simulation	19% misidentification of breathing	• Lack of training for participants except EMS
Eckstein and Suyehara 2002	None Specified	Congestive Heart Failure	Diagnosis	Retrospective Record Search	42% of patients diagnosed by EMS as something other than CHF later determined to be CHF	• Difficulty determining CHF in elderly or debilitated patients that are dehydrated or have been administered diuretics and nitrates

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Mitchell and Tallon 2002	None Specified	Aortic Emergencies	Diagnosis	Retrospective Record Search	14% of cases were misdiagnosed	• None Specified
Pitt 2002	None Specified	Cardiac Arrest	Determining thrombosis candidacy	Simulation	Paramedics incorrectly identified 8% of patients, but 0 cases were due to paramedic error	• Stringent inclusion criteria for prehospital thrombolysis for safety reasons • Patients not presenting the necessary ECG criteria in the early stages of the infarct
Nor et al. 2004	None Specified	Stroke/TIA	FAST assessment	Retrospective Record Search	Complete agreement between paramedic and physician for each neurological sign was: facial weakness, 78%; arm weakness, 98%; and speech disturbance, 89%	• Resolution of signs between assessments • Paramedics not considering or excluding hypoglycemia as a stroke mimic
Feldman et al. 2005	None Specified	STEMI	Diagnosis	Observation	6% of patients were incorrectly diagnosed	• None Specified
Ackerman and Waldron 2006	None Specified	Difficulty Breathing	Diagnosis	Retrospective Record Search	Paramedics achieved 86.4% sensitivity and 86.6% specificity for cardiac diagnoses, 71.4% and 93.6% for respiratory, and 82.1% and91% for other	• Wide range of diagnoses with difficulty breathing symptom • Difficulty examining chest noises
Benner et al. 2006	None Specified	None Specified	Diagnosis	Retrospective Record Search	Overassessment of the patient by the transport team occurred in 27 cases (1.9%), and underassessment occurred in 18 cases (1.3%)	• Tendency to base the assessment on mechanism of injury • Delay of presentation of symptoms • Poor neurological assessment
Cantor et al. 2012	None Specified	STEMI	Diagnosis	Retrospective Record Search	Cardiologist did not agree with paramedic diagnosis in 10% of cases	• None Specified

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Williams et al. 2013	None Specified	Acute pulmonary edema	Diagnosis	Retrospective Record Search	71% of patients with APE were missed by paramedics and 59% were misdiagnosed with APE by paramedics	• Limited patient history • No radiography or echocardiography
Gropen et al. 2014	None Specified	Stroke	Diagnosis	Retrospective Record Search	Of the stroke patients, 28/56 (50%) were missed by EMS (false negatives) and 9/254 (3.5%) were falsely considered to have stroke by EMS (false positives)	• Stroke screening tool used • Lack in stroke specific training • Inadequate documentation of screening scale
Brandler et al. 2015	None Specified	Stroke	Diagnosis	Retrospective Record Search	38% of stroke patients were missed and 0.3% of patients were incorrectly identified as having a stroke	• Strokes presenting with more subtle or nonspecific presenting symptoms
Williams et al. 2015	None Specified	Asthma or COPD	Diagnosis	Retrospective Record Search	paramedic diagnosis did not match ED for 59% of asthma patients and 43% of COPD patients	• Lack of clear criteria to identify the diseases • No verification of patient medical history • Limited diagnostic facilities in the prehospital setting
Christie et al. 2016	None Specified	Dyspnea	Diagnosis	Retrospective Record Search	The overall agreement between paramedic and either ED or hospital diagnosis was 186/293, 64%	• Shortness of breath is common to many conditions making it difficult to determine exact diagnosis • Data form only identified Chief complaint and not working diagnosis
Latimer et al. 2018	None Specified	Anaphylaxis	Medication decision	Retrospective Record Search	12% of cases paramedic decision did not match physician	• None Specified
Duignan, et al. 2018	None Specified	None Specified	Tourniquet use	Retrospective Record Search	9.5% of cases tourniquets were not appropriate	• “shock factor “may have contributed to the decision to apply tourniquets

* Also addressed procedure errors. APE: Acute Pulmonary Edema, CHF: Congestive Heart Failure, COPD: Chronic Obstructive Pulmonary Disease, ECG: Electrocardiogram, ED: Emergency Department, EMS: Emergency Medical Services, EMT: Emergency Medical Technician, STEMI: ST-elevation Myocardial infarction, TIA: Transient Ischemic Attack

Table 3.6: Adverse or Safety Events

Citation	Population	Condition	Procedure	Method	Error Occurrence	Possible Causes
Hobgood et al. 2004	None Specified	None Specified	None Specified	Survey	55% of EMT respondent reported making at least one error in the last year	• Authors cited high decision density for EMTs as cause for high error rate • Providers have limited insight into their own error patterns and do not inform others
Hobgood et al. 2006	None Specified	None Specified	None Specified	Survey	45% of EMT respondent reported making at least one error in the last year, and while only 7% of the time severe errors, in mild errors more than 50% of errors were identified in treatment administration and failure to act	• Lack of support to identify errors and poorly trained to identify and disclose errors
Fairbanks et al. 2008	None Specified	None Specified	None Specified	Survey and Interview	61 events were ported in 6 months, 44% were near misses, 56% were adverse events	• Lack of standardized training or inadequate training for pediatrics
MacDonald et al. 2008	None Specified	None Specified	None Specified	Retrospective Record Search	Adverse events occurred at a rate of 11.53 per 1,000 air ambulance flights, 21% of those were due to EMT performance, of those 25% could have caused patient harm	• Communication issues • Long hours and complex tasks
Zimmer et al. 2010	None Specified	None Specified	ALS, Asthma, Pulmonary Embolism, Trauma Care	Simulated Ambulance Room	More than 7 unsafe acts occurred per scenario, these were more common in trauma and bronchial asthma care scenarios. The highest rate of unsafe acts were during respiration acts at 13% of all types of acts	• Communication deficits • No consensus on diagnosis
Stella et al. 2010	None Specified	None Specified	None Specified	Survey	An average of 2 incidents were identified per dispatch, 71% of incidents were due to patient management or technique. 10% of incidents were major or deadly	• None Specified
Hohenstein et al. 2011	None Specified	Cardiac Arrest	CPR	Survey	65% of incidents recorded were due to EMT error and mostly preventable	• Insufficient training • Inattention or thoughtlessness

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Gallagher and Kupas 2012	None Specified	None Specified	None Specified	Retrospective Record Search	45% of errors reported were related to human judgement or behavior	• None Specified
Patterson et al. 2012	None Specified	None Specified	None Specified	Survey	41.1% of respondents reported at least one error or adverse event in the previous 3 months	• Poor sleep quality and fatigue • High workload during shifts
Weaver et al. 2012	None Specified	None Specified	None Specified	Survey	42% of respondents recorded an affirmative response for EMS-SI items measuring error or adverse event, 89% respondents reported safety-compromising behaviors	• None Specified
Hohenstein et al. 2014	None Specified	None Specified	None Specified	Survey	78% of incidents were caused by staff lack of knowledge or experience, communication or technique	• Insufficient techniques, wrong diagnosis, and underestimating severity
van den Berg et al. 2015	Neonatal	None Specified	None Specified	Retrospective Record Search	290 of 833 (35%) Adverse Events were human error related	• Poor control of multiple services helping during transports • Continual equipment failure
Hansen et al. 2016	Pediatric	None Specified	Airway Management	Retrospective Record Search	27.8% of patient cases had errors	• Cardiac arrest significantly increases odds of an airway management error • Multiple critical decisions and interventions performed quickly
Duby et al. 2018	Pediatric	None Specified	None Specified	Retrospective Record Search	2.6 safety events occurred per patient with a range of 0 to 6, 73% of patients had one or more safety event, 38.5% had a severe event	• Used techniques from wrong resuscitation protocols • Failure to obtain IV/IO access
Meckler et al. 2018	Pediatric	None Specified	None Specified	Retrospective Record Search	at least one UNSEM occurred in 69.3% of transports, 33% of these were errors	• Infrequent and insufficient training on pediatric resuscitation • Lack of standardized drug concentrations and packaging • Difficulty estimating weights and calculating dosages

ALS: Advanced Life Support, CPR: Cardiopulmonary Resuscitation, EMS- SI: Emergency Medical Services – Safety Inventory, IO: Intraosseous, IV: Intravenous, UNSEM: Unintended injury or consequences, Near misses, Suboptimal actions, Errors, and Management complications

UK and the US. In the US the most commonly investigated error type was diagnosis accuracy and adverse or safety events following in frequency. The relative amount of studies in each error type did not vary significantly by location.

Method

A variety of methods was used to determine the errors made in emergency services in these studies: In person observation, simulation of tasks, surveys or interviews of care providers, and retrospective record search. Most (56%) utilized a retrospective record tool to collect data, reviewing hospital or emergency service patient records to determine medication or procedure errors, adverse events, or departure from procedure. Past research has established that medical errors typically exhibit a low reporting level (Nguyen et al., 2005; Rowin et al., 2008), which appears to be the one most frequently cited in the available literature. Perhaps because of this phenomenon, several studies discussed the use of anonymous reporting systems to capture errors as part of an effort to ensure continuing improvement of the medical systems (Okafor et al., 2015; Stella et al., 2010; Westfall et al., 2004). Only 7% of studies included in this review used observational methods to determine the occurrence of errors in real time. Surveys and interviews were used in a few studies (14%) to obtain perceptions of errors, the frequency errors occurred per individual, or the accuracy of identifying potential errors. An interesting method introduced in some studies (22%) was simulation through the observation of an emergency care scenario in either a parked ambulance or in a simulated environment. This method is frequently used for educational training (McLaughlin et al., 2002; Small et al., 1999) and to complete observation studies particularly in areas such as medical services where observation of real patient care can be difficult to complete (Bond & Spillane, 2002; Hunt et al., 2008). Barriers to observation in patient care could be due to privacy concerns, patients withholding consent for observation or the loss of confidentiality, or the safety of the patient. Another barrier is logistics as in many emergency care scenarios, the stress involved in stabilizing the patient impairs the ability of researchers to observe or interact with caregivers, and in ambulances space is limited. Simulated observation using patient actors or patient mannequins can provide valuable data without the risks associated with live observation of patient care. The methods used to determine error occurrences varied by type of error. Protocol deviations, for example, were determined using mostly simulation (50%), then retrospective reporting (37%), then observation (13%). Using simulation to measure protocol deviations is expected as determining adherence to protocol in an emergency scenario may be difficult as previously discussed and from surveys or interviews would be skewed by bias. Diagnosis accuracy is similarly measured by simulation, retrospective reporting, and observation; however, the use of retrospective reporting is much higher (81%) as diagnoses are commonly documented at each stage of patient care and as such can be simply retrieved from records rather than simulated or real-time observation.

Population and Condition

Almost half of the studies included in this review did not specify the population or the condition studied (48%). Of the studies that did specify outside of general EMS care, 13 studies (19%) limited their population to pediatrics, children under the age of 12, or neonatal. However, it was more common to limit a study by condition (47%); while a wide variety of conditions were considered, most (57%) were cardiac- or stroke-related (chest pain, cardiac arrest, ST-Elevated Myocardial Infarction or STEMI, stroke symptoms). There were also some studies that isolated both a population and a condition (10%) focusing mostly on pediatric cardiac conditions (71%). All studies investigating diagnosis and procedure errors did not limit their population to pediatrics and of the studies that focused on medication errors almost half of them were specifically focused on pediatric care (45%). 75% of all studies of diagnosis accuracy and 63% of all protocol deviation studies specified a condition. This is expected as isolating a diagnosis or identifying an existing protocol to check deviations would be helpful in limiting the scope of an experiment.

Possible Causes

Most studies offered some discussion of possible causes for the errors reported or observed, ranging from causes within the types of errors to those related to conditions or procedures. Generally, possible causes listed concerned training, experience, cognitive demands, oversight, communication, documentation, support, protocols, skill or knowledge, fatigue, and various situational causes (patient movement, symptom masking, pre-existing conditions or medications). The full list of possible causes for each study can be found in the last columns of Tables 2-6, but there were some common causes of error among studies. In at least 43% of the studies, lack of training, knowledge, experience, or understanding was cited as a possible cause for error across all error reporting types. Another common possible cause cited was lack of supporting materials such as checklists or references for certain procedures, including Cardiopulmonary Resuscitation (CPR), intubation, medication dosing, and Intravenous/ Intraosseous (IV/IO). Some studies (10%) did not offer any reasons for the errors found; most of these were conducted using a survey or a retrospective record search, methods that limit the ability of researchers to determine the causes of errors as they are done remotely and after errors have occurred. However, many studies using the same methods were able to provide some information concerning why errors were made.

DISCUSSION

A review of the literature on error reporting in EMS finds relatively few papers quantifying the frequency and type of errors that occur in the prehospital domain, a situation that may be due to several factors. As mentioned previously, error reporting is known to be limited, especially in the medical field, because of the liability errors represent and a culture of blame rather than continuous improvement (Fairbanks et al., 2008). It may also be difficult to measure errors observationally because of issues such as the Hawthorne effect, a phenomenon in field research that occurs when participants feel they are being observed such that they deviate from normal behavior under observation, (McCambridge et al., 2014) or because of the fast-paced, high-stress environment with little space for in-person observation. Although there are in-depth systematic reviews of studies of patient safety in EMS (Bigham et al., 2012) and research into the recommendations to reduce error through auditing procedures (O'Connor et al., 2002), literature identifying the types of errors and causes is limited, and a systematic review of research specifically of human error in EMS was not found in the search for studies for this article.

Types of Error

Though few studies were found for this review, the error occurrence reported among them is considerable and varies widely within error types and methods. Error reporting or observation in these studies fell into 5 categories: procedure errors, protocol deviations, medication errors, diagnosis accuracy, and adverse or safety events.

Procedure Errors

Procedure errors found in these studies primarily focused on resuscitation, specifically intubation, with many studies identified in early stages of the review focusing on this medical process but not identifying errors related to the patient. Only 25% of studies did not focus on resuscitation (Alenyo et al., 2018; Brice et al., 2008; Williams et al., 2008). Misplaced intubation tube, incorrect tube selected, or overall intubation failure can affect the patient's breathing ability, but it can also impact the paramedic or the receiving emergency physicians and nurses as their treatment of the patient may be changed by the placement or success of the intubation tube. Failure to intubate can be attributed to factors other than the skill of the medical providers such as patient movement, age, obesity, or unconsciousness (Cook & MacDougall-Davis, 2012; McDermott et al., 2005; Moon et al., 2013). Some studies cited these difficulties as causes for error, others a lack of skill, training, and tools to support this complex procedure (Ghiyasvandian et al., 2018; Jones et al., 2004; Kaserer et al., 2017; Wang et al., 2006). One intervention suggested by a study in this review (Barnes et al., 2003) that shows promising results for difficult airways is an altered facemask called the LMA-Fastrach (Ferson et al., 2001). Changing the design of the tool used creates intervention at the highest level of hazard control priority, a technique to minimize hazards or accidents through the tiered use of system design to eliminate the hazard, system design for safeguards, and finally training or organizational control (Tweedy, 2005). Another supporting tool suggested in the literature (Jemmett et al., 2003) was end-tidal CO2 monitors to determine correct placement or placement detectors (Bhende et al., 1992; Foutch et al., 1992). Some of these devices have also been tested with paramedics (Donahue, 1994). However, other articles in this review provide support for instituting guidelines or protocols to prevent misplaced or failed intubations (Hein et al., 2008; Jones et al., 2004). New monitoring devices are not the only intervention that could be used at the top hazard control level. Telemedicine systems have been used to connect prehospital providers to information sources, provide support for procedures, and allow rich communication with specialists (Barrett et al., 2016; LaMonte et al., 2004; Pavlopoulos et al., 1998; Xiao et al., 2000). Connection to an airway specialist could improve performance in this complex procedure. This use of telemedicine support for emergency responders has been evaluated. A study comparing a control group using a physician in the room and an intervention group with telemedicine consultation found that the performance of the latter was comparable to the control group and that the telemedicine group collected allergy and current medications more frequently with significant p values of 0.002 and 0.004, respectively (Rörtgen et al., 2013). Furthermore, an investigation of the use of a telemedicine system to support prehospital providers in complex simulated procedures found that the survival rate of the teams with telemedicine connected physicians was significantly higher than for the control group (2 patients deaths for the telemedicine group compared to 16 in the control group) and that performance measured by the correct identification of pathological signs, processes and appropriate interventions was significantly higher in the telemedicine group compared to the control (96%, 98%, 92% versus 79%, 75%, 49%) (Charash et al., 2011). Studies investigating both the technique used in or performance of these tasks as well as the diagnostic accuracy of prehospital providers are found in both the procedure error and diagnostic accuracy themes.

Protocol Deviations

Studies in the protocol deviations focused on care that did not meet or deviated from guidelines, protocols, or checklists used to describe tasks in EMS. Deviations from protocol can involve missed steps or steps completed incorrectly and in either case the coordination of care tasks within the ambulance can be affected and it could also impact how the patient is treated at a hospital. For example in some healthcare systems the protocol for a suspected stroke is to gather blood samples in the ambulance when an IV is placed such that those samples can be processed at the emergency department lab upon arrival, if this step is not completed then that task is delayed and a nurse will have to gather blood from a different vein. The protocols studied in this review varied from general care to cardiac arrest or vehicular trauma to more specific tasks like cardiopulmonary resuscitation (CPR) or blood pressure measurement. The most common type of protocol in the literature was that applied to cardiac arrest symptoms (Kirves et al., 2007; Lammers et al., 2009, 2014b). Most studies referenced implementing changes at the lowest hazard control priority: improving guidelines for divisions of tasks (Lammers et al., 2014b), targeted training or increased practice (Lammers et al., 2009; Liberman et al., 1999; Salerno et al., 1991), or standardization of protocol (Boyle, 2009). One study in this review created a list of suggestions specific to the tasks monitored in the study that included training and organizational changes, but also safeguards and system changes such as labelling IV bags and medications, developing an EMS specific Broselow tape, and eliminating the use of certain syringes (Lammers et al., 2012).

Medication Errors

Medication errors in this review were primarily inappropriate or incorrect dosing of epinephrine, adenosine, or atropine (common medications with adverse effects at incorrect dosages) or errors in dosing calculation and application tests. Again, these errors mostly affect the patient, but the available medications or further dosing of these medications used in later treatment could also affect nurses' and physicians' processes. Many of the remediations suggested in the pediatric medication error literature (45% of studies in this theme) focuses on the use of Broselow tape, a measurement tool made to establish an estimate of children's weight by size to determine appropriate common medication dosing (DeBoer et al., 2005). Another study in this review suggested a safeguard approach to hazard control by supporting use of Broselow tape with color coded syringes, which eliminates any further errors of administration (Stevens et al., 2015). Other interventions suggested in this theme at the lowest hazard control priority were training and practice (Hoyle et al., 2012; Lammers et al., 2014a; Lim et al., 2013) or changes to protocol (Kaji et al., 2006). Telemedicine systems integrated with electronic health records (EHRs) could assist with medication dosing as a patient's EHR would contain his/her weight and any allergy information which can be used to improve dosing procedures. Telemedicine systems could also be integrated to support dosing calculations based on predetermined formulas as some studies in this review suggested support for error prone calculations (Hubble et al., 2000; Lammers et al., 2014a; Vilke et al., 2007).

Diagnosis Accuracy

Diagnosis accuracy was a significant theme in this review, with 32% of all studies evaluating human error in this way. Studies in this theme detailed the accuracy of prehospital providers in diagnosing strokes, congestive heart failure, acute pulmonary edema, and STEMI compared with emergency department (ED) or hospital discharge diagnosis for prehospital providers ability to determine differences in conditions such as asthma or chronic obstructive pulmonary disease (COPD). Studies in this theme focused on prehospital provider ability and possible causes for misidentification; however, it should be remembered that many of these conditions are difficult to diagnose without support from x-ray or computed tomography (CT) scans or lab results that EDs have access to. In almost 20% of studies possible causes for an incorrect diagnosis included certain injuries, symptoms, seizures or head and spine injuries that could mask others, making a correct diagnosis difficult (Ackerman & Waldron, 2006; Brandler et al., 2015; Christie et al., 2016; Linn et al., 1997). Other studies cited lack of experience and even shock as factors that could create inappropriate diagnosis (Duignan et al., 2018; Gropen et al., 2014; Kothari et al., 1995; Smith et al., 1998).In these cases, consultation with stroke or trauma specialists through telemedicine could assist in diagnosis especially when there is uncertainty in determining procedures and treatment in difficult cases. Additionally, having a telemedicine system that assists medics with completing demographic data collection and merging the new data with existing electronic health records (EHRs) could improve the ability of prehospital providers to diagnose patients accurately as it would allow for access to all health records and for connecting information from this care instance to the patient profile (Frank & Pape-Haugaard, 2011; Handel & Hackman, 2010; Moloney et al., 2017). Time to diagnosis has also been seen to improve with the use of telemedicine, with one study completing telemedicine diagnosis en route with on-call physicians at a local hospital 18 minutes sooner than the in-hospital diagnosis and that the prehospital diagnosis had a positive predictive value of 56% (Terkelsen et al., 2002). Yperzeele et al. (2014) investigated the use of a traditional ambulance equipped with bidirectional audio and video and automatic transmission of vitals, finding that the diagnoses developed with teleconsulted physicians reached high agreement with final in-hospital diagnoses (0.98), with a high kappa statistic for differencing neurological from non-neurological diseases (0.92).

Adverse or Safety Events

The final theme, adverse or safety events, was developed from studies that classified human error but typically defined an adverse event as that which could potentially harm the patient. Although such studies are common in the literature, only those that further isolated the events due to the technique, skill, or behavior of the prehospital provider were included in this review. This theme is defined by how general errors are measured. In 63% of studies no specific procedure, population, or conditions were identified to limit the scope. In the remaining 37% most (83%) studied focused on pediatrics. Given the general nature of these errors, interventions provided by individual studies in the literature were not focused on system design. The most common suggestion was that of increased training and experience for specific procedures (Duby et al., 2018; Fairbanks et al., 2008; Matthew Hansen et al., 2016; Hohenstein et al., 2011; Meckler et al., 2018), however these interventions are at the lowest hazard control priority. Few studies identified organizational changes through standardization of protocols or documentation (Fairbanks et al., 2008; van den Berg et al., 2015; Weaver et al., 2012) or design safeguards through the poka-yoke technique, preventing errors despite intentions or thoughtlessness such as pre-filled syringes or labelling (Hansen et al., 2018; Hohenstein et al., 2011). A more commonplace organizational change was that anonymous error reporting could enhance caregivers, healthcare providers, and policy makers knowledge of the type and preceding conditions errors in emergency medicine (Gallagher & Kupas, 2012; Hobgood et al., 2004, 2006; Hohenstein et al., 2011, 2014; Stella et al., 2010). Providing an open resource for communicating errors and understanding when errors occur can create an awareness for individuals of their own errors. Lack of error awareness in emergency medicine was discussed by studies in this theme which could be supported by telemedicine. Telemedicine systems provide a level of oversight and observation by nurses and physicians that could increase error reporting and make providers more aware of their error patterns, which was a concern for a study in the protocol deviations theme as well (Cienki & DeLuca, 2012).

Occurrence of Error

Overall there was no consistency among error occurrences in the studies selected for review, even within error types. The magnitude of error occurrences in many studies were large, for example missing 33% to 54% of the procedural steps required (Lammers et al., 2009, 2012, 2014b), dosing error occurrences in up to 54% of the cases (Coppler et al., 2016; Eastwood et al., 2012; Goebel et al., 2004; Hoyle et al., 2012; Hubble et al., 2000; Kaji et al., 2006; Lammers et al., 2014a; Lifshitz et al., 2012; Lim et al., 2013; Stevens et al., 2015), and incorrect diagnosis in up to 71% of cases (Ackerman & Waldron, 2006; Brandler et al., 2015; Cantor et al., 2012; Christie et al., 2016; Eberle et al., 1996; Eckstein & Suyehara, 2002; Gropen et al., 2014; Haynes & Pritting, 1999; Hollander et al., 1995; Kothari et al., 1995; Linn et al., 1997; Nor et al., 2004; Ruppert et al., 1999; Smith et al., 1998; Williams et al., 2013, 2015). There were some studies that cited relatively low error occurrences: 4% of cases with misuse of AED (MacDonald et al., 2001), 0 - 14% paramedic misdiagnosis (Benner et al., 2006; Feldman et al., 2005; Latimer et al., 2018; Mitchell & Tallon, 2002; Pitt, 2002), 5.8% cases with misplaced intubation tubes or 0.3% failed intubation cases (Hein et al., 2008; Jones et al., 2004). However, the majority of studies in this review had errors in over 20% of cases analyzed.

Possible Causes

Causes ranged from organizational factors such as fatigue or shift length to those that are more easily preventable such as lack of contact with physicians, lack of support or visual aids, dosing miscalculations, or lack of training. Many of the errors could be mitigated or even prevented with improved training in medical areas like pediatric care or stroke, visual aids for difficult procedures such as endotracheal intubation, or the use of a sophisticated telemedicine system to support providers in prehospital care. The SEIPS 2.0 model can provide some context for the causes of these errors identified in the review. Many studies cited lack of experience, training or skill as a cause for error which is identified within the person and task work system factors in the model. Situational causes can be linked to both the internal environment (movement of the ambulance) and task (inherent difficulty of a task). Lack of oversight, support, or standard protocols can be linked to the external environment or organization. Documentation issues can be linked to tools and technology. All these factors are connected in the SEIPS model meaning the factors impact each other, for example a task factor such as difficult tasks or person factor such as limited experience or training can be impacted by organization or external factors such as protocols or support from specialists. These work factors and their interactions make up the work processes which in turn have measurable outcomes. These outcomes are the results analyzed in the studies in this review which provide insight on the work processes and work system factors in the SEIPS 2.0 model. Interventions discussed in the studies in this review can be understood through the SEIPS 2.0 model by how they impact the work system factors. Improvements in protocols impacts the organization as demonstrated by factor interactions will also impact the person and task factors. An Anonymous error reporting system is an intervention of the tools and technology factor, but it impacts the organization culture and the external environment by creating accountability and awareness of errors and consequences. Telemedicine systems were also suggested interventions. Telemedicine systems use telecommunication technologies, video conferencing and real- time data tracking to support connections between patients or health care providers and specialists or other providers when separated by geographical distance. These systems have been implemented in ambulances with mild success in reducing diagnosis and treatment times and increasing positive task completion (Rogers et al., 2017).

The telemedicine interventions discussed in the previously can also be understood within the context of the SEIPS 2.0 model. It is an intervention in tools and technology, but it impacts the task (by providing connection to specialists to support difficult procedures), internal environment (by adding new technology elements to the environment), and person (by expanding the caregivers involved in the work system in the ambulance). Telemedicine also supports teamwork and rich communication with audio and visual connection that provides more detail and earlier in the caregiving process which was cited as a possible cause for error in this review (Lammers et al., 2014a; Russell D. MacDonald et al., 2008; Zimmer et al., 2010). This enhances the collaborative work process and previous research has shown the improved patient outcomes as a result of connecting caregivers through telemedicine.

Systematic Review Limitations

Few articles are available for this systematic review of the literature on human error in ambulance-based care, perhaps due to the factors previously mentioned concerning reporting rates and publication bias in which non-significant results are less likely to be published, and the exclusion of the non-English articles. This review considered only experimental or observation studies measuring error occurrences; reviews, commentaries, or studies that focused only on methods for measuring error in ambulances without data were not included. In addition, studies that did not classify errors in such a way that identified human errors were also not included in this review. As mentioned previously, reporting rates of human error are low, so this may bias the data of retrospective reporting studies.

Directions and Future Work

Many interventions are proposed in the studies reviewed and above, future studies are needed to assess how these interventions could be integrated into EMS systems that could function efficiently in the high-workload, fast-paced environment of an ambulance. Considerations of these interventions as to how they impact individual caregivers as well as the care process and patient safety should be investigated. Additionally, in at least one study, workload and fatigue were noted as possible causes for adverse and safety events. Studies have been conducted on the stress of prehospital providers, but based on a previous review, none has been conducted including a telemedicine system to determine the workload and workflow with this system (Rogers et al., 2017). Research needs to be conducted to determine how prehospital providers currently work with telemedicine systems before new features are added to prevent errors. Additional functionality without consideration for how these functions would fit into workflow or effect workload is inadvisable until their impact is fully researched and understood.

These studies should also determine how telemedicine systems themselves could cause error, a topic not covered by the current research. Careful consideration of their design for optimal workflow and protection of patient and provider safety and confidentiality is important in these systems. Some telemedicine systems take the format of simple video conferencing systems, while others include more functionality such as multiple viewpoints of the ambulance and patient or transfer of vital signs and ECGs. While the more complex systems provide more functionality, the work environment and the operator must be considered in both the design of the interface and the placement in the ambulance. Off-the-shelf systems for video conferencing may be suitable for home telemedicine or a starting point for ambulance telemedicine, but an entire systems approach is needed for these telemedicine systems to be effective in supporting physician and prehospital provider care for patients and in reducing errors.

CONCLUSION

This review systematically investigated the errors made by prehospital providers in ambulances via a variety of methods. The reviews, though few, generated established types of errors found in ambulance-based care: procedure errors, protocol deviations, medication errors, diagnosis accuracy, and adverse or safety events. Though interventions to mitigate error were identified in some studies, inferences from the SEIPS 2.0 model were made to develop suggestions for mitigations to common causes of human error described in this review. This literature explored human error, provided error occurrences, and frequently described the causes of errors. Further research is needed to determine how to effectively minimize these errors through system design, environment design, or training to improve patient safety in the prehospital environment.

CHAPTER FOUR

ANALYSIS OF AN AMBULANCE-BASED TELEMEDICINE-INTEGRATED SETTING FOR STROKE CARE

INTRODUCTION

Telemedicine in Stroke Care

Strokes are one of the most serious healthcare issues in the United States: they represent the fifth leading cause of death, resulting in 1 death about every 4 minutes and annually cost $34 billion in health care, medication, and lost work (Benjamin et al., 2017; Heron, 2019). To improve stroke outcomes, healthcare professionals seek to minimize the time to treatment to restore blood flow to the affected tissue (Saver, 2006). Strokes caused by a blood clot (ischemic strokes) result in brain tissue death as blood cannot circulate to the affected area. The earlier patients receive treatment, the more likely they are to have improved clinical outcomes and reduced long-term disability and treatment complications (Saver et al., 2013). Telemedicine, the use of telecommunications technology to remotely connect trained specialists to patients, has been recommended by the American Heart Association and the American Stroke Association to improve stroke care (Schwamm et al., 2009). Indeed, research shows that telemedicine has improved patient triage, increased accuracy of diagnosis, and most importantly, reduced time to treatment (LaMonte et al., 2004; Rogers et al., 2017). The quick access to stroke specialists or neurologists afforded telemedicine improves the process of correctly diagnosing a stroke (Barrett et al., 2016; Terkelsen et al., 2002). Telemedicine further coordinates receiving hospitals to allow for expedited care as ambulance-based telemedicine can permit stroke consultations en-route. This can decrease time between first provider contact and definitive therapy, as specialists can rapidly identify and triage stroke patients.

During prehospital stroke consultations, telemedicine helps coordinate patient care by a remote neurologist, the nurse at the receiving hospital and the paramedic in the back of the ambulance. A small rural county in South East United States in conjunction with a tertiary care hospital has implemented a pilot telemedicine system called REACH in their emergency department and ambulances which facilitates earlier contact with a neurology specialist, which the rural county hospital does not have access to on site. The REACH telemedicine platform serves two functions: as a tri-directional visual communication with the secondary hospital, the tertiary hospital, and the ambulance and as a tool to document information about the patient case (Adams et al., 2012). All caregivers have the same interface in REACH, which includes a view of the patient in the ambulance, the hospital, and the neurologist, and an information screen where patient history, vitals, assessment items, imaging, and other information can be accessed. A screenshot of the telemedicine system from the neurologist's view is shown in Figure 4.1.

The typical stroke care process with ambulance based telemedicine includes an Emergency Medical Service (EMS) doing a quick assessment of the patient and alerting a receiving hospital of the incoming patient and their information. Then once in the ambulance and connected to the telemedicine system a neurologist can conduct a detailed assessment until the patient arrives to the Emergency Department (ED) and admitted.

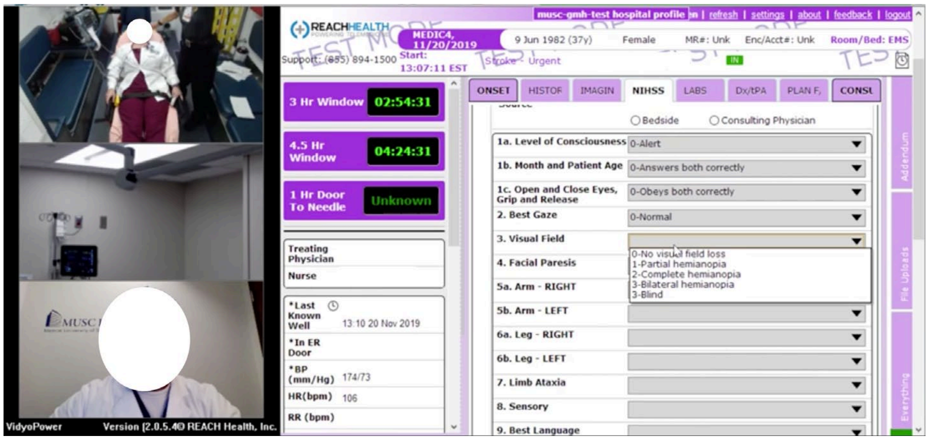

Figure 4.1: REACH interface (Participants' faces masked for confidentiality)

Neurologists awareness is of paramount importance for this system to be effective. The neurologist must gather information from the patient and paramedic to maintain an awareness of patient status and develop a diagnosis and care plan. Development and maintenance of this awareness is necessary specifically for ischemic strokes, which account for 87% of all strokes, as they are treated with a life-saving treatment referred to as a tissue plasminogen activator (tPA) (Benjamin et al., 2017). This treatment has multiple conditions and contraindications affecting its use, the most common being that the treatment must be given within 0 to 4.5 hours of stroke symptom onset (Powers et al., 2018). As such an awareness of the time from the symptom onset must be maintained. Time is not the only factor that neurologists must be aware of, a hemorrhage, high blood pressure or the use of blood thinners all prohibit a patient from receiving tPA (Fugate & Rabinstein, 2015). In addition, mimics for strokes such as low blood sugar or seizures must be ruled out.

Telemedicine has been researched extensively as a tool to improve time to treatment and ultimately patient care outcomes (Rogers et al., 2017); however, the current research lacks an understanding of the effect of this system on the caregivers involved. The objectives of this study are to (1) understand the tasks needed to complete a stroke assessment using telemedicine in an ambulance and how those tasks are completed; (2) determine the usability issues in the telemedicine system and the possible errors that could be made; and (3) provide recommendations to improve the telemedicine design to mitigate usability issues and errors. To understand how these recommendations impact the work system, work processes and ultimately outcomes in the healthcare system, the Systems Engineering Initiative for Patient Safety (SEIPS) 2.0 model was used as method to accomplish the third objective in addition to the heuristic evaluation and SHERPA. This model describes the work system factors in a healthcare system, how they interact to create work processes, how work system factors and work processes impact outcomes, and how outcomes feed back to the work processes and the work system (Holden et al., 2013). To accomplish these objectives, a Hierarchical Task Analysis was completed and used as input for a heuristic evaluation and in a Systematic Human Error Reduction and Prediction Approach (SHERPA). It is crucial to analyze how the telemedicine system is used by caregivers because the caregivers in this work system ultimately determine patient safety and patient outcomes. They need tools that support their processes easily and without causing additional human error. The analyses completed in this study were selected to investigate the tasks, human error, and usability because of their inexpensive cost and rich data results, as well as the prevalence of their use in the human factors field and the healthcare domain. In addition, SHERPA has been validated and found to be one of the most effective methods for determining human error in complex work systems (Kirwan, 1992; Salmon et al., 2002). Subsequent sections detail the background for this study including the effects of human error in stroke care and the approaches used to accomplish the objectives of this study; further sections detail the data collection and analysis methodologies, the results of the analyses, and a discussion of the results and recommendations for design based on the analyses.

Background

There is potential for human error in almost all healthcare delivery as evidenced by the reports from the Institute of Medicine (Institute of Medicine (US) Committee on Quality of Health Care in America, 2014). Several studies have been conducted on prehospital care and human error within stroke care (Brandler et al., 2015; Kothari et al., 1995; Nor et al., 2004; Smith et al., 1998), and there have also been studies on the use of telemedicine to improve stroke care (Barrett et al., 2016; LaMonte et al., 2004). However, there is no current research studies that has investigated potential errors using a telemedicine system with a focus on the caregiver. This lack of telemedicine research in stroke care focusing on the caregivers in the process and the ways to support their use of the system needs to be addressed given the importance of preventing usability issues and error in this domain. This research is doubly important in emergency medicine, specifically in telemedicine-integrated ambulance based environments as the use of a telemedicine system in such a constrained, high-stress environment may result in errors on the part of the health-care providers given the cognitive, physical, and temporal demands of this environment (Goldberg et al., 2017; Hobgood et al., 2006; Mould-Millman et al., 2018; Patterson et al., 2012; Rogers et al., 2017).

The consequences of error in medicine vary by procedure or patient from insignificant to significant harm and even death. Errors in determining if a patient is having a stroke and its severity can delay patient care, impacting the likelihood of improved outcomes. The potential for critical errors in prescribing tPA is especially high given the many conditions tied to its use. Telemedicine can help address this issue by providing access to specialists with the best training to assess these patients; however, the complex tasks involved and the interactions between team members in a stroke assessment make this process at risk for human error. Potential errors for nurses who administer the neurologist recommended tPA involve dosage calculation, mixing the medicine and intravenous administration. In addition, even after the neurologist recommends tPA, changes in blood pressure may contraindicate administration. The nurses administering the medication and the neurologists are responsible for ensuring that the blood pressure is within an acceptable range. Minor errors in this work system including incorrect history or patient information, misspelled medications, and the inability to locate important information could disrupt the patient care workflow and result in prolonged treatment times. Thus, it is vitally important that the work system be analyzed to determine where and how errors could occur. Insights provided by such an investigation can pinpoint the causes and allow designers to improve the system to prevent these errors, or they may highlight changes in the training and organization to improve system awareness, thus reducing the potential for errors.

Many human error investigation techniques are available for predicting human error in a process in any given domain, however, the consensus among researchers is that the Systematic Human Error Reduction and Prediction Approach (SHERPA) is more effective for exploring human error when compared to other tools like HEIST and Human Error HAZOP (Kirwan, 1992; Salmon et al., 2002). SHERPA was originally created for use in the nuclear power domain (Embrey, 1986), but has been used widely as a human error investigation tool in many other domains (Guarascio et al., 2019; Khandan et al., 2017; Stanton et al., 2002). It has been used extensively in healthcare for determining error modes for surgery (Mohammadfam & Saeidi, 2015), addressing errors in medication administration (Lane et al., 2006), or generally investigating care areas such as nursing stations or emergency wards (Ghasemi et al., 2015; Kermani et al., 2016). Even given the large variety of complex tasks represented in these studies, the consistent finding was that the SHERPA has the capability to determine errors and create strategies for improvement such that the errors found in these processes are either eliminated or the consequences are reduced. Based on the extensive use of SHERPA in healthcare and the consensus of SHERPA as an effective human error identification technique, it was used to investigate the possible human error in this stroke assessment process. However, SHERPA looks at a broad work system to determine errors that could be made, to understand one of the most important components, telemedicine itself, a more focused analysis is needed. To determine the issues specifically with the interface, one validated tool is heuristic evaluation, which is a simple and effective tool for determining the usability violations in a system design that could contribute to human error.

Just one of the many tools of an interface designer, user experience designer, or human factors researcher, heuristic evaluation is a usability inspection method for determining problems in a design. Heuristic evaluation, as currently used by designers and researchers, was developed by Jakob Nielsen in collaboration with Rolf Molich in 1990 (Nielsen & Molich, 1990). In 1994, Nielsen refined the heuristics based on a factor analysis of usability problems to create the 10 usability heuristics now used worldwide (Nielsen, 1994b). In healthcare, heuristic evaluation has been used extensively to improve the design of medical devices, medical web pages, and persuasive health technology (Allen et al., 2006; Kientz et al., 2010; Zhang et al., 2003) and in the design cycle of new healthcare technologies (Choi & Bakken, 2010; Preece et al., 2013). Others have also used it to evaluate telemedicine systems (Agnisarman et al., 2017; Lathan et al., 1999; Tang et al., 2006). Heuristic evaluation is an inexpensive tool that has been used in the development and improvement of many health care systems as it has been shown to find more usability issues than user testing using a fraction of the time and cost (Thyvalikakath et al., 2009).

To investigate the mechanisms for improving this ambulance-based telemedicine-enabled stroke assessment by understanding the human error and usability issues in the system, three analyses were selected as the tools for describing the work system process and developing design improvements: Hierarchical Task Analysis; heuristic evaluation, which focuses on the design and use of the interface based on usability heuristics; and SHERPA, which focuses on the reduction of human error in the system as a whole. These methods were selected to answer the following questions because they are powerful assessment tools for discovering and designing improvements to address issues in design and because they are used frequently as human factors tools in healthcare.

1. What tasks are involved in stroke assessment in a telemedicine integrated ambulance?
2. What are the usability issues in the telemedicine interface?
3. What are the potential errors that can be made using the telemedicine system?
4. How can the predicted errors and heuristic violations be mitigated through enhanced system design?

METHOD

To answer research questions and accomplish objectives, 4 methodologies were used: observations of the stroke caregiving process, HTA, Heuristic Evaluation, and SHERPA. These methods will be described further in the sections below.

Participants

To develop an understanding of the telemedicine system and the tasks completed during a stroke evaluation, nurses from the secondary hospital in the rural South Carolina county studied here, paramedics from the local Fire and EMS, and neurologists from the tertiary hospital were recruited to participate in telemedicine sessions such that researchers could observe their process. One of each type of caregiver-- a neurologist, nurse, and paramedic--was required for each session. In addition, an EMT was recruited to drive the ambulance during the session and a standardized patient was recruited from the secondary hospital. First, four pilot observation sessions were completed to test the observation protocol created. At the conclusion of those sessions, it was determined that the protocol did not require any changes. Then, nine final observation sessions were then completed using the same protocol as the pilot observations, resulting in a total of 13 sessions and 39 caregiver participants.

Procedure

The simulated stroke sessions began with the ambulance arriving at the ED of the secondary hospital where the standardized patient and a paramedic were loaded into the back of a functioning ambulance with real equipment, which included two stationary GoPro cameras to view the participants as they drove a loop around the area. The paramedic was told to connect to REACH and treat the simulated patient per the normal caregiving process. Two researchers observed the nurse and neurologist caregivers, one at the secondary hospital and one at the tertiary hospital. Similar to the paramedic, the nurse and neurologist were instructed to complete their normal work tasks as if they were assessing the symptoms of an actual patient. The sessions concluded when a full neurological assessment was complete, and the patient arrived back at the ED. At the conclusion of each session, the caregivers were asked to complete a Retrospective Think Aloud (RTA) session which involved watching either the screen recording of the REACH session (for the nurses and neurologists) or the video of the observation (for the paramedics) and commenting on what they were thinking during the session. These sessions gave the researchers insights into the mental processes involved in the caregiving tasks as well as when and why the order of tasks was created or changed. A full process flow diagram of the observation study can be found in Figure 4.2. These observations were used to determine the tasks required to assess a stroke patient in a telemedicine integrated ambulance, the instances of and possibility for error, and the issues that the caregivers experienced with the current telemedicine system. These insights were used as input for several analyses conducted by the research team to further understand the structure of the caregiving process, the usability issues of the system, and the probability and consequences of human error in this system.

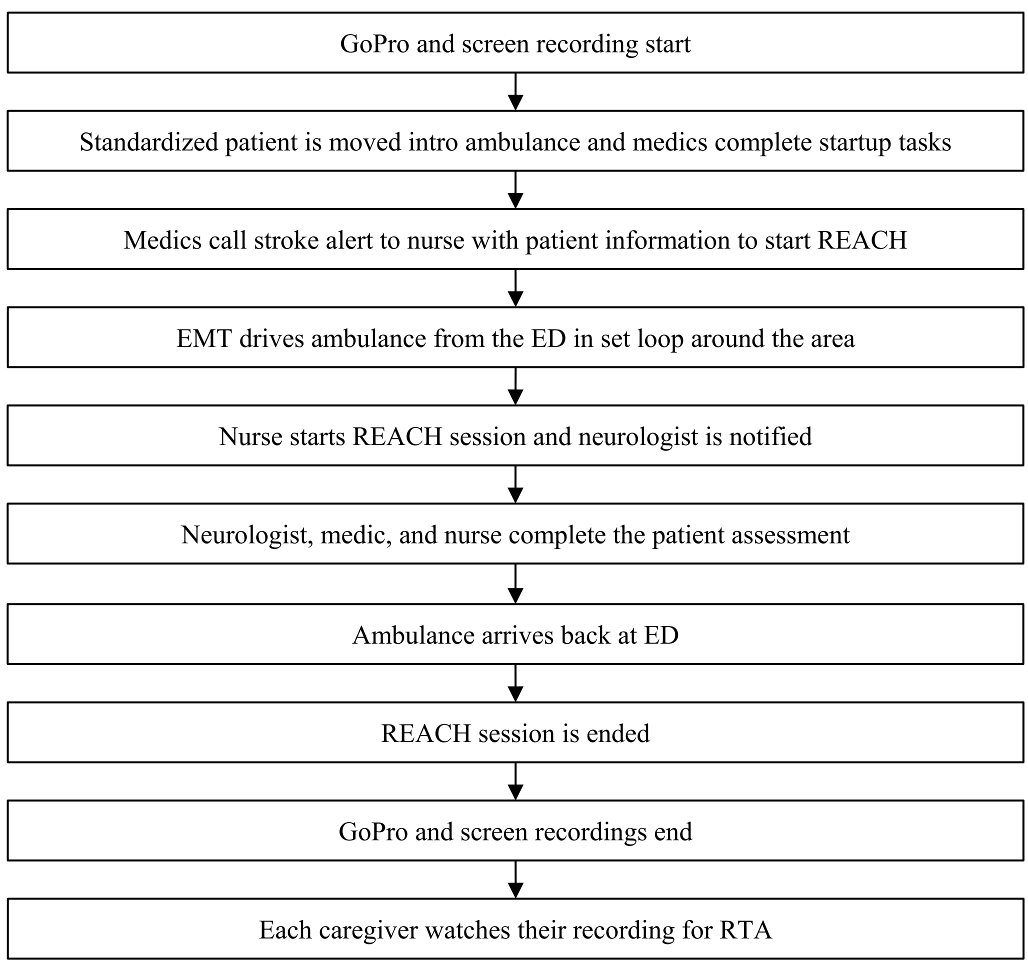

Figure 4.2: Process Flow Diagram of the Sessions

Analysis Techniques

Development of Hierarchical Task Analysis (HTA)

First, the development of a structure of the tasks including their goals and subgoals was necessary to create the subsequent complete structure of the complex process that requires several caregivers to complete and to serve as inputs in other analyses conducted. From the simple observations, an HTA was performed for each role, from the time a caregiver logged on to the telemedicine system to the patient leaving the ambulance after completing a stroke assessment. Given that many steps and protocols either followed a specified order or occurred simultaneously, a clear order is needed to fully understand both how the stroke assessment process should be completed and how the tasks and protocols deviated in various situations. Based on our observations, the researcher was able to list all tasks for all caregivers and establish a beginning and end point for the assessment. The RTA was used to detail the thought processes or protocols that supported this order and to identify deviations from the steps listed. After the list was created for each role, the tasks were grouped into goals and subgoals, and protocols were developed to identify how each goal and subgoal was completed based on the tasks. At this stage, the task lists were shared with the caregivers to obtain their feedback. The caregivers corrected the step lists, adding or removing steps when necessary and clarifying the protocols. Based on this feedback, a unique HTA diagram was developed for each caregiver role. These role specific HTAs served as the input for the heuristic evaluation as each role was evaluated separately. To create the input for the SHERPA, the tasks were combined into an overall process to create a Team Hierarchical Task Analysis. Again, the tasks were organized into goals and subgoals and each Subgoal was assigned a team member. New protocols were created for the overall process to reflect the timing of the tasks including all caregivers. An additional step was completed to identify where teamwork was required and the criterion measure to determine the goal was completed.

Heuristic evaluation

To conduct a heuristic evaluation, simplified task lists of the 3 caregivers input into an Excel sheet along with the knowledge requirements for each step, given that the evaluators, while experts in the usability heuristics used, may not have had the medical knowledge to complete the tasks unassisted. This Excel spreadsheet can be found in Appendix H. Nielsen's 10 heuristics, which are standard for this evaluation, were used in this study (Nielsen, 1994b). The heuristics and their description can be found in Table 4.1.

Three experts from Clemson University completed the evaluation (two men, one woman), each with experience in completing heuristic evaluations of other systems and with training in usability and design. These evaluators included one assistant professor from the Human-Centered Computing Department with a Ph.D. in Information Sciences and Technology, and two Ph.D. students, both with a Master of Science Degree in Industrial Engineering. The choice to use 3 experts was made based on Nielsen's recommendations for conducting heuristic evaluations (Nielsen, 1992; Nielsen & Landauer, 1993). Each evaluator completed the tasks for all 3 caregiver roles--paramedic, nurse, and neurologist--in the REACH system interface, subsequently describing the violations of the heuristics at each step and assigning each a severity on the scale of 0 to 4 developed by Nielsen, with 0 indicating not a usability problem, 1 a cosmetic problem only that does not need to be addressed unless extra time is available for the project, 2 a minor usability problem that is given a low priority for addressing, 3 a major usability problem that is important to fix and thus given a high priority, and 4 a usability catastrophe that is imperative to fix before the product can be released (Nielsen, 1994a).

Table 4.1. Nielsen's 10 Heuristics adapted from (Nielsen, 1994b)

Number	Heuristic	Description
1	**Visibility of system status**	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
2	**Match between system and the real world**	The system should follow real-world conventions, making information appear in a natural and logical order.
3	**User control and freedom**	Support undo and redo without having to go through an extended dialogue.
4	**Consistency and standards**	Follow platform conventions.
5	**Error prevention**	Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
6	**Recognition rather than recall**	Minimize the user's memory load by making objects, actions, and options visible.
7	**Flexibility and efficiency of use**	Allow users to tailor frequent actions.
8	**Aesthetic and minimalist design**	Dialogues should not contain information which is irrelevant or rarely needed.
9	**Help users recognize, diagnose, and recover from errors**	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
10	**Help and documentation**	Any help and documentation should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Each evaluator worked independently to assess all heuristic violations. Once the list was complete, a single researcher compiled all violations, averaging the severity rating for duplicate violations.

Development of SHERPA

To evaluate and predict human error in this process, a Systematic Human Error Reduction and Prediction Approach (SHERPA) was conducted by a single researcher. The first input for this analysis was the HTA developed for the overall process; then all tasks in the subgoals were classified according to a behavior taxonomy developed by Stanton (2006) as either Action, Retrieval, Checking, Selection, or Information Communication. Each behavior in a task involved different types of errors, all of which were described and labeled by behavior type according to the SHERPA error mode taxonomy shown in Table 4.2. If multiple error modes could be applied to the task, each was listed. For example, when entering a password to log in, a user could omit the action step or have an incomplete password or wrong password; in this case Action type error modes A7-9 were applied. The consequences and probability of making an error along with the criticality of the error were identified based on the observations and interactions with the caregivers. Probability is measured on a 3-item scale: Low (hardly ever happens), Medium (happens once or twice), or High (happens frequently), with criticality being measured on a similar scale, ranging from Low indicating a non-critical incident to High indicating a critical incident. It was also determined if the user could recover from each error and at which task step. For example, if the patient's name was incorrectly entered during patient creation, this error could be corrected later in the step asking for updated patient demographics. Finally, for each error at least one remedy strategy was identified based on four categories proposed by Stanton (2006): equipment, training, procedures, and organizational. The research team adapted these remediation strategies so that they could reasonably be implemented in the healthcare system. The items from the SHERPA technique (error type, error mode, consequence, recovery, probability, criticality, and remediation) were collected in tabular form to organize the information for each bottom level task in the HTA.

RESULTS

The results from the three analyses, which are presented in the sections below in the order in which they were conducted, detail the structure of the caregiving task and the number and type of issues found within the system based on the use of the heuristic evaluation and SHERPA.

HTA

The results of the HTA answer research question 1. The overall process of care for a stroke patient was described by the caregivers. When a person potentially experiencing a stroke calls 911, the local EMS sends one of their ambulances with an Emergency Medical Technician (EMT) and paramedic team to assess the patient. On arrival, they typically conduct a Rapid Arterial oCclusion Evaluation (RACE), a simple 5-item scale used to help identify a possible stroke. Based on the RACE score and the overall evaluation of the patient, the EMT and paramedic move the patient into the ambulance, call the receiving secondary hospital to begin a stroke consult and log on to the REACH program from a laptop in the ambulance.

Table 4.2. SHERPA Error Mode Taxonomy

Error Type	Code	Error Mode
Action	A1	Operation too long/short
	A2	Operation mistimed
	A3	Operation in wrong direction
	A4	Operation too little/much
	A5	Misalign
	A6	Right operation on wrong object
	A7	Wrong operation on right object
	A8	Operation omitted
	A9	Operation incomplete
	A10	Wrong operation on wrong object
Checking	C1	Check omitted
	C2	Check incomplete
	C3	Right check on wrong object
	C4	Wrong check on right object
	C5	Check mistimed
	C6	Wrong check on wrong object
Retrieval	R1	Information not obtained
	R2	Wrong information obtained
	R3	Information retrieval incomplete
Information Communication	I1	Information not communicated
	I2	Wrong information communicated
	I3	Information communication incomplete
Selection	S1	Selection omitted
	S2	Wrong selection made

The nurse at the receiving Emergency Department (ED) creates the patient encounter, and the system alerts the neurologist on call at the tertiary care hospital of the awaiting consult. The paramedic gathers vital information and stabilizes the patient until the neurologist and nurse can be connected. The neurologist obtains more health history and information about the patient and begins an assessment using the National Institutes of Health Stroke Scale (NIHSS). When the ambulance arrives at the secondary hospital, the patient is taken directly for a Computed Tomography (CT) brain scan, which is immediately uploaded to the telemedicine system such that the neurologist can make a treatment decision that may include transfer to the tertiary hospital for more intensive care. However, to evaluate the ambulance based assessment the start and endpoints of the telemedicine system use were used to scope the HTA. The HTA was developed first by role and then as an overall process conducted by a team. Overall, the goal of the team process is to care for the patient; however, individually for the nurse and neurologist, this goal takes different forms. The main goal of the nurse is to prepare for the arrival of the patient at the ED, while the neurologist determines the patient care plan. In the overall HTA, the subgoals for the process are distributed among caregiver roles as described below.

Log on to REACH

All participants must first log into the REACH system to begin the stroke consult, with the nurse typically logging on first after being alerted by the EMS and the neurologists last after a patent case has been created and the EMS has connected. Each caregiver has an individual user ID and password for accessing the system. In addition, the interface accessed is tied to the caregiver role: nurses begin with a create patient screen, neurologists a list of available and past consults, and paramedics with the main REACH screen and the accompanying video screens and data input.

Create a patient case

Nurses are contacted by EMS with the basic information needed to create the stroke consult on the REACH system, including the medic unit the EMS is calling from, an estimated age of the patient, and symptoms including the RACE score the EMS has collected. The nurse is responsible for inputting as much information into the patient's case as quickly as possible so that the neurologist can select the patient when the alert is received. Without a patient file, neither the neurologist nor the paramedic can access the REACH consult. In addition, inputting as much information as possible alleviates the need for updates once the case is created; however, according to the nurses in this study, time is the most important element in this process.

Gather and record demographics

Typically, the paramedic or EMT obtains a name and the date of birth from the patient or family when they arrive on scene, depending on the severity of the patient and if their family is present at the scene. If the medical personnel is able to obtain this information before the nurse or neurologist is connected to the REACH consult, then either caregiver asks the patient or the paramedic for this information once connected. It is the nurse's responsibility to record this information either when creating the patient case or in the data input screen when connected to the consult. This step is particularly important for the nurses who must connect this REACH chart information to the patient’s Electronic Health Record (EHR) at the receiving hospital.

Gather and record vitals

Once the patient is moved into the ambulance, the paramedics connect the patient to a vitals monitor that collects blood pressure, heart rate, and blood oxygenation (SpO_2%). They also obtain the patient's respiration rate by counting breaths over a 15 or 30 second interval to determine breaths per minute, and a glucose measure, usually obtained from a blood sample. The paramedic typically communicates these vitals over the audio connection in REACH, and the nurse records them in the system. These vital signs are important for the neurologist to determine if the patient has had a stroke, a low blood sugar incident or a stroke mimic as well as to form a mental model of patient status. Current vitals are updated either upon request from the neurologist or when they change drastically and are communicated verbally by the paramedic.

Gather and record patient history

Once the neurologist is connected, they collect information to create the patient history. If the nurse has obtained the medications the patient is taking, any allergies, and the medical or surgical history before the neurologist accesses the REACH consult, they review this information either with the patient or the nurse. Subsequently, the neurologist summarizes the patient history in REACH for the patient's chart. This process is necessary for the neurologist to develop the mental model of the patient's status and the severity of the patient's stroke. This initial step of recording the history is necessary for neurologist to form a complete view of the patient before they begin to evaluate the patient based on the stroke scale.

Conduct stroke assessment

The primary tool used by neurologists to determine the type, location and severity of a stroke is the NIHSS. This is the most complex process in a stroke consult because it requires the neurologist to communicate tasks to the patient and the paramedic as they are not physically in the ambulance. One of the most difficult items on the scale involves assessing the patient's peripheral vision and reaction to movement; to do so, the paramedic must place their hands outside the direct view of the patient but within a reasonable distance for the patient to see them peripherally; they then ask the patient the number of fingers they are holding up on each hand. The proper positioning of the paramedic in relation to the patient is not only difficult to communicate but also difficult to judge in the telemedicine system. There are many items on the scale that require paramedic assistance, and while some have experience or training in conducting these, it is not standard for them. As the patient completes the movements or responses needed to the best of their ability, the neurologist selects the level for each scale item to create the scale score, which is a measure of the severity of the stroke. Neurologists can do this as they complete each assessment or in batches, and while they usually complete this assessment in the order suggested by the NIH, they may deviate based on patient status, patient symptoms, or personal preference. As the neurologists enter selections, the REACH system records the score so that nurses can follow the assessment as the score increases. This monitoring helps the nurses prepare for the patient’s arrival as they can determine the neurologist’s judgement of the severity of the patient’s condition. The neurologist uses this assessment to develop a diagnosis and further develop a plan for the patient before they arrive at the ED. This process improves the efficiency and timing of the treatment and, more importantly the patient outcomes as quicker treatment saves brain tissue.

An excerpt of the nurse's role in the HTA can be seen in Figure 4.3. The full role specific HTAs can be found in Appendix E. An overall HTA diagram can be seen in Appendix F, and the Team HTA table can be found in Appendix G. The role specific HTAs were used for evaluating the heuristic violations of the interface by providing the overall goals for each user's tasks that evaluators then used to organize their analysis. The overall HTA was required input for SHERPA as errors are evaluated at the task level.

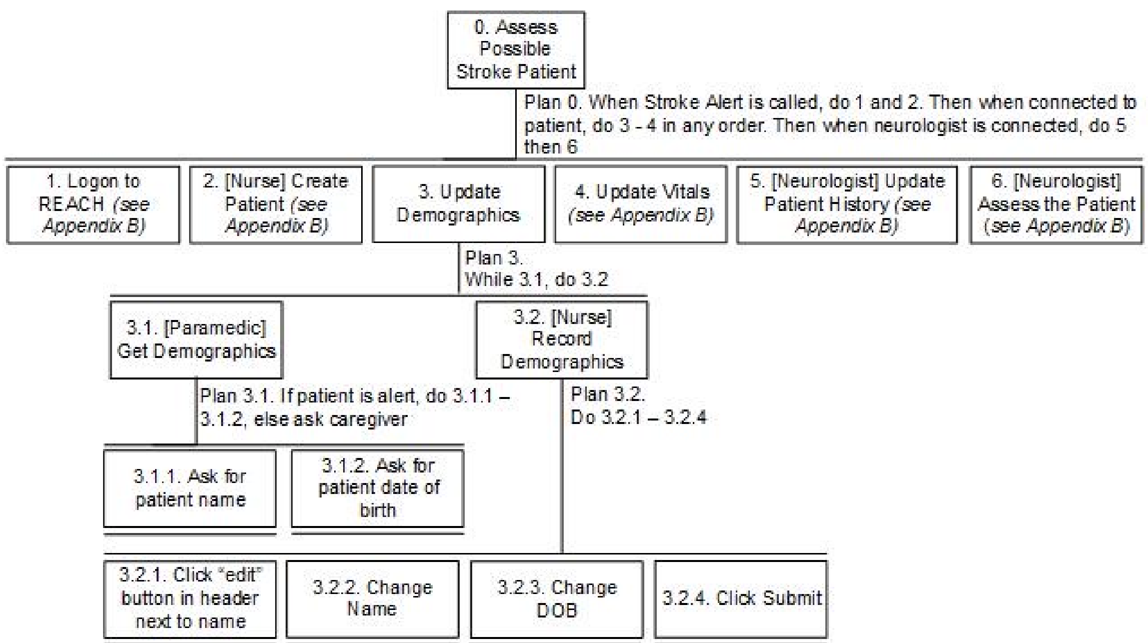

Figure 4.3. HTA Excerpt (See Appendices A and B for Detailed Task Analyses)

Heuristic evaluation

The heuristic evaluation answered research question 2. A total of 129 usability violations were found by the three reviewers for the 3 roles studied: 10 violations for the paramedic role, 69 for the nurse, and 46 for the neurologist. The average severity rating for each role was 3.375 for the paramedic role, 2.28 for the nurse, and 2.35 for the neurologist. The further breakdown of the violation counts and severities for each role can be seen in Table 3. Ninety-five percent of the violations found were unique; however there were many instances where a similar violation description was used, but evaluators assigned different violation types. In the log on task, for example, one evaluator described a violation to the Visibility of System Status as "No update on what (ID/password) was entered wrong," while another described a violation to Help Users Recognize, Diagnose and Recover from Errors as "No error message." The most frequent classification of severity was a minor usability problem with 45 violations rated at this level (35%), followed by 43 violations rated as a major usability problem (33%), 18 as a usability catastrophe (14%), 22 as a cosmetic problem (17%), and only one violation being rated as not a usability problem (1%). When the common violations were merged and severity ratings averaged, there were 123 violations among the three caregiving roles. All heuristics were used, but the most commonly used was the Visibility of System Status heuristic, which accounted for 24% of all violations, followed by Consistency and Standards with 20% and Error Prevention with 15%. A summary of the severity ratings by heuristic violated can be found in Table 4.3 and Figure 4.4.

Table 4.3. Summary of Heuristic Violations

	Paramedic		Nurse		Neurologist	
	Count	Average Severity	Count	Average Severity	Count	Average Severity
Visibility of System Status	3	3.67	19	2.53	8	3.00
Match Between System and Real World	0		6	2.17	4	1.25
User Control and Freedom	0		2	2.5	3	2.33
Consistency and Standards	0		14	2	10	2.25
Error Prevention	1	3	9	2.5	8	3.00
Recognition Rather than Recall	0		4	2.25	3	1.33
Flexibility and Efficiency of Use	2	3	3	2.33	5	2.00
Aesthetic and Minimalist Design	0		5	1.2	3	1.67
Help users recognize, diagnose, and recover from errors	2	3.5	5	3	2	3.50
Help and Documentation	0		2	2	0	

Some examples of violations found in this evaluation are that the distance from the labels to data input were too large making it unclear what label belonged to each text box, the interface for selecting consults was confusing as there did not seem to be a difference between active and pending consults, and that the consults and some tabs in the interface are not clearly clickable, inhibiting the function of the interface. The next most violated heuristic was Consistency and Standards. Some examples of these violations include inconsistent use of radio buttons, multiple conflicting data inputs for the same information, inconsistent date formatting, and inconsistent use of bolding and highlighting.

The role tasks with the most violation was the nurse role. Many violations for this role focused on the data formatting as the nurse role has several steps that require text input. Another frequently mentioned violation in this role was focused on the edit button used to change the demographics of the patient after a patient case is created, violating the Visibility of System Status heuristic as it was unclear that the edit button found when hovering over the patient's name, date of birth, and many other demographic data would allow the user to edit all information in one menu. This required the user to search after selecting the appropriate menu for the information that required updating rather than providing a singular input for that data. Error messages for missing or incorrect information when creating a patient were either not functioning or unclear which violates the Help Users Recognize, Diagnose, and Recover from Errors heuristic. A full list of violations by role can be found in Appendix I.

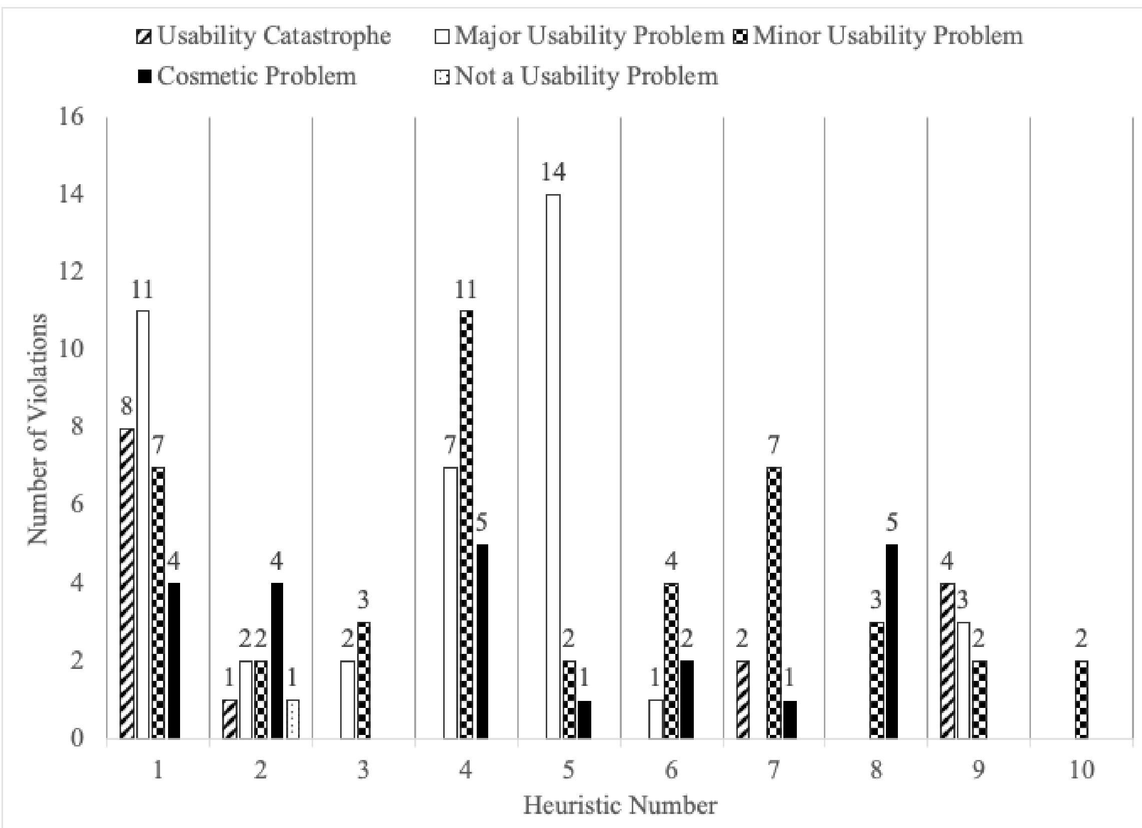

Figure 4.4. Heuristic Evaluation Severity Summary

SHERPA

The goal of these analyses were to better understand the tasks and process of each caregiver in the system and determine where environment, training, or system design remediations could be provided to address the errors made. This was a first step for the research team to develop system improvements to support the caregivers in using this telemedicine system for stroke assessment. A sample of the SHERPA table created for the two main goals of the process including the HTA can be found in Table 4. This analysis answered research question 3. At least one error was found for each of the 97 lowest level tasks (1.35 per task on average), with a total of 131 being documented. The potential errors found included almost all task types, with 49% being information communication errors, 35% action errors, 10% retrieval errors, 6% selection errors and 0% checking errors. The prevalence of information communication errors can be explained by the fact that most data needed for stroke assessment are collected from the paramedic and patient verbally. As a result, the most common error is miscommunication or not hearing the response to a communicated command. There are also many action errors for tasks involving recording vitals and creating the patient case. No errors were assessed as high probability or high criticality based on the information collected from the RTA; however, these were only assessed based on the task directly affecting the process. Most errors were found to occur at medium probability (53%), and overall most errors were considered of medium criticality (55%). In addition, 77% of medium probability errors were also considered medium criticality, and 73% of low probability errors were considered low criticality. Almost all errors (90%) were recoverable immediately after they were made, and for the remaining 10%, recovery steps were identified later when a process was repeated or the error was accessed in later steps. The full SHERPA table can be found in Appendix J.

DISCUSSION

The objectives of this study were to develop a detailed understanding of the task structure and flow for completing a stroke assessment in a telemedicine integrated ambulance, determine the usability issues of the REACH telemedicine system interface and possible human errors that could occur when using this system, and suggest remediations for usability issues and human error. The first objective was met using observational data to perform an HTA outlining the goals, subgoals, steps, and workflow for each caregiver role. The heuristic evaluation and SHERPA met the second objective, the former by identifying 129 usability violations and the latter by detailing the possible human error occurrences for each observed task. Both heuristic evaluation and SHERPA suggested remediations to improve usability and safe performance, addressing the third objective.

While there have been HTAs, heuristic evaluations and usability assessments conducted on telemedicine systems (Agnisarman et al., 2017; Lathan et al., 1999; Narasimha & Agnisarman, 2016; Tang et al., 2006), studies of human error in stroke care (Gropen et al., 2014; Hughes et al., 2015; Kothari et al., 1995; Mould-Millman et al., 2018; Nor et al., 2004), and limited study of human error using telemedicine (Dharmar et al., 2013), there is little human-centered research on the errors made using telemedicine for stroke care and none using SHERPA to evaluate human error. This study addresses that

Table 4.4: Sample of SHERPA Table

Task No.	Task	Error Mode	Error Description	Consequence	Recovery Task No.	Probability	Criticality	Remediation
2	Create Patient							
2.1	Enter medic unit as last name	A6, 8	Medic unit not correctly recorded in last name or placed elsewhere	Cannot create patient	Immediately	L	M	Highlight required field, Suggestions for how to fill
2.2	Enter current date as first name	A6, 8	Date not correctly recorded in first name or placed elsewhere	Cannot create patient	Immediately	L	L	Highlight required field, Suggestions for how to fill
2.3	Enter DOB greater than current date	A6, 8	DOB not correctly formatted or omitted	Cannot create patient	3.2.2	M	L	Create rigid formatting, Highlight required field
2.4	Enter Gender	A6	Gender not selected	Cannot create patient	3.2.2	L	L	Highlight required field, Suggestions for how to fill
2.5	Enter EMS as Room/Bed	A8	EMS not written as Room	Cannot create patient	3.2.2	L	M	Highlight required field
2.6	Select Stroke – Urgent in bottom selection box	A6, 8	Reason for consult not selected or stroke not selected	Cannot create patient with omitted, Will not be allocated to the right people if incorrectly selected	3.2.2	L	M	Highlight required field, Suggestions for how to fill
2.7	Enter Reason for Consult as Stroke Alert	A8	No reason for consult written	Cannot create patient	3.2.2	L	L	Highlight required field, Suggestions for how to fill
2.8	Click Submit Button	A8	Button not clicked	Cannot create patient	Immediately	L	L	Enlarge button
3	Update Demographics							
3.1	Gather Demographics							
3.1.1	Ask patient for name	I1,3	Patient did not hear paramedic or vice versa	Cannot properly update patient case	Immediately	M	L	Enhance audio quality of transmission, Closed captioning, Visual aid of normal requests made by caregivers
3.1.2	Ask patient for birthday	I1,3	Patient did not hear paramedic or vice versa	Cannot properly update patient case	Immediately	M	L	Enhance audio quality of transmission, Closed captioning, Visual aid of normal requests made by caregivers
3.2	Record Demographics							
3.2.1	Click Edit button as it appears in the header next to name	A8	Button not clicked	Cannot properly update patient case	Immediately	L	L	Highlight required field, Suggestions for how to fill
3.2.2	Change name	A6, 8	Name not correctly recorded in correct sections or placed elsewhere	Cannot properly update patient case	Immediately	L	L	Highlight required field, Suggestions for how to fill
3.2.3	Change DOB	A6, 8	DOB not correctly formatted or omitted	Cannot properly update patient case	5.1.2	L	L	Create rigid formatting, Highlight required field
3.2.4	Click Submit	A8	Button not clicked	Cannot properly update patient case	Immediately	L	L	Enlarge button

Task No. Taken from HTA

need by providing a detailed analysis of the types, consequences, probability, criticality, and remediations of human error in a telemedicine system for stroke care. Results of the heuristic evaluation revealed many violations of common design heuristics. Most prominently the Visibility of System Status, Consistency and Standards, and Error Prevention heuristic violations identified issues with error messages, the layout of the tab structure, data input formats, information architecture, and overall page formatting. Information architecture and the design of the tabs for navigating the system are both important for building a solid foundation for finding information and allowing users to move through the interface. Information architecture involves different models depending on the use of the system; an application focused on fixed steps, for instance, would have a different information architecture from one for browsing. Creating a structure that assists users and is consistent and easy to learn is important in the development of an information architecture (Danaher et al., 2015). This architecture can also be supported by page formatting, consistency in type face and the use of bold in headings, and effective organization which can guide a user through the system and make items on a page easy to find. Not only should the structure be easy to identify and follow, it should also be easy to access, meaning it should not require additional effort to determine the state of the system and how to navigate it, this is consistent with previous usability findings (Johnson et al., 2005). Other usability studies have also found similar issues with data input formatting as we found here; with open-ended data input or a nonrestricted format, users often ignore formatting, leading to errors in the system (Lai, 2007). The system studied here also exhibited a lack of error messages or a lack of specificity in the error messages. Error messages are critical feedback for the user, allowing them to move forward in a system and correct future behavior. These messages should be informative, identifying the location of the error and how to fix it, and succinct so that the correction is easy to understand and implement quickly (Bargas-Avila et al., 2010).

The lower number of heuristic violations found for the paramedic role was due to the limited number of interface interactions for that role. The paramedic has only two goals, to log on and select the correct patient case, compared to the nurse and neurologist, each of whom has four goals. The reason for the fewer interactions with the interface is that paramedics are focused solely on patient care. In many cases, the EMT completes the REACH setup before the patient is in the ambulance so that the paramedics only needs to interact with the other caregivers via the two way audio connection in the telemedicine system. They cannot input demographic information or vitals while attending to the patient, meaning the protocol dictates that they communicate this information verbally. This impacts the possibility for human error in this process as the noise level in the ambulance can be high with road noise and sirens and the audio connection through the telemedicine can be impaired because of poor data connections as the ambulance drives through rural areas.

The higher number of usability violations found for the nurse compared to the neurologist can be explained by the amount of free data entry required in this role. Nurses are required to enter dates, names, and vital signs during their tasks, none of which have formatting suggestions in the system, violating heuristics such as Visibility of System Status, Consistency and Standards, and Recognition Rather than Recall. In comparison, although the neurologist role includes data input, the majority is limited to checking boxes and radio buttons to record the patient history, current medications, or allergies or using the drop-down menus selections in the NIHSS. Even though boxes, radio buttons, and drop-down menus are rigid forms of data input which can be restrictive when extra detail is needed, they prevent confusion and errors.

Findings from the SHERPA included the common possible human errors in the telemedicine system for stroke assessment, most of which were information communication or action errors, specifically, miscommunicated, misheard, or unheard communications and incorrect formatting or selection of data input. Communication errors in this system can be caused by unheard or unclear audio, which then requires the communications to be repeated. More common with complex communications through computer systems is misunderstood communications, in which the messenger does not provide adequate information or the receiver does not comprehend the message communicated (Morrow et al., 2005; Jordan, 1996). Data input formatting issues were also an issue found in the heuristic evaluation of this system, with incorrect date formats or misunderstood data input labels with a lack of formatting being were some of the issues seen from the SHERPA. While these errors may seem minor, missing or incorrect data can negatively impact patient care (Cebul et al., 2011; Wells et al., 2013). Other healthcare informatics research finding high error and data input has concluded that drop down selection reduces input errors (Devine et al., 2010). These simple changes to the formatting to allow for restricted input can reduce human error in data input.

The consequences for most of the tasks in this process were that the information would not be documented correctly or that a full assessment of the patient could not be formed. While these may not be as severe as causing patient harm, given that tPA is not given until a CT scan can be conducted, the further consequences of incomplete patient documentation could lead to incomplete links to the EHRs, difficulty connecting to a neurologist, or an incorrect NIHSS, all of which could affect the nurses' and ED physicians' care plan in the hospital or the search strategies of the neurologist when searching the CT imaging for the clots or bleeds that potentially caused the stroke.

Almost all errors could be recovered immediately as the system allows for free data entry after creating the patient case. After the case is created, updating demographics requires entering a sub menu, which is necessary later in the process, meaning that some create patient tasks have a recovery mechanism under the update demographics goal. Other vital sign documentation tasks have recovery steps when the neurologist completes an overview of the patient history. These are advantages in the system, as free data manipulation in the system gives users the chance to correct mistakes and update information to its most current state.

Remediations

Remediations developed based on heuristic evaluation and SHERPA findings are organized below by work system category from the SEIPS 2.0 model (Holden et al., 2013).

Tools and Technology

Highlighting and labelling: Consistent use of color, bolding and labelling formats should be used in the design of the system not only to create a cohesive aesthetic but also to provide a sense of hierarchy and organization. Violations of the Aesthetic and Minimal Design and Consistency and Standards heuristics would be mediated by simple changes in the visual formatting of the labels used in the display. The location and text of the labels were also a focus of violations to the Aesthetic and Minimal Design, Visibility of System Status, Match Between System and Real World, and Consistency and Standards heuristics. Data labels for all input should be located close to the input boxes and be clear, concise and consistent. This not only allows the users to identify quickly and correctly where the data should be recorded but also is aesthetically pleasing on an interface. In terms of the SEIPS 2.0 model, changing the labelling and use of color on the interface impacts the work system through the tools and technology factor, but a clear organization can also impact how caregivers complete the task. The use of color, bolding, and size can provide a subtle structure to data input tasks and impact how users complete tasks or organize their work. This, in turn, can make users more efficient by making the organization of the system transparent.

Error messages: A common violation described in the heuristic evaluation involved data input tasks with requirements that have to be met before the user can log on, create a patient case or move through the system. Frequently there was little to no information about which items were the issue or how to fix those items. Providing salient error messages that help the user to recover is crucial to the usability of a system. A portion of this study focuses on methods for preventing human error; however, a system design needs to account for the possibility of human error and assist the users in correcting their mistakes. Error messages should follow design standards and include the item that needs to be changed, the severity of the error and suggestions for how to fix it. As this change affects only the interface of the telemedicine design, it impacts only the tools and technology factor. However, as the SEIPS 2.0 model describes, changes to the tools and technology in the interface impact the task, internal environment, organization, external environment, and person factors in the work system.

Layout: The organization of the data input screens in this telemedicine system were the consistent source of violations in the neurologist's role. This role is the only one that consistently uses the tab structure in the REACH system to complete their tasks. Many evaluators reported that the visual design of the tabs did not make it clear that they were able to click on them to access different data inputs, especially in the History tab, which includes multiple tabs as subsections as seen in Figure 5. This issue violated the Consistency and Standards, Flexibility and Efficiency of Use, Visibility of System Status, and Error Prevention heuristics. Each item in an interface should have a clear purpose and communicating that purpose through design is crucial to usability. This is typically done though platform conventions. For example, links should be underlined in a highlighted color or clickable tabs or buttons should have some coloring or positioning to indicate that they are selected or can be selected. In this system the tab selection is inverted; the selected tab is a lighter color than the others, which doesn't follow conventions as the selected tab should be darker and have other features to distinguish that it has been selected such as an outline. The main tab structure has an issue as well based on the task flow observed in the mock stroke sessions and confirmed in the RTA with the caregivers; the neurologists use the history tab first and then input medications and allergies on the onset tab, but the onset tab is first, not second, in the tab structure. The tab structure should follow the task flow, and items like medical history and current medications that are completed together should be supported in the layout. Evaluators also mentioned that the organization of the tabs and subtabs made moving through the system confusing as there were multiple scrolling sections in the display, violating the Flexibility and Efficiency of Use heuristic. A simpler design of tabs organized by the task flow of the user would improve user experience and efficiency as organization prevents extraneous movement in the system. Similar to the labelling remediation, these changes in layout affect the SEIPS model work system through the tools and technology factor and the task factor because of the impact on the task organization mentioned previously.

Formatting: Given the large amount of data entered into this system, many task remediations focused on changes to the telemedicine system such that the data required to be entered in the process is clear by highlighting areas for data input. Another remediation suggested was rigid or suggested formatting. For data input such as dates and times, rigid formatting was suggested, meaning segmenting the data input such that the data are entered in a format consistently (for example separate data inputs for month, date and year), could eliminate confusion and maintain consistency in data input.

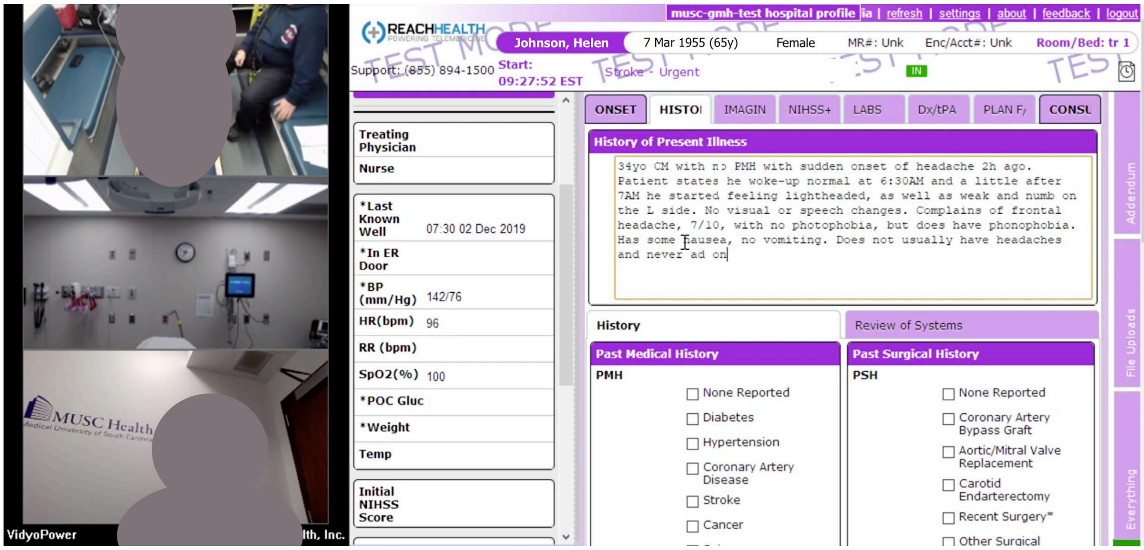

Figure 4.5: History Tab in REACH (Participants' faces masked for confidentiality)

This change reduces the number of errors involving switching day and month or entering month as an abbreviated word rather than a number. Suggested formatting could be used for such data as patient blood pressure, heart rate, or blood oxygenation by providing an example of a typical input with the correct units. For example, near the blood pressure data input, a text label could identify "132/88 mmHg" as an example of blood pressure formatting. This works well to mediate errors and address heuristic violations. Consistent and rigid formatting supports recognition rather than recall and helps users prevent errors and recover from them quickly as the formatting should make mistakes obvious. Again, this remediation focuses on the design of the interface and as such directly impacts the tools and technology work system factor in the SEIPS 2.0 model.

Tasks

Automation: For tasks that require manipulation of controls, such as the camera focused on the patient, automation could be implemented. A simple command or control would focus the camera on an area of the patient rather than requiring the neurologist to manually control the camera by clicking directional and zoom arrows. For assessment items that require a close view of the patient's facial movements, a control could allow the camera to detect the patient's face and zoom in, or for items requiring visuals of leg movements, the camera could move to the lower portion of the patient. Additionally, this functionality could be automated such that as assessment items are completed, the view the neurologist needs for the next item would be implemented as the previous assessment item was completed. Automating the movement within this system with set view controls could eliminate over or under correction of the camera location and reduce the instances that an assessment item is incorrectly recorded due to lack of detailed visibility. Further automating to set the views as neurologists work through assessment items would allow for a consistent assessment order for the neurologist and paramedics and simplify the movements needed to complete the task. Implementation of automation would impact the tools and technology work system factor, and automation based on tasks step would impact the task work system factor. The task change may also impact the communication in the system as a standardized task flow would limit the need for the neurologist to communicate the assessment needed, thus impacting the person work system factor.

Internal Environment

Audio/Video improvements: There are many communication tasks in this system that could be impacted by low quality data connections or audio equipment. Not being able to hear or understand from either the neurologist or paramedic perspective requires multiple repetitions of information or physical movement in the ambulance to view the neurologist. Improvements to the equipment in the ambulance could eliminate or reduce the instances of miscommunications or work arounds. Improved microphones and speakers could make the audio connection clearer for both the neurologist and paramedic, reducing the need for repeated communications. Easily accessible views of the neurologist from the patient's side would allow the paramedic to make use of nonverbal communication with them. Based on the RTA protocol applied in this study, many neurologists mentioned that they would mime movements they wanted paramedics to use in the assessment whether they could be seen or not.

Often the paramedics leave the laptop connected to the REACH program in the front of the ambulance as it is the most stable place for it and movement is restricted by the wired connections to the laptop. Many paramedics mentioned their frustration that when instruction is needed from the neurologist, they must leave the patient's bedside to access the laptop. A screen at the rear of the ambulance so that patient care tasks are not interrupted would be ideal for providing a visual of the neurologist for that visual communication. In addition, closed captioning on a visible screen for the paramedics and neurologists could possibly provide some support in understanding audio degraded by poor data connections. These improvements primarily impact the tools and technology work system factor. However, the implementation of these tools affects the physical layout of the ambulance; thus, the internal environment work system factor is impacted as well. In addition, the support of communication and use of the system without moving from the patient's bedside could impact the task factor, decreasing the effort or repetition of communication needed to complete the assessment items.

Organization

Training: Consistency in procedure steps and increased familiarity with the assessment steps are the training remediations suggested by this analysis. Specifically based on the NIHSS errors in communication, unheard or misheard assessment steps and under communicated instructions for physical assessment could be reduced with training for paramedics on the tasks they need to assist with in the assessment and knowing the order in which to expect those assessment tasks. This could reduce the instances of repeated communication from the neurologist and, thus, the probability of miscommunication. In particular, training in the movements needed for the assessment as well as their correct application could eliminate the need for the neurologist to communicate techniques, that are often either unheard or misunderstood. This remediation focuses on the changes to the organization work system factor, but this training could impact the person factor by providing knowledge about the assessment and the task factor by changing the sequence and reducing the difficulty of the assessment task.

Error remediation techniques suggested in this analysis primarily focus on interface system improvements rather than the use of training or environmental changes. This is due to the constraints of the physical environment in ambulances, meaning additional equipment would need to be carefully considered for necessity and placement, and the mobile and complex nature of the nursing stations makes it difficult to implement lasting environmental changes. In addition, all caregivers in this process have rigorous training that they complete for many aspects of their jobs, meaning additional training for this single process should be kept to a minimum.

Many remediations were developed so that the process of completing the assessment is consistent, correct, and as quick as possible. To do this, the main problems of data collection and data input needed to be assessed. Supporting the communications of the paramedic and the neurologist through the telemedicine system is the primary remediation for errors of information communication. Setting a protocol and order for data collection can create redundancy in the communications. The remediation from the NIHSS assessment requiring training of neurologists to complete the assessment in a specific order for each patient would allow for consistent evaluation and better prediction of commands for the paramedic or nurse. This remediation is two-fold: it prevents lost or incomplete assessment items by following a checklist and making use of retrieval cues which improves performance (Hales & Pronovost, 2006), and it eliminates the need for redundant communication and alleviates dependence on audio connection as all members of the team would be able to predict the next item to be assessed. Most of the other remediations focus on formatting suggestions, which allow for consistency and provides an error check for users before they enter the data.

Limitations

Analyses were conducted based on observations of mock sessions and supported with the questioning of caregivers to allow for further clarification on the order of tasks or deviations. The research team was not able to conduct live observations of a real stroke patient, meaning the errors developed and the probability of these errors occurring are the estimation of the research team. However, the team was able to obtain data about the consistent tasks that are completed by controlling the patient and the time to the hospital. This study was also conducted with one telemedicine system and with one county hospital system, the errors and usability found in this system may not be represented in others and the process of stroke care with telemedicine systems may differ slightly in other hospital groups.

CONCLUSION

Completing a stroke assessment in an ambulance using telemedicine is a complex process that is prone to error, as in all processes both simple and complex. Many usability violations were found in the interface, revealing problems with the system's design concerning information architecture, error messages, and page formatting. Predicted errors included miscommunication, omitted or incomplete steps, incorrect data entry, and insufficient assessment. The consequences were discussed with limited probability of patient harm, but some with implications to the patient care process beyond the ambulance. Finally, remediations were suggested for the heuristic violations and errors, mainly focusing on the support of clear communication, task flow, information retrieval, and data formatting. These remediations will be considered as the research team further investigates the use of this telemedicine system for prehospital stroke assessment and suggestions for system improvement.

CHAPTER FIVE

UNDERSTANDING THE DEMANDS PLACED ON CAREGIVERS IN A TELEMEDICINE-INTEGRATED AMBULANCE-BASED SETTING FOR STROKE CARE

INTRODUCTION

Telemedicine Use for Strokes

Using a telemedicine system in ambulances can significantly impact patient care by improving triage and expediting diagnosis and treatment (LaMonte et al., 2004; Rogers et al., 2017). Reduced time to diagnosis and treatment is crucial for time-sensitive conditions or incidents such as a stroke where "time is brain" (Hill & Hachinski, 1998). Stroke is the leading cause of disability and the fifth leading cause of death in the United States (Benjamin et al., 2017; Heron, 2019). While the broad category stroke comprises multiple types, ischemic strokes account for 87% of the occurrences of this disease (Benjamin et al., 2017). Tissue plasminogen activator (t-PA) is considered the most effective treatment for stroke care. However, to be effective, it must be administered within 3 hours of symptom onset. Using telemedicine en-route to the hospital to consult with stroke specialists or neurologists can improve the possibility of correctly diagnosing an ischemic stroke (Barrett et al., 2016; Terkelsen et al., 2002), allowing treatment to begin in the ambulance or streamlined upon arrival to the emergency department (ED).

Extensive research in the use of telemedicine systems to diagnose strokes shows improved patient treatment time and diagnosis accuracy, with some of these studies focusing on the usability of these systems (Mandellos et al., 2004; Sibert et al., 2008; Takeuchi et al., 2015; Valenzuela Espinoza et al., 2016; Xiao et al., 2000; Yperzeele et al., 2014). Limited research has been conducted to understand the impact of telemedicine on all caregivers involved in stroke care and on team distributed cognition. In light of the significant potential benefits of telemedicine systems for ambulance-based stroke care, its effects on clinicians must be studied to ensure the benefits are realized at reasonable cost to its users.

Stroke care typically involves a series of caregivers, determined by the hospital system, support staff, and how the patient arrives at the hospital. For patients arriving by ambulance, paramedics and Emergency Medical Technicians (EMTs) assess typically using a Rapid Arterial oCclusion Evaluation (RACE) scale to determine stroke and triage a patient (Pérez de la Ossa, Natalia et al., 2014). This scale is a simplified version of the National Institutes of Health Stroke Scale (NIHSS), which is the national standard for physicians and can be conducted through telemedicine with consulting neurologists with specialized stroke care training (Leifer et al., 2011; Ortiz & Sacco, 2014). For example, the emergency nurses at Tidelands Georgetown Memorial Hospital, a secondary hospital in a rural county in South Carolina, use a telemedicine system called REACH to connect an incoming ambulance from the local Emergency Medical Services (EMS) and a neurologist on call located at the Medical University of South Carolina (MUSC) approximately 50 miles away. Once the patient has arrived at the ED the patient may undergo a Computed Tomography (CT) scan, a procedure critical for determining the location and type of stroke required before treatment. A full description of the process flow for a stroke case using a telemedicine-integrated ambulance can be found in Figure 5.1.

Theoretical Background

The Systems Engineering for Patient Safety, or SEIPS 2.0 model, applies a system approach to healthcare to investigate how the work systems ultimately shape outcomes (Holden et al., 2013). This model has been used to systematically improve healthcare by applying human factors principles and focusing on human system integration. According to this model, the work system comprises six components: Tools and Technology, Organization, Tasks, Internal Environment, External Environment and Person(s). These components create processes that can be categorized as Professional Work, Collaborative Professional - Patient Work, and Patient Work, processes commonly referred to as workflow in many healthcare systems. They then create outcomes that can be categorized as Patient, Professional or Organizational and further described as desirable or undesirable and proximal, the direct result of a work process, or distal, a result of causal actions and observed over time. All stages of this model involve feedback or adaptation: based on the outcomes observed, appropriate changes are made to work processes or the work system.

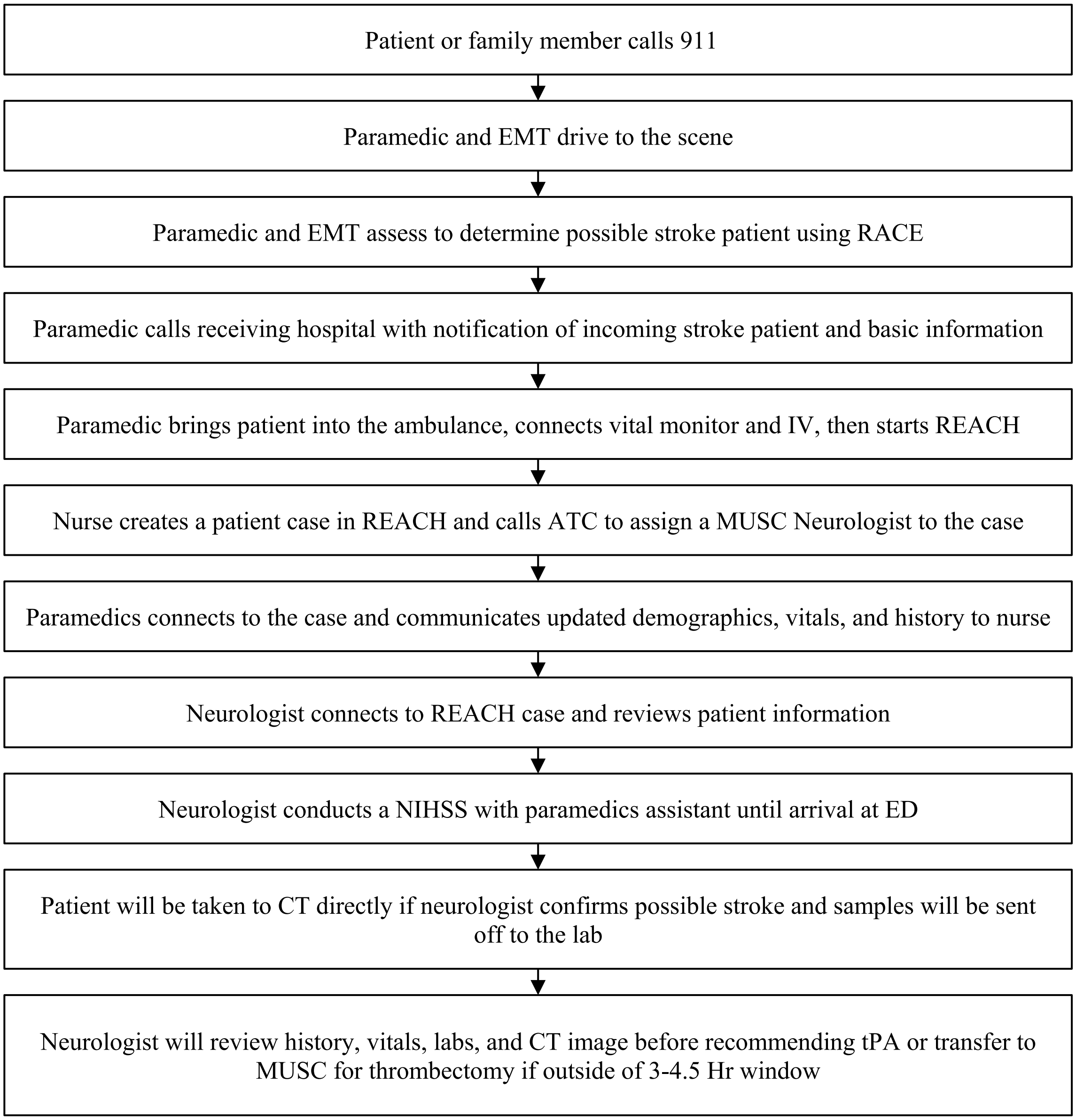

Figure 5.1. Emergency Stroke Care Process Flow

This model is frequently used in research as a framework for investigating work in a healthcare system. It can be applied to simple systems such as patient interaction with a computer system intervention (Martinez et al., 2017), implementing a new patient portal (Walker et al., 2018), or primary care processes (Wooldridge et al., 2017) to better understand the work system. The versatility of this model allows it to be applied to many systems ranging in complexity, patient interaction, and personnel, usually as a framework for understanding the interactions among the elements in a process by mapping the existing system or a potential system to the model.

This research investigates how telemedicine in an internal environment of an ambulance interacts with the organization, task, external environment, and human (EMTs or paramedics, nurses, and emergency physicians) components of a work system. This interaction was observed through the workflow or work processes identified in this model. Assessment of patient condition, communication of symptoms, and development of diagnosis and treatment plan are classified by this model as Collaborative Professional -- Patient work, with the assumption that the patient is conscious. Observations of mock telemedicine stroke evaluations were conducted with a patient actor and professional caregivers to determine the workflow and observe the interactions among the latter. Follow-up interviews were conducted to improve our understanding of the interaction among the components in this work system and how this interaction creates the current workflow as well as perceptions of how that workflow impacts the outcomes. This research considered how changes to the work system affect professional outcomes through system testing and provide feedback for future development of these work systems.

Research Questions

This research study investigated the following research questions:

1. What are the cognitive demands placed on caregivers while completing a stroke assessment in a telemedicine-integrated ambulance-based setting?

2. What are the barriers and facilitators for using telemedicine for stroke assessment in a telemedicine integrated ambulance?

METHOD

We used a qualitative research design consisting of observational studies and interviews to collect and analyze data during simulated stroke caregiving sessions in an ambulance-based telemedicine setting. This study was approved by the Institutional Review Board at IRB2018-465 and consent was gathered from participants prior to completing the study. The studies were conducted from November 7, 2019 to January 26, 2020.

Participants

Participants were recruited through purposive sampling from two major hospitals and a fire and EMS department in the southeast United States. Nine observation sessions were conducted with 3 caregivers recruited for each session, a nurse, paramedic, and neurologist for a total of 27 caregivers. In addition, an EMT to drive the ambulance and a standardized patient to allow for a simulated stroke were recruited for each session. Paramedics and nurses were recruited by their supervisors using word of mouth and the neurologists by email. The only inclusion criteria for these participants were their occupations: paramedics were currently employed in Georgetown County EMS; nurses were on staff at Tidelands Georgetown Memorial Hospital, and neurologists were completing a neurology Telehealth rotation at MUSC.

Equipment

A Dell 13-in laptop provided by MUSC with the REACH program installed was used for these specialists as seen in Figure 5.2a. Nurses used one of two available mobile REACH carts, which included a 24-in monitor, a keyboard, and a connected camera and overhead speaker as shown in Figure 5.2b.

The ambulance was outfitted with a Dell 13-inch laptop with the REACH program installed, connected to a wireless router to create a data connection when driving, an overhead speaker installed in the ceiling above the patient and a camera at the back facing the patient. GoPro Hero7 cameras were mounted inside the ambulance at the front and rear facing the patient from the back and the paramedic workstation at the front. The telemedicine set-up in the ambulance can be seen in Figure 5.2c. A functioning ambulance was used in these sessions and driven during the observations to simulate real conditions. The Xbox Game Bar was installed on the neurologist's and nurse's computers to record their screens during the session. The same laptops were used to deliver the surveys, and the follow- up interviews were recorded with an Olympus Digital Voice Recorder when conducted in person and using WebEx Virtual Meeting when conducted virtually.

Figure 5.2: from top down left to right a) Neurologist Set-Up (Participant's face masked for confidentiality), b) Nurse REACH Cart, c) Telemedicine Setup Diagram, d) Ambulance Overhead Speaker, e) Ambulance Laptop, f) Ambulance Camera

Procedure

On the day of the study, the participants were informed that the purpose of the research was to obtain information to help the researchers understand the system in order to generate ideas for improvement. One researcher was located at MUSC with the neurologist participants, while another researcher was located at Tidelands hospital with the paramedic, patient, and nurse as they completed the study. All participants completed their normal workflow, see Figure 5.1, during the observation while researchers observed. The sessions were also audio and video recorded. Participants then completed the National Aeronautics and Space Administration Task Load Index (NASA-TLX), International Business Machine Corporation Computer System Usability Questionnaire (IBM-CSUQ), and Team Effectiveness questionnaires. Interviews were conducted with each of the 3 participants (paramedic, nurse, and neurologist) for each of the 9 observation sessions completed. It took approximately 2 hours to complete the study. Interview transcripts were not returned to the participants; however, the results of the thematic analysis were shared with them to update them on the project and obtain their feedback.

Measures

The NASA-TLX was used to measure the caregivers' perceived workload during the simulation (Hart & Staveland, 1988). The NASA-TLX survey measures the six workload subscales of Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration on a scale from 0 to 100; these values along with the weightings of the importance of the subscales for each individual are then combined into a Total Workload score. The IBM-CSUQ was used to measure the participants' perception of the usability of the telemedicine system (Lewis, 2018). This survey measures usability based on level of agreement to 16 statements on a scale of 1 to 7, an overall score and 3 subscales (System Usefulness, Information Quality, Interface Quality). The Team Effectiveness scale, (Rentsch & Klimoski, 2001) which was used to measure quantitatively how individuals felt their team worked together, measures the level of agreement to eight statements on a scale of 1 to 5, with each statement reflecting different aspects of teamwork, such as team member commitment or satisfaction with performance; however, the agreement rankings can be averaged for an overall measure of team effectiveness.

Interview questions were adapted from an interview protocol developed by the Center for Quality and Productivity Improvement at the University of Wisconsin-Madison (*Interview Guide for Clinicians and Office Staff*, 2016), with questions specifically pertaining to teamwork, distributed cognition, barriers, and facilitators being added to the protocol. The questions were then pilot tested with neurologists, nurses, and paramedics for length and repetition. Adapted protocols used in the study can be found in Appendix K and L respectively. Notes were taken during the interviews to guide additional questions or focus the subsequent thematic analysis. The interview audio files were transcribed and analyzed to determine if the responses contained any common themes.

Analysis

The survey data were analyzed based on the descriptive statistics for each measurement. Two coders were assigned to descriptively code the interview data to ensure researcher bias did not influence the codes developed, and prior to consensus the researchers assessed intercoder agreement using the ATLAS.ti 8 program. This analysis function in the code management program assesses coder agreement in the use of a single code over all documents using Krippendorff's alpha. Open coding was used to create a code book from the pilot interviews. Once the code book was defined, the two coders used it to classify the responses of the 27 interviews. Themes were developed from the interviews by taking quotations from each caregiving role and from each descriptive code, and summarizing the quotations for each code. Next, the two researchers further summarized and organized the themes into major and minor themes and categorized them as barriers or facilitators to using telemedicine. A flat rather than a hierarchical structure was used for the descriptive coding.

The interviews were on average 36 minutes long. The total audio time for all 27 interviews conducted was approximately 16 hours and 13 minutes. Due to the complex nature of responses, and the number of documents, ATLAS.ti 8 was used in all levels of coding. Data saturation of responses was discussed with the research team. It was determined that after eight sessions we had reached repetitive responses.

RESULTS

The objectives of this study were to determine the cognitive demand of caregivers and the barriers and facilitators to using telemedicine to complete ambulance-based telemedicine stroke assessments. These were met by collecting quantitative data about the workload, team effectiveness, and usability, which are presented below in sections, and qualitative interview data to further describe the demands, barriers, and facilitators. The descriptive coding results and the themes developed from that coding process are organized by the barriers and facilitators they describe in the following sections.

Workload

The average total workload on a scale from 0 to 100 for all roles was 55.15 (SD = 16.68), and did not vary among roles. On average, users rated mental demand as 65.67 (SD = 25.67), physical demand as 17.33 (SD = 13.61), temporal demand as 71.00 (SD = 23.94), performance as 36.59 (SD = 31.25), effort as 38.48 (SD = 31.25), and frustration as 28.85 (SD = 20.49). More role specific changes were found in the sub-measures of workload as can be seen in Figure 5.3.

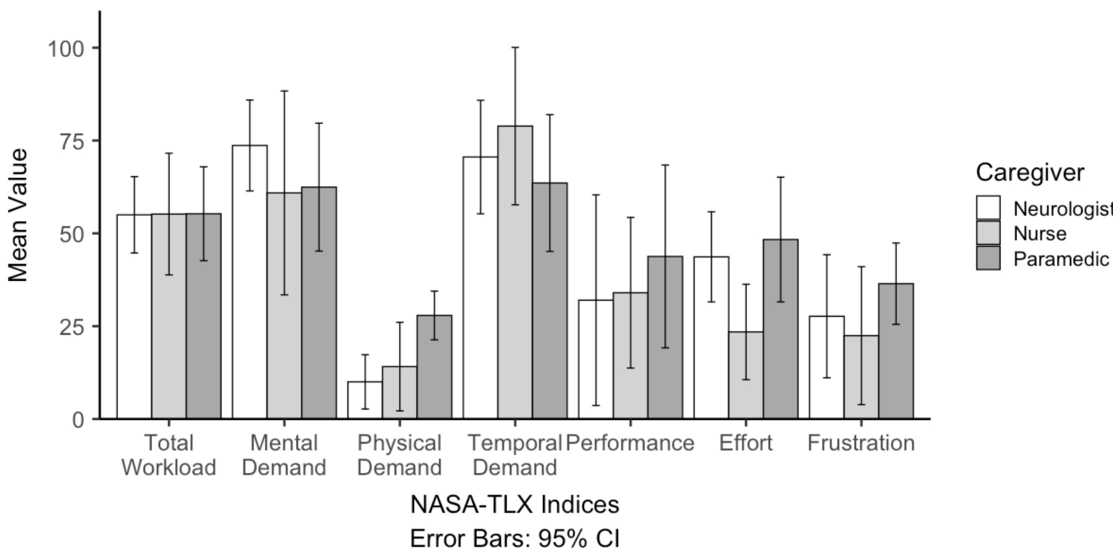

Figure 5.3: NASA-TLX Average Participant Response by Caregiving Role

Team Effectiveness

Mean team effectiveness was high overall; on a scale of 0 to 5, participants rated their team effectiveness in the simulated stroke session at 4.08 (SD = 0.81), with nurses rating higher on average than the other roles as seen in Figure 5.4.

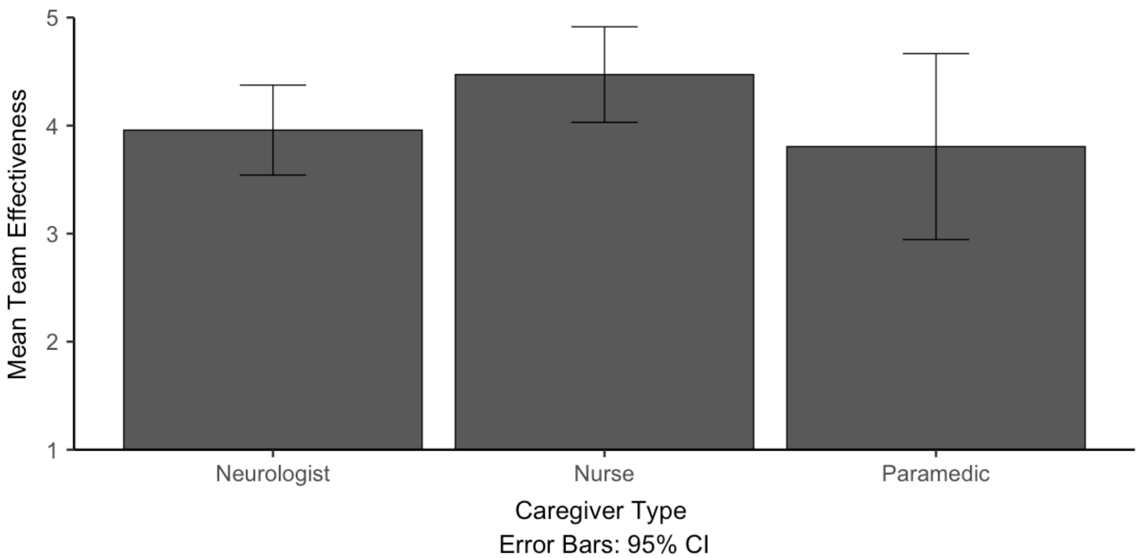

Figure 5.4: Average Team Effectiveness by Caregiving Role

Usability

Usability received high ratings from the participants, with overall usability being rated as 5.46 (SD = 0.97) on a scale from 0 to 7, system usability as 5.70 (SD = 0.99), interface quality as 5.30 (SD = 1.28), and information quality as 5.24 (SD = 1.06). The nurses' ratings were higher than the other caregivers in all categories as seen in Figure 5.5.

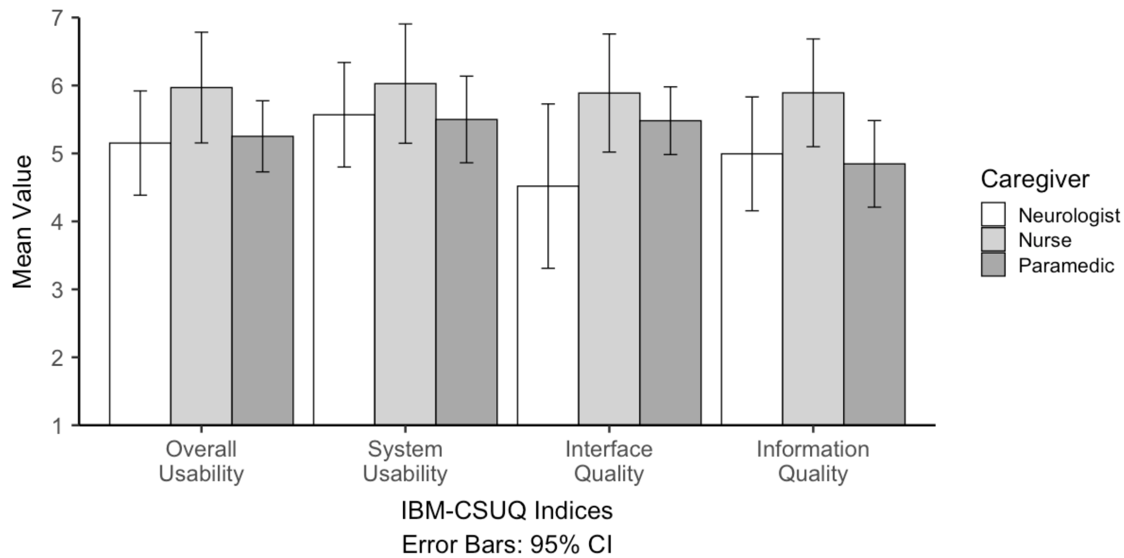

Figure 5.5: Average Usability Ratings by Caregiving Role

Interview Analysis

Descriptive Coding

The pilot interviews were inductively coded to describe the responses of caregivers. This process resulted in 52 codes, which were then used to deductively code the 27 final interviews. No new codes were added to the codebook during the deductive coding as the final interviews did not introduce any new content. Five codes were removed from the codebook during coding of the final interviews as they were not used to classify any responses. The average intercoder agreement for the deductive coding of the 27 interviews was 0.71. Consensus was then reached on the quotation size and code for each for all the final interviews.

Themes

From the 2,255 quotations for 47 codes and 78 unique themes, 10 major themes were developed. The themes, their associated codes, and illustrative quotes can be seen in Table 5.1.

Table 5.1: Description Codes for Themes and Quotations

Codes	Themes	Example Quotes
difficulty with system, technical difficulty, teamwork, visual assessment difficulty, frustration, technical support, workarounds, noise, delays, cost, system improvement	**Issues in the Telemedicine System**	"...common to have a poor connection, and then I can't hear them very well, or they can't hear me very well or the camera freezes. That's probably the most frustrating."- (T9) "...it's very hard to get someone who knows how to check visual fields well and that's frustrating because I cannot do it at all..." - (T5)
tech integration, work station, flexibility, telework, consult space	**Work Station and Consult Space Changes**	"I now have more flexibility of whether I work from home or if I'm working from my office during the daytime. It does give me that benefit." - T8 "...the computer system is hard to access from [the left side of the ambulance] but someone has to decide which side of the patient do I need to be on and why." - P8
documentation, usability, workload	**Simplistic Documentation**	"I think it's easy to complete the consult or there's a lot of parts that are not free text that I can just click. That part I like a lot" - T7 "we actually have to leave the cart and go over to our computer to pull up the patient's old records and stuff to see if there was a previous stroke or to see how many times they've been for the same problem." - N7
loss of face to face, patient interaction, increased computer interaction	**Patient Interaction Changes**	"You can't lay a comforting hand on their shoulder for example and if the patient's not used to the concept of telemedicine and the idea that they have to talk to a computer screen and that person over there that they can barely see in here is their doctor, that still actually puts some people off… " - T2
workflow, learning curve, staffing issues, efficiency, patient care, environment awareness, visual communication, frustration, usefulness, multitasking ability, access to the patient, trigger factors	**Efficiency and Focus**	"If we see something in the back of the ambulance where the neurologist says, 'Hey, go ahead and have TPA ready.' When that patient gets there, then we've got it mixed and we're ready to run." - N1 "telemedicine is not very efficient in a patient to doctor interaction. Because there's a lot of things that you can do when a patient is physically there, in examination of that patient, which you cannot do during over telemedicine, video and audio call." - T4
visual communication, access to the patient, efficiency, patient care, teamwork, task awareness, communication	**Team Visualization and Communication**	"I think it's a great way to communicate because you're actually looking at the neuro doctor, you're looking at the patient, and all three of us are on one page. You also have your attending doctor standing in the room. I just think it's a great way for everybody to communicate, it's like sitting down at the dinner table, and everybody eating and discussing what's going on, 'Okay, what do we do next?'" - N7

(Continues on next page)

benefit of neurologist, patient care, errors, efficiency, usefulness	**Access to Specialist Care**	“you're taking a physician who specializes in this area, this is all they do, they eat sleep and breathe stroke patients, neurological patients and they're going to be the ones to have the final say so and this is what's best for the patient.” - N3
usability, satisfaction, use for other conditions, best features	**System Usability and Satisfaction**	"I think that it's good that we have telemedicine, I think that we could probably tweak the system a little bit and make it more effective... in terms of making it physically easier for the people that do the consult." -T2
learning curve, teamwork, training, efficiency	**Training and Experience**	"the more you use, though you're going to be with the process itself and that streamlines itself." - P8
work station, privacy	**Privacy and Consult Surroundings**	"If you're having to do a consult on someone who's in a room that's just separated by a curtain, then it could leak that patient's privacy and their information just because it's not in a more secluded area or private area, but generally when we use the cart, we are trying to put these patients the best we can, 95% of the time in a room that has a door surrounded by walls so that their information is kept private for them and it abides by the laws." -N9

Barriers

Issues in the system was a major theme for both the paramedic and neurologist caregivers, with comments from six of the latter (46%) and all paramedic participants (13) contributing to this theme. The source of these issues when using the telemedicine system consistently involved difficulties with the internet connection or device malfunction. Loss of service or spotty and delayed communication as the ambulance moves into an area with a limited data connection can make many processes difficult; for example, it may make patient responses difficult to see or understand or freeze communications between the neurologist and the paramedic and patient.

According to one neurologist, it is

> *"common to have a poor connection, and then I can't hear them very well, or they can't hear me very well or the camera freezes. That's probably the most frustrating." - T9*

The work system factors mentioned in this comment focus primarily on the tools and technology in the system. These issues with the data connection were more frequently seen in the paramedic interviews as these caregivers are responsible for connecting the system to REACH, and any problems often interfere with patient care. A paramedic described this issue from that perspective, saying

> *"Maybe a little bit of frustration in the essence of sometimes the computer's slow or if the computer's not up to date or up to speed that's behind on the internet. Then at that point it's a frustration as I'm trying to do everything else on top of that." - P3*

This comment again addresses tools and technologies but also the task factor as it emphasizes the work paramedics must do concurrently with technical support. Another paramedic described the thought process as they make decisions about technical difficulties:

> *"Do we call it in and plug it up or do we do we not? How do we get there the fastest? What is in the best interest?" - P5*

This paramedic is describing the concern for patient outcomes, the tasks they must complete to care for the patient and weighing the potential benefit of using the tools and technology available against the time it will take to address the issue. More than one neurologist also mentioned having to communicate tasks for the paramedics that they would normally accomplish themselves, saying

> *"It's very hard to get someone who knows how to check visual fields well and that's frustrating because I cannot do it at all, it has to be the person who's examining there next to the patient and then sometimes I'm just not sure if the patient has a deficit or not because they just can't get it right. That is frustrating."* - T5

The neurologists mentioned issues with completing their tasks because they have to assist team members to do so. This was seen as due to a lack of training or experience in these members:

> *"I think it's primarily experience-based. Sometimes interestingly, we will find that there's a nurse who's actually doing it with us who is new. You can tell that they don't have any idea of what to do.* - T8

> *"I think it's experience-based. I think ones that do it enough or who are taught well understand that. I've certainly done a lot of consults where people either maybe they're not comfortable or they just don't want to do what they're asked to do or they've just not been experienced enough to do things to really understand the intricacies of a stroke consult that they require a little bit more with us pushing them or as king them to do things."* - T3

These neurologists' comments reflect the person work system factor as the training or experience of a team member can impact their process or sense of the ability of the team to work together effectively. Paramedics experienced this issue when receiving instructions from the neurologists as well:

> *"Then you get into a discussion about how to do a test or perform or procedure or whatever it is the doctor wants us to try and do and it's like, 'Oh, I don't know what the heck you're talking about.' Now you get frustrated because the doctor gets frustrated because you two aren't on the same page anymore."* - P2

In addition, noise also played a factor in communication:

> *"I think what was happening is that they were in order to remove background noise, they were actually doing that process twice. That actually made it really difficult for us to hear the nurses and the paramedics."* - T8

This comment best represents the internal environment work system factor as the immediate surroundings such as road noise impact effective communication with other caregivers. However, both the paramedics and nurses felt that the issues they had with communicating or with delays in the system improved with experience:

> *"If you've done it a few times, every time you do it, you get a little bit more efficient. We pick up on certain things that'll make things a little better the next time."* - P1

> *"Depending on what neurologist it is and what part of the brain is affected or what they're concerned about with the brain, it's depending on which cart they're going to use. Once you do enough, you know what cart they're going to or what test they're going to do before it ever happens. It's definitely where you're building routine."* - N6

These caregiver comments about how experience with the system or tasks improves efficiency supports the task and person work system factors.

In addition to the issues of communicating through telemedicine, 38% of neurologist participants (5) also mentioned that they felt a loss of personal connection during the virtual consults:

> *"Before it was all about physically being present at the bedside and being able to adjust some of the factors along the way physically. Like if I didn't think the patient was being moved along enough in the process, I would physically move them in the process but with telemedicine it's different."* - T2

The disconnect felt in telemedicine is due primarily to tools and technology, but it also impacts the task factor as these participants mention they feel limited in the tasks they can complete while distant from the patient. This adds to the feeling of disconnect for both neurologists and patients:

> *"You can't lay a comforting hand on their shoulder for example and if the patient's not used to the concept of telemedicine and the idea that they have to talk to a computer screen and that person over there that they can barely see in here is their doctor, that still actually puts some people off" - T2.*

However, neurologists mentioned that while this limits the interaction or the level of relationship you can have with the patient, it allows them to speak directly to patients who would not otherwise receive specialist care:

> *"It allows me to talk to patients directly, which before I wouldn't do it when we're just using the phone. When I see a patient via telemedicine and I decide that I'm going to transfer the patient somewhere, whether it's here or somewhere else, I have to interact with a lot of people to make that transfer happen. Yes, there's some interactions that have to happen, otherwise it would not happen." - T7*
>
> *"It's obviously different if you're seeing someone in person, a patient in person, touching the patient, having more connection than when you're just a face on a card. It's better than not having for sure, not having any connection, these patients not having access to any specialized care." - T5*

Paramedics experienced additional physical barriers, specifically, issues in the internal environment as a result of the placement and implementation of the technology according to 62% of these caregivers:

> *"The computer system is hard to access from [the left side of the ambulance] but someone has to decide which side of the patient do I need to be on and why." - P8*

Further, the layout of the telemedicine ambulance can hinder visibility of the REACH system:

> *"If you're sitting by the patient, monitors come in the way, but that's where they are mounted for our trucks. You just have to peer around it. Other than that, that's the one knock I would give on the way our ambulances are organized." - P5*

In addition, any movement in the ambulance to improve visibility of the REACH monitor is constrained:

> *"Anytime you're walking around the patient because you're trying not to fall on them and you're moving. Those are places that are constrained around the patient, around the computer, no. You don't want to make anything any harder than it is in the back of the ambulance." - P5*

Paramedics mentioned developing a more mobile system or one that would mount in the back of the ambulance where most patient care tasks occur would improve visibility.

> *"I would prefer to have a monitor that I could see the patient from where I'm sitting and the screen but we're making do." - P6*

Other paramedics mentioned a preference for a smaller mobile system:

> *"I think it's okay. If it can go to a tablet or something that is smaller." - P7*

> *"if you were able to take technology and put it into a tablet and stick it up on the back wall, that would be where my number one preference to have it, not only because it would be easy to access" - P2*

Of all the caregiving roles, the nurses have the least critical need of the REACH system; thus, these themes were not brought up by nurses in the interviews. However, one theme was considered a barrier for 30% of the nurse participants (4). Documentation in healthcare requires detailed notes on patient history, symptoms, medications, and the steps taken in a consult, and stroke care is no different:

> *"There's a lot more documentation so that you have to have it right in telemedicine, you have to have it the same in your notes, everything has to be across the board at the same time. It seems like it's a lot." - N4*

> *"I wouldn't say that it decreases the amount of paperwork that we have to do because there's still a lot of charting that goes along with stroke patients and documentation." - N9*

Nurses are responsible for creating the patient chart in REACH as well as for documentation in both REACH and in the hospital's electronic health record (EHR), creating duplicate tasks in their workflow:

> *"We actually have to leave the cart and go over to our computer to pull up the patient's old records and stuff to see if there was a previous stroke or to see how many times they've been for the same problem. That's the only thing that I feel would be a little better is if you could access your patient information at the cart" - N7*

These comments not only address the impact that the telemedicine interface has on the work system but also the impact on their tasks as their work must be duplicated in an EHR chart. A nurse also mentioned the increased accuracy and detail in their documentation afforded by the telemedicine system:

> *"No, I cannot say I spend less time. It just allows me to be more accurate with my documentations… a lot of the information that we obtain through the telemedicine and what we're relaying with the physician allows us to go back and use this information while we're charting and documenting in our computer systems. I feel it's a benefit." - N5*

Given the need for patient privacy or confidentiality in healthcare, the researchers included an interview question about this issue when using a telemedicine system. Their decision to do so is supported by findings from a review of previous telemedicine implementation studies (Rogers et al., 2017). Some caregivers, approximately 18% of all participants, conceded that privacy could potentially be a barrier:

> *"It can be if you're not in a private room just because some of the rooms in our department are-- I guess they're blocked off by curtains and not walls or doors. If you're having to do a consult on someone who's in a room that's just separated by a curtain, then it could leak that patient's privacy and their information just because it's not in a more secluded area or private area." - N9*

The perspective here focuses on the internal environment as nurses must consider or alter it to protect patient privacy. However, most caregivers (82%) stated it was not a concern for them or their patients as exemplified in the comment below :

> *"I don't think anybody worries about it and I never have had a patient say, 'I'm not comfortable with this because of security or privacy,' or anything like that." - P2.*

In addition, some nurses communicated that from a benefits versus cost perspective, privacy is not an issue:

> *"Why wouldn't the patient give you consent to do something that's going to help them? To me that's important." - N7*

> *"Is privacy really that much important when you're trying to save someone's life?" - N5*

Facilitators

The system is not without its benefits; in fact, facilitators were more frequently found than barriers in these interviews, and even when the barriers described previously were mentioned, they were more often than not followed by a caveat, suggesting that they were fairly insignificant compared to the benefits to the patient and the overall health system.

One of the major themes classified as a facilitator in the caregiving process for 69% of the caregivers was the visual connection to the patient and to the other members of the caregiving team which enhanced the awareness of each member's care tasks and the environment as seen in the responses to the question below:

> *"You're able to develop an awareness of what your other team members are doing. Do you think that that's enhanced by the telemedicine at all?"*
> *Interviewee: "Yes, because I can see them. Not just talking to them, you can see each other." - T6*

> *"Just being able to see everything, witness everything from the ride here to when they get here and to the time we go upstairs ship them to MUSC, You get to be part of the care from stage 1 of it. It's great that you can be that part " - N4*

In part, this ability to see one another helped highlight that they all used the same protocol, rather than using behavior triggers to complete tasks:

> *"We have certain things that the HealthStream classes that we take that have given you step by step on what to look for as far as stroke protocol and how to assess it. We're doing the same exact things that he's actually doing" - N4*

The confidence that this awareness gave to the team is enhanced by the neurologist's communication with the caregivers as seen in the comment below:

> *"The neurologist is telling you this is what will take place. You know what's coming up and everything." - P7*

Even with the protocol and communication, being aware of other caregivers' tasks can improve teamwork as all members are better able to predict future tasks:

> *"As you start flowing through and you understand what the doctor is looking for, yes, I think I have a better understanding and you can make some anticipation sometimes as to what's going to happen next." - P3*

> *"I think with the system because it's been now running for a while, I think the nurses at the sites and us, we all know what everybody's role is, so the nurse already will, most of the time, the nurse will already plug in the vital's data into the system and will put the last known normal in the system and then the radiology tech will push the patient's CAT scan into the system so we can review it. Then I know that my job is to enter everything else." - T8*

These comments on the visual communication aspect of the telemedicine support the impact of the tools and technologies on the communication and coordination among the team members, in turn, impacting how tasks are completed in the system.

The communication among caregiving team members is not only enhanced by being able to see one another with the new technology but caregivers specifically cited that live constant contact with their fellow caregivers improved their process, impacting the tasks as they can communicate with the various medical professionals with greater access. This openness primarily affects the communication between the paramedics and the specialist that is a direct result of telemedicine:

> *"It is nice to be able to see, you've got the nurse and you have open line of communication with the nurse. ... Then the doctor, to be able to get information from the doctor. I think in that aspect, it's a good teamwork and there's not really anything that impedes." - P2*

> *"Once you are connected, it's constant communication so there is potential to improve communication for sure." - P8*

This open line of communication coupled with being able to see the other caregivers, both a direct result of telemedicine, is seen as improving the caregiving process and, in turn, patient care:

> *"I think it's a great way to communicate because you're actually looking at the neuro doctor, you're looking at the patient, and all three of us are on one page. You also have your attending doctor standing in the room. I just think it's a great way for everybody to communicate, it's like sitting down at the dinner table, and everybody eating and discussing what's going on, 'Okay, what do we do next?'" - N7*

The open communication in the telemedicine system also creates a greater sense of teamwork as seen in the comment below:

"To provide the appropriate care for the patient, you have to work as a team to get to the essential end goal. You have to come in and essentially come in as a team in a group effort, and get everything done for this patient that needs to be done. Like I said, those first even couple minutes are just so hectic that one person cannot do that by themselves, and everybody have an understanding of that. Everybody comes in and work as a team, and we get the task accomplished. I definitely think that the telemedicine actually promotes the teamwork instead of inhibits it." - N9

In addition, to open communication impacting the teamwork, having a visual of the patient during the care tasks in the ambulance was also seen as a facilitator:

"Absolutely very useful and beneficial to have it in the ambulance because it will allow us to see them en route." - T8

"They're seeing what's taking place with the patient. They don't have to depend on me to say, 'Well, she can't lift her arm,' or, 'She can hold it out.' They're seeing the drifts. They're seeing it one-on-one just like we are. I just think for a patient, it's better, " - N7

While the neurologists mentioned interacting with a patient virtually can mean loss of personal connection, in contrast, the nurses and paramedics (30%) indicated that they believed their interaction with the patient has not changed with the use of telemedicine. Paramedics may have to get the system up and running and interact with the neurologist, but because it is mostly hands-free, their interaction with the patient has remained the same as seen in the comments below:

"Being hands-free, it's very easy to move about and get things done and get the tasks done that they want by the audio." - P5

"I don't think it really has an effect on how I care for my patients. It might add a little bit to it because they do have the neurologist on them, but it doesn't change how I act as a patient or whether I put an IV in them." - P9

For nurses as well, they interact with the patients the same, both while following the treatment in the ambulance and upon arrival at the ED:

"I would talk to them the same way whether they're in front of me or on the computer."
- N2

Especially for the nurses, the knowledge of steps taken with the patient allows them to prepare for the patient's arrival to the ED, increasing the efficiency of the care in the hospital. Increased efficiency was a major theme for both nurses and paramedics, with 77% of nurses and 100% of paramedics describing this theme in their interviews. One nurse talked about being aware of their place in the process is helpful:

"I'm able to see what's going on. On the nursing standpoint, I'm able to see what has already been done and what assessments have occurred. That's something that to me." - N5

Others described how they can prepare better with the telemedicine:

"Yes, we're going to start the process of everything we've talked about up until this point and have everything ready. As soon as they get here, the patient can be received and have a head CT down immediately as soon as they get here." - N3

"If we see something in the back of the ambulance where the neurologist says, 'Hey, go ahead and have TPA ready.' When that patient gets there, then we've got it mixed and we're ready to run." - N1

In addition, the neurologists see the increased focus in the assessment provided by telemedicine as an improvement to efficiency as well:

"Things are very, very quick and very short, very, very focused. You spend less time with the patient but in a more focused and acute manner." - T6

Again based on these comments, the telemedicine technology is seen by these healthcare professionals as impacting the task factor by increasing efficiency.

However, as was mentioned in the barrier themes, conducting the assessment through another person can be inefficient. Many neurologists followed this comment by adding that conducting this assessment with the visual, live communication is more efficient than bringing a patient to MUSC or trying to conduct it over the phone:

> *"Much better because you can communicate much better. You can assess the patient better and know what's going on so you get the patient to the right type of treatment sooner as opposed to getting the patient somewhere else and then assessing the patient and get and then getting the patient somewhere else. Yes, so it's much better." - T1*

Not only was improved efficiency in general seen to improve patient care, conducting these assessments improves the care of the patients as they receive access to a specialist, another major theme across all caregiving roles, with 97% of all participants commenting that they can see the improvement in process efficiency because of the capability of being able to connect to a neurologist, ultimately improving patient outcomes:

> *"The patients are getting the care quicker. They're getting a neurologist right then and there. They're getting diagnosed quicker, they're getting treatments done quicker, they're getting into rehab, or getting the procedures that they know they need to be completed quicker." - N6*

> *"You're taking a physician who specializes in this area, this is all they do, they eat sleep and breathe stroke patients, neurological patients and they're going to be the ones to have the final say so and this is what's best for the patient." - N3*

> *"Being more thorough, getting door to needle times reduced, seeing if they need TPA or if they have a brain bleed or getting them into the door to a CT scan and then already having the drugs pulled up to give them as soon as they need can absolutely have effect on the outcome."*
> *- P6*

Beyond improving the quality of care, caregivers also identified how they think access to a specialist reduces human error and increases patient safety:

> *"I think it improves safety and reduces the scenarios because you're bringing expert, coordinated, scripted care in places that did not have it." - T7*

> *"Maybe [the neurologist] picking up on something that you missed or something that you haven't had an opportunity to do when you, of course, get to the patient."*
> *- P1.*

Caregivers have also seen how patients appreciate the use of the system

> *"When a patient hears, 'I'm a neurologist. I'm a specialist,' it's like, 'I am getting the best care I can get.'" - N7*

Some patients even return to the hospital system to say how much the telemedicine has helped them:

> *"I've had some patients that were a successful TPA drug given candidate and everything turned out right. They were just really pleased that it went the way it went. We don't always get feedback from the patients that receive the medication. Some of them we never hear from again but the ones that get discharged from MUSC who come back two months walking and talking and they want to say thank you, they tell us about everything that happened and how appreciative they are about it." - N3*

In addition to the benefits to the patient care process and to the patients themselves, there are benefits for caregivers. While paramedics' tasks and work location do not change much with the addition of telemedicine, 69% of the neurologists and 30% of the nurses stated they gained flexibility in their work station because of the addition of telemedicine. This theme of flexibility describes the changes in the internal environment created with the use of telemedicine. Neurologists are able to work outside of the hospital, providing patient care from wherever they are:

> *"I now have more flexibility of whether I work from home or if I'm working from my office during the daytime. It does give me that benefit." - T8*

They also have flexibility in their scheduling with telemedicine:

> *"I can pick the days I want to work or not work or I can pick the place where I'd work with, where I work from or not. I can fix how many days that I want to work. I guess it gives me a lot of flexibility." - T7*

Nurses have increased flexibility with the introduction of the REACH system as everything they need for a stroke consult is located on a rolling cart. This allows them flexibility in a busy ED where patients are continually coming in and out rather than constraining them to a few beds reserved for stroke care:

> *"That cart can go anywhere in the hospital. Regardless if it's ER, whether it's coming into the ER or a patient is already there, it's giving improved patient care because it is mobile. It can go to east, it can go to new onset or This thing is going to get moved to east because that's our stroke ward." - N6*

In addition to increased flexibility, caregivers also experience simpler documentation procedures as a result of telemedicine implementation, which impacts the tasks of the caregivers. For paramedics, documentation is limited as the nurses can see all the tasks they complete in the ambulance during travel to the ED and take responsibility for documenting them; however, only 2 paramedics (15%) noted these changes to paperwork:

> *"The nurse kind of acts as our scribe, so I don't have to worry about the paperwork or documentation or anything like that, so that's a good system we have in place." - P2*

For 30 % of the neurologists documentation is easier as they are doing it in real time:

> *"We'll do the full exam because you're also documenting and ticking these boxes in real-time as you're doing the exam versus when you do it in person where you have to do the exam and then when you eventually go and sit in front of a computer, that's when you actually start documenting." - T8*

Both nurses and neurologists also mention the improvement to documentation and their overall workflow as the telemedicine system provides a centralized, easy-to-use format for documenting and finding patient information:

> *"I think it's easy to complete the consult or there's a lot of parts that are not free text that I can just click. That part I like a lot." - T7*

> *"We know everything's got to go in that page and that's the information that the neurologist needs to make his decision as to what happens with that patient so I*

think it's a great way to just localize one center for all the information that's needed for the patient." - N7

Further, 97% of participants representing all caregiver roles stated they were satisfied with the current telemedicine system, but improvements can always be made. Many cited that it was simple to use and easy to learn:

"Pretty satisfied. It's easy to use. It's typically easy to get a neurologist on. I think it's a great benefit to have. It's another resource tool. I think it's definitely a very useful tool." - N8

Several neurologists, however, were more critical of the system:

"From 0 to 10, I'm like five. I think we have improved a lot of things, like the access to patients first. Our access to the patients, but I think we still have like a good way to go in terms of improving both technically and in terms of appropriateness of use of it." - T5

"I think that it's good that we have telemedicine, I think that we could probably tweak the system a little bit and make it more effective. Some of the things that I have already mentioned, but also in terms of making it physically easier for the people that do the consult." - T2

Overall, the interviews supported a system that caregivers find effective, but one that has areas needing improvement.

DISCUSSION

Telemedicine supports collaborative work processes with visual communications and constant contact. Thus, it is logical that caregivers in these interviews discussed how this system improved teamwork and ultimately efficiency and patient care. This perception is supported by past research on stroke telemedicine, which has shown reduced door to needle times (Adams et al., 2012; Belt et al., 2016; LaMonte et al., 2004), and overall improved patient recovery and mortality (Levine & Gorman 1999; Wechsler et al., 2017).

The themes found in this research are tied to the SEIPS 2.0 model work system factors: Tools and Technology, Tasks, Person, Internal Environment, External Environment, and Organization, while the changes in telemedicine that support collaborative work can be linked to the work system factors: Task and Tools and Technology. Tools and Technology is impacted by the integration of the telecommunications system in the ambulance and this introduction changes how caregivers communicate and tasks are accomplished. As the interviews found, the tasks became more efficient, and their workflow adapted to streamlined processes such as taking a patient directly for a CT scan or the more in-depth NIHSS that the paramedics do not normally conduct.

More importantly, the interviews point to one possible reasoning for improved patient care outcomes in current research; not only access to a specialist but also an increased level of teamwork among caregivers including the specialist was perceived to improve patient outcomes. Research in the field of Computer Supported Collaborative Work (CSCW) can provide some clarity about how visual access to fellow team members increases performance and teamwork (Schlichter et al., 1996). When people are geographically distributed, they must rely on technology to support their communication and coordination. Research in CSCW, which primarily focuses on the development of collaborative virtual environments (Fleury et al., 2015), is based on the principle that providing a visual representation of the work environment helps the interaction among team members. Telemedicine provides this environment through the video feeds of the patient and caregivers as well as a central interface for charting that can be edited by all. Conducting collaborative work tasks in these virtual environments has been shown to be equal in performance to in-person collaboration (Narasimha et al., 2019). In addition, the awareness of the patients and their status that is created is valuable to the nurses as they can better prepare the ED for patient arrival, thus increasing efficiency and decreasing door to needle time.

The improvement in patient care and safety resulting from access to a specialist was a theme in these interviews as well. This supports previous research on telemedicine stroke care research that found increased diagnosis accuracy with access to a neurologist (Lumley et al., 2020). Many caregivers mentioned that multiple eyes on the patient or oversight by the specialist could reduce medical errors and increase patient safety, a finding supported by human error research, which has found, for example, that inadequate supervision is a pre-condition for errors (Shappell & Wiegmann, 2000). By providing for specialists to be involved in the stroke assessment through telemedicine, they can also serve in a supervisory capacity to deter and potentially eliminate unsafe acts and improve patient safety.

The training and experience of the caregivers was found to impact how other caregivers completed their tasks and the overall teamwork. These comments offered two perspectives: a lack of experience or training can inhibit efficiency or teamwork and increased training and experience can improve the collaborative work. Teamwork research supports this finding as well, suggesting that experience can improve task performance and teamwork and further that team training should be developed based on the experience levels of the members (Deering et al., 2011; Kleij, 2007; Rentsch et al., 1994).

Generally, lack of training can be frustrating for fellow caregivers, but the specifics from the interviews focused on neurologists being frustrated because of the need for repetitive communication. If the paramedics did not have the training needed to complete an assessment item on the NIHSS, the neurologists had to explain where to stand or what movements to make, often multiple times, before they were able to complete the assessment or if neurologists needed updated vital signs because the patient's condition changed, the specialist had to signal the paramedic to update them. This situation can create strain between the neurologist and the paramedic as they collaborate in the telemedicine system, ultimately resulting in the undesirable professional outcomes of distrust between caregivers and increased stress. The source of the frustration for the paramedics in this collaborative process is that neurologists are inconsistent in the order of steps required for the assessments; thus, they cannot learn from experience. Research on the use of checklists indicates that providing a structured list of tasks can improve both task efficiency and performance (Kelleher et al., 2014). In addition, providing standardized order lists can improve patient care outcomes (Berenholtz et al., 2004; Pronovost et al., 2003) and reduce the number of medical errors (Hales et al., 2008; Hales & Pronovost, 2006).

These findings also support another important theme from the interviews: the usability and satisfaction with the system. Nurses like the current system primarily because it acts as a checklist for their tasks. They appreciate the layout of the small segment of the screen they are responsible for because it enables them to check through the items they need to ask and document and easily see if any of these items have not been completed. However, neurologists were more critical of the layout, logical because they had more interaction with the interface than the caregivers. They had issues with the tab layout, which did not follow their typical process, and the amount of text input needed for entering medications or some history information. The tools and technology implemented in the work system should be designed such that they support the task, not requiring additional training or expertise to use the technology. As much as possible, the design, especially for complex tasks and work processes, should be simple and easy to use so as not to create additional burdens on caregivers. Neurologists and nurses both mentioned that they like how easy the checkbox input is to use and generally thought the system was easy to use, despite the specific comments from neurologists; these results, however do not support the heuristic evaluation of this system in previous research, which has found multiple violations, especially concerning data input that had no suggestions for formatting and the complex tab structure design.

Another impact of the introduction of the telemedicine was on the physical environment, the internal environment work system factor presented in the SEIPS 2.0 model. Many paramedics mentioned that the addition of the laptop, video and microphone components not only potentially creates extra work in the event of technical difficulties but also creates additional movement in a constrained environment. They described how the movements needed for the assessment or to see the telemedicine laptop to interact with the neurologist can be difficult in the limited space in an ambulance, a constraint they did not have to consider previously. Careful planning and consideration of the placement of these laptops for both accessibility during the tasks and technical limitations such as wiring is needed to eliminate additional movement or obstructed visibility in a confined and busy space. Work has been done in the field of architecture to determine ambulance design with caregivers; however, most of it has been conducted in a static environment (Goodwin et al., 2017). This movement can also cause harm to both the patient and the paramedic. As the ambulance is moving, the paramedics could fall or be rocked into the patient bed or other equipment. In addition, some ambulances have only limited handholds for stabilizing and preventing falls; however, these were not considered in light of the movements needed to see the telemedicine screen or adjust equipment when needed.

Opinions in the interviews were mixed about workload: some neurologists felt that tasks became more difficult as they could not do them themselves, and paramedics were frustrated with unclear communication from the neurologists. In contrast, the nurses felt telemedicine made their jobs easier. These trends are seen in the effort and frustration scales, with nurses rating effort and frustration below midway on the NASA-TLX and neurologists and paramedics at or above midway. However, overall the average workload was midway on the 0-100 scale, which corresponds to the interview responses as most caregivers said that their workload did not increase or decrease with the use of telemedicine.

Higher contributors to total workload in this task were mental demand and temporal demand. Neurologists rating an average mental demand of 73.7, this can be best explained by the comments from neurologists as to the level of mental analysis of patient responses needed to diagnose the patient and create a care plan. Temporal demand was rated highest by nurses on average with a rating of 78.9 in comparison to neurologist and paramedics who on average rated temporal demand as 70.6 and 63.6, respectively. The difference in average ratings by roles here can be explained by the nurses interview responses, their process is to create the patient case as soon as possible such that neurologists can be connected to the patient in the ambulance which could increase the feeling of time pressure. After this point their task is to observe the neurologist assessment and patient responses until addressed or the patient arrives to the ED. This waiting period as they watch the tPA window close can emphasize the lack of ability to speed up this process and impact temporal demand as well.

Teamwork was discussed by all caregivers in the interviews as something that was improved in the telemedicine system due to the open communication among the caregivers and a shared visual of the patient and their fellow members. In addition, most caregivers felt that they were able to coordinate and communicate effectively as well as develop a shared understanding of team tasks, related to items on the team effectiveness scale. Data from the survey, while not as detailed as the findings from the interviews, were consistent with the interview findings. First, the comments about usability, that the flow of the system and how to input data were easy to use, are supported by the high overall and system usability ratings from the IBM-CSUQ survey. Caregivers also rated team effectiveness, a quantitative measurement developed to rate teamwork, fairly high at 4 out of 5.

CONCLUSION

The quantitative data from this study determined that the demands of the telemedicine system on the caregivers was moderate; however, the technical support required, the communication with caregivers about vital signs and the required assessment tasks, and documentation are not supported by the current system, creating cognitive demands that should be addressed through system design. Further, barriers and facilitators were determined. Barriers included cognitive demands as well as the physical constraints of the ambulance, the loss of personal connection to patients, and maintaining awareness of the surroundings to protect patient privacy. These barriers indicate how telemedicine has made the work of caregivers more difficult. Facilitators, ways telemedicine has improved the caregivers' jobs, were much more common; these included flexibility in the consult space, the usability of the system, the streamlining of tasks, improved efficiency, an improved view of the patient and caregivers, and access to a specialist.

While current research in the field of telemedicine has found improved patient outcomes and process efficiencies, many of these studies do not focus on the people in the work system, the caregivers, who have to make sense of and use the system in their workflow The interviews and themes developed here provide a new perspective on the demands placed on stroke caregivers using telemedicine and the ways they think telemedicine has improved or made more difficult how they complete their tasks. These findings not only investigate problems with design and usability but also the difficulties with communicating with team members and troubleshooting the system. Improvements to stroke care are not just found in the numbers; caregivers felt more connected to their team members and indicated that as they conducted telemedicine consults, they began to learn more about how to treat strokes from interactions with the specialists. Based on these barriers and facilitators from the interviews, future research can be conducted to determine how system design can eliminate such barriers as redundant communication of vitals or the unorganized layout for data input as well as support the facilitators such as process efficiency and open communication for better task awareness. Further, these findings can inform design to support the distributed cognition of caregivers by focusing on their responses about task and environment awareness, for example that consistency in the assessment tasks can allow for a better understanding of the tasks in the consult and prediction of role in the assessment.

CHAPTER SIX

PRIORITIZED INFORMATION DISPLAY FOR ENHANCING DISTRIBUTED COGNITION IN A TELEMEDICINE-INTEGRATED AMBULANCE-BASED SYSTEM FOR STROKE CARE

INTRODUCTION

Technology platforms and software systems have seen increasing implementation in ambulance-based telemedicine (Rogers et al., 2017), with research on their efficacy finding that for a variety of healthcare conditions, including stroke care, patient care, task performance, and error management have improved. In fact, the use of telemedicine early in the care process has been suggested as a method for improving stroke care (Schwamm et al., 2009). This dissertation focused on REACH, the system used by the Medical University of South Carolina (MUSC) in coordination with several rural counties in South Carolina. It consists of a laptop, including speakers and a camera, connecting the ambulance both to a neurologist, also on a laptop, and to a rolling computer cart for nurses, enabling communication among these healthcare professionals as patients are transferred to the emergency department (ED). As this description suggests, the REACH interface involves three user roles: a nurse, neurologist, and paramedic. Initially, the nurse is the user who creates the patient case, while the neurologists and paramedics can view only those patients with a patient case. However, once connected to the patient, the REACH interface appears the same for all users and updates as they input information.

Not all users have the same interactions with the interface. Paramedics simply connect to patient case, and no further input to the system is required of them unless a technical issue arises. They communicate all information to the neurologist and nurse verbally and interact with the patient in the ambulance. Nurses are responsible only for updating the patient information in the "nurses lane" on the left side of the data input as seen in Figure 6.1 and monitoring the patient responses and neurologist communications. Neurologists interact with the REACH interface the most as they are responsible for developing the patient history, documenting it in the system and conducting a neurological exam to diagnose the patient's condition using the National Institutes of Health Stroke Scale (NIHSS). The neurologists' tasks require them to use the full range of tabs on the right side of the interface and monitor the patient in the video screens on the left as seen in Figure 6.1.

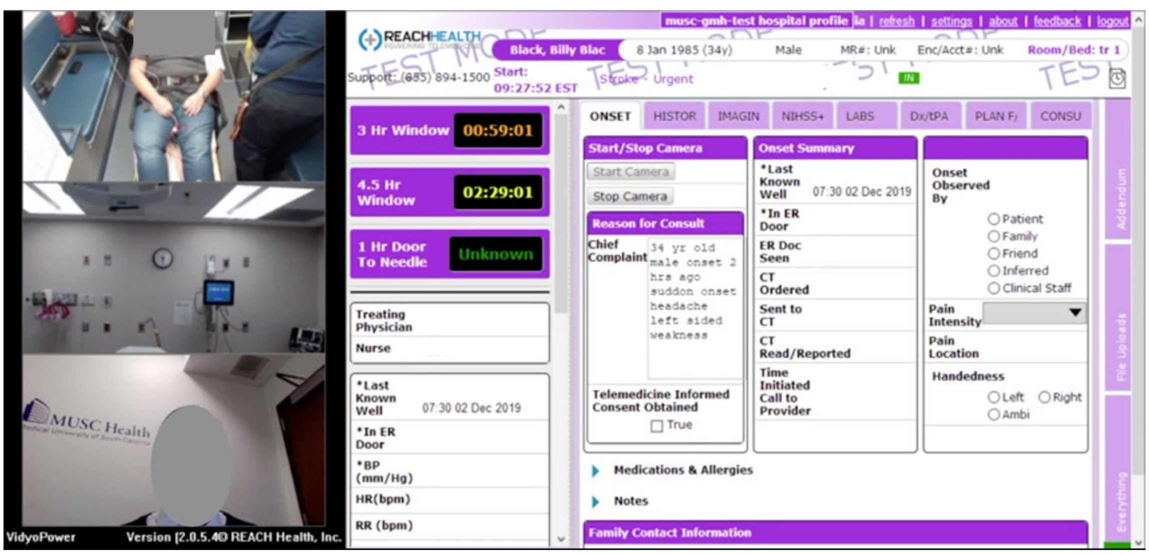

Figure 6.1: REACH interface (Participants faces masked for confidentiality)

The previous work conducted in this dissertation examined the usability issues, possible human error occurrences, the demands on the caregivers, and the barriers to and facilitators in the REACH system when conducting a stroke assessment in a telemedicine-integrated ambulance. The overall impression of the REACH system provided by the caregivers in previous studies was positive, and the benefits of the system were thoroughly represented both by the caregiver participants and research investigating time to treatment and patient outcomes (Adams et al., 2012). However, the usability evaluation and SHERPA of the REACH system indicated issues in the design of the user interface (Rogers et al., 2020). In addition, analysis of the interviews found barriers to the use of this telemedicine system that increased caregiver workload (Rogers et al., 2020). These previous findings in conjunction with the lack of research on the role of caregivers in telemedicine stroke care point to a need for system design. While previous work details the current system and its strengths and weaknesses, further research needs to be conducted to redesign the system interface to minimize the demands and workload on caregivers while supporting their processes and the distributed cognition necessary to care for stroke patients.

Distributed Cognition

Distributed Cognition (DC) Theory is applied to enhance our understanding of the organization of cognitive systems, not only the individual's but the interactions with other people and resources in the environment (Hollan et al., 2000). In this way, Distributed Cognition Theory, at its most basic level, is similar to situation awareness with its focus on the interactions between the individual, external factors, and cognitive processes (Hollan et al., 2000; Endsley, 1995). Hollan et al. (2000) defines distributed cognition as cognitive processes occurring across members of a social group across time and involving coordination of material and environmental structures. This theory assumes that systems including more than one person have cognitive properties that differ from the processes of the individuals within that system (Rogers & Ellis, 1994), and as such, it was developed to understand the cognitive processes that occur in a system, defining cognition as an emergent property of interactions between people and their environment rather than within the singular person (Liu et al., 2008). While researchers have developed methodologies to analyze complex systems, few have been applied to multiple domains (Jenkins et al., 2011; Patrick et al., 2006; Walker et al., 2010; Waterson, 2009).

For example, Blanford and Furniss (2006) developed Distributed Cognition for Teamwork, or DiCoT, a methodology for applying distributed cognition to the study of teamwork. This methodology defines three themes of distributed cognition, determined from DC literature, that form the basis for analysis: physical layout, information flow, and artifacts. These themes include principles, 18 total, that can be used to assess the system in terms of how it supports distributed cognition and how to improve system design. Some of the principles in the physical layout theme include Don Norman's (1993) perceptual and naturalness principles, the arrangement of equipment, and situation awareness, while the information flow theme includes the principles information hubs, buffering (an affordance for delaying the processing of new information until an appropriate time), and information transformation, and the principles in the artifacts theme include coordination of resources, creating scaffolding (for example, setting reminders to complete a task at a later time), and mediating artifacts (things brought into the system to coordinate task completion).

Using DiCoT, Blanford and Furniss (2006) analyzed the London ambulance service using observations and interviews to determine how the system for receiving and dispatching ambulance service calls could be improved. More recently, researchers have used DiCoT to assess systems and provide a basis for design recommendations. For example, in the mobile health care domain, McKnight and Doherty (2008) examined patient processing in a cancer treatment center, finding that the principles within the themes were effective in identifying the shortcomings of the system in general, understanding the technology locations, and determining the needs of the people in the system. A DiCoT model-based evaluation of a training simulation used to prepare medical professionals in emergency and disaster management found a need for greater flexibility in the interaction with artifacts in the system and better management of the physical layout to avoid unintended information movements (Rybing et al., 2016).

Proposed Interface Design

Observation and interview themes and principles from the DiCoT model were used to define features to support distributed cognition and facilitators of the current system and address its barriers. While all caregivers' tasks were considered in the design changes and many of the features impact multiple caregivers, the display of the neurologist is the primary focus of the interface features as they have the most interaction with it. Four primary features were developed based on the data from the observations and the theoretical frameworks used in this study. Figure 6.2 shows the proposed interface design.

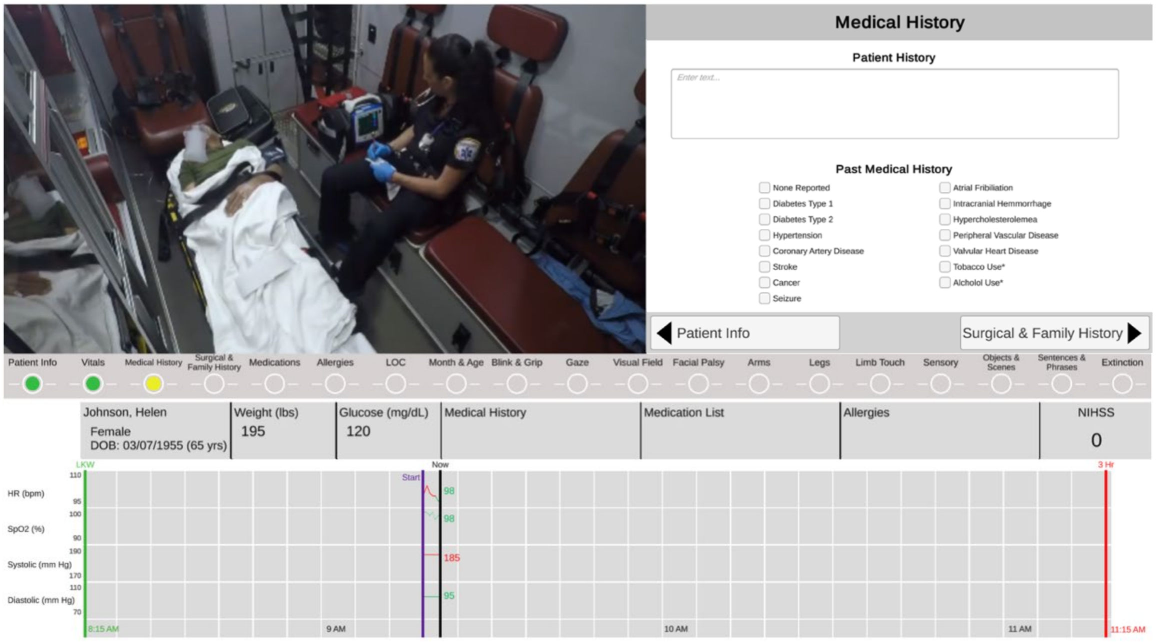

Figure 6.2: Proposed Interface Design

The first new feature provides real-time vital signs displayed on a graphical timeline shown in Figure 6.2. This feature was developed to support the creation of neurologist's mental model and its subsequent updating, thus reducing the workload for both the paramedic by eliminating the need to repeat vital signs and the neurologist asking for a vital sign update. All caregiving roles communicated in the interview that updating vital signs was important and could be simplified. Paramedic 4 provided an example of the issue in the REACH interface, saying *"Because he's, 'Did you check the BGL?' 'Whoops. We'll check it again doc. We got you.'"* Neurologist 2 emphasized that *"having the vitals be able to be seen on a display. Those would be important things,"* and Nurse 1 offered more specific feedback supporting this idea, "*Then being able for them to automatically or Bluetooth-feed their vitals and stuff in or even their patient information.*" Updating vitals in real time improves information flow through the use of automatic mechanisms, supporting the information flow principle, information movement, in the DiCoT model (Furniss & Blandford, 2006). Providing an information mechanism supports this general principle, but automating this flow of communication can alleviate the demands on caregivers as the mechanisms of information flow, thus reducing the workload and the redundant communication.

However, updating vitals is not the only information can be displayed using a timeline, the current system provides a tPA window countdown from the last known well time as shown in Figure 6.1. Neurologist 8 specifically mentioned the usefulness of these markers of time: "*I like the fact that it auto-calculates the window times to four and a half hours and three hours and one hour door to needle once you plug in the last known normal time.*" However, representing this time to end of window value can be improved by providing a graphical representation of the current time to that window, which can be implemented through the vital sign monitoring. The feedback from providing a clear and active representation of the closing of this window will ensure the tPA window is met if a patient is a candidate.

The DiCoT model was also used to determine features to be implemented in conjunction with the principle to support the use of artifacts, specifically the goal parity principle (Furniss & Blandford, 2006). This principle states that providing explicit representation of the current state in relationship to a goal state can aid cognition. The proposed representation of the tPA window addressed this principle by providing a visual representation not just of the distance to the goal but also progress to it. Another proposed design element in the vital monitor that applies this principle is the color coding of the vital signs signaling if the value is within normal bounds or if the patient needs stabilization. For example, if the systolic blood pressure rises above 180 or the diastolic above 105, the neurologist can recommend actions to lower these numbers as they too high for tPA. Providing a cue to determine the status of the patient and how it compares to the goal (normalized vital values) again supports the goal parity principle and allows for an effective and efficient check to update the mental model of the patient's status.

Table 6.1: DiCoT Principles and Barriers or Facilitators Used for Design Features

Design Elements	DiCoT Model Principle	Barrier or Facilitator
Real Time Graphic Vitals	Information flow - -Information Movement Principle	Barrier for Neurologist and Paramedic -- Repetitive Communication required to update vitals
Color Coded Vitals	Artifacts -- Goal Parity Principle	
tPA Window Timeline	Artifacts -- Goal Parity Principle	Facilitator for Neurologist -- Increased awareness of patient with current telemedicine system
Centralized Patient Info	Artifacts -- Coordination of Resources Principle	
Task Progress Bar	Information Flow -- Trigger Factors Principle Artifacts -- Scaffolding Principle	Barrier for Neurologist and Paramedic -- Unclear communication and expectations in tasks
Simplified and Ordered Documentation	Artifacts- - Scaffolding Principle	Facilitator for Neurologist -- Checkbox layout for creating efficient documentation
Enlarged View of Patient		Facilitator for Neurologist -- Visual of the patient and caregivers to increase the awareness of team members' care tasks

Improving how vital signs are represented also changed how patient information in general is presented; in the current system demographics, vital signs, history, and current medications and allergies are presented separately. Patient history and medications and allergies are also presented such that navigation in the system is required to view them as they are found under either the history tab or onset tab, both of which cannot be viewed at all times as seen in Figure 6.3. Demographics provide an initial perception of the patient; for instance, age can play a role in decision making: for a person under 35 having a stroke, a neurologist could look to drugs, medications, or underlying conditions for the cause. Vital signs, medications, and patient history can influence the decision to give a patient tPA treatment for a stroke, and all should be represented and accessible at all times. To do so, a feature was added to summarize demographics, patient history and current medications in one place; furthermore, this information can easily be updated using selections in the data input screen. This feature is supported by another artifact principle in the DiCoT model, the coordination of resources (Furniss & Blandford, 2006), which states that an information structure that assists in the coordination of plans, goals, affordance, history, action-effect, and current state can aid in cognition. Providing information about patient history that is constantly available supports its use to inform future decision making. In addition, the presentation of this information together and the collocation of the monitoring of the patient's vital signs supports the design principle, proximity compatibility (Wickens et al., 2015): activities or information used in the same process should be represented together or in close proximity to one another.

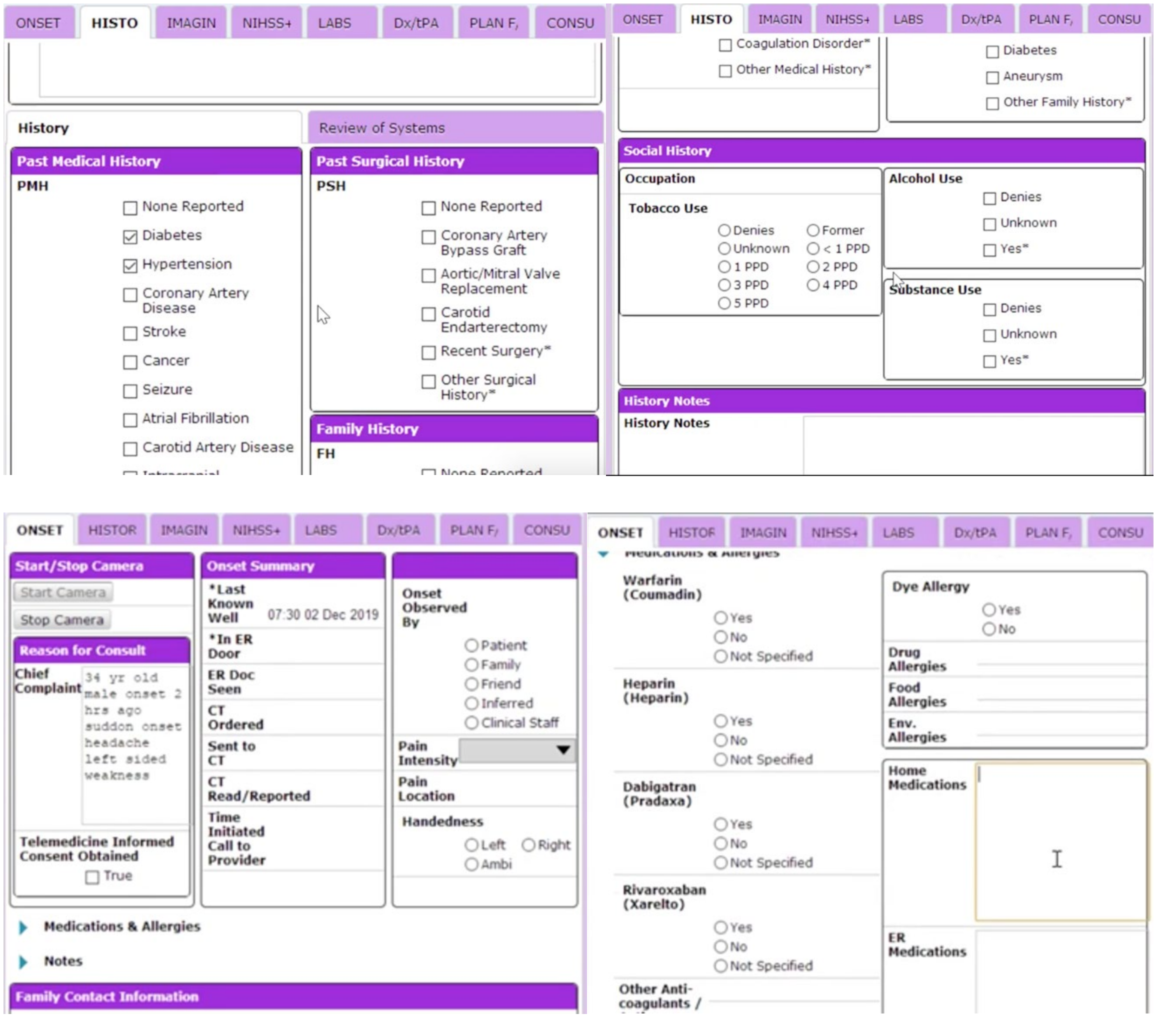

Figure 6.3: REACH Patient History and Medication Input

A common theme among paramedics was the need for consistency and structure in the neurologists' assessment of the patient so that they could better anticipate the actions they needed to perform for the neurologist. As Paramedic 2 stated,

> *One of the harder things for us is the fact that it's not standardized. Each individual doctor does it a little different every time they do it, so I would like to see a standard-- Give me a script, give the doctor a script, give the nurse script.*

Everybody knows what questions are going to be asked, in what order they're going to be asked, what every test is, what the expectation of the test is.

Further, Paramedic 6 mentioned how consistency could improve efficiency: "*If there is more of a set guideline of, 'This is the order, this is what we're looking for, here is this process that were looking for, this is what I want the medic to do during these sessions.' If it was more everything is based on, then we would be more efficient in getting the same result."* This standardization of the process was supported by Neurologist, 7 who said, *"I think I would have a checklist in place. The medic, just go see a checklist and gives me all the pertinent information that I would need as opposed to just a medic trying to talk, 'Oh, this is a guy with this and that.' I think he should have a specific script to follow."* While this can be supported with scripts or protocols as suggested by caregivers, interface design can provide a visual representation of the task list and the progress within a task to further enforce the use of the list. This design can be developed by applying gamification principles like progression mechanics to engage users to use the task progress map. A structure of the tasks and an indication of those completed can provide reinforcement of achievement and communicate progression (Robson et al., 2015).

The use of a progress map also supports the artifact principle, creating scaffolding, in the DiCoT model (Furniss & Blandford, 2006). According to this principle, the use of scaffolding or a physical representation of where we are in a task can simplify cognitive tasks. This design feature supports this principle by providing a visual of the tasks to be completed, determined from a task analyses of the stroke caregiving process, and an indication of our location in it. In addition, as paramedics stated, a consistent process and knowledge of upcoming tasks can improve their process and efficiency, both of which support the information flow principle, behavioral trigger factors, in the DiCoT model (Furniss & Blandford, 2006). This principle explains how individuals involved in a task can operate without a communicated plan, only responding to factors in their system. This scaffolding can provide the factors that trigger behaviors for paramedic caregivers such as moving in relation to the patient to test the peripheral vision for the neurologist.

The task monitoring feature created a need to change how data input should be presented to ensure that the protocol and movement through tasks are also supported by the design for imputing patient information and the neurologist' stroke assessment. For this reason, the data input process was redesigned. First, the neurologists' need for a large visual of the patient was made clear through observations and their responses in the interviews. Neurologist 6 explained how she resizes the windows in the current system: "*I'm in a consult, the first thing that I do is I grab that far-- let's say left because I'm a physician, but the right side of the patient, and I pull it all the way to the right. Basically, it's almost all patient and then on the right is the NIH stroke scale, really skinny.*" However, other neurologists were not aware of this feature, often attempting to move the camera for a better view of the patient, something not currently possible in the ambulance but supported in hospital nursing carts. To support this use of the system, the proposed design prioritized making the data input a smaller portion of the screen and the visual of the patient, the primary focus for caregivers.

For this change to be effective, the data input itself was simplified, not merely made smaller. Data input items from the system were compiled into screens similar to its current tab structure, with changes based on the task analysis conducted and on feedback from the neurologist. One notable change was to move the medications and allergies data input into the history data input as these tasks are conducted simultaneously. This change addresses the frustration with the current system expressed by Neurologist 6:

> *Yes, we always ask what's your past medical history, surgical history, social history? What medications are you on? Do you have any allergies? It's not in a different section of the whole encounter. It's all right there, so you have to click around a lot. A lot of times when you ask people what's their past medical history, they'll be like, 'Oh, I don't have one. Oh well, maybe I have hypertension. I'm on Lisinopril for hypertension and I'm on Metformin.' Then you're like, so now you're in the medicine list, but now they're naming of medicines that prove that they have diabetes.*

However, many neurologists also mentioned a facilitator in the current system being the checkboxes that allow for quick data input. As Neurologist 7 stated, "*I think it's easy to complete the consult or there's a lot of parts that are not free text that I can just click. That part I like a lot.*" In the current system, patient history utilizes this checkbox design, while medications and allergies are provided as text input as seen in Figure 6.3.

The new data input design uses non-free text input for most inputs with optional text boxes for unique responses. As a result of previous research identifying issues with the tab structure and the design of the current system and the need to align data input to the task progress monitor, the navigation through data input screens was also changed. The grouping of the all items for a task and the prescribed navigation of the new design are supported by pagination buttons. Users can move to the next screen when they are ready to complete the next tab by clicking the next button. These screens are presented in the order of the task flow in a circular menu, meaning that users can move forward or backward through the pages with no end points. As they reach the final page for input based on the task list, they can return to the first data input page by clicking the next, or forward, button. Examples of these screens can be seen in Figure 6.4. This feature supports the artifact principle, create scaffolding (Furniss & Blandford, 2006). The titles of the buttons and the title of the current page are additional place markers indicating where users are in the task flow as they progress through the tasks completing data input and moving to the next screen.

The foundation for the features developed for this design is a focus on creating a view of the system based on distributed cognition principles that emphasizes and prioritizes the information found to be important in previous research. For this reason, the new design proposed here is called the Prioritized Information Display and will be referred to by this name throughout the study.

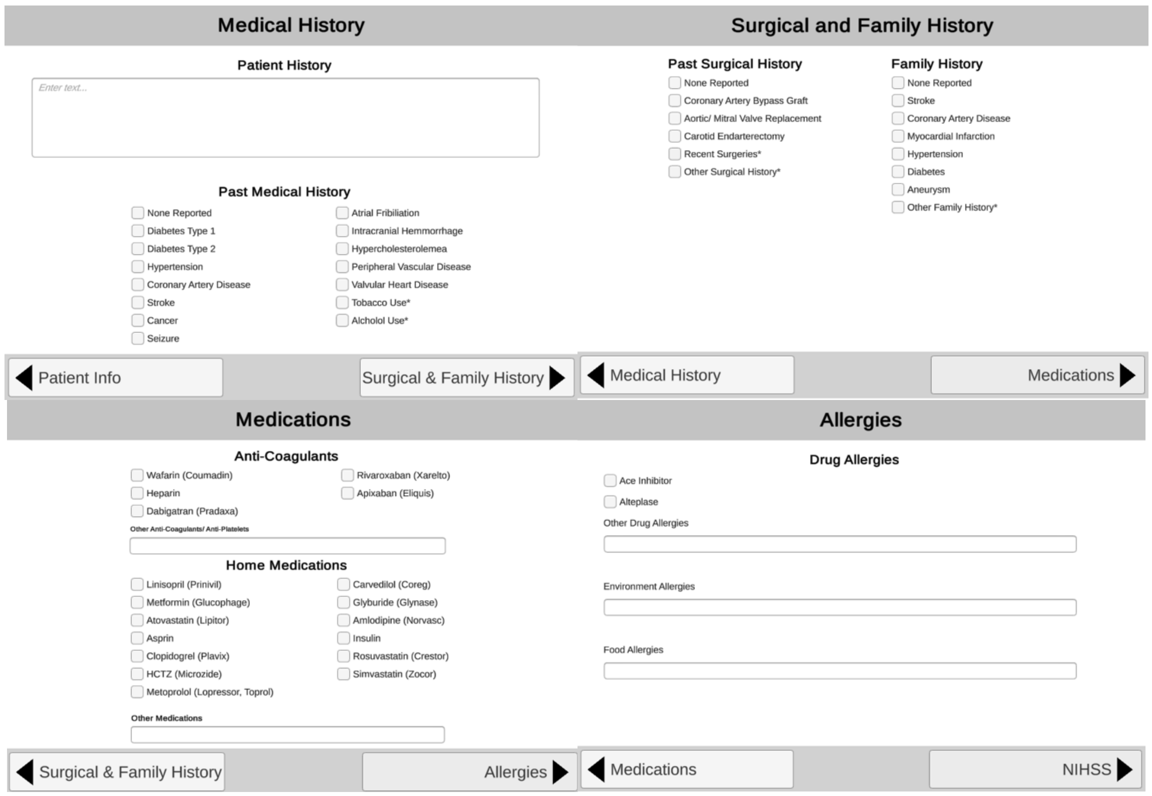

Figure 6.4: History, Medication, and Allergy Input for Proposed Design

Research Questions

Based on the principles in the DiCoT model and previous research conducted on the current system, design features were developed to support distributed cognition and the demands of caregivers while improving general usability. Distributed Cognition Theory, specifically the DiCoT model, was selected to address the research questions for several reasons. First, because of the distributed location of the telemedicine team members geographically, the information flow and interaction with the artifacts in the DiCoT model helped us evaluate crucial elements of this complex system. Second, the focus on the interaction between not only the individuals in their environment but also the team members inherent in distributed cognition will be useful for assessing how the system should be designed to accommodate for these interactions. While team situation awareness describes the knowledge gathering process of teams, it primarily focuses on the interactions between team members and the environment as they contribute to decision making. Finally, this study aims to improve the workload of the caregivers. The diagnosis and treatment of stroke patients require many decisions, but the focus of this research goes beyond the decision-making processes that a situation awareness model describes. The focus of this study is on cognitive processes on a broader scale, and the elements required to facilitate those processes so that multiple caregivers can contribute to providing quality patient care. Specifically, this research aims to investigate how interface design can support the distributed cognition of caregivers and improve the demands made on and the workload of the caregivers in the system. It investigates the following questions:

1. What interface features can support distributed cognition in telemedicine-integrated ambulances for stroke assessment?
2. How can the usability of the telemedicine system interface be improved and the workload of caregivers be reduced for telemedicine stroke assessment?

METHODOLOGY

Participants

As the design features proposed here are primarily to support neurologists, their testing in comparison with the current system used neurologists or physicians with neurology experience as participants as they are the caregivers with experience in stroke caregiving and the NIHSS specifically. In addition, two internal medicine residents were also recruited as they had completed a stroke rotation during their residency. All other participants were neurology residents. To further ascertain they had the experience to complete a stroke evaluation, they were specifically asked if they had experience in treating stroke patients. To ensure an unbiased assessment of the current system and the Prioritized Information Display, these neurologists were recruited from multiple hospital systems in South Carolina and were additionally screened to eliminate participants with prior experience with REACH. Twenty participants meeting these criteria were recruited through contacts in Clemson University's Department of Public Health. The participant demographic information is shown in Table 6.2 below.

Table 6.2: Participant Demographics

Characteristic		n	%
Gender			
	Male	13	65%
	Female	7	35%
Age			
	20-30	5	25%
	31-40	14	70%
	41<	1	5%
Years of Experience			
	>1	7	35%
	1-5	5	25%
	5-10	6	30%
	10<	2	10%

Experimental setup

A Zoom video conference call was used to connect the research moderator with the participants, with this platform's screen sharing and record meeting functions being used to capture the participants' experience in the telemedicine systems. Participants were asked to use a PC with a monitor measuring at least 13" diagonally. Their screen resolution ratios were checked to verify a setting of 16:9 or 16:10 to ensure a clear view of the system. Surveys were conducted through Qualtrics by emailing anonymous links before the study. The simulation, built in the Unity development program, includes both telemedicine interfaces and a wireless connection to the moderator. Interviews were conducted and recorded through the Zoom video conference system.

Experimental Design

Independent variables

This study used a repeated measures experimental design with a single independent variable involving 2 conditions: the current telemedicine system, REACH, and the new design, he Prioritized Information Display. All participants completed a stroke assessment in both conditions, which were counterbalanced to distribute order effects.

Task Design

Further, two stroke diagnoses were used for the patient and paramedic responses. One involved a large vessel stroke, called a Middle Cerebral Artery (MCA) stroke, on the right hemisphere of the brain, presenting as major motor and sensory deficits including a forced gaze deviation and inattention to any stimuli on the left side of the patient, but with the patient still able to respond to commands from the participants, allowing them to evaluate the condition. The other was a small vessel stroke in the right hemisphere, which again allows for similar commands to be followed by the participants but presents significantly different symptoms, meaning a different diagnosis was required. Symptoms for the small vessel stroke includes some sensory and motor deficits, but not as severe as the Right MCA stroke, and limb ataxia which is a delay in coordination movements such as touching their finger to their nose. Both conditions were determined in collaboration with a telemedicine neurologist on the research team with extensive stroke experience and were considered equal in difficulty and interaction with the patient, but allowed participants to arrive at two separate diagnoses. These two diagnoses were also counterbalanced to account for learning effects.

Dependent Variables

Workload: The National Aeronautics and Space Administration's Task Load Index (NASA-TLX) was used to measure the workload of the participants after each condition (Hart & Staveland, 1988).

Usability: The International Business Machines Computer Systems Usability Questionnaire (IBM-CSUQ) was used to measure the usability of each condition (Lewis, 2018).

Performance: The time taken to complete the assessment was measured by the simulation software, starting from the time the participants entered the simulation condition to the time the simulation ended excluding any surveys for each condition. The errors made during each assessment were defined as either conceptual or documentation errors. Conceptual errors are defined as an error in selecting or misunderstanding the patient history or the NIHSS levels even when the correct information was provided in the patient responses. Documentation errors are defined as omitted or documentation of relevant history or medications in an incorrect location.

Situation awareness: Scores on a situation awareness global assessment technique or SAGAT were assessed twice during each assessment (Endsley, 1988), once after completing the patient history documentation and once after completing the assessment.

Preference: During the interviews, participants were asked which system they preferred for evaluating a stroke patient in an ambulance, their responses representing the measurement.

Interview responses were obtained to determine support for the distributed cognition in each system in addition to evaluations of the system to support the quantitative findings.

Procedure

Participants were contacted to schedule a two-hour window for the study. Prior to their scheduled time, participants were sent an email with a Zoom meeting link to connect to the research moderating the study, links to the surveys in the study and a file for downloading the simulation program. This program provided the REACH interface and the Prioritized Information Display in a format that could be easily downloaded to most PC laptops. Before the participants began the study, they connected with the researcher moderator through Zoom to ensure the program was downloaded and that their screen resolution was set to the correct image ratio for viewing the simulation.

The procedure task flow of the study can be found in Figure 6.5. First, the researcher provided an overview of the tasks to be completed; then the informed consent and demographic survey was administered through one of the survey links provided to the participant through email. Next, the participants were shown a brief training session, which included screenshots of the simulator for both conditions and identified where participants could find and document information during the study. After the training, participants began the simulation program and were directed to the simulation they were to complete. In it, the participants were asked to complete a patient history and input a full NIHSS exam. They obtained the information they needed to complete the assessment through pre-recorded video responses from a standardized patient, for this study a retired nurse, and an assistant acting as a paramedic. The videos were recorded in an environment emulating an ambulance with the camera view and positioning of the patient and paramedic similar to the views currently available in the REACH system.

The patient and paramedic were presented with questions or commands from a list generated from the task analysis completed in previous research (Rogers et al. 2020) and commands observed in previous simulated stroke sessions (Rogers et al. 2020). This list was also confirmed with a consulting telemedicine neurologist to ensure all appropriate questions and responses for the two diagnoses were included. Participants in the study completed the assessment by communicating verbally to the patient or paramedic, and the moderator selected the response video that best matched the request or question through a Wizard of Oz connection to the simulation (Steinfeld et al., 2009). Participants were made aware that responses were simulated, and if a question was asked that was outside the scope of the simulator, the moderator alerted the participant to ask yes or no questions to collect the information. In addition, pilot testing of the system with 3 consulting physicians was conducted to ensure responses and transitions were appropriate for the session. When the participant completed the NIHSS exam and arrived at a diagnosis for the patient, the simulation was stopped. Once during the simulation and once at the end, participants were asked to answer questions about the patient and their diagnosis to assess their situation awareness, following the SAGAT protocol.

After the simulation, the participant was directed to complete a survey, which contained the NASA-TLX and IBM-CSUQ assessments, evaluating only their experience with the telemedicine system, not the content of the video simulations. The participant was then asked to complete the second simulation and the surveys in the same manner. When both simulations and follow-up surveys were complete, the participant was asked to complete a short semi-structured interview about their experiences in the two systems focusing on any difficulties, their feedback on the design, their identification of the features supporting distributed cognition, and their preferences. After the interview was completed, the participants were emailed their incentive, a $100 Amazon gift card.

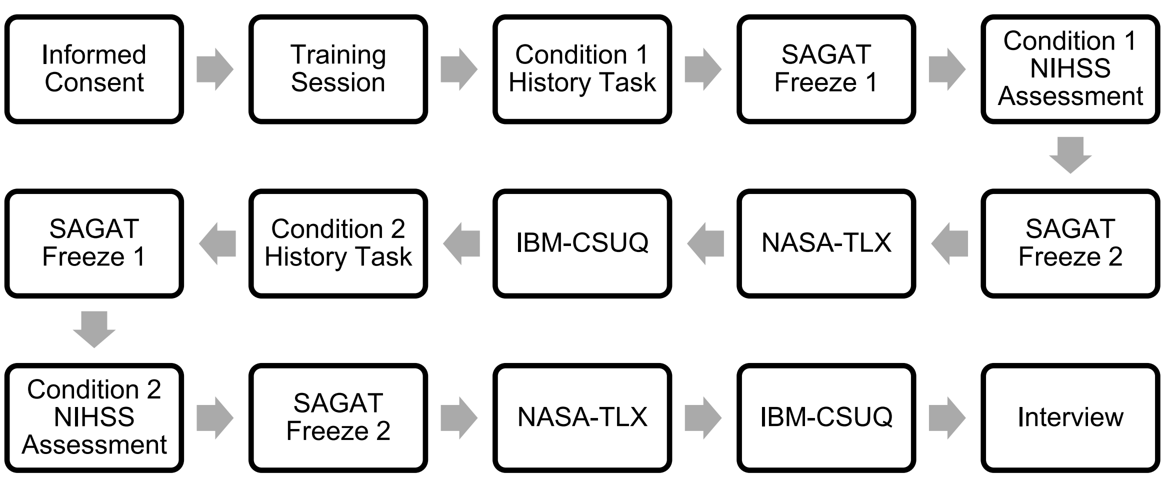

Figure 6.5: Study Procedure Task Flow

Measures

During the simulation SAGAT was used to measure the participant's situation awareness (Endsley, 1988). Two freezes were conducted, once after the patient information was obtained and inputted (10 seconds after moving to the NIHSS data collection) and once after the simulation ended. At each freeze questions pertaining to Level 1, 2, and 3 situation awareness were asked about patient information including vitals, medications, the impact of the history on the assessment, and the diagnosis. These questions were developed in coordination with a telemedicine neurologist on the research team and focused only on items for which an awareness would need to be maintained by the participants for assessing a stroke. The questions asked for each diagnosis and freeze can be found in Appendix N. SAGAT was used as a measure to assess situation awareness since currently there is no validated quantitative measure of distributed cognition.

Time to complete the assessment tasks was measured during the simulation as well as any conceptual or documentation errors made during the assessment. The NASA-TLX survey was used to determine the participant's perceived workload for each design condition, and the IBM-CSUQ survey was used to determine the perceived usability of each condition. Interviews were conducted using a retrospective think-aloud protocol to determine participant's feedback on the design, asking, for example, what they thought about the layout of the information in the first interface and to assess how they perceived the support for distributed cognition in each interface through such questions as "How did each system perform in creating scaffolding (a reminder of where you are in the task)?"

The semi-structured interview protocol can be found in Appendix O. The interviews were audio recorded and later transcribed for content analysis.

Analysis

All quantitative dependent variables were analyzed using paired t-tests to determine the differences, if any, between the two systems. The SAGAT responses were analyzed by taking the average accuracy for each freeze and for each situation awareness level within each freeze and conducting a paired t-test on the average accuracy to determine if the responses at each freeze vary by system. Additionally, preference between the two systems determined in the interviews were analyzed with a Chi-Square goodness of fit test to determine if the occurrence of preference between systems observed was statistically different from the assumption that systems are preferred equally, meaning 50% preferred each system. Finally, a content analysis was conducted on the transcripts of the follow-up interviews to determine commonalities in them, the feedback for both systems and how both systems support distributed cognition. The transcripts were organized into Excel spreadsheets by question groups, and for each group coding categories were identified for each participant answer. For example, for each DiCoT model question and for each participant answer, the categories included which system supports the principle, the features cited, which system is preferred, and the recommendations made. Two coders independently evaluated each participant's answers. Sample pilot coding was conducted using 20% of the interviews to determine if the categories were appropriate. The overall percentage agreement for the pilot coding was 82%, and categories were determined to effectively summarize the data. Final coding was conducted using the same categorization for the rest of the interviews. The final overall percentage agreement was 84%. Percentages of answers for each category and a list of features or recommendations were generated for each question group for the analysis of the participant interviews.

RESULTS

The first objective of this study was to determine the effects of the system design on the perceived workload, situation awareness, and task performance of participants for each condition, and a second was to determine the effect of system design on the usability and support for distributed cognition for each condition.

Workload

Total Workload

Total workload experienced by the participants during each stroke evaluation was measured subjectively using the NASA-TLX tool. A paired t-test was conducted to determine the difference between the system conditions on the subjective total workload experienced by participants. As shown in Figure 6.6, the average total workload for the REACH condition (M = 41.30, SD = 19.89) was higher than that for the Prioritized Information Display condition (M = 38.23, SD = 19.99). However, no significant difference in the total workload was observed among the participants $t(19) = 1.34$, $p = 0.19$.

Mental Demand

The perceived mental demand experienced by the participants during each stroke evaluation was measured subjectively using the NASA-TLX tool. A paired t-test was conducted to determine the difference between system conditions on the perceived mental demand experienced by participants. As shown in Figure 6.6, mental demand was higher for the REACH condition (M = 46.65, SD = 29.52) than for the Prioritized Information Display condition (M = 46.15, SD = 28.95). However, no significant difference in the mental demand was observed among the participants t(19) = 0.18, $p = 0.86$.

Physical Demand

The perceived physical demand experienced by the participants during each stroke evaluation was measured subjectively using the NASA-TLX tool. A paired t-test was conducted to determine the difference between system conditions on the perceived physical demand experienced by participants. As shown in Figure 6.6, the physical demand was higher for the REACH condition (M = 12.30, SD = 13.33) than for the Prioritized Information Display condition (M = 9.95, SD = 13.69). However, no significant difference in the physical demand was observed among the participants t(19) = 1.18, $p = 0.25$.

Temporal Demand

The perceived temporal demand experienced by the participants during each stroke evaluation was measured subjectively using the NASA-TLX tool. A paired t-test was conducted to determine the difference between system conditions on the perceived temporal demand experienced by the participants. As shown in Figure 6.6, temporal demand was higher for the REACH condition (M = 49.05, SD = 27.37) than for the Prioritized Information Display condition (M = 44.00, SD = 27.66). However, no significant difference in the temporal demand was observed among the participants t(19) = 1.34, $p = 0.19$.

Performance

The performance perceived by the participants during each stroke evaluation was measured subjectively using the NASA-TLX tool, with higher performance ratings indicating a lower perceived performance. A paired t-test was conducted to determine the difference between system conditions on the perceived performance of participants. As shown in Figure 6.6, perceived performance was lower for the REACH condition (M = 35.75, SD = 26.07) than for the Prioritized Information Display condition (M = 29.90, SD = 22.79). However, no significant difference in the perceived performance was observed among the participants t(19) = 1.88, $p = 0.08$.

Effort

The effort perceived by the participants during each stroke evaluation was measured subjectively using the NASA-TLX tool. A paired t-test was conducted to determine the difference between system conditions on the participant's perceived effort. As shown in Figure 6.6, perceived effort was lower for the REACH condition (M = 35.7, SD = 25.75) than for the Prioritized Information Display condition (M = 37.80, SD = 25.39). However, no significant difference in the perceived effort was observed among the participants t(19) = -0.73, $p = 0.47$.

Frustration

The frustration perceived by the participants during each stroke evaluation was measured subjectively using the NASA-TLX tool. A paired t-test was conducted to determine the difference between system conditions on the perceived frustration of the participants. As shown in Figure 6.6, perceived frustration was higher for the REACH condition (M = 35.75, SD = 21.29) than the Prioritized Information Display condition (M

= 28.30, SD = 17.62). However, no significant difference in the perceived frustration was observed among the participants t(19) = 1.72, $p = 0.10$.

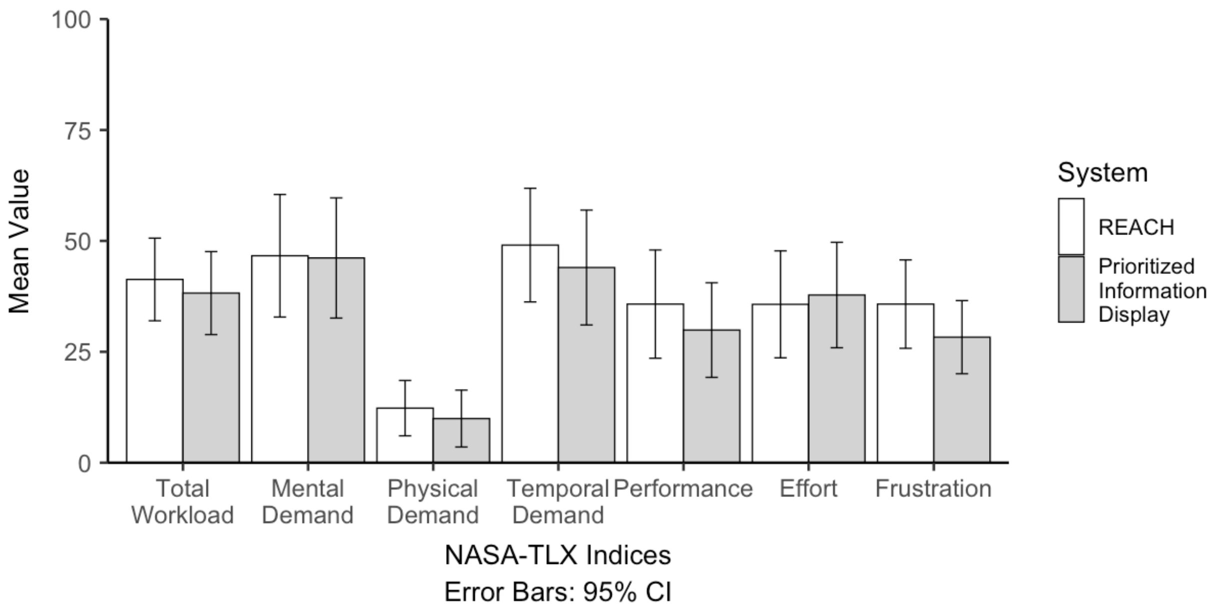

Figure 6.6: Average Perceived Workload

Usability

Overall

The perceived usability of the system was measured subjectively using the IBM-CSUQ tool. A paired t-test was conducted to determine the difference between system conditions on the perceived usability. As shown in Figure 6.7, perceived usability was lower for the REACH condition (M = 5.61, SD = 1.07) than for the Prioritized Information Display condition (M = 5.71, SD = 0.98). However, no significant difference in the perceived usability was observed among the participants t(19) = -0.62, $p = 0.54$.

System Usability

The perceived system usability of the system was measured subjectively using the IBM-CSUQ tool. A paired t-test was conducted to determine the difference between system conditions on the perceived system usability. As shown in Figure 6.7, perceived system usability was lower for the REACH condition (M = 5.68, SD = 1.17) than for the Prioritized Information Display condition (M = 5.89, SD = 1.01). However, no significant difference in the system usability was observed among the participants t(19) = -1.20, $p = 0.24$.

Information Quality

The perceived information quality of the system was measured subjectively using the IBM-CSUQ tool. A paired t-test was conducted to determine the difference between system conditions on the perceived information quality. As shown in Figure 6.7, perceived information quality was lower for the REACH condition (M = 5.53, SD = 0.97) than for the Prioritized Information Display condition (M = 5.60, SD = 0.91). However, no significant difference in the information quality was observed among the participants t(19) = -0.40, $p = 0.69$.

Interface Quality

The perceived interface quality of the system was measured subjectively using the IBM-CSUQ tool. A paired t-test was conducted to determine the difference between system conditions on the perceived interface quality. As shown in Figure 6.7, perceived interface quality was higher for the REACH condition (M = 5.63, SD = 1.13) than for the Prioritized Information Display condition (M = 5.46, SD = 1.23). However, no significant difference in the interface quality was observed among the participants t(19) = 0.73, $p = 0.48$.

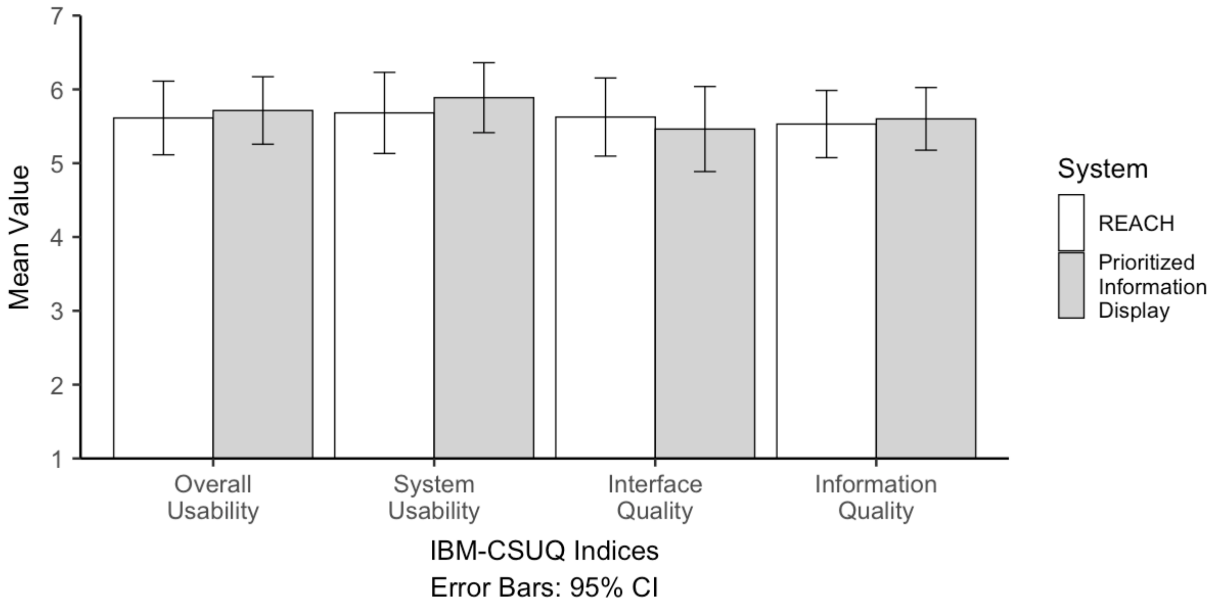

Figure 6.7: Average Usability

Situation Awareness

The SAGAT responses were recorded as 0 (if the response was incorrect) and 1 (if the response was correct). Each SAGAT freeze was analyzed separately. The averages of the responses for each level of situation awareness and the overall average were calculated to create the accuracy measures. The accuracy measures for each level and overall were then analyzed to determine the difference between the system conditions.

SAGAT Freeze 1

Overall: The overall SAGAT accuracy for the participants for Freeze 1 was calculated using the average response to all of the SAGAT questions. A paired t-test was conducted to determine the difference between system conditions on the overall SAGAT accuracy. As shown in Figure 6.8, overall SAGAT accuracy was lower for the REACH condition (M = 0.85, SD = 0.15) than the Prioritized Information Display condition (M = 0.91, SD = 0.11). However, no significant difference in the overall SAGAT accuracy was observed among the participants t(19) = -1.76, p = 0.09.

Level 1: The Level 1 SAGAT accuracy of participants was calculated using the average response to only Level 1 SAGAT questions. A paired t-test was conducted to determine the difference between system conditions on the Level 1 SAGAT accuracy. As shown in Figure 6.8, Level 1 SAGAT accuracy was lower for the REACH condition (M = 0.82, SD = 0.18) than for the Prioritized Information Display condition (M = 0.90, SD = 0.09). However, no significant difference in the Level 1 SAGAT accuracy was observed among the participants t(19) = -2.03, p = 0.06.

Level 2: The Level 2 SAGAT accuracy of the participants was calculated using the average response to only Level 2 SAGAT questions. A paired t-test was conducted to determine the difference between system conditions on the Level 2 SAGAT accuracy. As shown in Figure 6.8, Level 2 SAGAT accuracy was the same for both the REACH condition (M = 0.88, SD = 0.22) and the Prioritized Information Display condition (M = 0.88, SD = 0.22). No significant difference in the Level 2 SAGAT accuracy was observed among the participants t(19) = 0.00, p = 1.00.

Level 3: The Level 3 SAGAT accuracy of the participants was calculated using the average response to only Level 3 SAGAT questions. A paired t-test was conducted to determine the difference between system conditions on the Level 3 SAGAT accuracy. As shown in Figure 6.8, Level 3 SAGAT accuracy was lower for the REACH condition (M = 0.95, SD = 0.22) than for the Prioritized Information Display condition (M = 1.00, SD =

0.00). However, no significant difference in the Level 3 SAGAT accuracy was observed among the participants t(19) = -1.00, p = 0.33.

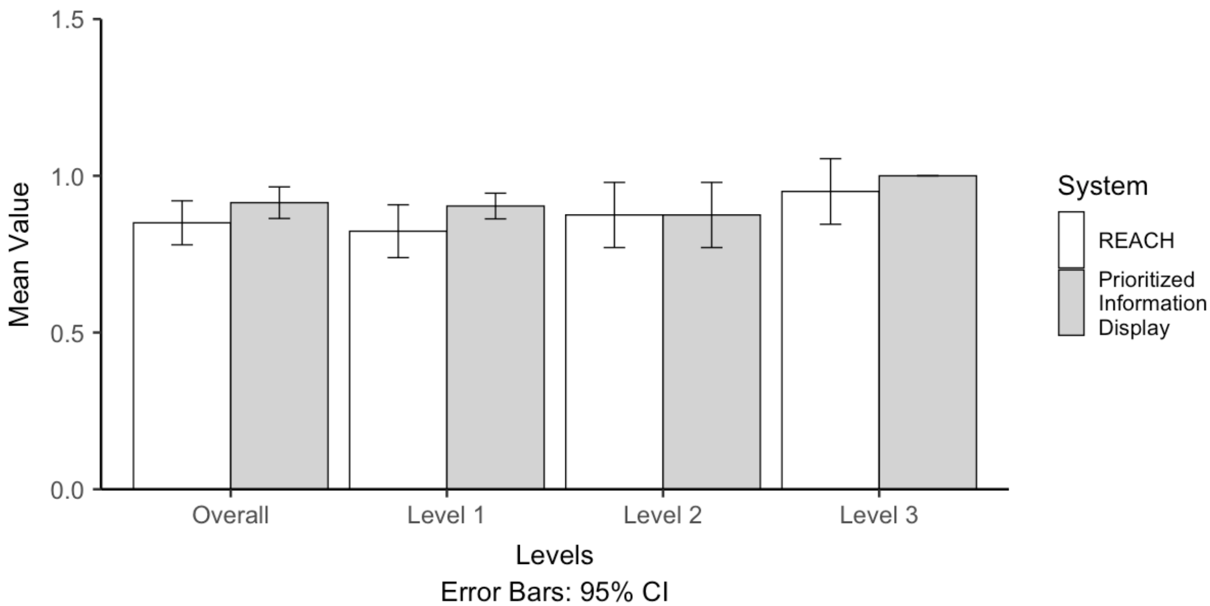

Figure 6.8: Average Accuracy of SAGAT Freeze 1

SAGAT Freeze 2

Overall: The overall SAGAT accuracy of the participants for Freeze 2 was calculated using the average response to all SAGAT questions. A paired t-test was conducted to determine the difference between system conditions on the overall SAGAT accuracy. As shown in Figure 6.9, the overall SAGAT accuracy was lower for the REACH condition (M = 0.84, SD = 0.13) than for the Prioritized Information Display condition (M = 0.89, SD = 0.10). However, no significant difference in the overall SAGAT accuracy was observed among the participants t(19) = -1.28, p = 0.22.

Level 1: The Level 1 SAGAT accuracy of the participants was calculated using the average response to only Level 1 SAGAT questions. A paired t-test was conducted to determine the difference between system conditions on the Level 1 SAGAT accuracy. As shown in Figure 6.9, Level 1 SAGAT accuracy was lower for the REACH condition (M = 0.76, SD = 0.19) than for the Prioritized Information Display condition (M = 0.85, SD = 0.15). However, no significant difference in the Level 1 SAGAT accuracy was observed among the participants t(19) = -1.58, $p = 0.13$.

Level 2: The Level 2 SAGAT accuracy of the participants was calculated using the average response to only Level 2 SAGAT questions. A paired t-test was conducted to determine the difference between system conditions on the Level 2 SAGAT accuracy. As shown in Figure 6.9, for the Prioritized Information Display condition (M = 1.00, SD = 0.00). No significant difference in the Level 2 SAGAT accuracy was observed among the participants t(19) = 0.00, $p = 1.00$.

Level 3: The Level 3 SAGAT accuracy of the participants was calculated using the average response to only Level 3 SAGAT questions. A paired t-test was conducted to determine the difference between system conditions on the Level 3 SAGAT accuracy. As shown in Figure 6.9, Level 3 SAGAT accuracy was the same for the REACH condition (M = 0.93, SD = 0.18) as for the Prioritized Information Display condition (M = 0.93, SD = 0.18). No significant difference in the Level 3 SAGAT accuracy was observed among the participants t(19) = 0.00, $p = 1.00$.

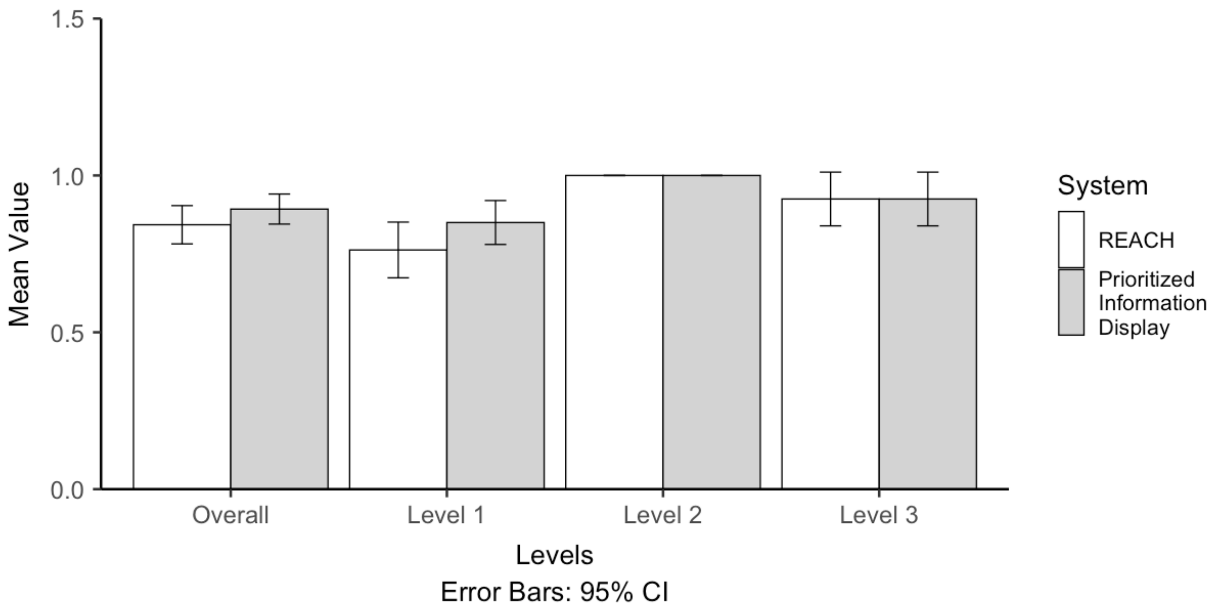

Figure 6.9: Average Accuracy of SAGAT Freeze 2

Performance

Time

The time taken to complete the assessment was measured by the simulator in seconds from when the participants entered the system to when they verbally stated they had completed their assessment without the time taken to complete the SAGAT freezes. A paired t-test was conducted to determine the difference between system conditions on the time taken to complete the assessment. A significant difference in time taken was observed among the participants $t(19) = 2.10$, $p = 0.049$. More time was needed for REACH condition (M = 791.05, SD = 189.62) than for the Prioritized Information Display condition (M = 731.81, SD = 128.21).

Errors

Total Errors: Errors were documented by the moderator during the study session, with occurrences being totaled for two types of errors, documentation and conceptual. A paired t-test was conducted to determine the difference between system conditions on the total number of error occurrences. As shown in Figure 6.10, total error occurrences were higher for the REACH condition (M = 0.95, SD = 0.89) than for the Prioritized Information Display condition (M = 0.45, SD = 0.76). However, no significant difference in the total error occurrences was observed among the participants $t(19) = 2.03$, $p = 0.06$.

Documentation Errors: Documentation errors were documented by the moderator during the study session. A paired t-test was conducted to determine the difference between system conditions on the number of documentation error occurrences averaged over participants. A significant difference in documentation error per participant was observed $t(19) = 2.98$, $p = 0.01$. As shown in Figure 6.10, documentation error occurrences were higher for the REACH condition (M = 0.85, SD = 0.75) than for the Prioritized Information Display condition (M = 0.30, SD = 0.57).

Conceptual Errors: Conceptual errors were documented by the moderator during the study session. A paired t-test was conducted to determine the difference between system conditions on the number of conceptual error occurrences averaged over participants. As shown in Figure 6.10, conceptual error occurrences were fewer for the REACH condition (M = 0.10, SD = 0.31) than the Prioritized Information Display condition (M = 0.15, SD = 0.37). However, no significant difference in the conceptual error occurrences was observed among the participants $t(19) = -0.44$, $p = 0.67$.

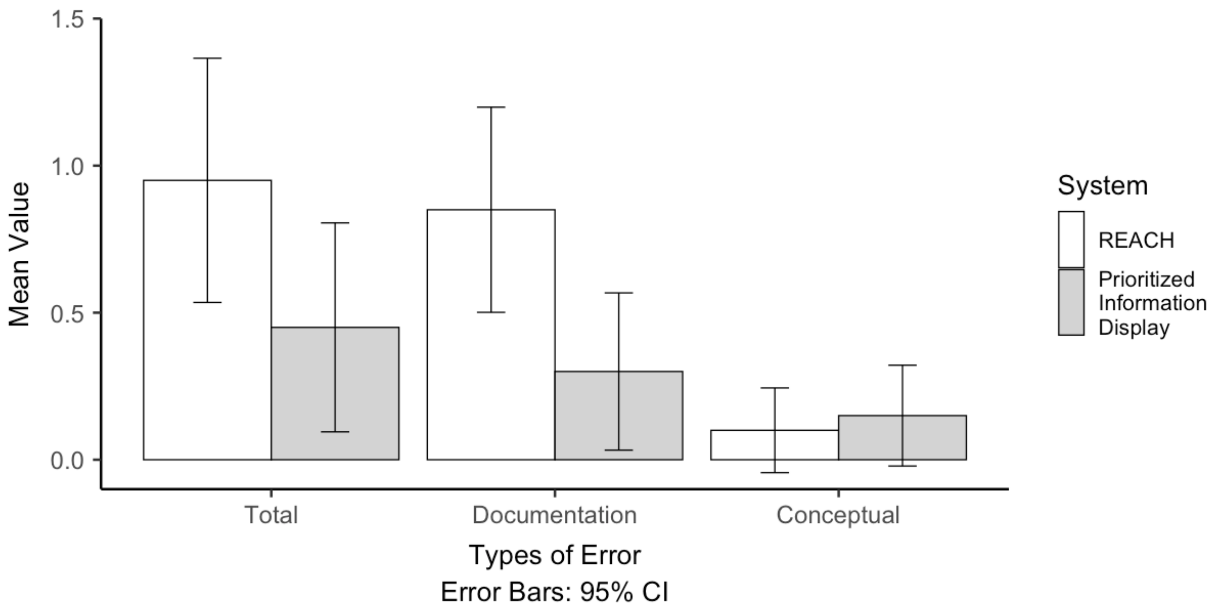

Figure 6.10: Average Errors by Type

Preference

In the interview, participants were asked which system they preferred for telemedicine stroke assessment in an ambulance setting. A Chi Square goodness of fit test was conducted on the number of participants who responded that they preferred REACH and the number who preferred the Prioritized Information Display to determine if there was a difference between the two systems. The number of participants who preferred REACH was 6 compared to 14 who preferred the Prioritized Information Display. However, there was no significant difference between the observed preference counts compared to the expectation that they would be evenly distributed $\chi^2(1, N = 20) = 3.2, p = 0.07$. The reasons for preferring the Prioritized Information Display varied among the participants. Of those participants who explained the reason for their preference, 66% mentioned the guided navigation, the completion of the tasks in a predefined order and the use of only next buttons to navigate in the system. Other reasons mentioned included the streamlined presentation of the documentation, the task progress bar, and the vitals presentation. Participant 15 described their preference, saying

> *I like the second system [Prioritized Information Display] a little better just because the workflow is linear and they are streamlined that until you complete one task you're not navigating to the other. Having a big graphical interface for the vitals, I like the second system [Prioritized Information Display] better. – P15*

Approximately a third of the participants who preferred the REACH system offered a reason. The ability to input more documentation on one screen, or general usability, were the only explanations given when asked for their preference. Of the participants who preferred REACH, two participants (11 and 17) mentioned that it was closer to the system they currently use or their typical process:

> *The first system [REACH], it was more similar to what I've used in the past. I think it was about as equally organized, so it was more familiar to me than the second system [Prioritized Information Display]. - P17*

Distributed Cognition

The responses to interview questions asking participants if the systems supported principles of distributed cognition were divided fairly evenly as at least 45% of participants believed that both systems supported each principle. To assess support of the information flow principle of information movement, the first question focused on obtaining the information needed in each system. Most participants, 70%, felt both systems supported this principle; however, 55% expressed a preference for the Prioritized Information Display, with 15% preferring REACH and 30% having no preference. In addition, 5% of the participants thought only REACH supported this principle, 20% only the Prioritized Information Display, and 5% neither. Participant 7 explained their thoughts on the information gathering in each system, saying

> *I think both of them allowed you to gather information correctly. The second one [Prioritized Information Display] though, because it put everything on the main page, you could quickly see what drugs they were taking, if they had any allergies, with thrombolytic, and blood thinners and stuff. That's just information that you would remember as soon as you ask the patient, but say if you weren't to remember that, the second system [Prioritized Information Display] would show that on the page with the little boxes in the middle page. I think it gives you a big picture when you're trying to come up with a diagnosis and just make an assessment. – P7*

The most common features mentioned as specifically supporting this principle were the streamlined interface (25% of participants) and the large graphical representation of vitals in the Prioritized Information Display (20%).

A second information flow principle, information transformation, was assessed by asking participants about the level of detail in each system, with 75% of the participants thinking both systems were equal in level of detail, 10% only REACH had sufficient detail, and 15% only the Prioritized Information Display had sufficient detail. In addition, Additionally, 35% of the participants indicated no preference in the level of detail in either systems, 30% indicating that they preferred the Prioritized Information Display and 25%

that they preferred REACH. The primary feature mentioned in reference to the level of detail was the streamlined layout of the Prioritized Information Display (20% of participants), with others stating more specifically that the organization of the documentation for components like medications or patient history in the Prioritized Information Display was an important feature (20%). Participant 6 described their thoughts on the relative level of detail, saying

> *I don't recall seeing the antiplatelet questions on the [REACH] like there was on the second one [*Prioritized Information Display*]. I think [REACH] was decent, but it certainly seemed to be missing some key things. It just didn't seem like it was developed by a neurologist if you will. [chuckles] They were both adequate. I think the second one [Prioritized Information Display] was more relevant to what I need as a neurologist trying to determine whether a patient is, A, having a stroke and, B, a TPA candidate or a thrombectomy candidate. – P6*

Trigger factors was another principle assessed during the interviews, with the participants being asked if any features of either interface triggered or cued them to complete a task. Only 45% of the participants expressed that both systems had some form of trigger factor, 25% thought neither did, 25% said only the Prioritized Information Display, and 5% said only the REACH system had trigger factors. Half of the participants expressed a preference for the Prioritized Information Display in terms of supporting trigger factors, the same 5% who stated only REACH had trigger factors preferred that system, and 45% had no preference. Features that participants identified as supporting trigger factors were the labeling (35% of participants) and guided navigation (15%) in the

Prioritized Information Display, and the tPA window countdown clock (5%) and documentation headers (5%) in REACH. Participant 1 describes the features they felt supported trigger factors:

> *I know both systems had all of those columns [surgical, family history]. It would remind us to make sure we ask those questions. The first one [Prioritized Information Display] was just better labeled, I think. – P1*

Principles in the artifacts component of the DiCoT model were also assessed, the first being creating scaffolding. The participants were asked if any features in either system created a reminder of where they were in their task list, with 50% saying both had some features, 35% only the Prioritized Information Display, 5% only REACH, and 10% thought neither system included scaffolding features. Most participants believed that the Prioritized Information Display offered better scaffolding (60%), while 10% felt REACH did and 30% didn’t state a preference for either system. Several of the Prioritized Information Display features that participants identified as creating scaffolding were its guided navigation (45% of participants) and the task progress bar (10%). Participant 18 describes the guided navigation in creating scaffolding:

> *I don't remember any alert or anything, but I do feel like system two [Prioritized Information Display], just navigating through it, it was like a list reminder. It was all in perfect order. – P18*

The REACH system features that were identified included the tab navigation structure (5%) and the collection of all patient history on one tab (5%).

The second artifact principle assessed was representation goal-parity, which describes the way a system can represent how near or far a user is from a goal in their tasks. Participants were asked how both systems performed in the representation of their place in relation to such goals as the end of the tPA window, normal patient vitals, or the end of the assessment. Most participants, 65%, stated that both systems supported this principle, 10% only the Prioritized Information Display, 10% only REACH, and 15% stated that neither system supported this principle. Most participants, 60%, thought REACH performed better in supporting this principle, with 65% of participants specifically listing the tPA countdown clock as the feature they believed supported representation goal-parity. Participant 2 described this feature:

> *I think the first system [REACH] was a little easier for me personally to figure out the time to three hours and training time to four and a half hours. I tried to look for something comparable in the second system [Prioritized Information Display], and I noticed that it was a little different. Maybe the time the thrombolysis incorporating the last known well equals of the time of symptom onset, and then directly giving us a countdown, I think is a very neat feature. – P2*

Those that thought the Prioritized Information Display performed better (25%) listed the graphical representation of vitals (15% of participants), color coding of vitals (20%), and the visual representation of the tPA window (20%). Participant 15 described their use of the timeline:

> *The second system [Prioritized Information Display], I was able to track it. . . . I think I have to also keep a tab on the blood pressure because if the pressure*

is so high, you cannot administer the drug. Rather than focusing on the patient until the time and then I decide to do the tPA, then if the blood pressure is 250/110, then, I'm stuck on how to decide on giving those medications first before I can administer the tPA. . . . I think having that vital graph or trend, information for the physician also helps him as the EMT to work on the blood pressure with the patient. Following my commands, I can actually do the NIH myself. We can prepare the patient to as close as possible to get the medication as soon as the CT scan is done, because we actually have a good control of the blood pressure and things like that. I think it allows us some freehand when the physician is able to have that vital trend information and presented to him in a nicer way. That's how I felt the system to update the job in a more elegant fashion compared to system one [REACH]. – P15

Benefits of Telemedicine

Almost all participants, 95%, saw a general benefit in using these telemedicine systems for ambulance-based stroke caregiving. The most common benefit listed was increased efficiency in patient care (60%). Participant 14 describes the benefit of using either of these telemedicine systems:

Being able to evaluate the patient before they even come in is a huge advantage. Being able to preemptively prepare and to have a-- For example, if they are applicable for the tPA, like to get them right away and be able to effectively treat them without wasting any time. I think it could be a huge advantage moving forward to be able to utilize that. – P14

No participants discussed a specific benefit of the REACH system over the Prioritized Information Display; however several participants, 15%, described benefits of the Prioritized Information Display specifically, listing a streamlined view of documentation, guided navigation, and larger view of the patient creating a more reliable assessment. Participant 8 describes their thoughts on the relative benefits between the systems:

> *Obviously, for both of them, I feel like the time aspect. They're pretty quick, you really get through and get it in NIHSS score quickly, and then you're able to see that tPA window, make sure you know what you're dealing with, whatever a stroke or not pretty quickly with both systems, honestly. I will say that the first one felt quicker [Prioritized Information Display], just because there's less to distract me from it and my goal is to be efficient. The first one [Prioritized Information Display] I feel like is doing a better job and my goal was to get a great history and chart awesomely. – P8*

DISCUSSION

This study investigated the effect of the design changes implemented in the Prioritized Information Display on the perceived workload, situation awareness, and performance of the participants and the usability evaluation of the system. These changes were developed based on the information flow and artifact principles of the DiCoT model and feedback from neurologist, nurse, and paramedic caregivers currently using telemedicine for stroke care in ambulances. In general, trends were seen in improved workload, usability, situation awareness, and task performance for the Prioritized

Information Display compared to the REACH telemedicine system currently in use. However, the dependent variables of time to assessment and documentation errors were statistically significant.

NASA-TLX workload measures six subscales, one being mental demand. On average mental demand was higher for participants using the REACH telemedicine system; several theories could explain this change. First, one of the main differences between the REACH system and the Prioritized Information Display is the relative video sizes of the patient and paramedic in the ambulance setting, with the latter providing a larger view. In the interviews, 50% of the participants indicated that the visibility of patients' movements impacted their assessment, with the smaller video making it more difficult to rely on their view of the patient. Participant 14 described their experience:

> *For the [Prioritized Information Display], the other thing that I preferred about it was the fact that the video is bigger. Because on the [REACH], I was having trouble trying-- I was going more by what the paramedic was saying, then being able to actually see myself what was going on. Whereas in the [Prioritized Information Display], I thought having the bigger video was definitely an advantage. - P14*

As many participants mentioned in the interviews in the previous study, a video of the patient improves the ability to consult over the phone; although patients are not seen face to face by neurologists, video allows for quality communication. A study conducted on distanced collaborating teams of software engineers found using video in addition to audio adds to or improves the ability to show understanding, forecast responses, give non-verbal information, enhance verbal descriptions, manage pauses and express attitudes (Isaacs & Tang, 1993). In addition, incorporating quality video for increased visibility is a contributing factor to mental demand as the better the quality, the better movements can be seen and interpreted, making the assessment easier and more reliable. Similar effects of video quality have been found in studies on video conferencing systems for digital learning investigating the bandwidth and size presentation for non-verbal communication and quick visual confirmation of movements (Watson & Sasse, 1996).

Mental demand could also be increased in the REACH system because of the difficulty participants had in finding documentation. Of those mentioning having any issues in the systems they evaluated (55% of participants), 72% specifically mentioned having difficulty finding medication documentation or the correct location for documenting the patient history in REACH, citing the unclear tab labels. Participant 10 describes their difficulty in documentation despite the training they received:

> *Despite you telling me where they were, when I got to it [in REACH], it wasn't obvious to me which tab to push to get to those allergies and medication so I just scripted them. - P10*

Design and labelling of navigation structure are essential for clear and efficient movement through any system. These results are consistent with a usability study of a tab navigation system for a college library website that found increased specificity of tab labeling created more use of the pages in the structure (Pittsley & Memmott, 2012).

Another subscale of workload, physical demand, was also seen to increase when using the REACH system. One possible reason identified by participants in their interviews was the amount of scrolling and movement between tabs required to accomplish the tasks in REACH compared to the Prioritized Information Display, which concentrated the input on a small area of the screen. According to Participant 8, it was hard to manipulate the display in REACH:

> *Honestly, I feel like the information was harder. I had a scroll bar in the left, it was hard. I had to manipulate. I just was not able to see everything right away as readily as the previous one [Prioritized Information Display]. - P8*

Almost half the users in this study (45%) were using trackpads to complete their stroke evaluation. Although we did not see an increase in the amount of time taken to complete the assessment when using a trackpad compared to a mouse, research in ergonomics investigating the two found that users indicated that the scrolling techniques on their trackpads were exhausting and jumpy compared to mouse control or positioning with the trackpad (Bial et al., 2010).

Temporal demand, or time pressure felt by participants, another subscale of workload, also was higher for the REACH system, perhaps because of the clutter of the screen, a problem mentioned by 45% of participants. As Participant 15 describes,

> *System 1 [REACH] it's always been problem is like a lot of boxes, colors are not that good because there's no differentiation between what is what. Everything is one color. It's a very busy interface, whether it is scrolling off a lot of up or down. I think, for physicians, especially, you're evaluating the patient, I think if it's less of a use of a mouse, or some sort of scrolling, it really helps because sometimes they don't know how to scroll that they miss that there is a scrolling element in an*

interface, sometimes they may not be able to see where to document information. That can create frustration and can increase the amount of pressure they feel compared to the linear system where you present one information or one element of the clinical evaluation at once. - P15

REACH also includes additional documentation items not pertinent to acute stroke consult, such as the review of the systems assessment, that could contribute to the increase in time pressure. Participant 6 expressed their opinion about the additional documentation required:

I think if you're going to have review systems on there, then have the ones that are only pertinent to your stroke alert or then just other. There were some things in there that I was like, "What? No, this a--"They had sleep apnea, nocturnal dyspnea in there. I was just like in a way, it makes you sometimes feel like you have to ask that question, but then it's like, first of all, sleep apnea is a diagnosis and not a review systems. - P6

Perceived performance on the tasks is another measure that was higher in the REACH telemedicine system. This result could be tied to the increased number of documentation errors made in this system when participants either omitted documentation or documented in the incorrect input. Participants' interviews pointed to time as the cause for these errors, the tradeoff being the time to find the correct documentation area and completing the patient evaluation. Participant 1 explained their thought process for finding medication documentation:

Yes, I was just putting it wherever I could because I just wanted to make sure she was not on any blood thinners and to remind myself what all she is on. That's why I just wrote it down wherever I could find an empty box, I guess, to type in . - P1

Difficulty finding documentation could be linked to the issues with the tab labelling described earlier when discussing mental demand, but the medication and allergies documentation was located at the bottom of the screen. In a study of web surveys comparing scrolling to clicking through pages to complete a questionnaire, participants in the scrolling condition recorded higher rates of item non-response, meaning within pages requiring scrolling, documentation could be difficult to find and, thus, not worth the effort to complete (Peytchev et al., 2006).

The final subscale of workload found to be higher for the REACH system was frustration. This finding is also supported by comments made by the participants in the interviews. Scrolling was a theme that emerged again in these comments as seen in Participant 15's description of the stress involved when scrolling in REACH

There is a lot of up and down scrolling that needs to happen [in REACH], which again especially when you're trying to figure out and you're also trying to perform a stressful assessment, but with another person. Having less grueling and less information on one screen with that load helps. - P15

A usability study of scrolling websites found similar low ratings for navigation and orientation, suggesting confusion and loss of orientation when using scrolling designs (Koukouletsos et al., 2014). The tab structure in REACH was also identified as a source of frustration for participants. As Participant 9 said about their experience with REACH, *Interviewee: Yes. I was trying to figure out where everything was and everything. Fonts were a little bit tiny for the vitals and all that.*

Interviewer: When you were talking about trying to figure out where everything was, do you feel like that made it take longer or was that more frustrating for you having to-

Interviewee: Yes, I think more frustrating. - P9

Unnecessary documentation was another aspect of REACH that was mentioned in connection with frustration in this study. Participant 6, in particular, mentioned the review of systems as a frustrating aspect of REACH:

That actually frustrated me because when I was going through it, the things that were listed on the review systems didn't even seem very relevant. - P6

Findings from research in form design recommend showing only input for those fields which are necessary (Beaumont et al., 2002). Form design research also provides some context for why unnecessary documentation in REACH may increase frustration as REACH provides many options for documentation with no indication of required input tasks in the system. Providing formatting or indication of required input is a recommendation based on findings from usability testing of documentation forms (Linderman & Fried, 2004).

The only subscale with a higher workload in the Prioritized Information Display than in REACH was effort. Few participants mentioned any increase in effort to complete their assessment during the interview, one participant (11) commented that the guided navigation system required more clicks in the system:

It [Prioritized Information Display] felt more clicky like I have to go from, for example, this screen for medical history and then I have to do surgical and family like the histories are not all on one screen as the meds. At least practically I think of my history is all one thing. - P11

The documentation for patient history in the Prioritized Information Display was divided into two documentation screens to avoid scrolling, medical history on conditions and substance use on one page and family and surgical history on the other. Usability research supports the use of pagination rather than scrolling to improve data input completion and time to complete data input (Peytchev et al., 2006).

Usability was also, on average, rated higher in the Prioritized Information Display (M= 5.71) than in the REACH system (M= 5.61). The first of the indices used to measure usability was system usability. These data collected through the IBM-CSUQ are supported by findings from the interviews. When participants were asked about the ease of use for each system individually, the Prioritized Information Display was referenced as easy to use by 100% of participants compared to 55% for the REACH system. Participant 13 describes the ease of use of each, saying

It [Prioritized Information Display] was easier to use, and the layout was easier to interpret relative to the second system [REACH]. The second system had more, but there was too much going on at the screen at one time. - P13

Functionality, however, participants felt was about equal in the systems as referenced by Participant 5:

Like I said, I feel like functionally, they're pretty similar where they both do the job. - P5

Information Quality, another IBM-CSUQ index, was rated higher for the Prioritized Information Display. Although most participants thought the level of detail in the systems was the same (75%), several (10%) believed there was more detail in the Prioritized Information Display, citing the checkbox items as Participant 8 did:

> *I think when I was trying to pick options, it was nice and there wasn't a lot of options [in Prioritized Information Display*]. *There weren't too many quick bubbles because otherwise, it takes me— in some ways, I could type faster hypertension than I could if I needed to look down the list and find hypertension and click it, but there weren't too many options which made it more amenable to that. - P8*

Others (15%) felt there was more detail in REACH, with more data input locations as Participant 7 describes:

> *I feel like there were more options to select on that, not on the scale, but on the history tabs, I feel because I'm trying to think if I had to run through a more elaborate list on the first one [REACH]. I'm just trying to think, because the second one [Prioritized Information Display] seemed more concise and also with that-- You can correct me if I'm wrong. Maybe that was because things were sort of squished together, so it'd look like a smaller, list but for the first one, I felt like there was a larger list to go through. - P7*

However, the relevancy of the extra data input was questioned by some participants, in particular Participant 6:

That actually frustrated me because when I was going through it [REACH], the things that were listed on the review systems didn't even seem very relevant. - P6

Usability guidelines for designing web-based forms provides some support for this finding, with Bargas-Avila et al. (2010) recommending streamlining the level of detail and asking for documentation of only relevant information.

Interface quality was the only usability index that was higher on average for the REACH system than the Prioritized Information Display. A possible reason for this finding is that some participants (10%) preferred the aesthetics of REACH: Participant 4 offers their opinion of this system:

Much sleeker, seems more professional - P4

Participant 5 echoes this sentiment in their response when asked about the layout of REACH:

It was more aesthetically pleasing - P5

A more common response about the features in the system that may explain this finding was the preference for the countdown clock in REACH compared to the visual tPA window in the Prioritized Information Display; 65% of participants stated they like the countdown clock when asked about maintaining awareness of patient status as Participant 1 explains:

Like I said, just digital numbers, there's just one more hour while they're within the time window. That just is more clearly communicating. - P1

Some participants (25%) also preferred the location of vitals next to the view of the patient in REACH compared to as the bottom of the screen in the Prioritized Information Display as explained by Participant 14:

I preferred having all the vitals in that one area in the second one [REACH. . . . I think that I just felt it easier to just look at it. I think just visually it was easier to have all that information lined under where I was looking at the patient. - P14

Situation awareness for each system, was measured twice in this study, once after completing the patient history, medication, and allergy documentation and again at the end of the assessment. Endsley's model of situation awareness describes 3 levels of situation awareness: Level 1, the perception of elements in the environment; Level 2, the comprehension of those elements in relation to current knowledge; and Level 3, the ability to predict future states of a system from the comprehension of those elements (Endsley, 1995). During the first freeze the average accuracy of all situation awareness questions was higher for the Prioritized Information Display, but the largest difference was found for the Level 1 questions which focused on accurately identifying the current vital signs of the patient, the medications the patient was taking or the patient's condition. This result was expected as the presentation of vitals in the Prioritized Information Display was not only larger and more obvious but also more informative, showing the trend of the vital signs over time and using color coding to provide guidance as to the normal their ranges. This finding, based on the accuracy of the participants' responses, was further confirmed by interviews. Participant 6 describes the advantages of the display of the vitals in the Prioritized Information Display:

That's where having the vital signs be much more prevalent or obvious is helpful. I was definitely paying more attention to the changes in the blood pressure on the *second one [Prioritized Information Display]. Whereas on the first one [REACH], it was a little bit even harder for me to remember to look at it. - P6*

Similar results have been found in assessments of remote experts consulting on trauma care. For example, a study conducted by Nilsson et al. (2013) found a live presentation of vitals was the most important information for consulting trauma experts to determine a patient's condition. The same analysis can be applied to the increase in accuracy found in the Level 1 questions in the second freeze. In addition to the presentation of the vitals, having a summary available of all documentation including the patient's conditions, medications, allergies, and current NIHSS was identified as one possible reason for increased accuracy in Level 1 situation awareness. Participant 5 describes their use of these patient summaries:

Actually, something that was good about this [Prioritized Information Display] is how it, say for the meds, what you clicked on was saved there in that bar as you scrolled on and were still being listed and the allergies had no, no, no. That was good. I liked that.- P5

In addition, Participant 19 specifically mentioned using the same patient information summary location for keeping track of the NIHSS score, supporting the increased accuracy for the Prioritized Information Display found by the Freeze 2, Level 1 situation awareness questions:

I guess in the second system [REACH], the NIH score was there as well. I think the first system [Prioritized Information Display], when I did the NIH was a little bit easier for me to keep in track of than the second one [REACH]. - P19

This finding is supported by researchers investigating the situation awareness of users in multiple systems. First, the constant availability of critical information is a recommendation resulting from research on team situation awareness in the operating room, with studies focusing on developing interfaces that integrate all critical information into a single screen (Lai et al., 2006) and others on maintaining a persistent view of demographic and case information (Levine et al., 2005). This support for the continual view of task information can be found in other domains as well. Quick glances at updated documentation supports peripheral awareness or background situation awareness of the patient case while focused on documentation and forming assessment, a recommendation from a study on displays allowing pilots to be aware of all background tasks simultaneously, supporting their situation awareness (Wickens, 2000).

Accuracy in the responses to the Level 2 situation awareness questions in the first freeze was found to be equal between the two systems, with the incorrect answers being the response to the question, "does the patient have a stroke indicating history?" This result may be explained by a personal bias to determine whether patient history is indicative of a stroke rather than an effect of the system and is further supported by the fact that most incorrect answers to this question for both systems came from the same participants (10, 14,16).

Level 3 situation awareness question accuracy was higher in the Prioritized Information Display, again the constant display of patient information could be a reason for this result. In this freeze the only question asked at this level was for participants to determine if anything in the patients' history would prevent them from being a tPA medication candidate. This difference could again be explained by the continual presence of the patient history, medications, and vitals as seen in Level 1, all of which would contribute to more effectively determining the patient's candidacy for this treatment.

In the second freeze the situation awareness Level 2 question was a single question asking participants to present their preliminary diagnosis of the patient. All participants were able to determine from the assessment that the patient was having a stroke, meaning the accuracy was equal between the systems for this question.

During the second freeze the Level 3 question asked participants to identify that if the patient is indeed having a stroke, was it caused by a clot in a large or small blood vessel. The accuracy of the answers to this question were equal for both systems (92.5%). As mentioned in the experimental design of this study, two stroke diagnoses were used to create patient cases for participants to assess in the telemedicine systems. Each participant evaluated both patients, the pairing of the cases and the systems being counterbalanced with no cases repeated in a single session. All incorrect responses to the concerned diagnosing Case 2, the small vessel stroke, with the participants mistakenly determining the patients were having a large vessel stroke; thus, this incorrect answer is due to diagnosis, not the system, as it occurred equally for REACH and the Prioritized Information Display.

According to Endsley's situation awareness model, higher levels are not achieved without lower levels first being reached (Endsley, 1988). However, the results from this study do not support this model as the average accuracy of participants answering questions at the perception level is lower than the accuracy of questions at the prediction level. These findings may be explained by participants responding in the interview that typically exact knowledge of vital signs is not required to determine tPA candidacy, just knowledge that vital signs are under certain limits. For example, most participants indicated that only if systolic blood pressure is above 200 mmHg should action be taken and tPA reconsidered. Thus, accuracy at the granularity selected for these questions, whether the blood pressure was under 95, between 95 and 120, between 120 and 170, or above 170, does not suggest that a Level 3 prediction cannot be made. In further research, the responses to the SAGAT questions should be tailored to this level of detail to better measure situation awareness levels.

Time to complete the assessment was significantly longer in the REACH system than for the Prioritized Information Display. Many of the reasons for the increased workload can be used to analyze this finding as well, in particular the participants' comments about scrolling in the REACH system. The study of the design of a web survey referenced previously also provides context for the longer time taken using the REACH system due its scrolling design. In that study the time to complete the survey was significantly longer than for survey using page navigation (Peytchev et al., 2006). In addition to scrolling, completing extra documentation tasks in REACH and the time taken to find documentation of the medications and allergies that was frequently described as an issue in the REACH system could also contribute to longer assessment time in that system.

Average documentation errors were also significantly higher in the REACH system. Similar to the discussion of the performance on the workload subscale performance, participants had trouble determining where the medications and patient history should be documented and, thus, did so in the incorrect location. Participant 10 described their experience with this issue:

> *It wasn't obvious to me which tab to push to get to those allergies and medication so I just scripted them. - P10*

Participant 19 also experienced this documentation problem, explaining their thought process:

> *Your time is of the essence, so you don't really want to spend a lot of time looking for things. You just want to move on to figure out your management strategy. - P19*

Few conceptual errors were made, meaning the participants did not mis-select or misunderstand the patient history or NIHSS levels even when the correct information was provided to them through the responses. These errors primarily occurred when the patient response was slurred, a symptom confirmed by the paramedic, yet the participants selected that their voice was clear; they also incorrectly indicated no ataxia, or drift, when it presented in patients' arm movements. The overall trend indicated a higher average number of conceptual errors in the REACH system than for the Prioritized Information Display. Based on the examples of conceptual errors made, the video size may contribute to the misinterpretation of movements in the ataxia assessment for REACH. Participant 15 emphasized the need to be able to visually confirm movements during the assessment:

> *For me, I think the impression that I think she's [paramedic] not giving me the adequate feedback or the correct feedback because I do my observation. I think that might be a little more- NIHSS is all about the level of visibility or that level of the symptoms. Right?*

Interviewer: Right. It's easier to see it yourself rather than get that feedback?

Interviewee: Yes. - P15

Other participants, including Participant 12, also mentioned the large video size in the Prioritized Information Display resulting in more reliable assessments:

I feel like the exams would be more reliable using the second one [Prioritized Information Display] because of the video being larger. - P12

However, these interview responses contradict the finding of higher average conceptual errors in the Prioritized Information Display.

The effects of the display features discussed in the introduction were confirmed in the interviews, with participants specifically mentioning the increased view of the patient, the streamlined information, the guided navigation, and the size of the trends in and summary of the vitals as improving experience and supporting distributed cognition. However, only a few mentioned the task progress bar and the visual tPA window as contributing to distributed cognition. When directly asked about the former, most participants indicated that they either didn’t notice it or noticed it but followed the guided navigation or were focused on documentation. Participant 19 described their use of the progress task bar:

Yes, I didn't really use it. I noticed that. I think it's because it's a-- Whenever I'm doing a stroke scale on a normal patient, I'm not paying attention to anything else except for the information I need, because time is just such a huge, relevant factor. - P19

For the second feature, the tPA window, participants overwhelmingly preferred having a numerical countdown rather than a visual representation. Although some liked the use of the visual tPA window for the same reasons it was chosen for the design, those comments were often qualified with the idea that the digital clock was useful because it provided a cut-off, as can be seen in Participant 8's response:

> *It was certainly easier to check on for that TPA window or making sure we're eligible [in Prioritized Information Display]. Then, the second one [REACH], what I really liked was that just like stark, 'This is the TPA window time. This is your cutoff.' Being a little bit more obvious than stop this bar where it says the time or the end. - P8*

Limitations

This study was conducted during the COVID-19 pandemic, and for this reason all study participation was virtual, with the participants completing it on their home computers using simulation files and surveys sent to their email and connected with a researcher through an Internet connection and a Zoom conference call. The size of the screens, the computer setup, and the mouse or trackpad use were, thus, unable to be controlled in this study. However, conducting the study under these conditions is perhaps how most neurologists conduct stroke telemedicine sessions. During the interviews, data about the computer setup were collected to determine if trends could be found in time to complete or workload; however, no such trends were found.

For this study to be conducted virtually, a simulated patient and paramedic were needed to provide the responses for the participants to conduct their assessment realistically. Although all questions that could be asked were carefully considered and confirmed with multiple physicians, some participants asked questions that the researchers did not anticipate. However, the video responses increased the consistency of the responses for each assessment, addressing one limitation resulting from using live actors. In addition, due to the COVID-19 pandemic, these recorded responses could not be conducted in an ambulance. While the positioning of the patient and paramedic were made to simulate an ambulance environment as much as possible, factors such as noise or movement were not able to be replicated.

Limiting the scope of this experiment to neurologists was necessary, and conducting the study virtually meant that the design changes that could be made were limited to the interface. Physical changes to the ambulance equipment or layout and the neurologist workstation were not considered in this study. As such, further research is needed to determine the effectiveness of the telemedicine systems in the actual environment as the physical layout could impact how these systems are used.

CONCLUSION

This study investigates the effect of a redesign of a telemedicine system for stroke care in ambulances based on the perceived usability of the system, the perceived workload and situation awareness of the neurologists, and task performance. In addition, the designs examined were evaluated for their support of distributed cognition principles. The findings suggest that participants performed better, experiencing lower workload and higher situation awareness in the redesigned system. This system also received higher ratings for usability, and the features were identified more frequently as supporting distributed cognition than the system currently in use at a major hospital system to connect neurologists to rural hospitals and the EMS.

The system, however, could be improved. For example, the participants preferred the countdown clock feature of the current system, although overall they preferred the redesigned system. Thus, further research should be conducted on the Prioritized Information Display, with additional iterations improving it based on the results from this study including the recommendations from the participants for a countdown clock. In addition, this study was conducted using a small convenient sample of neurologists or physicians with neurology experience from one state and virtually moderated with simulated videos of a patient and paramedic in a simulated ambulance environment. Further research of the application of this system in its actual environment with a wider sample is necessary to confirm the results of this research.

CHAPTER SEVEN

CONCLUSION

Telemedicine systems, specifically those used in ambulances, have the potential to improve stroke care with improved time to treatment, diagnosis accuracy, and patient outcomes. The first systematic review in this dissertation investigated the outcomes of the implementation of telemedicine systems in ambulances. It found that most of the current research has focused on the outcomes of the system in terms of efficiency and improved patient care; however, few have considered the caregivers using the telemedicine systems to meet, diagnose, and treat patients.

To investigate the impact of such systems on the caregivers in ambulances, the second review was of the types and occurrences of human error in ambulance-based care, with the results suggesting these could be categorized as procedure errors, protocol deviations, medication errors, diagnosis accuracy, and adverse or safety events with their occurrences varying among these categories. Many of the studies included in this review along with those found in the telemedicine implementation study focused on stroke care. However, the review of human error found no studies investigating the error occurrences within telemedicine systems.

To address this limitation, the first study in this dissertation focused on telemedicine in ambulances designated for stroke care based on the reviews conducted. Specifically, it investigated the tasks involved in stroke care by observing caregivers conducting simulated stroke consults using REACH, one of the current telemedicine systems. Further, this task analysis was used as input for a heuristic evaluation and in a Systematic Human Error

Reduction and Prediction Approach (SHERPA) to evaluate this telemedicine system based on usability and possibility for human error. The heuristic evaluation found several violations, including the visibility of the system status, impacting the usability of the REACH system. The SHERPA also indicated potential errors when using the REACH system, many of which could be remediated with basic display changes such as a streamlined and correctly formatted data input.

To develop design improvements to this telemedicine system required further study of the caregivers' experience with the REACH telemedicine system, specifically of the barriers and facilitators to using the current telemedicine system implemented in stroke caregiving. To do so, 13 observations of simulated stroke consults were conducted with neurologists, nurses, and paramedics using the REACH telemedicine system. After these simulations of stroke consults, the participants completed surveys on their perceived workload, the usability of the system, and their evaluation of teamwork, followed by semi-structured interview with each of the three caregivers in each team, 39 participants in total. The data collected were then analyzed for themes documenting the barriers and facilitators identified by the caregivers. The barriers found included frustration with equipment and with their training, both of which increased their perceived cognitive demand; the loss of the personal connection between the neurologists and the patients; and the physical constraints in the ambulance. The facilitators found were more numerous, including live and visual communication that increased teamwork and efficiency, the ease of access to specialists, increased flexibility, and high overall satisfaction and usability.

The final study evaluated a prototype design developed for neurologists in stroke care based on the feedback from the interviews of the caregivers conducted in the previous study and the principles of the distributed cognition for teamwork model, the DiCoT, specifically those in the information flow and artifacts components of the model. This proposed display included a streamlined, linear navigation through documentation tasks, graphical representation of vital trends, a dynamic task progress bar, a summary of the documentation, and larger video display for patient playback. In a study using a within-subjects design, 20 neurologists participated in an evaluation of both the REACH telemedicine system and the prototype, named the Prioritized Information Display for its focus on streamlined and emphasized presentation of only necessary documentation and data. The results found reduced workload, higher usability, higher situation awareness, and improved task performance, including time to complete assessment and fewer errors, for the Prioritized Information Display. During the interviews conducted after evaluating both systems, the neurologists indicated the features in the Prioritized Information Display that supported distributed cognition, most notably the streamlined layout of the system and the guided navigation. Most participants also stated that they preferred using the Prioritized Information Display when evaluating stroke patients in an ambulance setting.

The findings from this research can be used to develop ambulance-based stroke telemedicine systems, important because such care is difficult, given the time constraints to limit brain tissue death and the need to communicate complicated assessment tasks between neurologists in the hospital and the paramedics at the scene. The changes made in the proposed design were found to reduce the time to complete assessment and documentation errors in addition to indicating increased usability and situation awareness and decreased workload. The most frequently mentioned improvement identified by the participants was the linear, guided navigation though stroke caregiving tasks. Simplifying the documentation and cognitive effort required to move to the next step allowed them to focus on their assessment and only the tasks necessary to treat the patient. In addition, the increased size of the video showing the patient and paramedic in the ambulance improved their view of the patient's movements and made them more confident and their assessments more reliable. Some participants also mentioned that the constantly updating vitals, graphical representation of trends in addition to current values, and color coding of non-normal vital signs all contributed to higher awareness of the patient status. Most caregivers also agreed that these features more effectively supported distributed cognition during this process than REACH.

However, the neurologist participants in this study offered further recommendations. Many noted that the location of vitals in the lowest point of the screen with no connection to the patient video and documentation area where their attention was focused created difficulty for both noticing and maintaining awareness of the vital signs. Participants also frequently mentioned their preference for the countdown clock in the REACH telemedicine system, which showed a numeric value of time left to the end of the 3 hour and 4.5 hour tPA window, over the visual representation in the Prioritized Information Display. Some participants also mentioned that while the detailed patient information summary was useful for giving them an update on the documentation that had been completed, they expected this information to be at the top of the screen as many

Electronic Health Record (EHR) systems place demographic information about a patient in screen headers. Based on these recommendations further research should be conducted to determine if changes such as duplicating the countdown next to the end of the vitals timeline, duplicating vitals near the patient video, and moving the patient information bar to the top of the screen, as shown in a mockup of a new iteration in Figure 7.1, will further improve the stroke caregiving process for neurologists and possibly other members of the caregiving team as well.

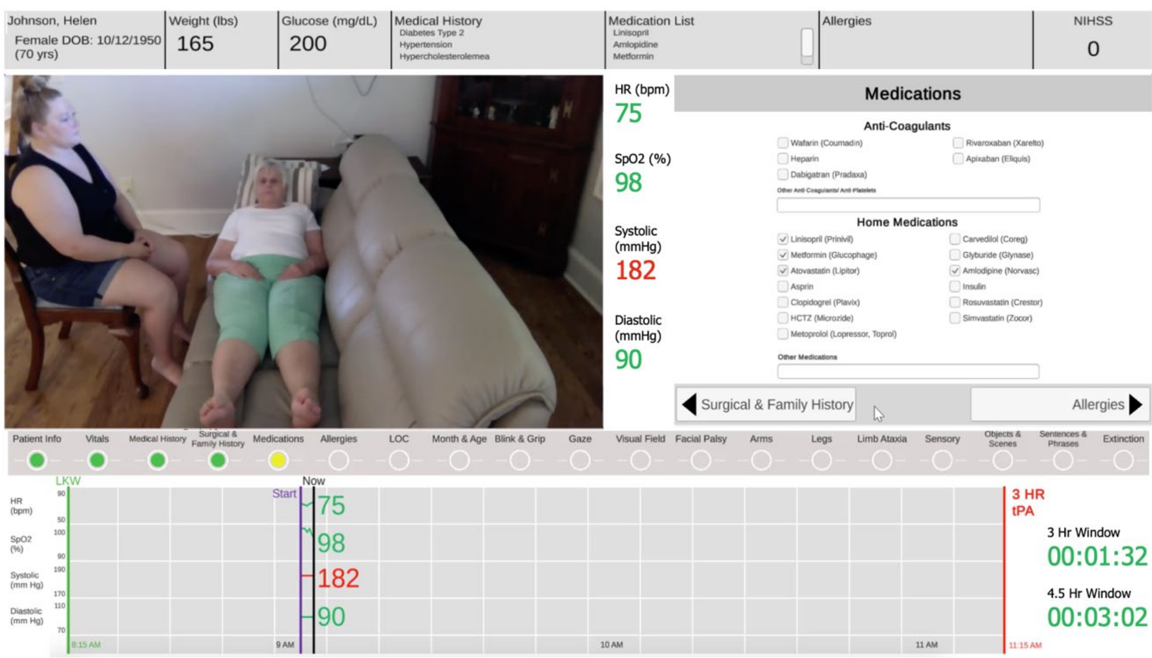

Figure 7.1: New Iteration of Prioritized Information Display

The broader applications of the findings from this research could be used to improve telemedicine or collaborative interfaces in other areas. Identifying task specific protocols and tailoring interfaces to only what is necessary streamline the amount of information presented, facilitating faster and more effective movement through tasks. This efficiency is especially important in emergency care where caregivers are under both time pressure and the environmental pressures of the limited resources in most ambulances. Streamlining documentation and creating rigid formats for input were two of the recommendations found in earlier studies in this dissertation, and the results from this final study indicate they also appear to reduce errors in a high risk and high stress situation. Creating an easy, uncomplicated navigation that requires minimal effort from the user to understand the structure of the system and how to move from one task step to the next was a useful feature of this system that could be applied in a variety of collaborative interfaces. Further, supporting scaffolding artifacts, interface features such as labelling or progress maps, can assist users working both alone or as a team to coordinate tasks or self-regulate their progress. Finally, and perhaps the most obvious, the largest possible view of the main source of information or the ability to zoom or focus on specific areas, both for the view of a patient and a collaborative document, is key to improving task performance, the usability of the system, and collaboration on a task. These recommendations can not only have a broader impact on the design of telemedicine and other collaborative systems but they also increase knowledge about the features required in these systems and adds to the human factors literature. Further, the research presented in this dissertation provide not only recommendations for telemedicine systems in general, but the research methods used to evaluate and determine improvements are generalizable to other interface designs in other domains. A focus on design for the user, understanding their needs and any barriers or facilitators of current systems to generate design recommendations and iteratively implement changes with user evaluation is a critical research method for any interface design project. Additionally, the models and theories presented in this dissertation, the distributed cognition theory and the distributed cognition for teamwork or DiCoT model, can be applied to many systems involving collaboration of teams. The principles with in the DiCoT model that were used to guide the redesign of the telemedicine systems will be applicable for teams collaborating regardless of the artifacts or technology used in the future.

Limitations and Future Research

The studies in this dissertation, like all research, have several limitations, especially Studies Two and Three in Chapters Five and Six, respectively. These two studies are limited because of their use of convenient sampling of neurologists and other caregivers in local healthcare systems. Further study of the telemedicine systems in other healthcare systems or other telemedicine systems for stroke care should be conducted. The primary limitations of the final study, Study Three, were the restrictions necessitated for conducting the study virtually because of the COVID-19 pandemic. Selections of pre-recorded videos were used in lieu of live patient actors, and the study was moderated over Zoom Video Conferencing. Further studies should be conducted to investigate the prototype system in comparison to the REACH system in an ambulance-based setting and with live simulated stroke patients. There is also a need to test new iterations of the prototype developed for the final study including the recommendations from the caregivers. In addition, future iterations and subsequent recommendations should be tested using telemedicine caregiving processes in other emergency situations such as cardiac arrests. The limitation of using a simulated study method and therefore reducing the scope to designing for and testing with only neurologists and only within the interface also needs to be assessed with further design studies. As mentioned through this dissertation, teamwork of these caregivers must be supported within these designs and as such should be considered in testing design recommendations. Through a communications analysis of the observation sessions conducted in Chapter Five, it was also found that the patient should be treated as a member of this team and considered in system design as they contribute to the communication of important information for stroke assessment (Joseph et al., in press). For this reason, further studies should investigate how to support the communication and experience of the patient as well. Suggestions were made by paramedics when completing interviews during the observation study in Chapter Five, mentioning that patients can be disoriented by the disembodied voice of a neurologist with no visual representation in the ambulance and that a video screen facing the patient could improve their experience. This would further assist neurologists to be able to non-verbally communicate movements required for assessment. Considerations not only for interface design to support all team members, but system design such as adding video of the neurologist for the patient should be carefully considered in future research.

My Contributions

During my four years as a Ph.D. student at Clemson University, I have been involved in several research projects investigating human factors problems. Through these projects I have developed skills in multiple research approaches including systematic review and meta-analysis, content analysis, surveys, interviews, and controlled behavioral experiments. I have conducted several studies on the effect of latency, display design, and automation in teleoperated robots used for search and rescue. One journal and conference publications resulted from this research project (Khasawneh et al., 2019; Rogers et al., 2017). I have also investigated how the design of Unmanned Aerial Vehicles (UAVs) control interfaces impact trust and decision making (Rogers et al., 2018, 2019), assisted with a review of usability studies of telemedicine systems for geriatric patients (Narasimha et al., 2016), and I participated in a study on how Alzheimer's patient caregivers reach out to others on a peer support portal (Scharett et al., 2017).

The first systematic review in this dissertation was published in *Telemedicine and eHealth* (Rogers et al., 2017). The task analysis and SHERPA in the first study were published as in the *Proceedings of the Human Factors and Ergonomics Society's Annual Meeting* (Rogers et al., 2020).

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APPENDICES

APPENDIX A

Database Search Strategy for Chapter 3

PubMed 1988 to present (initial search 23 January 2019)

1. ("emergency medical technicians"[MeSH Terms] OR "allied health personnel"[MeSH Terms] OR "ambulances"[MeSH Terms] OR "emergency medical services"[MeSH Terms] OR "emergency medical technicians"[MeSH Terms] OR "emergency treatment"[MeSH Terms]) AND ("medical errors"[MeSH Terms] OR "drug-related side effects and adverse reactions"[MeSH Terms] OR "medical errors"[MeSH Terms] OR "risk management"[MeSH Terms]) AND ("1988"[Date - Publication] : "3000"[Date - Publication])
2. ((“prehospital”[Title/Abstract] OR “pre hospital”[Title/Abstract] OR “pre-hospital” [Title/Abstract]) OR (“Emergency Medical Services”[Title/Abstract] OR “EMS”[Title/Abstract]) OR “paramedic”[Title/Abstract] OR (“Emergency Medical Technician”[Title/Abstract] OR “EMT”[Title/Abstract]) OR “emergency care”[Title/Abstract] OR “ambulance”[Title/Abstract]) AND (error*[Title/Abstract] OR (“incident reporting”[Title/Abstract] OR “incident”[Title/Abstract]) OR “mistake”[Title/Abstract] OR “adverse event”[Title/Abstract] OR “safety event”[Title/Abstract] OR “mistake”[Title/Abstract] OR “failure”[Title/Abstract]) AND("1988"[Date - Publication] : "3000"[Date - Publication])

Web of Science 1988 to present (initial search 18 January 2019)
Databases= WOS, BCI, BIOSIS, CCC, DRCI, DIIDW, KJD, MEDLINE, RSCI, SCIELO, ZOOREC Timespan=1988-2018
Search language=English

((TS=“prehospital” OR TS=“pre hospital” OR TS=“pre-hospital”) OR (TS=“Emergency Medical Services” OR TS=“EMS”) OR TS=“paramedic” OR (TS=“Emergency Medical Technician” OR TS=“EMT”) OR TS=“emergency care” OR TS=“ambulance”) AND (TS=error* OR (TS=“incident reporting” OR TS=“incident”) OR TS=“mistake” OR TS=“adverse event” OR TS=“safety event” OR TS=“mistake” OR TS=“failure”)

Academic One File 1988 to present (initial search 23 January 2019)

((Abstract (prehospital) Or Abstract (Emergency Medical) Or Abstract (paramedic) Or Abstract (emergency care) Or Abstract (ambulance)) And (Abstract (error) Or Abstract (mistake) Or Abstract (incident) Or Abstract (adverse event) Or Abstract (failure)))

ACM Digital Library 1988 to present (initial search 18 January 2019)

"query": { recordAbstract:(prehospital, pre-hospital, pre hospital, EMS, emergency medical*, ambulance, EMT, paramedic, emergency care) AND recordAbstract:(error, incident, mistake, adverse event, safety event, failure) }

"filter": {"publicationYear":{ "gte":1988, "lte":2019 }},
{owners.owner=HOSTED}

AgeLine 1988 to present (initial search 23 January 2019)
((AB“prehospital” OR AB"pre hospital” OR AB“pre-hospital”) OR (AB“Emergency Medical Services” OR AB“EMS”) OR AB“paramedic” OR (AB“Emergency Medical Technician” OR AB“EMT”) OR AB“emergency care” OR AB“ambulance”) AND (ABerror* OR (AB“incident reporting” OR AB“incident”) OR AB“mistake” OR AB“adverse event” OR AB“safety event” OR AB“mistake” OR AB“failure”)

Alt HealthWatch 1988 to present (initial search 23 January 2019)
((AB“prehospital” OR AB"pre hospital” OR AB“pre-hospital”) OR (AB“Emergency Medical Services” OR AB“EMS”) OR AB“paramedic” OR (AB“Emergency Medical Technician” OR AB“EMT”) OR AB“emergency care” OR AB“ambulance”) AND (ABerror* OR (AB“incident reporting” OR AB“incident”) OR AB“mistake” OR AB“adverse event” OR AB“safety event” OR AB“mistake” OR AB“failure”)

Applied Science and Technology 1988 to present (initial search 23 January 2019)
((AB“prehospital” OR AB"pre hospital” OR AB“pre-hospital”) OR (AB“Emergency Medical Services” OR AB“EMS”) OR AB“paramedic” OR (AB“Emergency Medical Technician” OR AB“EMT”) OR AB“emergency care” OR AB“ambulance”) AND (ABerror* OR (AB“incident reporting” OR AB“incident”) OR AB“mistake” OR AB“adverse event” OR AB“safety event” OR AB“mistake” OR AB“failure”)

BioOne 1988 to present (initial search 23 January 2019)
((ABSTRACT:(prehospital) OR ABSTRACT:(Emergency Medical) OR ABSTRACT:(Emergency Care) OR ABSTRACT:(Ambulance) OR ABSTRACT:(paramedic)) AND (ABSTRACT:(error) OR ABSTRACT:(incident) OR ABSTRACT:(mistake) OR ABSTRACT:(failure) OR ABSTRACT:(adverse event))

Health Reference Center Academic 1988 to present (initial search 23 January 2019)
((Abstract (prehospital) Or Abstract (Emergency Medical) Or Abstract (paramedic) Or Abstract (emergency care) Or Abstract (ambulance)) And (Abstract (error) Or Abstract (mistake) Or Abstract (incident) Or Abstract (adverse event) Or Abstract (failure)))

PsychINFO 1988 to present (initial search 23 January 2019)
((AB“prehospital” OR AB"pre hospital” OR AB“pre-hospital”) OR (AB“Emergency Medical Services” OR AB“EMS”) OR AB“paramedic” OR (AB“Emergency Medical Technician” OR AB“EMT”) OR AB“emergency care”

OR AB“ambulance”) AND (ABerror* OR (AB“incident reporting” OR AB“incident”) OR AB“mistake” OR AB“adverse event” OR AB“safety event” OR AB“mistake” OR AB“failure”)

ScienceDirect 1988 to present (initial search 18 January 2019): search was limited to 8 Boolean connectors

title-abs-key (“prehospital” OR “Emergency Medical Services” OR “paramedic” OR “Emergency Medical Technician” OR “emergency care” OR “ambulance”) AND (error OR “incident” OR "mistake”)

Appendix B

Results of Search

Database	Search	Counts	Date
Web of Science	Topic	7992	1/23/19
Science Direct	Title/Abstract/Keywords	483	1/23/19
Applied Science and Technology	Abstract	49	1/23/19
PsychINFO	Abstract	144	1/23/19
ACM Digital Library	Abstract	4594	1/23/19
PubMed	Mesh Terms	12443	1/23/19
PubMed	Title/Abstract	3051	1/23/19
Health Reference Center Academic	Abstract	1	1/23/19
BioOne	Abstract	0	1/23/19
Alt HealthWatch	Abstract	4	1/23/19
AgeLine	Abstract	11	1/23/19
Academic OneFile	Abstract	1	1/23/19
Total		28773	
Duplicates		6844	
Without Duplicates		21929	

Appendix C

Adjusted STROBE Checklist

Section	No.	Item
Abstract	1	Either: (1) Indicate the study's design with a commonly used term in the title or the abstract or (2) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction	2	Explain the scientific background and rationale for the investigation being reported
	3	State specific objectives, including any prespecified hypotheses
Methods	4	Present key elements of study design early in the paper
	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
	6	Give the eligibility criteria, and the sources and methods of selection of participants
	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
	9	Describe any efforts to address potential sources of bias
	10	Explain how the study size was arrived at
Optional if there are quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Results	12	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed and Give reasons for non-participation at each stage
	13	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders, Indicate number of participants with missing data for each variable of interest
	14	Report numbers of outcome events or summary measures
	15	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included, Report category boundaries when continuous variables were categorized, If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Discussion	16	Summarize key results with reference to study objectives
	17	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
	18	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
	19	Discuss the generalizability (external validity) of the study results

Appendix D

Quality Assessment

Authors	Year	Quality Item																			Total Qual.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Hein, Owen, and Plummer	2008	1	0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	0.789
Alenyo, Smith, McCaul and Van Hoving	2018	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Haynes and Pritting	1999	1	1	1	1	1	1	1	1	0	1		1	0	1	0	1	1	1	1	0.833
Eckstein and Suyehara	2002	1	1	1	1	1	1	0	0	0	1		1	1	1	0	1	1	1	0	0.722
Goebel, Daya, and Gunnels	2004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0.895
Brice, Friend, and Delbridge	2008	1	1	1	1	1	1	1	1	0	1		1	1	1	1	1	1	1	1	0.944
Smith, Isaacs, and Corry	2009	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0.842
Coppler et al.	2016	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	0.842
Lim et al.	2013	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0.947
Christie, Costa-Scorse, Nicholls, Jones, and Howie	2016	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0.947
Kirves et al.	2007	1	1	1	1	1	1	0	1	0	0	1	1	1	1	0	1	1	0	0	0.684
van den Berg, Olsson, Svensson, and Hakansson	2015	1	1	1	1	1	1	1	1	1	1		0	1	1	1	1	0	1	0	0.833
Rudd, Martin, Harrison, and Price	2016	1	0	1	1	1	1	0	0	0	0		1	1	1	0	1	1	0	0	0.556
Nor et al.	2004	1	1	1	1	1	1	1	1	0	1		1	1	1	1	1	0	1	0	0.833
Cienki and DeLuca	2012	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0.895
Mitchell and Tallon	2002	1	1	1	1	1	1	1	0	0	1		1	1	1	0	1	0	0	0	0.667

Patterson et al.	2012	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Barnes, Reed, Weinstein, and Brown	2003	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	0.789
Liberman, Lavoie, Mulder, and Sampalis	1999	1	1	1	1	1	1	1	1	1	0		1	1	1	1	1	1	1	0	0.889
Ruppert et al.	1999	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	0	0	0	0.737
Eberle et al.	1996	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	0	0.789
Stevens et al.	2015	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Boyle	2009	1	1	1	1	1	0	0	0	0	1		0	1	1	0	1	1	1	0	0.611
Hohenstein, Hempel, Schultheis, Lotter, and Fleischmann	2014	1	1	0	1	1	1	1	1	1	0		1	1	1	0	1	0	1	0	0.722
Hohenstein, Rupp, and Fleischmann	2011	1	0	1	1	1	1	1	0	0	0		1	1	1	0	1	0	1	0	0.611
Holliman, Wuerz, and Meador	1994	1	1	1	1	1	0	0	0	1	0		1	1	1	0	0	1	0	0	0.556
Ackerman and Waldron	2006	1	0	1	1	1	1	1	1	1	0		1	1	1	0	1	1	1	0	0.778
Benner et al.	2006	1	1	1	1	1	1	1	1	0	1		1	1	1	0	1	0	1	0	0.778
Hobgood, Bowen, Brice, Overby, and Tamayo-Sarver	2006	1	1	1	1	1	1	1	1	0	1		1	1	1	1	1	1	1	1	0.944
Fairbanks et al.	2008	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0.947
Kaji et al.	2006	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0.895
Jones, Murphy, Dickson, Somerville, and Brizendine	2004	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0.947
MacDonald, Banks, and Morrison	2008	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0.947

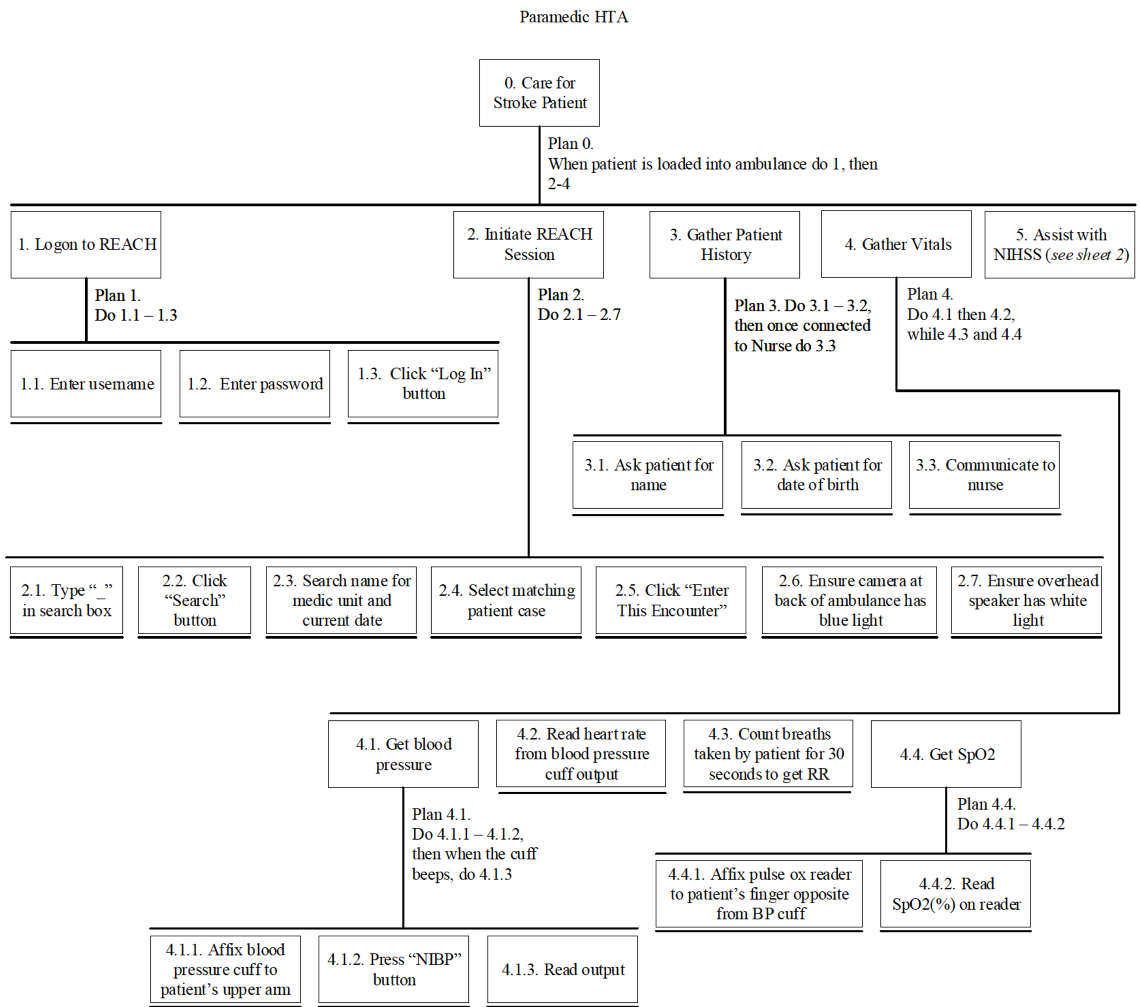
Hobgood, Xie, Weiner, and Hooker	2004	1	0	1	1	1	1	0	1	0	0		1	1	1	0	1	1	1	0	0.667
Lammers, Willoughby-Byrwa, and Fales	2014	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0.895
Ghiyasvandian et al.	2018	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0.895
McDermott, Cooper, Hogan, Cordner, and Tremayne	2005	1	0	0	1	1	1	1	1	0	0	1	1	1	1	0	1	0	1	0	0.632
Gallagher and Kupas	2012	1	1	1	1	1	0	1	1	1	0	0	1	1	1	0	1	1	1	0	0.737
Gropen et al.	2014	1	1	1	1	1	1	1	1	0	0		1	1	1	1	1	1	1	1	0.889
Kaserer et al.	2017	1	1	1	1	1	1	1	1	0	0		1	1	1	0	1	1	1	1	0.833
Glaeser, Hellmich, Szewczuga, Losek, and Smith	1993	1	1	1	1	1	0	1	0	0	0		1	1	1	0	1	0	0	0	0.556
Kothari, Barsan, Brott, Broderick, and Ashbrock	1995	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1	0.842
Zimmer et al.	2010	1	1	1	1	1	1	1	1	1	0		1	1	1	1	1	1	1	1	0.944
Stella, Bartley, and Jennings	2010	1	1	1	1	1	1	1	1	0	0		1	1	1	1	1	1	1	0	0.833
Hubble, Paschal, and Sanders	2000	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	0.842
Hoyle Jr. et al.	2012	1	1	1	1	1	1	1	1	0	0		1	1	1	1	1	1	1	0	0.833
Lammers, Willoughby-Byrwa and Fales	2014	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0.947
Einan-Lifshitz et al.	2011	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0.895
Salerno, Wrenn, and Slovis	1991	1	0	1	1	1	1	1	0	1	0		1	1	1	0	1	0	0	0	0.611
Hollander, Delagi, Sciammarella,	1995	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1	0.842

Viccellio, Ortiz, and Henry																					
Meckler et al.	2018	1	1	1	1	1	1	1	1	1	0		1	1	1	0	1	1	1	0	0.833
Wang, Cook, Chang, Yealy, and Lave	2009	1	0	1	1	1	0	1	0	0	0		1	0	1	1	1	1	0	0	0.556
Williams et al.	2015	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0.842
Williams, Finn, Celenza, Teng, and Jacobs	2013	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	0	0.789
Williams, Boyle, and Lord	2008	1	1	1	1	1	0	1	1	0	0		1	1	1	1	1	1	1	1	0.833
Wang, Lave, Sirio, and Yealy	2006	1	1	1	1	1	1	1	1	0	0		1	1	1	0	1	1	1	0	0.778
Vilke et al.	2006	1	1	0	1	1	1	1	1	0	0		1	1	1	0	1	1	1	1	0.778
Hansen et al.	2016	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0.947
MacDonald, Swanson, Mottley, and Weinstein	2001	1	1	1	0	1	1	1	1	0	0		1	1	1	1	1	1	1	0	0.778
Potter et al.	2013	1	0	0	0	1	0	1	1	0	0		1	0	1	0	1	0	1	0	0.444
Cantor et al.	2012	1	1	0	0	1	1	1	1	0	0		1	0	1	0	1	1	1	0	0.611
Pitt	2002	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0.737
Brandler et al.	2015	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Feldman, Brinsfield, Bernard, White, and Maciejko	2005	1	1	1	1	1	1	1	1	1	0		1	1	1	1	1	1	1	1	0.944
Lammers, Byrwa, and Fales	2012	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0.947
Duby et al.	2018	1	1	1	1	1	1	1	1	1	0		1	1	1	0	1	1	1	1	0.889
Hansen, Eriksson, Skarica, Meckler, and Guise	2018	1	1	0	1	1	1	1	1	1	0		1	1	1	1	1	1	1	0	0.833
Lammers, Byrwa, Fales, and Hale	2009	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0.947

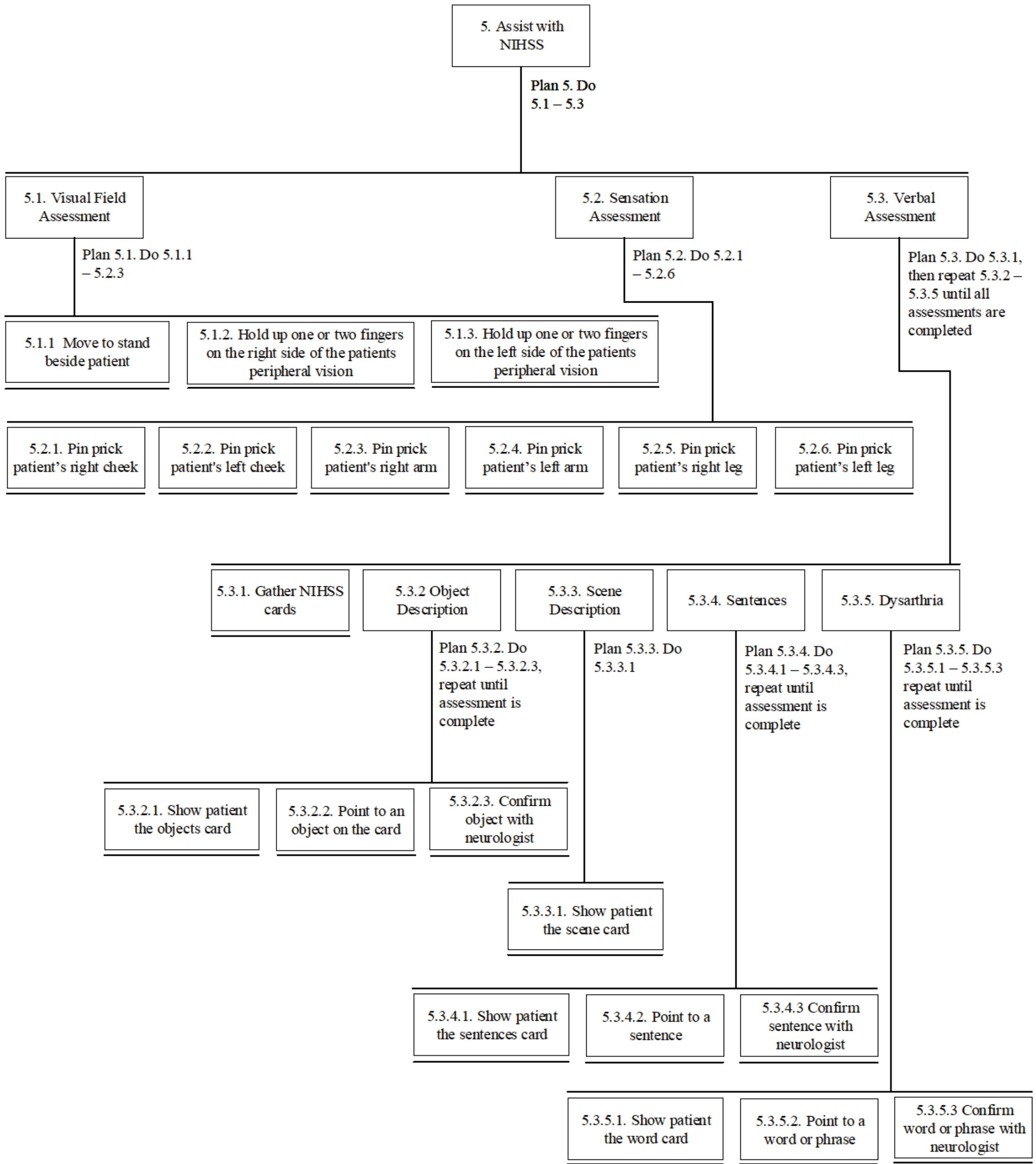
Latimer et al.	2018	1	1	0	1	1	1	1	1	0	0		1	1	1	0	1	1	0	1	0.722
Weaver, Wang, Fairbanks, Patterson, and Patterson	2012	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0.895
Linn, Knoller, Giligan, and Dreifus	1997	1	0	1	1	1	1	1	1	0	0		1	0	1	0	1	0	1	0	0.611
Duignan, Lamb, DiFiori, Quinlavin, and Feeney	2018	1	1	0	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	0	0.737
Eastwood, Boyle, and Williams	2012	1	1	1	1	0	1	1	1	0	0		1	1	1	0	1	1	1	1	0.778
Jemmett, Kendal, Fourre, and Burton	2003	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	1	0	0.789

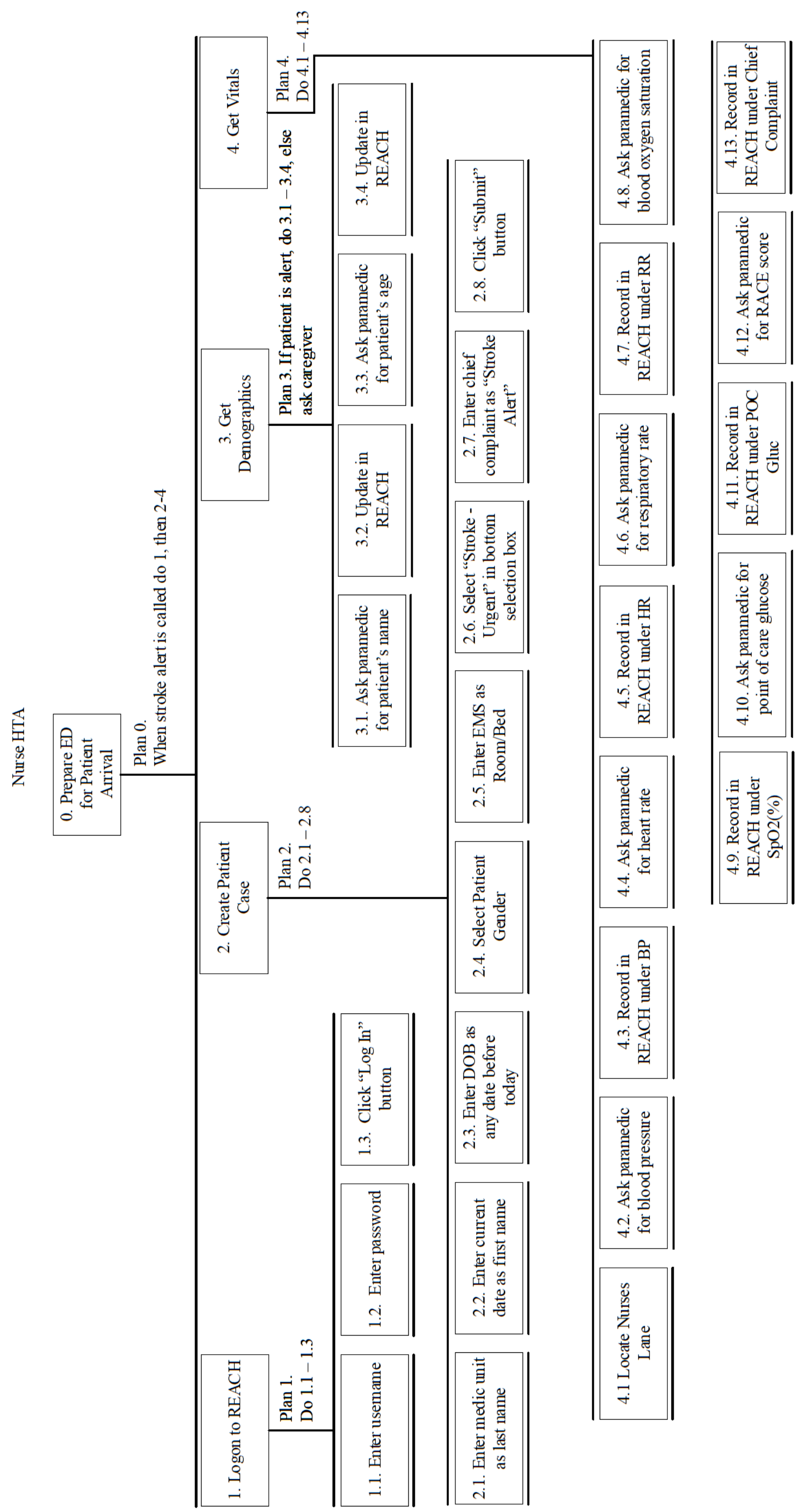
Appendix E

Role Specific HTA Diagrams

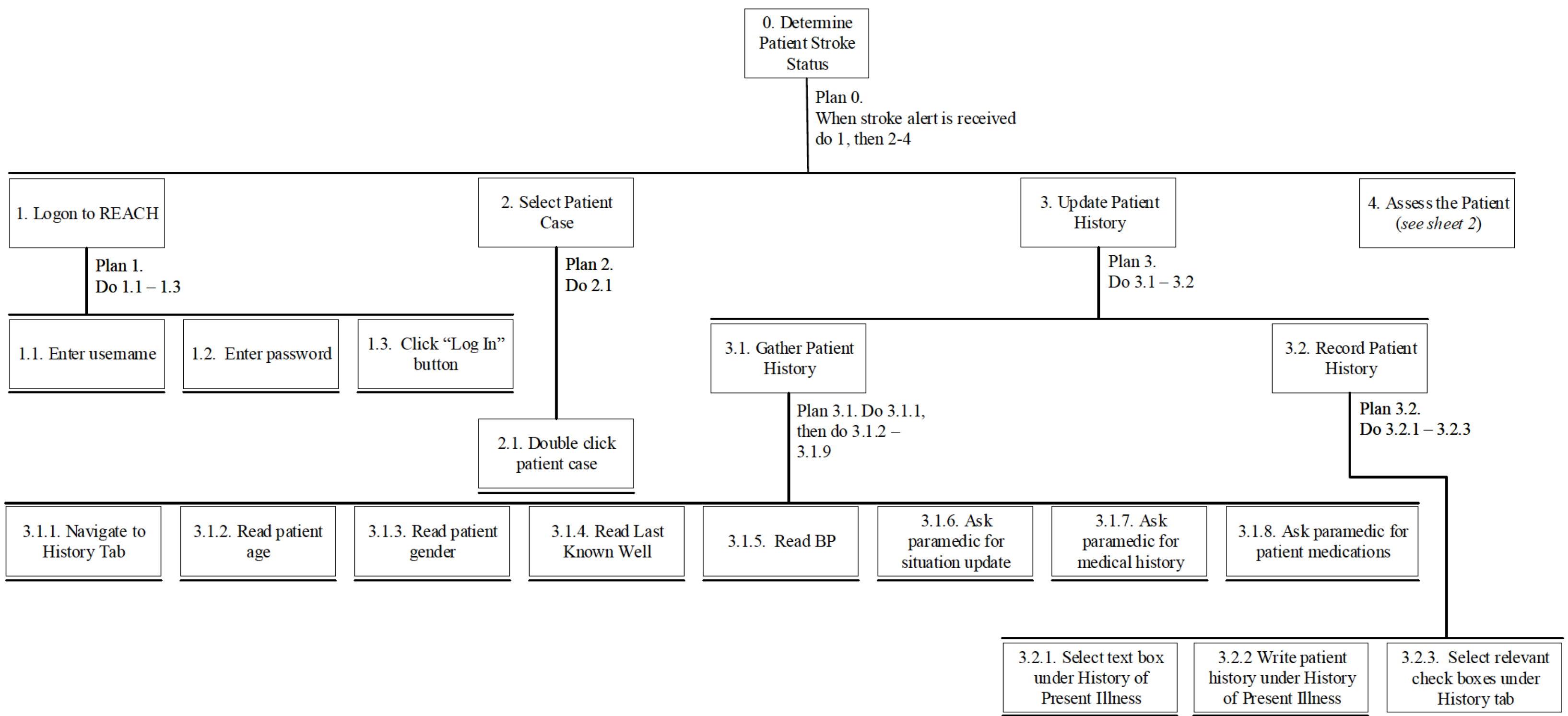


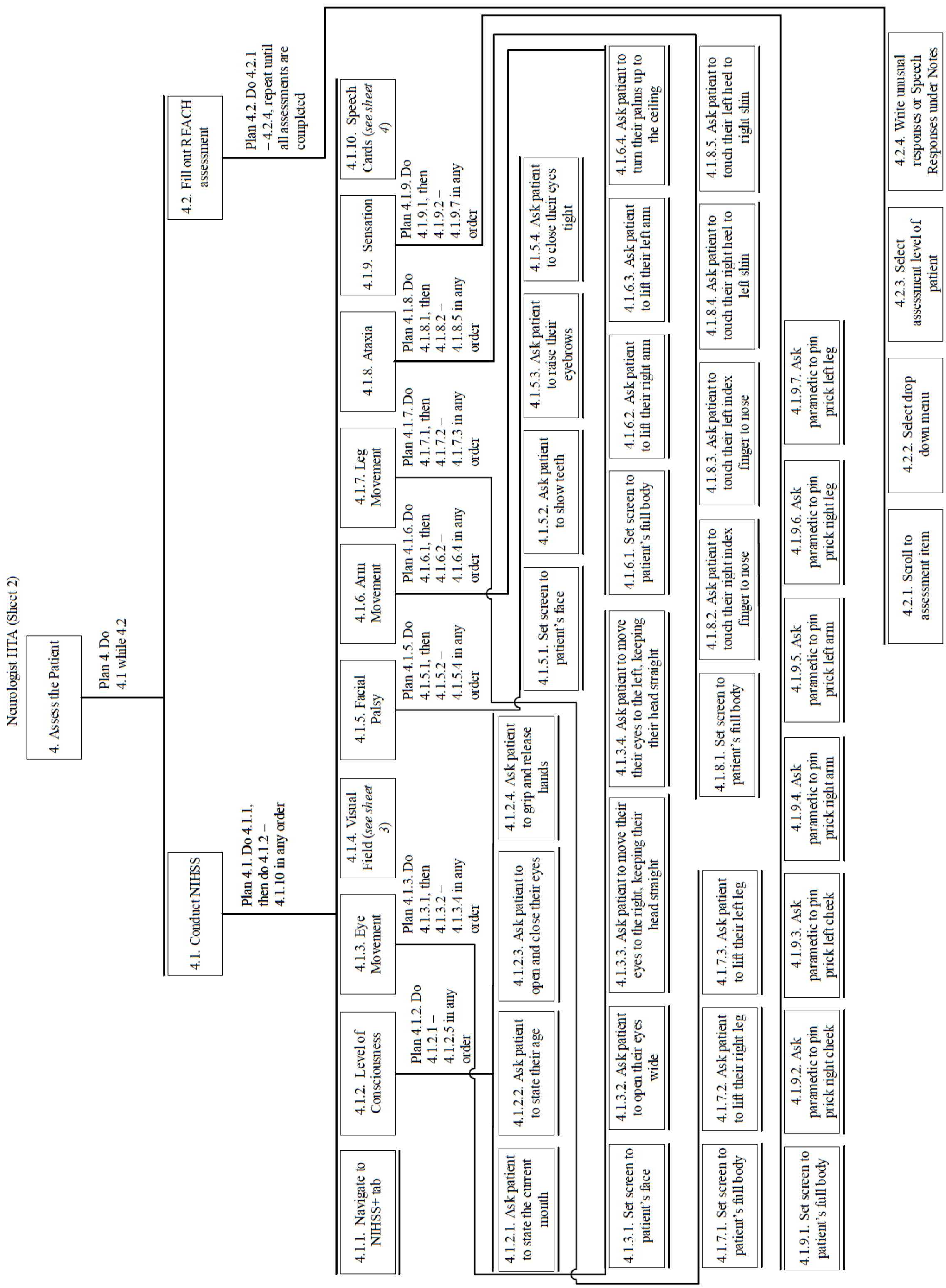
Paramedic HTA (Sheet 2)




Nurse HTA
0. Prepare ED for Patient Arrival
Plan 0. When stroke alert is called do 1, then 2-4
1. Logon to REACH
Plan 1. Do 1.1 – 1.3
1.1. Enter username
1.2. Enter password
1.3. Click "Log In" button
2. Create Patient Case
Plan 2. Do 2.1 – 2.8
2.1. Enter medic unit as last name
2.2. Enter current date as first name
2.3. Enter DOB as any date before today
2.4. Select Patient Gender
2.5. Enter EMS as Room/Bed
2.6. Select "Stroke - Urgent" in bottom selection box
2.7. Enter chief complaint as "Stroke Alert"
2.8. Click "Submit" button
3. Get Demographics
Plan 3. If patient is alert, do 3.1 – 3.4, else ask caregiver
3.1. Ask paramedic for patient's name
3.2. Update in REACH
3.3. Ask paramedic for patient's age
3.4. Update in REACH
4. Get Vitals
Plan 4. Do 4.1 – 4.13
4.1 Locate Nurses Lane
4.2. Ask paramedic for blood pressure
4.3. Record in REACH under BP
4.4. Ask paramedic for heart rate
4.5. Record in REACH under HR
4.6. Ask paramedic for respiratory rate
4.7. Record in REACH under RR
4.8. Ask paramedic for blood oxygen saturation
4.9. Record in REACH under SpO2(%)
4.10. Ask paramedic for point of care glucose
4.11. Record in REACH under POC Gluc
4.12. Ask paramedic for RACE score
4.13. Record in REACH under Chief Complaint

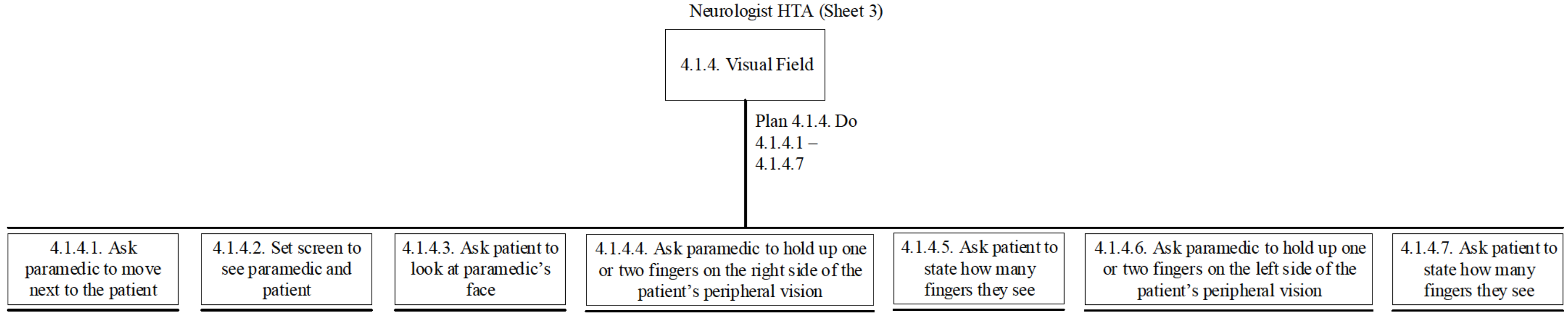
Neurologist HTA

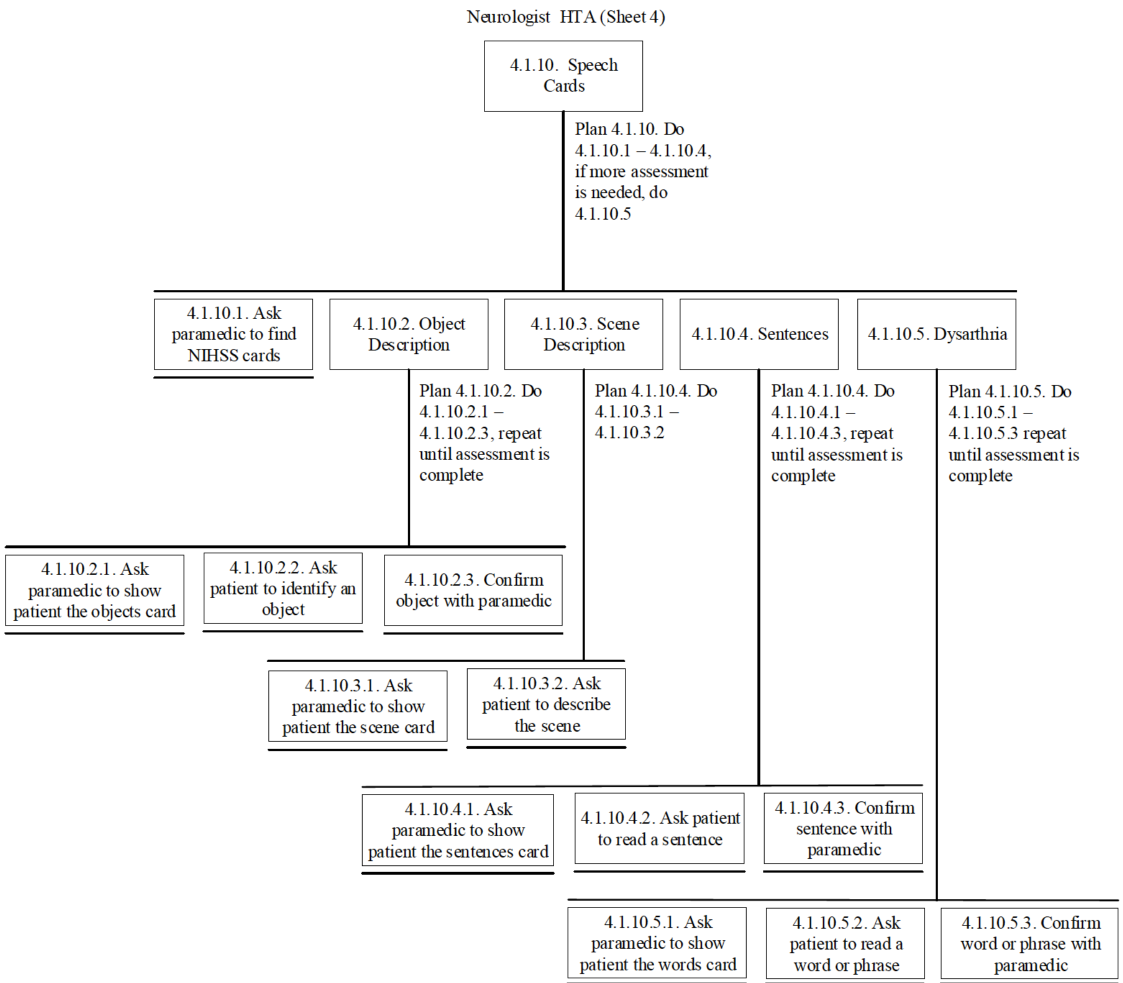




Neurologist HTA (Sheet 2)
4. Assess the Patient
Plan 4. Do 4.1 while 4.2
4.1. Conduct NIHSS
Plan 4.1. Do 4.1.1, then do 4.1.2 – 4.1.10 in any order
4.2. Fill out REACH assessment
Plan 4.2. Do 4.2.1 – 4.2.4, repeat until all assessments are completed
4.1.1. Navigate to NIHSS+ tab
4.1.2. Level of Consciousness
Plan 4.1.2. Do 4.1.2.1 – 4.1.2.5 in any order
4.1.3. Eye Movement
Plan 4.1.3. Do 4.1.3.1, then 4.1.3.2 – 4.1.3.4 in any order
4.1.4. Visual Field (see sheet 3)
4.1.5. Facial Palsy
Plan 4.1.5. Do 4.1.5.1, then 4.1.5.2 – 4.1.5.4 in any order
4.1.6. Arm Movement
Plan 4.1.6. Do 4.1.6.1, then 4.1.6.2 – 4.1.6.4 in any order
4.1.7. Leg Movement
Plan 4.1.7. Do 4.1.7.1, then 4.1.7.2 – 4.1.7.3 in any order
4.1.8. Ataxia
Plan 4.1.8. Do 4.1.8.1, then 4.1.8.2 – 4.1.8.5 in any order
4.1.9. Sensation
Plan 4.1.9. Do 4.1.9.1, then 4.1.9.2 – 4.1.9.7 in any order
4.1.10. Speech Cards (see sheet 4)
4.1.2.1. Ask patient to state the current month
4.1.2.2. Ask patient to state their age
4.1.2.3. Ask patient to open and close their eyes
4.1.2.4. Ask patient to grip and release hands
4.1.5.1. Set screen to patient's face
4.1.5.2. Ask patient to show teeth
4.1.5.3. Ask patient to raise their eyebrows
4.1.5.4. Ask patient to close their eyes tight
4.1.3.1. Set screen to patient's face
4.1.3.2. Ask patient to open their eyes wide
4.1.3.3. Ask patient to move their eyes to the right, keeping their head straight
4.1.3.4. Ask patient to move their eyes to the left, keeping their head straight
4.1.6.1. Set screen to patient's full body
4.1.6.2. Ask patient to lift their right arm
4.1.6.3. Ask patient to lift their left arm
4.1.6.4. Ask patient to turn their palms up to the ceiling
4.1.7.1. Set screen to patient's full body
4.1.7.2. Ask patient to lift their right leg
4.1.7.3. Ask patient to lift their left leg
4.1.8.1. Set screen to patient's full body
4.1.8.2. Ask patient to touch their right index finger to nose
4.1.8.3. Ask patient to touch their left index finger to nose
4.1.8.4. Ask patient to touch their right heel to left shin
4.1.8.5. Ask patient to touch their left heel to right shin
4.1.9.1. Set screen to patient's full body
4.1.9.2. Ask paramedic to pin prick right cheek
4.1.9.3. Ask paramedic to pin prick left cheek
4.1.9.4. Ask paramedic to pin prick right arm
4.1.9.5. Ask paramedic to pin prick left arm
4.1.9.6. Ask paramedic to pin prick right leg
4.1.9.7. Ask paramedic to pin prick left leg
4.2.1. Scroll to assessment item
4.2.2. Select drop down menu
4.2.3. Select assessment level of patient
4.2.4. Write unusual responses or Speech Responses under Notes

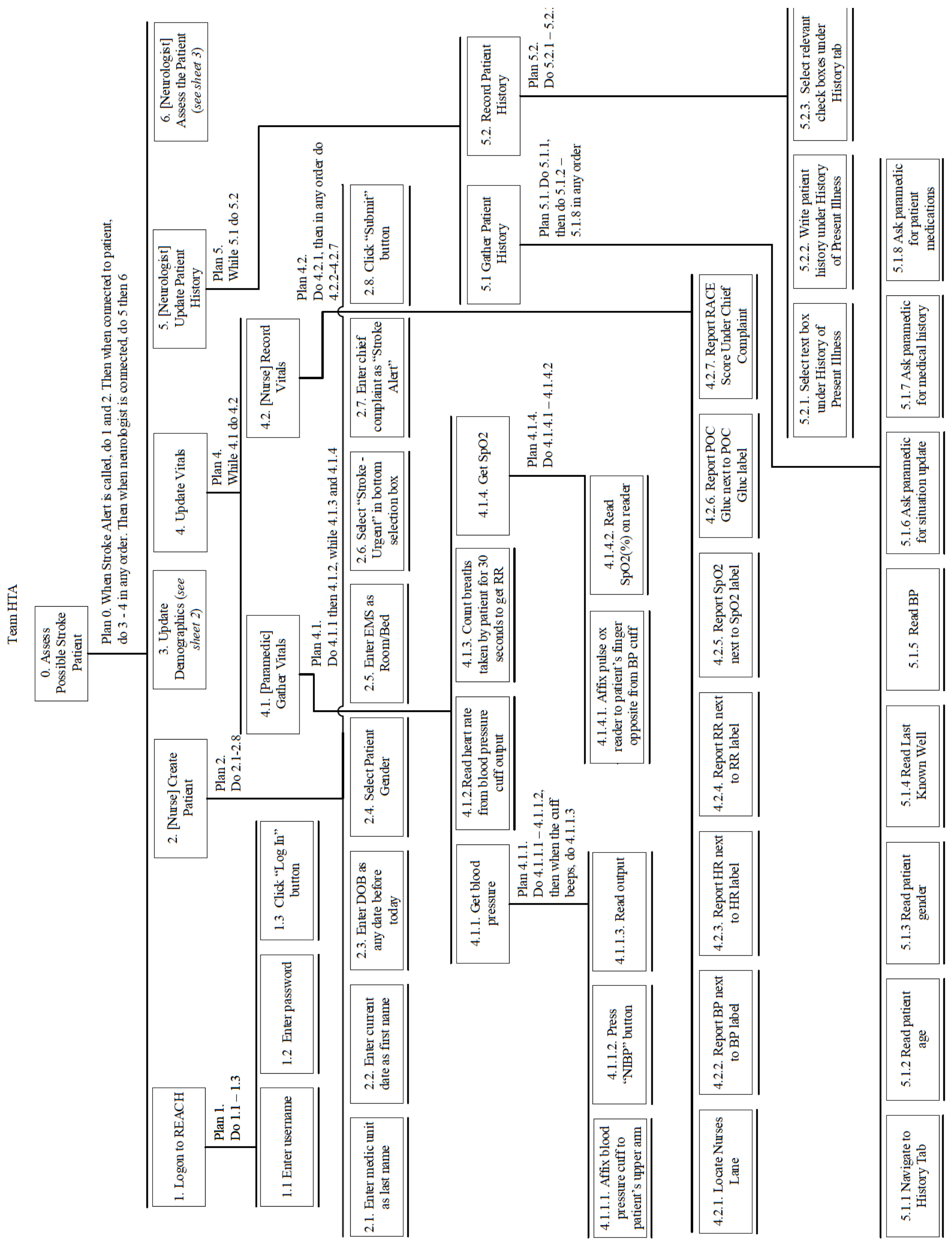
Neurologist HTA (Sheet 3)



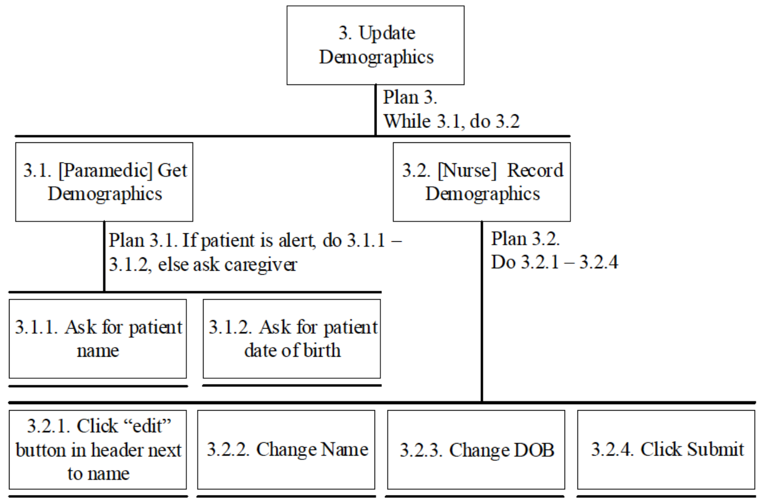

Neurologist HTA (Sheet 4)
4.1.10. Speech Cards
Plan 4.1.10. Do 4.1.10.1 – 4.1.10.4, if more assessment is needed, do 4.1.10.5
4.1.10.1. Ask paramedic to find NIHSS cards
4.1.10.2. Object Description
4.1.10.3. Scene Description
4.1.10.4. Sentences
4.1.10.5. Dysarthria
Plan 4.1.10.2. Do 4.1.10.2.1 – 4.1.10.2.3, repeat until assessment is complete
Plan 4.1.10.4. Do 4.1.10.3.1 – 4.1.10.3.2
Plan 4.1.10.4. Do 4.1.10.4.1 – 4.1.10.4.3, repeat until assessment is complete
Plan 4.1.10.5. Do 4.1.10.5.1 – 4.1.10.5.3 repeat until assessment is complete
4.1.10.2.1. Ask paramedic to show patient the objects card
4.1.10.2.2. Ask patient to identify an object
4.1.10.2.3. Confirm object with paramedic
4.1.10.3.1. Ask paramedic to show patient the scene card
4.1.10.3.2. Ask patient to describe the scene
4.1.10.4.1. Ask paramedic to show patient the sentences card
4.1.10.4.2. Ask patient to read a sentence
4.1.10.4.3. Confirm sentence with paramedic
4.1.10.5.1. Ask paramedic to show patient the words card
4.1.10.5.2. Ask patient to read a word or phrase
4.1.10.5.3. Confirm word or phrase with paramedic

Appendix F

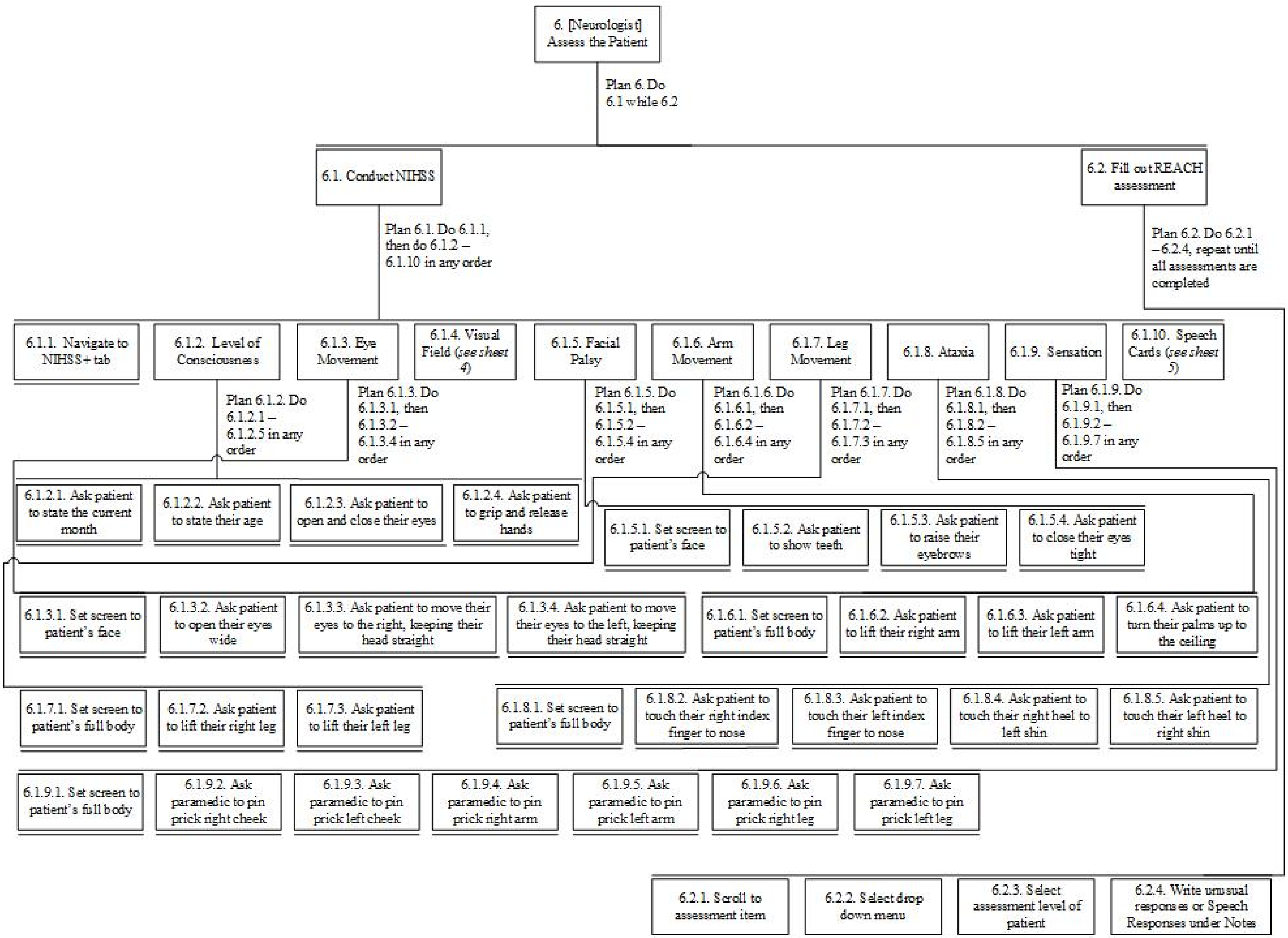
Team HTA Diagram



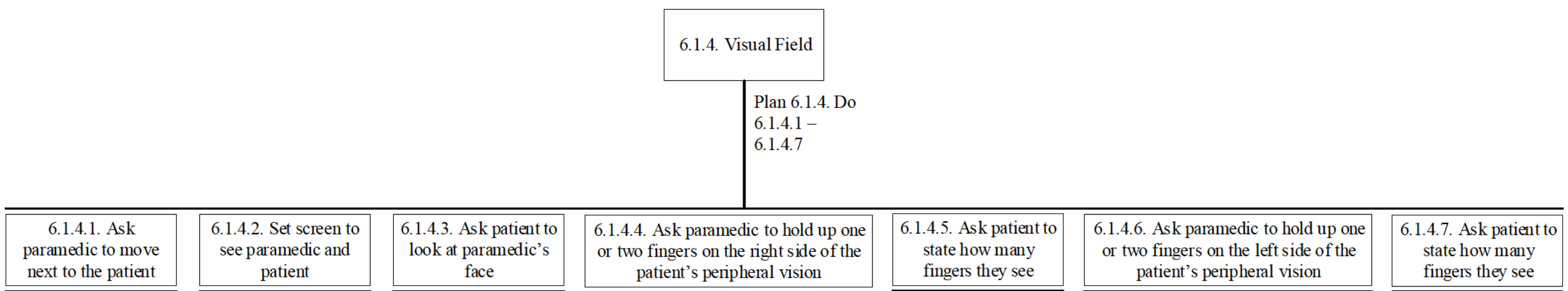
Team HTA (Sheet 2)



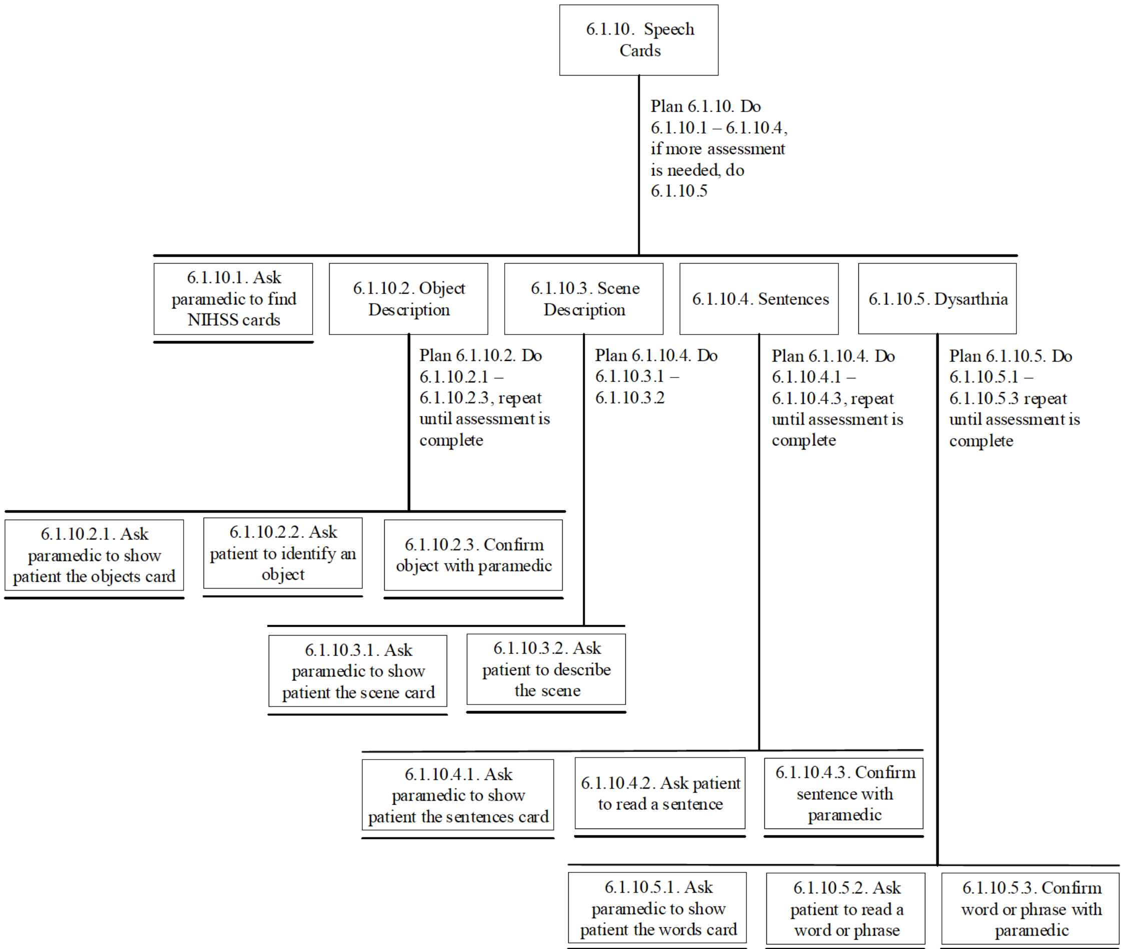
Team HTA (Sheet 3)



Team HTA (Sheet 4)



Team HTA (Sheet 5)



Appendix G

Team HTA Table

Subgoal and Plan	Teamwork Description
0. Assess Possible Stroke Patient Plan: When Stroke Alert is called, do 1 and 2. Then when connected to patient, do 3 - 4 in any order. Then when neurologist is connected, do 5 then 6	Goal: determine if a patient is experiencing or has experienced a stroke to further inform care decisions and alert emergency department Teamwork: This requires input from EMS, collecting patient information and vitals, and neurologist, conducting assessment. Nurses are also involved to manage recording of information and for successful handoff to ED Plan: log on and then create the patient in the system, then collect necessary information from patient or EMS to conduct an assessment Criterion measure: determination of stroke and handoff to ED
1. [Everyone] Log on to REACH Plan: Do 1.1-1.3	Does not require teamwork
2. [Nurse] Create Patient Plan: Do 2.1-2.8	Does not require teamwork
3. [Nurse] Update Demographics Plan: While 3.1 do 3.2	Goal: update patient case to reflect actual patient demographics Teamwork: to gather demographics from paramedics Plan: ask paramedic verbally over REACH audio system for information Criterion measure: patient name and accurate date of birth identified and updated in REACH
3.1. [Paramedic] Gather Demographics Plan: If patient is alert and can respond, do 3.1.1-3.1.2, else ask caregiver	Does not require teamwork
3.2. [Nurse] Record Demographics Plan: Do 3.2.1-3.2.4	Goal: record accurate patient demographics in REACH Teamwork: to gather demographics from Paramedics Plan: ask paramedic verbally over REACH audio system for information Criterion measure: patient name and date of birth are changed in REACH
4. [Nurse] Update Vitals Plan: While 4.1, do 4.2	Goal: update patient case to reflect actual patient vitals Teamwork: to gather vitals from paramedics Plan: ask paramedic verbally over REACH audio system for information after seeing paramedic collect information visually Criterion measure: patient case vitals are complete and correct
4.1. [Paramedic] Gather Vitals Plan: Do 4.1.1 then 4.1.2, while doing 4.1.3 and 4.1.4	Does not require teamwork

4.2. [Nurse] Record Vitals Plan: Do 4.2.1, then in any order do 4.2.2-4.2.7	Goal: record accurate patient vitals in REACH Teamwork: to gather vitals from paramedics Plan: ask paramedic verbally over REACH audio system for information Criterion measure: patient vitals are changed in REACH
5. [Neurologist] Update Patient History Plan: While 5.1 ,do 5.2	Goal: update patient case to include a detailed patient history Teamwork: to gather and understand patient history from paramedics Plan: ask paramedic verbally over REACH audio system for information Criterion measure: patient history is complete and accurate
5.1. [Neurologist] Gather Patient History Plan: Do 5.1.1, then in any order do 5.1.2-5.1.8	Goal: record accurate patient history in REACH Teamwork: to gather history from paramedics Plan: ask paramedic verbally over REACH audio system for information Criterion measure: patient history are updated in REACH
5.2. [Neurologist] Record Patient History Plan: Do 5.2.1-5.2.3	Does not require teamwork
6. [Neurologist] Assess Patient with NIHSS Plan: While 6.1, do 6.2	Goal: To determine if patient is experiencing or has experienced a stroke and the severity of that stroke Teamwork: to gather and understand information from the patient and patient responses Plan: ask patient directly for information and have paramedic help in assessment Criterion measure: NIHSS score is completed
6.1 [Neurologist] Conduct NIHSS Plan: Do 6.1.1, then do 6.1.2-6.1.10 in any order	Goal: evaluate severity of a potential stroke with a series of sub scales Teamwork: to gather assessments through paramedic interaction with the patient Plan: ask patient directly for information and have paramedic help in assessment Criterion measure: all assessment categories are evaluated
6.1.2 [Neurologist] Level of Consciousness Plan: Do 6.1.2.1-6.1.2.4 in any order	Does not require teamwork
6.1.3 [Neurologist] Eye Movement Plan: Do 6.1.3.1-6.1.3.4 in any order	Does not require teamwork
6.1.4 [Neurologist] Visual Field Plan: Do 6.1.4.1-6.1.4.7	Goal: evaluate the width of the patients visual field Teamwork: gather patient peripheral vision ability using paramedic interaction with the patient Plan: Explain to paramedic what motions are needed to help in assessment and evaluate patient response Criterion measure: determine if patient can see in peripheral vision, and if not, determine deficit

6.1.5 [Neurologist] Facial Palsy Plan: Do 6.1.5.1, then 6.1.5.2-6.1.5.4 in any order	Does not require teamwork
6.1.6 [Neurologist] Arm Movement Plan: Do 6.1.6.1, then 6.1.6.2-6.1.6.4 in any order	Does not require teamwork
6.1.7 [Neurologist] Leg Movement Plan: Do 6.1.7.1, then 6.1.7.2-6.1.7.3 in any order	Does not require teamwork
6.1.8 [Neurologist] Ataxia Plan: Do 6.1.8.1, then 6.1.8.2-6.1.8.5 in any order	Does not require teamwork
6.1.9 [Neurologist] Sensation Plan: Do 6.1.9.1, then 6.1.9.2-6.1.9.7 in any order	Goal: evaluate the patients sensation reactions Teamwork: gather patient limb sensation response using paramedic interaction with the patient Plan: Explain to paramedic what limbs to pin prick to help in assessment and evaluate patient response Criterion measure: determine if patient has normal stimuli reactions in all limbs
6.1.10 [Neurologist] Language and Processing Cards Plan: Do 6.1.10.1 then 6.1.10.2-6.1.10.3, if more assessment is needed do 6.1.10.4 then 6.1.10.5	Goal: evaluate the speech and mental processing of the patient Teamwork: gather patient mental and speech ability using paramedic interaction with the patient Plan: Explain to paramedic which cards to use to evaluate patient and confirm correct responses to assess patient responses Criterion measure: determine if patient has speech or cognitive deficits
6.1.10.2 [Neurologist] Object Description Plan: Do 6.1.10.2.1-6.1.10.2.3	Goal: evaluate the ability of the patient to recall object description Teamwork: use paramedic to show patient the object card Plan: Explain to paramedic which card to use and confirm correct responses to assess patient responses Criterion measure: determine if patient has cognitive deficits
6.1.10.3 [Neurologist] Scene Description Plan: Do 6.1.10.3.1-6.1.10.3.2	Goal: evaluate the ability of the patient to recall scene description Teamwork: use paramedic to show patient the scene card Plan: Explain to paramedic which card to use and confirm correct responses to assess patient responses Criterion measure: determine if patient has cognitive deficits
6.1.10.4 [Neurologist] Sentence Repeat Plan: Do 6.1.10.4.1-6.1.10.4.3	Goal: evaluate the ability of the patient to correctly read sentences out loud Teamwork: use paramedic to show patient the sentence card Plan: Explain to paramedic which card to use and confirm correct responses to assess patient responses Criterion measure: determine if patient has speech deficits

6.1.10.5 [Neurologist] Dysarthria Plan: Do 6.1.10.5.1-6.1.10.5.3	Goal: evaluate the ability of the patient to correctly read phrases out loud Teamwork: use paramedic to show patient the phrase card Plan: Explain to paramedic which card to use and confirm correct responses to assess patient responses Criterion measure: determine if patient has speech deficits
6.2 [Neurologist] Record Assessment Plan: Do 6.2.1-6.2.3, then do 6.2.4 as needed	Does not require teamwork

Appendix H

Heuristic Evaluation Form

Nurse Role Tasks

Start	Task No	Task	Knowledge Requirement
You get a call from a dispatcher with the stoke alert, Now do tasks 1 and 2	1.0	Log on to REACH system	User ID: nurse@email.com and Password: 1234
	2.0	Create patient	
	2.1	Enter Medic unit as last name	
	2.2	Enter todays date as first name	
	2.3	Enter DOB greater than today's date	Stroke Alert: "We have a possible stroke in Medic 1, 60 year old Female with Last Known Well at 8 this morning, please prepare for REACH consult and notify MUSC"
	2.4	Enter Gender	
	2.5	Enter EMS as Room/Bed	
	2.6	Select "Stroke – Urgent" in bottom selection box	
	2.7	Enter Reason for Consult as "Stroke Alert"	
Once EMS logs onto REACH do task 3 and 4	3.0	Demographics	
	3.1	Update Patient Name	"Patient's Name is Ann Job, date of Birth is August 12 1959"
	3.2	Update Patient Date of Birth	
	4.0	Get vitals	
	4.1	Record Last Known Well	Stroke alert
	4.3	Record Blood Pressure	
	4.4	Record Heart Rate	
	4.5	Record Respiratory Rate	"BP is 180 over 90, Heart rate is 110, Respiratory rate is 25 per minute, pulse ox is 98 percent, Glucose is 104, and RACE is 6"
	4.6	Record Blood Oxygen Saturation	
	4.7	Record Point of Care Glucose	
	4.8	Record RACE score under Chief Complaint	

Paramedic Tasks

Start	Task No	Task	Knowledge Requirements
Once you enter the ambulance do 1 and 2	1	Log on to REACH	User ID: ems@email.com and Password: 1234
	2	Enter Patient Case	

Neurologist Tasks			
Start	Task No	Task	Knowledge Requirement
You get a call from the hospital for a consult, do steps 1 and 2	1	Log on to REACH system	User ID: neuro@email.com and Password: 1234
	2	Select Patient Case	
Once connected with paramedic do 3, then 4	3	Record patient history	"After the patient woke up this morning at 8 her husband noticed she was slurring her speech, she said she had a headache and couldn't see well" "The patient is retired, has a history of high blood pressure, and a family history of diabetes, Nonsmoker and drinker, and no drugs"
	4	Conduct NIHSS Exam	
	4.1	Level of Consciousness	
	4.2	Eye movement	
	4.3	Visual Field	patient can answer age but not the current month and needed to be asked multiple times
	4.4	Facial Palsy	patient has trouble opening eyes and gripping, gaze is direct, shows partial hemianopia
	4.5	Arm Movement	minor paralysis on the left side, right arm and leg responds normally to movement and sensation, the left arm and leg drift and are only partially responsive to stimuli, limb ataxia present on the left
	4.6	Leg Movement	
	4.7	Ataxia	patient slurs speech and shows indicators of mild aphasia, commands needed to be repeated and loudly to be understood
	4.8	Sensation	
	4.9	Dysarthria and Language	

Appendix I

Heuristic Violations

Nurse Tasks (1)

Task No	Task	Violation Type	Description	Severity
1.0	Log on to REACH system	Visibility of System Status	No update on what (ID/password) was entered wrong	4
		Error Prevention	No indication of format for email or password	3
		Help users recognize, diagnose, and recover from errors	No error message	4
		Help users recognize, diagnose, and recover from errors	System does not show password to check the entered information	3
2.0	Create patient	Visibility of System Status	No feedback on what was being entered incorrectly	4
		Aesthetic and Minimalist Design	The heading and the data entry box are not aligned. Also, there is unnecessary space between them which confuses where to enter the data correctly	1
		Help users recognize, diagnose, and recover from errors	No error message on what is entered incorrectly	4
2.1	Enter medic unit as last name	Visibility of System Status	No indication of what kind of inputs	1
		Visibility of System Status	Medic unit is not clear	3
		Aesthetic and Minimalist Design	Inconsistent use of gray highlights	1
		Help users recognize, diagnose, and recover from errors	No error messages of incorrect name formats	2
2.2	Enter current date as first name	Visibility of System Status	No indication of what kind of inputs	1
		Help users recognize, diagnose, and recover from errors	No error messages of incorrect name formats	2

Nurse Tasks (2)

Task No	Task	Violation Type	Description	Severity
2.3	Enter Gender	Consistency and Standards	Label for gender input is far separated from the input	2
		Aesthetic and Minimalist Design	Label is not in line	1
2.4	Enter DOB greater than current date	Visibility of System Status	Distance of label makes it unclear what input is needed	1
		Visibility of System Status	Date requirements not known in system until after pressing submit	3
		Match Between System and Real World	The system does not have a calendar drop down as seen often with other systems	1
		Match Between System and Real World	Certain date formatting is not allowed	3
		User Control and Freedom	Certain date formatting is not allowed	3
		Consistency and Standards	In most of the places, the date is entered in DD/MM/YYYY format. Either this should follow the same standards or accept multiple formats	3
		Error Prevention	The space between the words "Date of birth" and the data entry column is too much and is not aligned. This creates the doubt on whether that's the correct space to enter the information	2
		Error Prevention	The date entry format cannot be seen. Ideally, it should have a previous entry of format that is required (like MM/DD/YYYY or DD/MM/YYYY) or have a calendar input	2.5
		Recognition Rather than Recall	It would be easier if there was a drop down list for dates	2

Nurse Tasks (3)

Task No	Task	Violation Type	Description	Severity
2.5	Enter EMS as Room/Bed	Visibility of System Status	Distance of label makes it unclear what input is needed	1
		Match Between System and Real World	EMS is not a room or bed; label should be more inclusive	1
		Error Prevention	No set up for input to tell user what formats are available	3
		Aesthetic and Minimalist Design	Distance from input	1
2.6	Select "Stroke – Urgent" in bottom selection box	Visibility of System Status	If the gray background changing to white is to highlight that option, a better color contrast could be used since most of the other parts of the website has a white background	2
		Consistency and Standards	There is no label for check boxes	1
		Recognition Rather than Recall	There is no label for check boxes, which means that because the check boxes are attached to the reason for consult, they assume that is what it is	2
2.7	Enter Reason for Consult as "Stroke Alert"	Visibility of System Status	Reason for consult box does not change with the change of consult type	2
		Error Prevention	No framework for input	1
3.0	Demographics	Visibility of System Status	Hard to gain access to the next part of the system- had multiple issues submitting	4
		Consistency and Standards	Bolding and type of the demographics bar are not consistent	1
		Consistency and Standards	Non-consistent use of blocks	1
		Consistency and Standards	The patient name is highlighted in the same way as other headings like start/stop camera. However, they are not the same. If the name needs to be highlighted, use different color combination	2
		Help and Documentation	Support number is small and hard to read	2

Nurse Tasks (4)

Task No	Task	Violation Type	Description	Severity
		Visibility of System Status	Edit button does not make it clear that you edit all demographics with that button	2
		Visibility of System Status	With so much pink on the page, the edit button may not be visible	3
		Consistency and Standards	Format for filling out demographics is different than patient creation	2
		Consistency and Standards	The patient name has a pink background and white letters while the rest 4 has white background and black letter while the last column (room/bed) has white background and pink letter. All these inconsistencies are not required	2
3.1	Update Patient Name	Aesthetic and Minimalist Design	Unnecessary use of multiple (6) edit buttons on the top when everything leads to the same place	2
		Visibility of System Status	Edit button does not make it clear that you edit all demographics with that button	2
3.2	Update Patient Date of Birth	Consistency and Standards	Format for filling out demographics is different than patient creation	2

Nurse Tasks (5)

Task No	Task	Violation Type	Description	Severity
4.0	Get vitals	Visibility of System Status	Not clear that there is a box to input this until you scroll over it	3
		Consistency and Standards	Vitals heading is on the right; however, the Last Known Well information is not under the vital section (it is on the right)	2
		Consistency and Standards	Headings are not provided to the section on the left and the ones at the bottom (Medications and allergies) have headings, but are not consistent with the others	2
		Consistency and Standards	The data entry box could have information in it to show the format in which the data needs to be entered. For example, if it is time the information can be HH:MM AM/PM or something similar in a lighter font	3
		Error Prevention	There should be feedback given that you entered valid information	3
		Error Prevention	Vitals heading is on the right; however, the Last Known Well information is not under the vital section (it is on the right)	2
		Error Prevention	The data entry box could have information in it to show the format in which the data needs to be entered. For example, if it is time the information can be HH:MM AM/PM or something similar in a lighter font	3
		Flexibility and Efficiency of Use	Multiple areas for data entry which may make things confusing	2
		Match Between System and Real World	Abbreviations are used, not full names	1
		Visibility of System Status	Updated vital signs are denoted with an icon that must be clicked additionally	2
		Consistency and Standards	No formatting to detail which measurement are required like in demographics	2
		Recognition Rather than Recall	No set format for measurement	2
		Help and Documentation	Should be able to scroll over each and have info about data to be entered	2

Nurse Tasks (6)

Task No	Task	Violation Type	Description	Severity
4.1	Record Last Known Well	Visibility of System Status	No format for date and time	2
4.3	Record Blood Pressure	Flexibility and Efficiency of Use	Having a "/" between mm and Hg would be an accelerator	1
4.4	Record Heart Rate			
4.5	Record Respiratory Rate			
4.6	Record Blood Oxygen Saturation	Visibility of System Status	The data entry box for blood oxygen is not clearly marked or is using a different term which is not in line with the real world usage of the term	4
		Match Between System and Real World	The data entry box for blood oxygen is not clearly marked or is using a different term which is not in line with the real world usage of the term	4
4.7	Record Point of Care Glucose			

Nurse Tasks (7)

Task No	Task	Violation Type	Description	Severity
4.8	Record RACE score under Chief Complaint	Visibility of System Status	RACE score option was not visible. (This option was noticed later when I was going through the neuro page)	4
		Match Between System and Real World	EMS saying, "RACE is 6" and the title of the data entry box "chief complaint" is not matching	3
		Consistency and Standards	No label for RACE score or indication to put in under complaint in interface	3
		User Control and Freedom	Could not use return button to enter information	2
		Error Prevention	No set location for RACE score	3
		Recognition Rather than Recall	EMS saying, "RACE is 6" and the title of the data entry box "chief complaint" is not matching	3
		Flexibility and Efficiency of Use	RACE score option was not visible. (This option was noticed later when I was going through the neuro page)	4

Paramedic Tasks				
Task No	Task	Violation Type	Description	Severity
		Visibility of System Status	No update on what (ID/password) was entered wrong	4
		Error Prevention	No indication of format for email or password	3
1	Log on to REACH	Help users recognize, diagnose, and recover from errors	No error message	4
		Help users recognize, diagnose, and recover from errors	System does not show password to check the entered information	3
		Visibility of System Status	Data entry box for patient case is not visible	4
2	Enter Patient Case	Visibility of System Status	Not clear that you can click on patient case until you scroll over	3
		Flexibility and Efficiency of Use	Medic unit identified in name but this could be a separate field for the patient	2
		Flexibility and Efficiency of Use	Data entry box for patient case is not visible	4

Neurologist Tasks (1)

Task No	Task	Violation Type	Description	Severity
1	Logon to REACH system	Visibility of System Status	No update on what (ID/password) was entered wrong	4
		Error Prevention	No indication of format for email or password	3
		Help users recognize, diagnose, and recover from errors	No error message	4
		Help users recognize, diagnose, and recover from errors	System does not show password to check the entered information	3
2	Select Patient Case	Visibility of System Status	"Pending consults" and "my active consults" should be differentiated more (for example, by highlighting them)	3
		Visibility of System Status	Not clear you can select until scroll over	3
		Match Between System and Real World	Patient name should be in stroke alert, but could be written as something else	1
		User Control and Freedom	Assigned patients should be separated from unassigned patients	2
		Consistency and Standards	The tab is for active consults. However, the pending consults are in the same tab too. Ideally, when the neuro logs in, it should just show the pending tabs which would save time and avoid errors	3
		Error Prevention	"Pending consults" and "my active consults" should be differentiated more (for example, by highlighting them)	3
		Error Prevention	The tab is for active consults. However, the pending consults are in the same tab too. Ideally, when the neuro logs in, it should just show the pending tabs which would save time and avoid errors	3
		Recognition Rather than Recall	There is no indication that this patient is assigned to me, other than its under pending consults, I would have to remember the name of the patient to identify	2
		Flexibility and Efficiency of Use	Medic information in stroke alert could be its own field rather than name to indicate the correct session	2
		Aesthetic and Minimalist Design	Only relevant information about the patient to identify should be shown, the reason for the consult may not be necessary if you have the consult type already	2

Neurologist Tasks (2)

Task No	Task	Violation Type	Description	Severity
3	Record patient history	Visibility of System Status	"Review of systems" did not look clickable. It took some time and luck to figure that out	3
		Match Between System and Real World	The heading "history of present illness" is kind of confusing since it is a history of present! Better words can be recommended	0
		Consistency and Standards	First task is not on the first page	2
		Consistency and Standards	The use of radio button is inconsistent. Alcohol use and substance use should also have radio buttons since they are single answer questions than multiple choice	2.5
		Consistency and Standards	"Review of systems" did not look clickable. It took some time and luck to figure that out	3
		Consistency and Standards	Not clear how to actually enter information in other than having to click outside the box	3
		Consistency and Standards	More than one location to enter text for history	2
		Error Prevention	None reported selection does not prevent other items from being selected or deselects none reported	3
		Error Prevention	Should be an input button to confirm input	3
		Error Prevention	"Review of systems" did not look clickable. It took some time and luck to figure that out. Initially, I entered those information manually under the "history of present illness" option	3
		Recognition Rather than Recall	No format for completing patient history except check boxes	1
		Recognition Rather than Recall	"ROS notes" is not clear. I had to go to the top and figure out it meant review of systems. It had me recalling the information than recognizing it	1
		Flexibility and Efficiency of Use	Need to click on the history tab to complete the first task	2
		Flexibility and Efficiency of Use	Multiple scroll bars can get complicated and confusing to use	2
		Aesthetic and Minimalist Design	More than one text box with history labels	2
		Aesthetic and Minimalist Design	Unnecessary use of abbreviations (PMH, PSH, FH) which can take additional time or confuse. The information architecture of the page could be improved by removing such unnecessary information.	1

Neurologist Tasks (3)

Task No	Task	Violation Type	Description	Severity
4	Conduct NIHSS Exam	Visibility of System Status	"Repeat NIHSS" did not look clickable	3
		Visibility of System Status	Each drop down box should specifically have text indicating the menu drops down	3
		Visibility of System Status	Answers cannot be seen properly for all the options	3
		Match Between System and Real World	Add colors indicating different levels of severity	2
		User Control and Freedom	Very little flexibility in the options for NIHSS	2
		User Control and Freedom	No option to undo the radio button in the page (bedside and consulting physician)	3
		Consistency and Standards	Some items have multiple selections that could be a 3 on the scale	1
		Consistency and Standards	"Repeat NIHSS" did not look clickable	3
		Consistency and Standards	Not all items have the same highest level	2
		Consistency and Standards	Unnecessary use of bold letter throughout	1
		Error Prevention	Should be a final confirmation button that forces you to review all of the inputs before moving to next area in system	3
		Error Prevention	"Repeat NIHSS" did not look clickable	3
		Flexibility and Efficiency of Use	With the options being limited and notes may be needed, there’s only an overall note section rather than individual notes for each selection	2
		Flexibility and Efficiency of Use	Multiple scroll bars can get complicated and confusing to use	2

Neurologist Tasks (4)

Task No	Task	Violation Type	Description	Severity
4.1	Level of Consciousness	Match Between System and Real World	Unclear as to why the items are labelled 1a-c, do the items add up to a score for 1 item?	2
4.2	Eye movement			
4.3	Visual Field			
4.4	Facial Palsy			
4.5	Arm Movement	Visibility of System Status	Unclear as to how the unstable selection contributes to overall score	2
4.6	Leg Movement			
4.7	Ataxia			
4.8	Sensation			
4.9	Dysarthria and Language			

Appendix J

SHERPA Table

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
0	Assess Possible Stroke Patient							
1	Log on to REACH							
1.1	Enter UserID	A7, 8, 9	Incorrect or incomplete User ID	Cannot enter system	Immediately	L	M	Highlight required field, saved personal info, role specific log in
1.2	Enter Password	A7, 8, 9	Incorrect or incomplete Password	Cannot enter system	Immediately	L	M	Highlight required field, saved personal info, role specific log in
1.3	Click Log In button	A8	Button not clicked	Cannot enter system	Immediately	L	L	Enlarge button
2	Create Patient							
2.1	Enter Medic unit as last name	A6, 8	Medic unit not correctly recorded in last name or placed elsewhere	Cannot create patient	Immediately	M	L	Highlight required field, suggestions for how to fill
2.2	Enter todays date as first name	A6, 8	Date not correctly recorded in first name or placed elsewhere	Cannot create patient	Immediately	L	L	Highlight required field, suggestions for how to fill
2.3	Enter DOB greater than current date	A6, 8	DOB not correctly formatted or omitted	Cannot create patient	3.2.2	L	M	Create rigid formatting, highlight required field
2.4	Enter Gender	A6	Gender incorrectly selected	Will need to change later	3.2.2	L	L	
2.5	Enter EMS as Room/Bed	A8	EMS not written as Room	Cannot create patient	3.2.2	M	L	Highlight required field, suggestions for how to fill

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
2.6	Select Stroke – Urgent in bottom selection box	A6, 8	Reason for consult not selected or stroke not selected	Cannot create patient when omitted, will not be allocated to the right people if incorrectly selected	3.2.2	M	L	Highlight required field, suggestions for how to fill
2.7	Enter Reason for Consult as Stroke Alert	A8	No reason for consult written	Cannot create patient	3.2.2	L	L	Highlight required field, suggestions for how to fill
2.8	Click Submit Button	A8	Button not clicked	Cannot create patient	Immediately	L	L	Enlarge button
3	Update Demographics							
3.1	Gather Demographics							
3.1.1	Ask Patient for Name	I1,3	Patient did not hear paramedic or vice versa	Cannot properly update patient case	Immediately	L	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
3.1.2	Ask Patient for Birthday	I1,3	Patient did not hear paramedic or vice versa	Cannot properly update patient case	Immediately	L	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
3.2	Record Demographics							
3.2.1	Click Edit button as it appears in the header next to name	A8	Button not clicked	Cannot properly update patient case	Immediately	L	L	Enlarge button or make it constantly visible
3.2.2	Change Name	A6, 8	Name not correctly recorded in correct sections or placed	Cannot properly update patient case	Immediately	L	L	Highlight required field, suggestions for how to fill
3.2.3	Change DOB	A6, 8	DOB not correctly formatted or omitted	Cannot properly update patient case	5.1.2	L	L	Create rigid formatting, highlight required field
3.2.4	Click Submit	A8	Button not clicked	Cannot properly update patient case	Immediately	L	L	Enlarge button
4	Update Vitals							
4.1	Gather Vitals							
4.1.1	Get BP							
4.1.1.1	Affix blood pressure cuff to patient upper arm	A6,8,9	Step omitted, cuff incorrectly placed or not secured properly on arm	Cannot assess blood pressure or heart rate	Immediately	M	L	Visual aids in environment displaying proper placement or alignment instructions for sleeve
4.1.1.2	Press NIBP button	A6, 8	Step omitted, wrong button pressed	Cannot assess blood pressure or heart rate	Immediately	M	L	Button label to read Start BP, visual aid
4.1.1.3	Read output	R1	Cannot read output or output not generated by machine	Cannot assess blood pressure	4.1.2	L	L	Bright simplified screen

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
4.1.2	Read HR output from blood pressure cuff	R1	Cannot read output or output not generated by machine	Cannot assess heart rate	Immediately	L	L	Bright simplified screen
4.1.3	Count breaths taken for 30 seconds to get RR	A1,9	Miscount, count breaths for more or less than a minute	Cannot assess respiratory rate	Immediately	M	M	Provide clicker or counter with timer to measure for time
4.1.4	Get SpO2							
4.1.4.1	Affix pulse ox reader to patient fingertip on opposite hand from BP cuff	A6,8,9	Step omitted, reader incorrectly placed or not secured properly on finger opposite from BP cuff	Cannot assess blood oxygenation	Immediately	M	L	Visual aid for placement
4.1.4.2	Read SpO2(%) on reader	R1	Cannot read output or output not generated by machine	Cannot assess blood oxygenation	Immediately	L	L	Bright simplified screen
4.2	Record Vitals							
4.2.1	Locate Nurses Lane	R3	Cannot find nurses lane	Cannot update vitals for all caregivers	Immediately	L	L	Highlight nurses lane for nurse log on, simplify system such that only task relevant screens are available
4.2.2	Report BP next to BP	A7,8	Cannot find correct input, report in the wrong format	Cannot update vitals for all caregivers	5.15	L	L	Highlight required vitals, ordered fill out form, obvious input boxes
4.2.3	Report HR next to HR	A7,8	Cannot find correct input, report in the wrong format	Cannot update vitals for all caregivers	Immediately	L	L	Highlight required vitals, ordered fill out form, obvious input boxes

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
4.2.4	Report RR next to RR	A7,8	Cannot find correct input, report in the wrong format	Cannot update vitals for all caregivers	Immediately	L	L	Highlight required vitals, ordered fill out form, obvious input boxes
4.2.5	Report SpO2 next to SpO2	A7,8	Cannot find correct input, report in the wrong format	Cannot update vitals for all caregivers	Immediately	L	L	Highlight required vitals, ordered fill out form, obvious input boxes
4.2.6	Report POC Gluc next to POC Gluc	A7,8	Cannot find correct input, report in the wrong format	Cannot update vitals for all caregivers	Immediately	L	L	Highlight required vitals, ordered fill out form, obvious input boxes
4.2.7	Report RACE Score in Chief Complaint	A7,8	Cannot find correct input, report in the wrong format	Cannot update information for all caregivers	Immediately	L	L	Highlight required vitals, ordered fill out form, obvious input boxes
5	Update Patient History							
5.1	Gather Patient History							
5.1.1	Navigate to History tab	S1,2	Cannot locate or incorrectly select a different tab	Cannot form a written patient history for chart	Immediately	L	L	Simplified screen for user relevant tasks, training
5.1.2	Read Patient Age	R1	Cannot locate	Cannot form a concept of patient history	Immediately	L	L	Automated highlight of important information, placement of important information on history tab
5.1.3	Read Patient Gender	R1	Cannot locate	Cannot form a concept of patient history	Immediately	L	L	Automated highlight of important information, placement of important information on history tab

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
5.1.4	Read Last Known Well	R1	Cannot locate	Cannot form a concept of patient history	Immediately	M	L	Automated highlight of important information, placement of important information on history tab
5.1.5	Read BP	R1	Cannot locate	Cannot form a concept of patient history	Immediately	M	L	Automated highlight of important information, placement of important information on history tab
5.1.6	Ask paramedic for situation update	I1	Paramedic cannot hear request, cannot hear response	Cannot form a concept of patient history	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
5.1.7	Ask paramedic for medical history	I1	Paramedic cannot hear request, cannot hear response	Cannot form a concept of patient history	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
5.1.8	Ask paramedic for Medications	I1	Paramedic cannot hear request, cannot hear response	Cannot form a concept of patient history	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
5.2	Record Patient History							
5.2.1	Select text box under History of Present Illness	S2	Does not select correct text box	Patient chart will be incomplete and patient care could suffer	Immediately	L	L	Highlight or require response
5.2.2	Write out patient information	A9	Incomplete history	Patient chart will be incomplete and patient care could suffer	Immediately	M	L	Natural language check for necessary completion, training of necessary items in history

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
5.2.3	Select relevant check boxes below History tab	S1,2	Incorrect selections made or insufficient selections made	Patient chart will be incomplete and patient care could suffer	Immediately	M	L	Require response for categories, highlight in order of normal processing
6	Assess Patient with NIHSS							
6.1	Conduct NIHSS							
6.1.1	Navigate to the NIHSS+ tab	S1,2	Cannot locate or incorrectly select a different tab	Cannot record assessment for patient chart	Immediately	L	L	Simplified screen for user relevant tasks, training
6.1.2	Level of Consciousness							
6.1.2.1	Ask patient for current month	I1	Patient cannot hear request, cannot hear response	Cannot form an assessment of how alert the patient is	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.2.2	Ask patient for current age	I1	Patient cannot hear request, cannot hear response	Cannot form an assessment of how alert the patient is	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.2.3	Ask patient to open and close eyes	I1	Patient cannot hear request	Cannot form an assessment of how alert the patient is	6.1.5.4	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.2.4	Ask patient to grip and release hands	I1	Patient cannot hear request	Cannot form an assessment of how alert the patient is	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
6.1.3	Eye movement							
6.1.3.1	Set screen to patient face	A3,4	Overshoot or under correct camera zoom or position	Cannot see patient movements with clarity to form assessment	Immediately	L	L	Automatic camera adjustments
6.1.3.2	Ask patient to open eyes wide	I1	Patient cannot hear request	Cannot form an assessment of patient eye movement	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.3.3	Ask patient to move eyes to the right, keeping their head straight	I1	Patient cannot hear request	Cannot form an assessment of patient eye movement	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.3.4	Ask patient to move eyes to the left, keeping their head straight	I1	Patient cannot hear request	Cannot form an assessment of patient eye movement	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.4	Visual Field							
6.1.4.1	Ask paramedic to move next to the patient	I1	Paramedic cannot hear request	Incorrect placement, faulty assessment	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.4.2	Set screen to see patient and paramedic	A3,4	Overshoot or under correct camera zoom or position	Cannot see patient movements with clarity to form assessment	Immediately	L	L	Automatic camera adjustments

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
6.1.4.3	Ask patient to look at paramedic face	I1	Patient cannot hear request	Cannot form an assessment of patient visual field	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.4.4	Ask paramedic to hold up one or two fingers in the patient peripheral on the right side	I1	Paramedic cannot hear request	Cannot form an assessment of patient visual field	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.4.5	Ask patient to say out loud how many finger they see	I1	Patient cannot hear request	Cannot form an assessment of patient visual field	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.4.6	Ask paramedic to hold up one or two fingers in the patient peripheral on the left side	I1	Paramedic cannot hear request	Cannot form an assessment of patient visual field	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.4.7	Ask patient to say out loud how many finger they see	I1	Patient cannot hear request	Cannot form an assessment of patient visual field	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.5	Facial Palsy							
6.1.5.1	Set screen to patient face	A3,4	Overshoot or under correct camera zoom or position	Cannot see patient movements with clarity to form assessment	Immediately	L	L	Automatic camera adjustments
6.1.5.2	Ask patient to show teeth	I1	Patient cannot hear request	Cannot form an assessment of severity of patient facial palsy	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
6.1.5.3	Ask patient to raise eyebrows	I1	Patient cannot hear request	Cannot form an assessment of severity of patient facial palsy	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.5.4	Ask patient to close eyes tight	I1	Patient cannot hear request	Cannot form an assessment of severity of patient facial palsy	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.6	Arm Movement							
6.1.6.1	Set screen to full body	A3,4	Overshoot or under correct camera zoom or position	Cannot see patient movements with clarity to form assessment	Immediately	L	L	Automatic camera adjustments
6.1.6.2	Ask patient to move right arm up	I1	Patient cannot hear request	Cannot form an assessment of severity of stroke effect to arm movement	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.6.3	Ask patient to move left arm up	I1	Patient cannot hear request	Cannot form an assessment of severity of stroke effect to arm movement	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.6.4	Ask patient to turn palms up	I1	Patient cannot hear request	Cannot form an assessment of severity of stroke effect to arm movement	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.7	Leg Movement							
6.1.7.1	Set screen to full body	A3,4	Overshoot or under correct camera zoom or position	Cannot see patient movements with clarity to form assessment	Immediately	L	L	Automatic camera adjustments
6.1.7.2	Ask patient to lift right leg	I1	Patient cannot hear request	Cannot form an assessment of severity of stroke effect to leg movement	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
6.1.7.3	Ask patient to lift left leg	I1	Patient cannot hear request	Cannot form an assessment of severity of stroke effect to leg movement	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.8	Ataxia							
6.1.8.1	Set screen to full body	A3,4	Overshoot or under correct camera zoom or position	Cannot see patient movements with clarity to form assessment	Immediately	L	L	Automatic camera adjustments
6.1.8.2	Ask patient to touch their finger to their nose with right hand	I1	Patient cannot hear request	Cannot form an assessment of severity of ataxia	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.8.3	Ask patient to touch their finger to their nose with left hand	I1	Patient cannot hear request	Cannot form an assessment of severity of ataxia	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.8.4	Ask patient to touch their right heel to left shin	I1	Patient cannot hear request	Cannot form an assessment of severity of ataxia	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.8.5	Ask patient to touch their left heel to right shin	I1	Patient cannot hear request	Cannot form an assessment of severity of ataxia	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.9	Sensation							
6.1.9.1	Set screen to full body	A3,4	Overshoot or under correct camera zoom or position	Cannot see patient movements with clarity to form assessment	Immediately	L	L	Automatic camera adjustments
6.1.9.2	Ask paramedic to pin prick right cheek	I1	Paramedic cannot hear request	Cannot form an assessment of patient limb sensation	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
6.1.9.3	Ask paramedic to pin prick left cheek	I1	Paramedic cannot hear request	Cannot form an assessment of patient limb sensation	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.9.4	Ask paramedic to pin prick right arm	I1	Paramedic cannot hear request	Cannot form an assessment of patient limb sensation	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.9.5	Ask paramedic to pin prick left arm	I1	Paramedic cannot hear request	Cannot form an assessment of patient limb sensation	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.9.6	Ask paramedic to pin prick right leg	I1	Paramedic cannot hear request	Cannot form an assessment of patient limb sensation	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.9.7	Ask paramedic to pin prick left leg	I1	Paramedic cannot hear request	Cannot form an assessment of patient limb sensation	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10	NIH Stroke Scale Cards							
6.1.10.1	Ask paramedic to use NIHSS cards	I1	Paramedic cannot hear request	Cannot use NIHSS cards to assess patient cognition and speech	Immediately	L	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10.2	Object Description							

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
6.1.10.2.1	Ask paramedic to show the patient the objects card	I1	Paramedic cannot hear request	Cannot use NIHSS cards to assess patient cognition and speech	Immediately	L	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10.2.2	Ask patient to identify an object in the card	I1	Patient cannot hear request	Cannot assess patient object recognition	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10.2.3	Confirm object with paramedic	I1	Paramedic cannot hear request, cannot hear response	Cannot assess patient object recognition	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers, training to use cards to confirm with neurologist rather than verbal
6.1.10.3	Scene Description							
6.1.10.3.1	Ask paramedic to show the patient the scene card	I1	Paramedic cannot hear request	Cannot use NIHSS cards to assess patient cognition and speech	Immediately	L	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10.3.2	Ask patient to describe scene on the card	I1	Patient cannot hear request	Cannot assess patient cognition	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10.4	Sentences							
6.1.10.4.1	Ask paramedic to show the patient the sentences card	I1	Paramedic cannot hear request	Cannot use NIHSS cards to assess patient cognition and speech	Immediately	L	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
6.1.10.4.2	Ask patient to read a sentence on the card	I1	Patient cannot hear request	Cannot assess patient speech	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10.4.3	Confirm object with paramedic	I1	Paramedic cannot hear request, cannot hear response	Cannot assess patient speech	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers, training to use cards to confirm with neurologist rather than verbal
6.1.10.5	Dysarthria							
6.1.10.5.1	Ask paramedic to show the patient the words card	I1	Paramedic cannot hear request	Cannot use NIHSS cards to assess patient cognition and speech	Immediately	L	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10.5.2	Ask patient to read a word or phrase on the card	I1	Patient cannot hear request	Cannot assess dysarthria	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers
6.1.10.5.3	Confirm object with paramedic	I1	Paramedic cannot hear request, cannot hear response	Cannot assess dysarthria	Immediately	M	M	Enhance audio quality of transmission, closed captioning, visual aid of normal requests made by caregivers, training to use cards to confirm with neurologist rather than verbal
6.2	Record Assessment							
6.2.1	Find assessment item	R2	Cannot locate correct assessment item	Cannot record assessment for patient chart	Immediately	L	L	Training to complete NIHSS in order

Task No.	Task	Error Mode	Error Description	Consequence	Recovery	Criticality	Probability	Remediation
6.2.2	Select drop down menu	S2	Select the wrong assessment item	Inaccurate assessment on patient chart	Immediately	L	L	Training to complete NIHSS in order
6.2.3	Select level of patient in assessment item	S2	Incorrect assessment level selection	Inaccurate assessment on patient chart	Immediately	M	L	Visual aid of selection options or examples of behavior for each selection
6.2.4	Write unusual responses or patient responses to NIHSS cards in Notes section	A9	Insufficient notes on assessment	Incomplete assessment to lower level of patient care	Immediately	M	L	Prompts for extra notes when making certain selections or training to use notes with assessment items

Appendix K

Sample Interview Guide: Nurse and Neurologist

Thank you again for agreeing to participate in the study. The goal of the study is to understand the influence of factors such as provider characteristics, physical environment and layout, worker roles, staff workload, stress, job satisfaction and communication flows on the caregiving process. We would like to audio-record the interview to help us capture your responses. May we record the interview?

- *If subject has agreed to audio-recording:*

I have set up the tape recorder here in front of us. Please speak clearly during the interview so that the tape will record your voice accurately. I may ask you to repeat a response to make sure that it is recorded.

- *If subject has not agreed to audio recording and a note taker is not available:*

I will take notes during our conversation today. I may ask you to slow down or pause for a moment so that I can record what you say accurately.

- *If subject has not agreed to audio recording and a note taker is available:*

My colleague [NAME] will take notes during our conversation today. He/she may ask you to slow down or pause for a moment so that he/she can record what you say accurately.

During the interview, please use only your first name if you refer to yourself. This will help us keep your responses private. Your answers will not be individually reported to your care team members here at the clinic. If we do share information from the interview with clinic staff, we will only report it at the aggregate level, so that it is not obvious who said what. The interview will take about 60 minutes to complete. If you need to take a break during the interview to use the restroom or get a drink, please let me know and we will pause the interview.

If any of my questions aren't clear or you don't understand a word that I use, please let me know and I will rephrase the question for you. Most of these questions refer to the differences between your work before and after using the telemedicine system, here we are talking about the REACH program.

Please remember that you are not required to answer any specific question. You may also leave the interview at any time.

Do you have any questions before we start the interview?

1. Changes with regard to the (physical) environment

- What changes did telemedicine implementation create for your work environment? PROMPTS IF NEEDED:
    - Less paper to deal with?
    - Spending more time with computers? Less on the phone?
    - Changes to computer work stations?
- How does the space available to you support your ability to use the telemedicine system for providing stroke care?

Interactions: Did changes in the physical environment cause changes in the way your work is organized? ** specific to physical space

Interactions: Did changes in the physical environment cause changes in the way you interact with other people (colleagues and patients)?

2. Changes with regard to the person(s)

- Did you receive (extensive) training in the telemedicine?

3. Changes with regard to tasks you perform

- What activities do you do now (with telemedicine) that you did not do before? PROMPTS IF NEEDED:
    - Spending more on certain tasks than before telemedicine implementation?
        - More or less time examining the patient? Talking with the patient? Talking to the remote caregiving team?
        - Talking about different things with patients (e.g., histories vs. current problems)?

Interactions: What effects have these changes in tasks had your workflow (e.g. what steps you do in what order)?

4. Changes with regard to tools and technology

- How did telemedicine implementation in the ambulance for stroke care change the way you use *tools and technology, such as the telephone, and computers*? PROMPTS IF NEEDED:
    - Using certain tools less or more?
        - Spending more/less time looking for patient information?
        - Spending more/less time passing information back and forth with others, or waiting for someone else to finish with an activity?

5. Changes with regard to the organization

This section is asking about your group, your organization (MUSC telehealth, Georgetown EMS, Tidelands Hospital)

- How has telemedicine affected the existing *processes*? Do you do other things and you spend your time differently?
- After telemedicine implementation, do processes seem more or less efficient?

6. Use of telemedicine in daily caregiving

- What does your workday look like? How do you use telemedicine during your workday?
- How does telemedicine affect your workload (physical, mental, effort, frustration)?
- How does telemedicine affect communication?
    - with caregivers?
    - with patients?
- How aware are you of your surroundings in your care environment with the telemedicine system?
- Does the system make you more accessible to the team of caregivers and the patient?
- Do you feel informed of the past, current, and planned tasks during a patient care scenario?
- Think about your caregiving environment, what are you able to see and hear during a care scenario?
- Are you aware of any trigger factors in this system, any actions made by a caregiver that signals others to complete a task or set of tasks without a set plan (cookie assembly example)?

7. Use of teamwork in telemedicine

Your team being the telestroke doctor, the paramedic, and the nurse

- Do you feel that you are able to communicate and coordinate information effectively with team members with the telemedicine?
- Does a shared understanding of both the task and the methods to accomplish the task develop during the session with the telemedicine?
- Does a shared understanding of both the task and the methods to accomplish the task develop during the session with the telemedicine?
- Does everyone on the team fully understand their team role and responsibilities during the session with the telemedicine?
- Are you able to develop awareness of what your other team members are doing during the session with the telemedicine?
- In what ways does telemedicine limit the ability to conduct teamwork?
- Likewise, are there ways telemedicine helps to achieve teamwork?

8. Usefulness and usability of telemedicine

- What do you think about the ***usefulness*** of telemedicine and potential benefits of telemedicine integrated ambulance-based setting? Does ambulance-based telemedicine have benefits? PROMPTS IF NEEDED:
    - Useful for you individually
    - Useful for patients
    - Useful to redesign the system for improved efficiency or effectiveness
- What do you think of ***usability*** of telemedicine? PROMPTS IF NEEDED:
    - Easy for yourself
    - Easy for patients
- What part(s) of telemedicine integrated ambulance-based system do you like best?
- What part(s) of telemedicine integrated ambulance-based system could be improved?

9. Telemedicine implementation and quality and safety of patient care

- How do you think that telemedicine affects quality of care?
- How does telemedicine affect care coordination?
- How do you think that telemedicine affects patient safety or reducing medical errors?

10. Security and privacy

- How much of an issue is security, privacy, and confidentiality for you? For your patients?

11. Telemedicine implementation and patient satisfaction

- Do you think that patients appreciate the use of telemedicine?

12. Barriers

- What are the main barriers against using telemedicine to do your work?

PROMPTS IF NEEDED:

- Privacy, security
- Privacy and security concerns of patients
- Skills of you and your colleagues
- Computer skills of patients
- Workflow adjustments
- Training
- Increase in workload
- Lack of computer support in your workplace
- Legal risks
- Loss of face-to-face contact with patients

    - Start-up costs
    - Maintenance costs
    - Others

13. Facilitators

- Does telemedicine make your life easier?
- Do you think telemedicine makes life easier for patients?
- Others

14. Final questions

- How does a telemedicine-integrated ambulance-based setting affect you (personally)
- Overall, how satisfied are you with telemedicine?

Appendix L

Sample Interview Guide: Paramedic

Thank you again for agreeing to participate in the study. The goal of the study is to understand the influence of factors such as provider characteristics, physical environment and layout, worker roles, staff workload, stress, job satisfaction and communication flows on the caregiving process. We would like to audio-record the interview to help us capture your responses. May we record the interview?

- *If subject has agreed to audio-recording:*

I have set up the tape recorder here in front of us. Please speak clearly during the interview so that the tape will record your voice accurately. I may ask you to repeat a response to make sure that it is recorded.

- *If subject has not agreed to audio recording and a note taker is not available:*

I will take notes during our conversation today. I may ask you to slow down or pause for a moment so that I can record what you say accurately.

- *If subject has not agreed to audio recording and a note taker is available:*

My colleague [NAME] will take notes during our conversation today. He/she may ask you to slow down or pause for a moment so that he/she can record what you say accurately.

During the interview, please use only your first name if you refer to yourself. This will help us keep your responses private. Your answers will not be individually reported to your care team members here at the clinic. If we do share information from the interview with clinic staff, we will only report it at the aggregate level, so that it is not obvious who said what. The interview will take about 60 minutes to complete. If you need to take a break during the interview to use the restroom or get a drink, please let me know and we will pause the interview.

If any of my questions aren't clear or you don't understand a word that I use, please let me know and I will rephrase the question for you. Most of these questions refer to the differences between your work before and after using the telemedicine system, here we are talking about the REACH program.

Please remember that you are not required to answer any specific question. You may also leave the interview at any time.

Do you have any questions before we start the interview?

1. Changes with regard to the (physical) environment

- What changes did telemedicine implementation create for your work environment? PROMPTS IF NEEDED:
    - Less paper to deal with?
    - Spending more time with computers? Less on the phone?
    - Changes to computer work stations?
- How does the space available to you support your ability to use the telemedicine system for providing stroke care?

    Follow up if needed:
    - Which areas in the ambulance seem most constrained for the tasks you need to perform?

- What are some existing features in your work area that either enhance or impede your ability to perform tasks or interact with team members while using telemedicine to provide stroke care?
    - What is the best positioning of the telemedicine workstation with respect to the patient, ambulance door etc?
    - What is the optimum positioning of screens to support the use of telemedicine for stroke care?
    - Does the lighting in ambulance affect your ability to use telemedicine while performing tasks associated with stroke care?
- What are some common problems you have encountered related to obstructed visibility to people, equipment and tools while using the telemedicine system for providing stroke care?

Interactions: Did changes in the physical environment cause changes in the way your work is organized? ** specific to physical space

Interactions: Did changes in the physical environment cause changes in the way you interact with other people (colleagues and patients)?

2. Changes with regard to the person(s)

- Did you receive (extensive) training in the telemedicine?

3. Changes with regard to tasks you perform

- What activities do you do now (with telemedicine) that you did not do before? PROMPTS IF NEEDED:
    - Spending more on certain tasks than before telemedicine implementation?
        - More or less time examining the patient? Talking with the patient? Talking to the remote caregiving team?
        - Talking about different things with patients (e.g., histories vs. current problems)?

Interactions: What effects have these changes in tasks had your workflow (e.g. what steps you do in what order)?

4. Changes with regard to tools and technology

- How did telemedicine implementation in the ambulance for stroke care change the way you use *tools and technology, such as the telephone, and computers*? PROMPTS IF NEEDED:
  - Using certain tools less or more?
    - Spending more/less time looking for patient information?
    - Spending more/less time passing information back and forth with others, or waiting for someone else to finish with an activity?
- Do you think that "automation" of certain processes in the existing telemedicine integrated system allows you to enhance the caregiving process? How do you adapt when the system is down and you cannot use telemedicine?

Interactions: Has the way you changed your use of tools and technology impacted the tasks that you do and the way the work is organized?

5. Changes with regard to the organization

This section is asking about your group, your organization (MUSC telehealth, Georgetown EMS, Tidelands Hospital)

- How has telemedicine affected the existing *processes*? Do you do other things and you spend your time differently?
- After telemedicine implementation, do processes seem more or less efficient?

6. Use of telemedicine in daily caregiving

- What does your workday look like? How do you use telemedicine during your workday?
- How does telemedicine affect your workload (physical, mental, effort, frustration)?
- How does telemedicine affect communication?
  - with caregivers?
  - with patients?
- How aware are you of your surroundings in your care environment with the telemedicine system?
- Does the system make you more accessible to the team of caregivers and the patient?
- Do you feel informed of the past, current, and planned tasks during a patient care scenario?
- Think about your caregiving environment, what are you able to see and hear during a care scenario?
- Are you aware of any trigger factors in this system, any actions made by a caregiver that signals others to complete a task or set of tasks without a set plan (cookie assembly example)?

7. Use of teamwork in telemedicine

Your team being the telestroke doctor, the paramedic, and the nurse

- Do you feel that you are able to communicate and coordinate information effectively with team members with the telemedicine?
- Does a shared understanding of both the task and the methods to accomplish the task develop during the session with the telemedicine?
- Does everyone on the team fully understand their team role and responsibilities during the session with the telemedicine?
- Are you able to develop awareness of what your other team members are doing during the session with the telemedicine?
- In what ways does telemedicine limit the ability to conduct teamwork?
- Likewise, are there ways telemedicine helps to achieve teamwork?

8. Usefulness and usability of telemedicine

- What do you think about the ***usefulness*** of telemedicine and potential benefits of telemedicine integrated ambulance-based setting? Does ambulance-based telemedicine have benefits? PROMPTS IF NEEDED:
    - Useful for you individually
    - Useful for patients
    - Useful to redesign the system for improved efficiency or effectiveness
- What do you think of ***usability*** of telemedicine? PROMPTS IF NEEDED:
    - Easy for yourself
    - Easy for patients
- What part(s) of telemedicine integrated ambulance-based system do you like best?
- What part(s) of telemedicine integrated ambulance-based system could be improved?

9. Telemedicine implementation and quality and safety of patient care

- How do you think that telemedicine affects quality of care?
- How does telemedicine affect care coordination?
- How do you think that telemedicine affects patient safety or reducing medical errors?

10. Security and privacy

- How much of an issue is security, privacy, and confidentiality for you? For your patients?

11. Telemedicine implementation and patient satisfaction

- Do you think that patients appreciate the use of telemedicine?

12. Barriers

- What are the main barriers against using telemedicine to do your work?

PROMPTS IF NEEDED:

  - Privacy, security
  - Privacy and security concerns of patients
  - Skills of you and your colleagues
  - Computer skills of patients
  - Workflow adjustments
  - Training
  - Increase in workload
  - Lack of computer support in your workplace
  - Legal risks
  - Loss of face-to-face contact with patients
  - Start-up costs
  - Maintenance costs
  - Others

13. Facilitators

- Does telemedicine make your life easier?
- Do you think telemedicine makes life easier for patients?
- Others

14. Final questions

- How does a telemedicine-integrated ambulance-based setting affect you (personally)?
- Overall, how satisfied are you with telemedicine?

Appendix M

Study Protocol

1. Send email to set up a time and date to complete study, send follow up email the day of with the study materials and instructions on how to download the simulator
2. At the study time, call the participant to explain the study and lead them through the session.
    a. "Hello, thank you for taking the time to complete this study. Your participation will provide valuable data to improve telemedicine stroke care. Please open the first survey link to read through and agree to the consent form provided. If you do not wish to participate you can select 'No, I do not wish to be a part of this study' and we will end this session. If you do wish to continue, please select the 'Yes, I have read the above information and agree to be a participant in this study' and complete the following demographics form"
    b. "You will be completing two stroke evaluations in two different telemedicine systems using the National Institutes of Health Stroke Scale. You will be connected to a simulated patient and paramedic in an ambulance, they will provide you with all the information you need to complete the assessment. A nurse will have connected before you to collect patient demographics and vitals, it is up to you to determine the patient history, medications, allergies and conduct a NIHSS evaluation. During the sessions we will pause the simulations to ask you questions about the simulation, we will also ask you to evaluate your workload, usability of the telemedicine system, and perceived teamwork after each session. Please do not worry, we are trying to evaluate the telemedicine system, not your performance."
    c. "When you have completed one of the telemedicine sessions please open the second survey link to evaluate the telemedicine system and your workload during the session."
    d. "When you have completed that survey you will need to open the simulator again and complete the same evaluation with the other telemedicine system, then complete that second survey again, this time evaluating the second system and your workload and perception of teamwork in that session only."
    e. "When you have completed both sessions and surveys I will ask you to connect to a zoom call to complete a short interview about your experience in the system"
    f. "At the conclusion of the interview you will receive your incentive for participation in this study"
    g. "Again thank you so much for taking the time to complete this study it should take no longer than 90 minutes to complete"

3. Once they have confirmed they have completed the consent/demographic survey, have them open the simulator and select the telemedicine condition they will complete first
    a. "Now that you have completed the consent and demographics you will need to open the simulation program, when that opens please select telemedicine system (A/B). Again, You will be connected to a simulated patient and paramedic in an ambulance, they will provide you with all the information you need to complete the assessment. A nurse will have connected before you to collect patient demographics and vitals, it is up to you to determine the patient history, medications, allergies and conduct a NIHSS evaluation. During the sessions we will also pause the simulations to ask you questions about the simulation. Are you ready to begin?"
4. They will complete the first simulation, the researcher will select the correct video response as they listen to the commands of the neurologists. Once they have finished the simulation, direct them to complete the second survey
    a. "Now that you have completed the simulation please open the second survey, the first survey will ask you to read the definitions of 6 subscales of workload, mental demand, physical demand, temporal demand, performance, effort, and frustration. Please read through those definitions such that you understand each of them before continuing. The next section will ask you to select which of a pair of these subscales is most important in contributing to your workload, for example: when you are completing a task is it more stressful when that task is physically demanding or frustrating? Please complete a selection for all pairs, then you will be asked to rate your experience in the session for each of these subscales on a scale of 0 to 100, please note that performance is rated from low performance rated as 100 and high performance as 0 as low performance typically represents higher workload."
    b. "the second survey will be an evaluation of how easy the telemedicine system was to use, and the final survey will be an evaluation of how well you felt you and the paramedic worked together as a team during the evaluation"
5. When they have completed this survey direct them to start the second session
    a. "Now that you have completed the evaluation of the first telemedicine system you will need to conduct a session in the second system. You will need to open the simulation program again, when that opens please select telemedicine system (A/B). As before, please complete the history, medications, and allergy information and then the NIHSS to complete the evaluation."
6. They will complete the second simulation, the researcher will select the correct video response as they listen to the commands of the neurologists. Once they have finished the simulation, direct them to complete the second survey
    a. "Please conduct the surveys just as before, only evaluating the second telemedicine system and session experience."

7. Once they have completed the survey guide them to the zoom call link to complete the survey
    a. “Now that you have completed the telemedicine sessions we will complete a short interview through a zoom call. Please select the conference call link to connect to that session such that the interview can be audio recorded to create verbatim transcription of your responses. This should take no more than 30 minutes to complete and you will be given your inceptive for participation at the conclusion of the interview”
8. Once they have connected ask them for their permission to audio record the session
9. If they agree to recording, read through the interview question protocol
10. Once the interview is completed, send them their incentive and thank them for their time.

Appendix N

SAGAT Questions

Current System First Freeze (10s after clicking on NIHSS tab)

Level 1

1. Is your patient taking Eliquis?
   a. Yes
   b. No
2. What is your patient's current systolic blood pressure?
   a. < 95 mmHg
   b. 95–120 mmHg
   c. 120-170 mmHg
   d. >170 mmHg
3. Does your patient have a history of atrial fibrillation?
   a. Yes
   b. No
4. What is your patient's glucose level?
   a. <130
   b. >130

Level 2

1. Is your patient on a blood thinner or blood clot prevention medication?
   a. Yes
   b. No
2. Does the patient have stroke indicating history?
   a. Yes
   b. No

Level 3

1. Does the patient have any history that would prevent them from being a tPA candidate?
   a. Yes
   b. No

Current System Second Freeze (end of simulation)

Level 1

1. What is the patient's NIHSS score?
   a. 0
   b. 1-4
   c. 5-15
   d. 16-20
   e. 21-42
2. What is your patient's current heart rate?
   a. <75 bpm
   b. 75-95 bpm

        c. >95 bpm
    3. State your assessment of the patient's speech
        a. Clear, smooth
        b. Slurring present
    4. What is your patient's diastolic blood pressure?
        a. < 60 mmHg
        b. 60-80 mmHg
        c. 80-100 mmHg
        d. >100 mmHg

Level 2

1. State your diagnosis of the patient
    a. Stroke
    b. Other condition

Level 3

1. Will this patient be a candidate for tPA?
    a. Yes
    b. No
2. If the patient is having a stroke, do you think that this is a large vessel stroke or small vessel stroke?
    a. Large vessel
    b. Small vessel
    c. Not a stroke

New System First Freeze (10s after clicking on NIHSS tab)

Level 1

1. Is your patient taking Metformin?
    a. Yes
    b. No
2. What is your patient's diastolic blood pressure?
    a. < 60 mmHg
    b. 60-80 mmHg
    c. 80-100 mmHg
    d. >100 mmHg
3. Does your patient have a history of atrial fibrillation?
    a. Yes
    b. No
4. What is your patient's glucose level?
    a. <130
    b. >130

Level 2

1. Is your patient on an ACE inhibitor?
    a. Yes
    b. No
2. Does the patient have stroke indicating history?

    a. Yes
    b. No

Level 3

1. Does the patient have any history that would prevent them from being a tPA candidate?
    a. Yes
    b. No

New System Second Freeze (end of simulation)

L

evel 1

1. What is the patient's NIHSS score?
    a. 0
    b. 1-4
    c. 5-15
    d. 16-20
    e. 21-42
2. What is your patient's current heart rate?
    a. <75 bpm
    b. 75-95 bpm
    c. >95 bpm
3. State your assessment of the patient's Limb Ataxia
    a. No ataxia present
    b. Ataxia present
4. What is your patient's current systolic blood pressure?
    a. < 95 mmHg
    b. 95–120 mmHg
    c. 120-170 mmHg
    d. >170 mmHg

Level 2

1. State your diagnosis of the patient
    a. Stroke
    b. Other condition

Level 3

1. Will this patient be a candidate for tPA?
    a. Yes
    b. No
2. If the patient is having a stroke, do you think that this is a large vessel stroke or small vessel stroke?
    a. Large vessel
    b. Small vessel
    c. Not a stroke

Appendix O

Interview Protocol

We would like to audio-record the interview to help us capture your responses. May we record the interview?

• *If subject has agreed to audio-recording:*
I have set up the tape recorder here in front of us. Please speak clearly during the interview so that the tape will record your voice accurately. I may ask you to repeat a response to make sure that it is recorded.

• *If subject has not agreed to audio recording and a note taker is not available:*
I will take notes during our conversation today. I may ask you to slow down or pause for a moment so that I can record what you say accurately.

During the interview, please use only your first name if you refer to yourself. This will help us keep your responses private. If we do share information from the interview with anyone, we will only report it at the aggregate level, so that it is not obvious who said what. The interview will take about 30 minutes to complete. If you need to take a break during the interview to use the restroom or get a drink, please let me know and we will pause the interview.

If any of my questions aren't clear or you don't understand a word that I use, please let me know and I will rephrase the question for you. Please remember that you are not required to answer any specific question. You may also leave the interview at any time.

Do you have any questions before we start the interview?

1. Have you used a telemedicine system for your work before, can you describe that experience?
    a. If yes, how did these systems compare?
2. Can you tell me what you thought of the first system you experienced?
    a. Layout of the information
    b. Detail of information provided
    c. General ease of use
    d. Awareness of the patient status
3. Can you tell me what you thought of the second system you experienced?
    a. Layout of the information
    b. Detail of information provided
    c. General ease of use
    d. Awareness of the patient status

4. How did the interface support information movement and transformation? Ex. how did you gather information for your diagnosis, how did the two systems differ in this process?
5. Was there a difference in the detail of information provided by the interface? How rich was the information communicated to you by the patient, paramedic, and the display?
6. Did you experience any trigger factors in either interface, e.g. an action in the system that triggered you to complete a task?
7. How did each system perform in creating scaffolding (a reminder of where you are in the task)?
8. Were there ways in either system that supported your awareness of how near or far you were from some goal (the tPA window, normal patient vitals, end of the NIHSS assessment)?
9. What do you think are the biggest differences between the two systems?
10. What do you think are the potential benefits of using either of these systems to complete a stroke evaluation?
11. Did you have any problems or issues in either systems?
12. Was one of the diagnoses you experienced more difficult than the other? How so?
13. What was the most difficult process?
14. Which system do you prefer?
15. What is your current computer set up (e.g. mouse vs trackpad, desktop, laptop)?