HUMAN FACTORS ENGINEERING ASSESSMENT OF MEDICAL EMERGENCY DEPARTMENTS

By

Scott Ryan Levin

Thesis

Submitted to the Faculty of the

Graduate School of Vanderbilt University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

in

Biomedical Engineering

December, 2004

Nashville, Tennessee

Approved:

Professor Daniel J. France

Professor Paul H. King

ACKNOWLEDGEMENTS

This project would not have been possible without the support of the National Science Foundation funded Integrative Graduate Education and Research Traineeship Program (IGERT). The Vanderbilt University IGERT program in Risk and Reliability Engineering and Management has provided me the resources and guidance needed to complete this project and attain a Masters of Science degree.

I would like to personally thank my advisor Dr. France for the direction he has provided me throughout the course of this project. I greatly appreciate the time and effort he has devoted to teaching and working with me over the past two years. I look forward to working, playing basketball, and fly fishing with him in the future. Next, I would like to thank Dr. King for the assistance he has given me since the beginning of my graduate career and for being a helpful contact within the biomedical engineering department. I would like to acknowledge Dr. Mahadaven, the IGERT program director, Bruce Hallbert, Dr. Chen, Megan Neumann, Rene Makowski, Dorsey Rickard, Dr. Hemphill, and Dr. Aronsky for the various help they have given me in completing this project.

Last, I would like to thank my family for their endless encouragement. The support and guidance that they have given me has proven to be valuable as I progress through life.

TABLE OF CONTENTS

Page

Appendix

LIST OF TABLES

Table Page

LIST OF FIGURES

LIST OF ABBREVIATIONS

HDS	health care delivery system
PSI	patient safety indicators
AHRQ	Agency for Healthcare Research and Quality
HFE	human factors engineering
ED	emergency department
VASNET	video data acquisition system network
PSF	performance shaping factors
HEP	human error probability
EM	emergency medicine
eWB	electronic whiteboard
LOS	patient length of stay
TLX	task load index
TD	temporal demand
IOM	Institute of Medicine
PEM	pediatric emergency medicine
GSR	galvanic skin response
VUMC	Vanderbilt University Medical Center

CHAPTER I

HUMAN ERROR IN MEDICINE

Vast unplanned advancements in medical technology and medical knowledge have woven a tangled interdependent web known as the healthcare delivery system (HDS). This system, although effective in providing care, is prone to many unforeseen accidents. The nature of the HDS has lead to its categorization as a complex and tightly coupled system.[1] The complexity arises from the system's numerous specialized inter-reliant sub-components. The tight coupling is a result of the many time-dependent processes that occur when a patient is being cared for. Charles Perrow, developed this two-dimensional categorization scheme and stated, "Some systems are sufficiently complex to allow the unexpected interactions of failures in such a way that safety systems are defeated and sufficiently tightly coupled to allow a cascade of increasingly serious failures."[2] Although Perrow has never himself categorized health care as a complex tightly coupled system, others have.[1] In addition to this unfavorable system foundation is the unexplored consequences of technological advancement. Over the past five decades medicine has experienced an overwhelming surge in technology designed to improve patient care. However, these advancements "have one major drawback: They have increased enormously the opportunities for accidents attributable to human error."[3] Perrow contends that in many industries 60 – 80 percent of accidents are caused by human error.[4] Healthcare seems to be no exception. A study in anesthesiology concluded that 82 percent of all preventable incidents were caused by human error. [5]

Arguably as a result of the inherent vulnerability associated with these types of systems and humans working within them, many accidents have been retrospectively discovered.[2] Before continuing, it is helpful to clarify some more standardized nomenclature used when discussing accidents in medicine. The two terms “error” and “adverse event” must be appropriately defined:

> An error is defined as the failure of a planned action to be completed as intended (i.e., error of execution) or the use of a wrong plan to achieve an aim (i.e., error of planning).[6]
>
> An adverse event is an injury caused by medical management rather than the underlying condition of the patient. An adverse event attributable to error is a “preventable adverse event.”[7]

In addition, the occurrence of an error that does not result in an adverse event is classified a "near-miss". Thus, the type and frequency of adverse events were reported in two prolific studies. The Harvard Medical Practice Study conducted in New York consisted of a retrospective review of 31,429 randomly sampled patient medical records from the year 1984. [7] The results of this study were later substantiated in 1992 through similar research in Utah and Colorado.[8] The findings suggested that the percentage of hospitalizations in which adverse events occurred was 2.9 and 3.7 percent respectively.[7,8] “The proportion of these adverse events that are attributable to error (i.e., preventable adverse events) was 58 percent in New York and 53 percent in Utah and Colorado.” Thus, preventable adverse events in hospitals cause approximately 44,000 to 98,000 deaths annually when extrapolated to the 33.6 billion hospital admissions experienced in 1997.[4] This suggests that preventable adverse events constitute the leading cause of death in the United States, surpassing motor vehicle accidents (43,458), breast cancer, (42,297) and AIDS (16,516).[4] A more recent study by HealthGrades Incorporated reported that up to 195,000 deaths occur annually due to potentially preventable medical errors.[9] This study used a set of patient safety indicators (PSI) developed by the Agency for Healthcare Research and Quality (AHRQ) to screen medical records that warrant patient safety concerns. These sobering reports have fueled many studies that involve researching the quality of healthcare. However, a common contention is that this aspect of medicine is still not getting the attention it deserves for several different cultural and economic reasons.

The study of human error in medicine is starting to become more standardized, streamlining in a common direction behind several prominent leaders. Knowledge previously concealed in psychology and engineering is being merged with newer intelligence in business, technology and healthcare. This fusion has created a rather conventional way of understanding human error in medicine that allows researchers to be more aligned in their independent efforts. Psychologists James Reason and Jens Rasmussen have developed a distinguished cognitive classification of human error. This taxonomy is based upon the skill-rule-knowledge model of human performance displayed in Figure 1.[6,10] This model has become standard in high reliability organizations such as nuclear power and aviation. Each level of performance (skill, rule, knowledge) categorizes specific types of human errors. A skill-based error is appropriately named a slip. Slips often occur when there is an interruption in routine and attention is diverted. A mechanism of a slip is capture, when a more frequently used plan is substituted for a similar, but less frequently used one.[10]

(1) SKILL BASED – Patterns of thought and action that are governed by stored patterns of preprogrammed instructions (schemata) and largely unconscious.
(2) RULE BASED – Solutions to familiar problems are governed by store rules of the "if X, then Y" variety.
(3) KNOWLEDGE BASED – Synthetic thought, which is used for novel situations requiring conscious analytic processing and stored knowledge.

Figure 1 Skill-Rule-Knowledge Model[6,10]

Another type of slip is labeled a description error.[6] This is when the right action is performed on the wrong object. There are associative activation slips that are products of incorrect mental associations. The last type of slip is classified as loss of activation that results from temporary loss of memory also called lapses. Rule-based errors are deemed mistakes. Rule-based mistakes occur when a wrong rule is applied either because of misinterpretation of the situation or because of misapplication of the rule. [11] Knowledge-based errors also fall under the category of mistakes. Knowledge-based mistakes arise when a unique problem is presented. These mistakes are more complex and are often a result of "lack of knowledge or a misinterpretation of the problem." [11] This fundamental framework for classifying errors of an individual using a cognitive approach is accompanied by several other error classifications schemes that come from other perspectives. It is important to understand that all error taxonomies are developed for a specific purpose. [6] There are no universally accepted taxonomies that are applicable to a variety of problems in all environments.

However, when concerned with human contribution to error in a complex system such as healthcare, one last discrimination must be made. This is the distinction between active and latent errors.[6] Active errors occur at the level of patient-provider interaction also known as the “sharp end”. [1] The consequences of these errors are usually experienced immediately. Latent errors are more suppressed. These errors “lie dormant within the system for a long time, only becoming evident when they combine with other factors to breach the system’s defenses.”[6] They occur distant from the sharp end and are thus encompassed by the “blunt end.”[1] These errors include such things as poor design, incorrect installation, faulty maintenance, bad management decisions, and poorly structured organizations. Latent errors are the most hazardous to complex systems and they have the ability to trigger numerous active errors.[4] In outlining the skill-rule-knowledge based taxonomy and active vs. latent classification, it is quite clear that error can be studied from a variety of vantage points. The skill-rule-knowledge model uses a cognitive psychological approach to understand human errors at the level of the individual. The active vs. latent distinction attempts to assess the influence of humans on system error.

This leads into the differentiation between the personal and systems approach to studying human error.[12] The traditionally taken personal approach to solving the problem concentrates on dangerous acts performed at the sharp end. Hazards in medicine are a result of inherent human characteristics such as forgetfulness, carelessness, inattention, lack of motivation, and negligence. All are variable in human beings. Thus, countermeasures are directed toward suppressing unwanted variability in human behavior.[12] This methodology has remained the most common means of dealing with error in medicine. Blaming individuals for their choice not to be safe seems much easier, more satisfying and more convenient than holding the institutions accountable. A systems approach provides an opposing conjecture. This methodology assumes that humans are imperfect and that errors are to be expected. “Errors are seen as consequences rather than causes, having their origins not so much in the perversity of human nature as in “upstream” systemic factors.”[12] There are specific factors within a work environment and organization that provoke the occurrence of errors. The assumption in combating errors is that, “we cannot change the human condition, we can change the conditions under which humans work.”[12] In addition, the traditionally discouraged human variability should instead be harnessed. Variability in the form of adaptability and compensation should be used as a means of increasing safety.[12] Just as the system should be designed to minimize error-provoking circumstances, defense barriers and safeguards should be put in place to eliminate the ability of a human error to actually create an adverse outcome.

High reliability organizations have taken major technological strides in appropriately safeguarding their systems. In medicine, there is more reliance on procedural and administrative regulations.[12] Ideally these barriers would be unyielding and impossible to penetrate. Taking a more realistic viewpoint, James Reason chose to represent defense barriers as Swiss cheese in Figure 2.

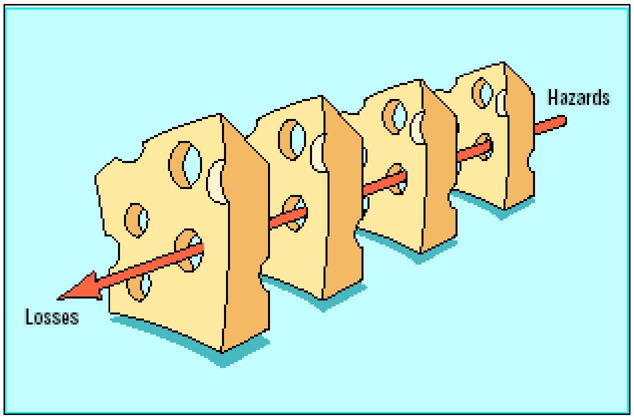

Figure 2. Swiss Cheese Model[12]

Under normal circumstances the “holes” in each of the defense layers would not allow an error “hazard” to penetrate into an adverse event “loss”.[12] However, under hopefully rare circumstances it may be possible for the holes in the Swiss cheese to align. These situations make it possible for a latent error to penetrate all defense barriers and result in an adverse outcome. It is obvious from this analogy that the best way to reduce probability of an adverse event is by either reducing the number and size of the holes in the Swiss cheese or by increasing the number of cheese pieces. This involves eliminating error provoking circumstances and strengthening or adding defense barriers, but unfortunately the tight-coupled complex nature of healthcare keeps many holes intact and economic pressures tend to hinder the adding of more cheese.

No industry is completely immune to errors; however, high reliability organizations have been able to experience extremely low frequencies of accidents by taking a systems approach and properly safeguarding. It seems quite simple that healthcare should just imitate these high reliability organizations and the problem is solved. This may be somewhat true; however, healthcare is in many respects quite unique.[4] A major difference between healthcare and other industries is the characteristics of the system. “In no other human endeavor do a wider variety of people perform tasks in more diverse conditions than in health care.”[3] In most other industries, the workers and the company are directly affected by accidents that occur. The patients feel the direct brunt of an error in medicine. Also, patients are harmed one at a time, making accidents less visible.[4] These major discrepancies make healthcare different from many other industries. Despite these differences, it seems that a systems approach to reducing adverse outcomes shows the most promise. It has been effective in other industries and there is no evidence to suggest that it is inadaptable to healthcare. “Trying harder will not work. Changing systems of care will.”[13]

CHAPTER II

HUMAN FACTORS ENGINEERING APPROACH

Thus far, a dichotomy has arisen between human error and system error. We know that human error contributes to a high percentage of errors that occur in a system.[14] However, a systems approach to reducing errors has been advocated. Thus, in medicine, system safeguards should prevent the conception of adverse outcomes from human error, especially latent errors. There seems to be a missing link. How is it possible to discover system issues that provoke human error? How can we develop systems that are immune to human error? It seems that other industries have been able to bridge this gap through the development and employment of human factors engineering (HFE). This philosophy is akin to the Institute of Medicine's (1999) recommendation to learn from knowledge and experiences of other industries to improve patient safety. Currently, the National Academy of Engineering and the Institute of Medicine are completing a collaborative study assessing the potential of engineering and related fields to improve the HDS.[15] Previously, HFE has been utilized in the medical domain, notably in anesthesiology.[16] However, there still seems to be a significant knowledge gap between patient safety professionals and human factors engineers and conversely, between human factors engineers and medicine.

HFE is a field of study concerned with the interaction of humans with the tools, machines, and systems that make up their work environment. The design of these tools, machines and systems strongly take into account human capabilities, limitations and characteristics.[17] Objectives of HFE research are broad and seem cyclic in nature. HFE is applicable to the design or redesign of systems that include a human interface aforementioned. The field also expands to the study of system and human performance and reliability. In harmony with this is the potential to improve ease of use, user satisfaction, and efficiency. HFE may also be applied in efforts to reduce operator stress and fatigue. In addition, a major focus of HFE is the reduction of human error. HFE merges several disciplines including: design engineering, cognitive psychology, and several biomedical areas of study. This cross-disciplinary nature allows for the study of the “human-system” interaction, which is often the culprit that induces and transforms human error into adverse events.

The area of study developed during World War II exclusively within aviation. The rapid advancements in technology during and just after World War II spawned the more technical side of the discipline. The earliest human factors engineers were primarily concerned with the “man-machine” interface. Knowledge gained, allowed engineers to better design airplane cockpits and nuclear power control rooms. Concurrently, cognitive psychologists were developing models of human cognition and decision-making. The two parallel yet formerly independent fields intersected to form the more modern discipline of HFE. Many of the cognitive models developed by psychologists were tested, improved and validated by human factors engineers using empirical data.[11] As of 1957 HFE has been formally recognized as a discipline in the United States. The inauguration was accompanied by the first annual meeting of the Human Factors Society. Ergonomics, a field very closely related to human factors, was developing simultaneously in Europe. Ergonomics, during its early phases, focused primarily on the biomechanical and biophysical properties of a human in a specific work environment. Preceding the development of the Human Factors Society came the forming of the Ergonomics Research Society in 1949 in England. The division between ergonomics and human factors vanished over time and this merge was signified by the recent name change of the Human Factors Society to the Human Factors and Ergonomics Society. Currently, the field of HFE is broadening in scope while simultaneously harvesting wisdom. Advancements in technology are ever continuing to expand the field's range of practicality. Expert psychologists, ergonomists and engineers are continuously being recognized for their contributions to specific organizations and industries. The accomplishments and recognition ascertained has spurred a more mainstream interest within the medical community.

Although HFE is just beginning to gain a high profile in medicine, several researchers saw the connection before. As early as 1970 Rappaport recognized several aspects of medicine that could greatly benefit from HFE. Closely thereafter, Ronco supported the use of HFE in the design of hospitals and Picket and Triggs edited a book on HFE in healthcare. In *Error in Medicine*, Leape vindicates the use of HFE in medicine and stresses the importance of learning lessons from previous human factors research. Two coupled facets of HFE that have shown promise in allowing researchers to understand a medical professional's work environment is task analysis and time-motion studies. Coiera, Chisholm and Graff have all independently used these methods to study workload, communications and distractions in the emergency department (ED).[18-22] Coiera and Tombs studied communication within a hospital, describing in great detail the methods, technologies and patterns observed. From this basis Coiera discussed the unknown effects of information technology as well as the impact of interruptions on physician cognition and memory.[18,19] Chisholm followed by focusing his research on the nature and frequency of interruptions in an ED in comparison to primary care offices.[20,21] Graff et al., used task analysis and time-motion studies to characterize the workload of emergency physicians based upon the nature of patient illness.[22] Reason has proposed the use of task analysis to figure out ways to reduce errors of omission. Recently, audio and visual systems have been employed to help characterize providers' work environment. Investigators at the University of Maryland and the University of Virginia, respectively, have developed systems used to analyze team behavior and performance within a specific setting. Xiao and MacKenzie have used their video data acquisition system network (VASNET) to study team performance and structure in trauma resuscitations.[23] Anesthesiologists have been at the forefront of the human factors movement into medicine. Knowledge gained and resultant improvements provide concrete evidence that HFE research in medicine will be effective. Gaba, Howard, Weinger, Cooper, Cook and others have been exploring the role of human factors in the operating room long before this recent surge.[24-34] These research efforts include providing some new methodologies for workload measurement of anesthesiologists as well as measuring anesthesiologist workload during different situations in the operating room. Intermingled is well-grounded discussion encompassing the effective usage and adaptation to new technologies in the operating room. Encasing much of this research are efforts to explore human factors that influence performance, vigilance, and impact the occurrence of errors within anesthesiology. They have made valuable assessments of the operating environment that have lead to improvements in provider and patient safety. During this same period, Donchin was doing similar work relating to errors in the intensive care unit.[35] Other notable researchers have chosen to use human factors principles to analyze past events. Wears and Gosbee have used HFE principles to perform root cause analysis on clinical incidents within a hospital.[36,37] Gosbee has used much of this knowledge to build an error-in-medicine curriculum for medical students and residents that is firmly grounded in HFE.[38] Pharmacies have become an important focus of human factors research since much of the dispensing of medicine occurs at this junction. Flynn et al., have used audio and visual systems to study the effects of ambient noise on pharmacists' prescription filling accuracy.[39] Grasha and Flynn have conducted several HFE studies on simulated and non-simulated pharmacy dispensing tasks. This representative sample of human factors engineering research in medicine seems to be just the tip of the iceberg. The leading researchers in the field have laid much of the groundwork for which future researchers may build on. Few of these investigators have had formal training in HFE, thus most of the tools and techniques used were self-taught. Although some foundation has been set, it will take further collaboration among clinicians, human factors professionals, patient safety researchers, and psychologists in order to proficiently progress.

It is fitting that HFE is becoming more mainstream as a result of drastic technological advancement and increased system complexity. Although the environment being studied is changing, many of the HFE principles remain the same. Much of the HFE techniques implemented today mimic what has been done in the past. There is an extensive amount of current methods being utilized within the HFE community. It would be excessive to detail or even mention all of the HFE techniques being implemented presently. However, Gosbee has been able to categorically summarize HFE methods quite effectively in Table 1 below. Inherent in the methods summarized above are the recognition and understanding of performance shaping factors (PSF). These are many factors, internal or external, that influence the performance of an individual in a situation. Many methods in human reliability analysis (HRA) use PSFs as the focal point of study. In high-risk domains such as nuclear power, several methods convert the nature of PSFs to quantitative values based upon their influence. These values are then used to determine human error probabilities (HEP) that may be incorporated into probabilistic risk assessments of nuclear power plants under specific circumstances. In the Standardized Plant Analysis Risk-Human

Reliability Analysis (SPAR-H) technique the following PSFs are recognized: available time, stress and stressors, experience and training, task complexity, human-machine interaction (ergonomics), quality of procedures, fitness of duty, and work processes.[40]

Table 1. Human Factors Engineering Methods[16]

Human Factors Analysis Activity	General Description	Analysis Products
Field Observations	Unobtrusively observe actual users in the typical work environment carrying out typical tasks. Take note of how work is carried out, who carries it out, what they use to carry it out, who they interact with, environmental factors (e.g., light levels, noise, crowding from equipment or people).	Characterizes typical work environment, identifies factors that might affect how clinicians perform (e.g., limitations of equipment, low light levels, high risk or time pressure, frequent distractions).
Simulation or Bench Tests	Simulate a process or an operation of a device, using different scenarios (e.g., different tasks, time pressure, lighting, errors that one must recover from). Simulation involves end users, whereas bench tests can be performed by the analyst.	Mapping of the system structure (e.g., where do all the menus in a software program lead? Where does the pharmacist have to go to retrieve XYZ?).
Information Requirements or Functional Needs Assessment	Information requirements analysis identifies what information a user needs to carry out specific tasks or activities (from micro to macro—How can a user tell he must push that button next? How does a user know he must perform that task next? How does he or she know whom to contact to relay information?). Similarly, a functional needs assessment identifies what tools or information a user requires to accomplish a task.	Information and functional needs of the user. Identifies task-related activities that depend on short-/long-term memory, identifies where information should be supplied and how it should be supplied, and identifies what tools a user needs to accomplish a task.
Heuristic Evaluation	Evaluates equipment or a process against a set of human factors principles.* Sample questions might include Does the software provide functionality needed by the user? Are buttons grouped in a logical fashion? Is there sufficient feedback to tell the user he or she has completed a task correctly? Is it obvious what a user must do next?	Identifies areas where human factors principles are violated, which may lead to unwanted consequences, such as frequent user errors, slips, high mental work load, user frustration, inefficient or inaccurate task completion, misunderstanding of policies, and deviation from prescribed guidelines or procedures.
Cognitive Walkthrough	A user is asked to demonstrate or walk through a device or process, thinking out loud or providing commentary on what he or she is doing and thinking at each step of the task or process.	Characterizes where human decision making is involved in a task, factors that influence decision making, including, for example, expertise a user might rely on, where information is retrieved from, strategies adopted, and workarounds invented to circumvent a deficiency.

I would expect that most of the PSFs in this example are self-explanatory except the last. Work processes refer to aspects of performing work that may involve organization, culture, policies, procedures, management, social pressures, etc. These facets that shape the work environment are often times out of a worker's or physician's control. In the medical domain Marilyn Sue Bogner eloquently uses a hierarchical diagram to holistically display what she calls, "An artichoke model of the systems of context of performance."[3] The model is displayed below in Figure 3.

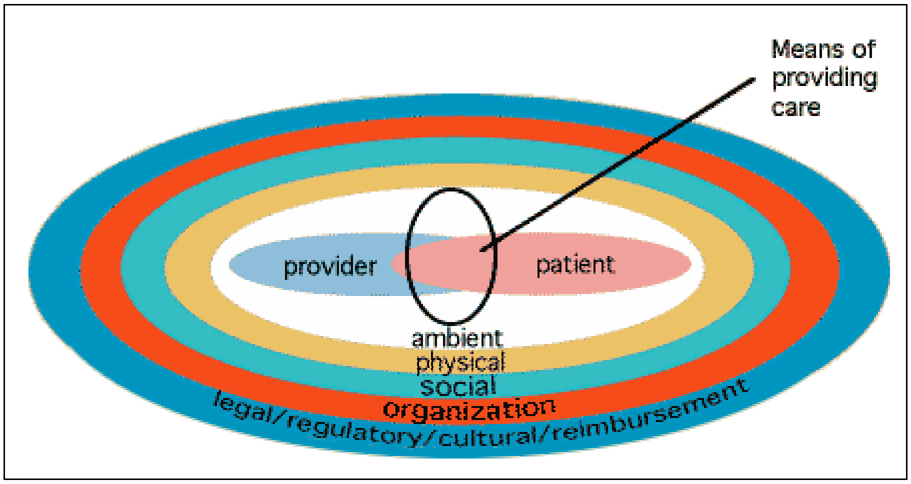

Figure 3. Artichoke Model[3]

The outer three rings of the model are akin to the work process PSF that is often times beyond the control of the physician. The model further demonstrates the range of factors that influence performance from the provider's personal characteristics to the regulatory guidelines placed on the system. It is important to understand that any change made to a ring will affect all of the rings it encompasses down to the provider and the patient. This is known as the "reverse ripple affect."[3] Bogner stresses the importance of understanding how changes at any level in the system will trickle down to affect provider performance and thus impact the patient. The study of HFE is restricted to the inner two rings of the model; however, it is still important to realize the context of effects when performing HFE research before implementing changes.

To this point HFE has been introduced and defined. Its historical development was discussed and application to medicine briefly touched upon. With this background gained it is appropriate to further relate HFE to patient safety and discuss this alignment with a systems approach to reducing adverse events. Reason defines a system as, “a set of interdependent elements interacting to achieve a common aim. The elements may be both human and non-human (equipments, technologies, etc.)”[6] It is important to then realize that major safety problems do not belong exclusively to the human or technical domains.[41] These problems surface in the interactions between the social and technical aspects of the system. HFE explores these interactions in an effort to change the system as a whole, making it safer. Studying these interactions provides valuable evidence for change in the work environment that accounts for human capabilities, limitations, and characteristics. Studying human performance within a work environment can lead to the discovery of error provoking aspects of the system. Similarly, it can lead to the recognition and understanding of PSFs that have a high impact on providers. In medicine, much of the research is directed toward finding out why errors occur or how errors were able to develop into an adverse event. Lessons learned from these studies are undoubtedly valuable, however they will not holistically address the problems within a system. Perrow concludes that inherent in the nature of casual reasoning is the resultant product of a record.[42] It should be emphasized that casual analysis produces records, not models of the functional structure of the system. Generalizations based upon these findings are insufficient in system problem diagnosis. This casual reasoning must be coupled with the analysis of the normal functioning system in order to accurately assess system performance. This theory parallels James Reason's contention that, "Correct performance and systematic errors are two sides of the same coin."[6] It is important that performance in its entirety be analyzed, not just errors, in order for system ailments to be diagnosed using HFE.

CHAPTER III

EMERGENCY PHYSICIANS' BEHAVIORS AND WORKLOAD IN THE PRESENCE OF AN ELECTRONIC WHITEBOARD

Introduction

Data published in the Centers for Disease Control and Prevention's 2004 report *National Hospital Ambulatory Medical Care Survey: 2002 Emergency Department Summary* indicate that EDs in the U.S. are approaching a boiling point in terms of increasing patient demand and shrinking bed capacity. The report estimates that between 1992 and 2002 ED visits increased 15 percent while the number of EDs decreased 22 percent.[43] U.S. EDs receive more than 100 million patient visits (80 million adults and 20 million children) per year. ED overcrowding often causes hospital diversion (i.e., ambulances diverted from hospital), increased patient wait times, increased length of stays, and decreased patient satisfaction.[43-47] The crisis is only expected to worsen as increases in non-urgent ED visits drive demand upward and growing financial pressures cause more hospitals to close their EDs. EDs in use today were not designed to handle the volume of patients they are now seeing. For example, the adult ED central to our study, was designed in the 1970's to handle an annual volume of 20,000 patients, but today receives approximately 43,000 patient visits per year.

Just prior to the time that popular media outlets began publishing reports on ED overcrowding in the U.S. the Institute of Medicine (IOM) released its sobering report on medical errors and adverse events in healthcare.[4,48] In *To Err is Human: Building A Safer Health System*, the IOM estimated that between 44,000 and 98,000 patients die of iatrogenic injuries each year. The ED has specifically been identified as a location where adverse events are highly likely to be attributable to error. Studies estimate that the proportion of ED adverse events deemed preventable range from 53 to 82 percent, compared with overall estimates of 27 to 51 percent for hospital-based adverse events.[49]

Other outcomes such as patient satisfaction are also suffering in the ED, as demonstrated by recent research findings and increasing rates of patient complaints. [50-52] Although researchers have reported inconsistent findings concerning which factors lead to patient dissatisfaction in the ED they overwhelmingly agree on two general findings: (1) patient dissatisfaction is on the rise and (2) failures or breakdowns in provider-to-provider and provider-to-patient communications are the primary cause. [53]

Communication failures have also been implicated and associated with medical errors and preventable adverse events in the ED. [54-59] A retrospective review of ED closed claims revealed that teamwork behaviors would have prevented or mitigated the adverse event in 43 percent of the cases reviewed. [60]

In light of the poor outcomes (i.e., safety and satisfaction) associated with acute patient encounters with the ED system, it is evident that there are serious implications for the professionals who work in this environment on a daily basis. In fact, research has shown that emergency physicians and staff experience high rates of stress, depression, and career burnout.[61-72] Three sets of factors have been shown to contribute to these outcomes in ED personnel: (1) organizational characteristics, (2) patient care, and (3) the interpersonal environment.

As the demands on emergency medicine (EM) continue to increase, improvements in the organization of work and the access to timely clinical and system information will be required for providers to manage their workload in a safe and timely manner. Advances in medical informatics are beginning to facilitate clinical improvements in the ED aimed at addressing these needs. For example, ED information systems are being developed that integrate, either in part or in full, the following systems: electronic tracking bed board displays, electronic medical records, computerized provider order entry, and laboratory and radiology systems. ED information systems have great potential to significantly streamline conventional paper-based ED work processes.

The study presented here applied observational methodologies previously employed in the ED and other clinical areas to study and describe provider work and communication processes in an ED equipped with a distributed electronic Whiteboard (eWB).[18-22,73-75] The results of the study are compared and contrasted with results from previously published observational studies performed in EDs unsupported by integrated informatics systems.

Methods

Sample population

The study was conducted in the adult ED at Vanderbilt University Medical Center (VUMC) in Nashville, Tennessee between September 8, 2003 and May 14, 2004. VUMC is a Level 1 Trauma Center and the adult ED receives over 43,000 patient visits annually. A convenience sample of 10 faculty EM physicians, 5 post-graduate year-three (PGY-3) resident physicians, and 5 PGY-2 resident physicians were observed during this period. The study was approved by Vanderbilt University's institutional review board, and all participating subjects provided verbal consent prior to their observational sessions.

Design

Time-in-motion, primary task analyses lasting approximately 180-minutes in duration were conducted on individual EM faculty and resident physicians.[20] A single trained observer used a standardized data collection form to continuously record the type and duration of all primary tasks and work interruptions. The data collection form was installed on a wireless handheld computer to facilitate mobile data collection. The observer shadowed EM physicians throughout the entire observational period except when patients or physicians requested privacy for patient care or other personal reasons.

System workload metrics were collected concurrently from the ED information system. Central to the ED information system is a 60-inch touchsensitive electronic whiteboard (eWB) that serves as the command and control center of the ED. The ED information system displays are also accessible from any networked computer in the ED. The eWB displays and records patient data and a number of system workload metrics including chief complaint, patient wait time, patient length of stay (LOS), patient acuity, managing physician, number of patients in the waiting room, ED occupancy, diversion status, and average wait times and LOS for all patients. The eWB also monitors and displays ED bed status for providers and cleaning staff. These parameters are recorded and stored in the central ED information system database at a sampling rate of once per minute.

Observers administered the NASA-Task Load Index (TLX) to EM physicians at the end of each observational session to measure subjective workload associated with the clinical activities performed during the preceding 180-minute work period. The NASA-TLX is a "multi-dimensional rating that provides an overall workload score based on a weighted average of ratings on six subscales: mental demands, physical demands, temporal demands, own performance, effor, and frustration."[76,77]

Finally, observers wore a pedometer during each observational session to approximate the amount of walking performed by each study subject.[73]

Instrument development and statistical analysis

Prior to initiating the full study, a pilot study was performed on three volunteers to develop the observational data collection form. The two observers achieved an inter-rater reliability of 0.81 (Kappa statistic) after two 3-hour observation sessions. Thirteen clinical activities or tasks were determined to represent the majority of the work activities undertaken by EM faculty and residents during typical work shifts (see Table 2).

Table 2. Categorization of Tasks

Task Name	Description
Charting	Written charting
Dictating	Verbal charting
Direct patient care	Physician at patient's bedside
Electronic whiteboard view	Physician views or scans eWB for information
Electronic whiteboard interaction	Physician uses touch screen to pull or add information from the eWB
Exchanging patient information	Provider-to-provider verbal exchange of patient-specific clinical information
Getting charts/records/documents	Physician retrieves paper charts, records, or documents
Phone calls and consults	Phone consultation with another provider
Supervising	Supervision (observation) of a junior physician or resident
Teaching/Learning	Formal interactive clinical teaching or learning
View diagnostic test results	Viewing laboratory results or radiology
Answering EMS calls	Physician responding to phone call from EMS
Verbal orders to a provider	Physician gives verbal orders to a resident, nurse, or other clinical staff member

The investigators adopted Chisholm's convention for categorizing the outcomes of tasks performed.[20] That is, tasks could have any one of the following outcomes: (1) task completed without interruption (i.e., "End Task"); (2) task interrupted and new task started (i.e., "Break in Task"); or (3) task temporarily interrupted but completed before new task started (i.e., “temporary interruption”). Table 3 summarizes the nine major types of interruptions recorded during the observations.

Table 3. Categorization of Interruptions

Interruption Name	Description
Face-to-face physician	Another physicians interrupts task with verbal communication
Face-to-face nurse	Nurse interrupts physician task with verbal communication
Face-to-face other	Another provider interrupts physician task with verbal communication
Lost chart, form or document	Lost chart or documentation interrupts task
Page	Alpha-numeric page alert interrupts task
Direct patient care	Urgent patient care interrupts current task
Phone call	Phone call (clinical or non-clinical) interrupts task
Equipment malfunction	Computer or diagnostic equipment malfunction interrupts task
Other	Any other event that interrupts physician tasks

Descriptive statistics (i.e., mean ± standard deviation) were used to characterize physician work activity, interruption patterns, workload, and eWB activity in the ED. Mann-Whitney U tests were used to compare continuous variables between EM faculty physicians and resident physicians (i.e., PGY-3 and PGY-2 pooled). A significance level 0.05 was used for all analyses.

Results

Work and Interruption Patterns

In aggregate, 50 hours of work activity were observed and recorded for 20 EM physicians working in the adult ED during the study period. Physicians performed 2053 tasks during this time and averaged 103 ± 19 tasks per 180-minute observational period. Three hundred and three interruptions, comprising breaks-in-tasks (N = 93) and temporary interruptions (N = 210), were recorded. On average, PGY-3 residents performed the most tasks (108 ± 10) and experienced the most interruptions (18 ± 6) per observational. PGY-2 residents completed the least number of tasks (98 ± 13) and experienced the fewest interruptions (11 ± 2). Faculty physicians experienced an interruption once every 9.6 minutes, PGY-3 residents every 8.8 minutes, and PGY-2 residents every 13.0 minutes.

The tasks performed most frequently by the pooled EM physician group were exchanging patient information, direct patient care, and charting. The tasks requiring the greatest time commitment per observation were direct patient care and exchanging patient information. Figure 4 shows the relationship between the frequency of tasks performed and the amount of time EM physicians spent completing those tasks. As the figure illustrates (see direct patient care and exchanging patient information for examples), the frequency and duration of tasks performed were not always positively correlated. In terms of differences between training levels, faculty physicians and resident physicians differed most on exchanging patient information and charting tasks. Faculty physicians performed approximately 8 percent more exchanging information tasks than residents. Conversely, residents performed nearly 10 percent more charting tasks than faculty physicians. Similar gaps were found to exist in the amount of time faculty and residents spent performing these tasks. In addition, faculty physicians were found to spend nearly 12 percent of their observed time performing dictation tasks, whereas residents spent virtually no time dictating. Residents performed 58.6 percent (N = 173) of all direct patient care tasks observed.

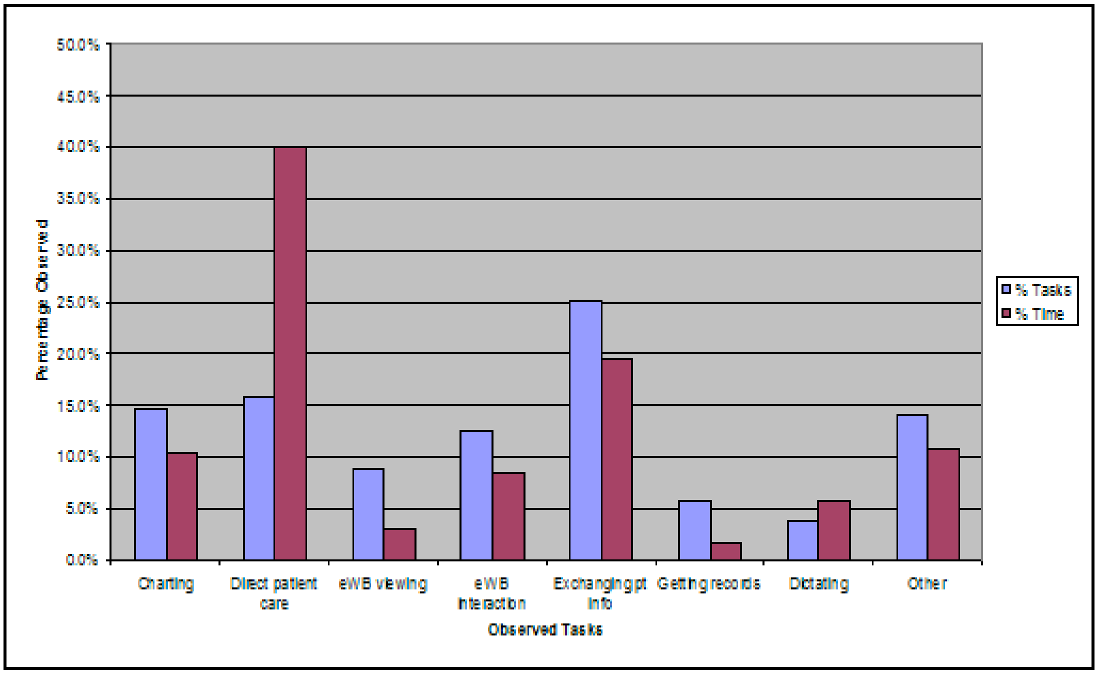

Figure 4. Distributions of Tasks Observed - Frequency and Duration

The mean duration of uninterrupted tasks was 1:21 ± 2:03 (minutes:seconds), and the mean duration of tasks temporarily interrupted was

2:00 ± 1:45, excluding the duration of the temporary interruption. Breaks-in-tasks and temporary interruptions each occurred about 1 minute into the start of a clinical task. The mean duration of observed temporary interruptions was 0:23 ± 0:16, and there were no statistically significant differences between faculty and resident physicians groups.

Nine percent (N = 27) of all direct patient care tasks were interrupted by either breaks-in-tasks or temporary interruptions. The most common interruptions (figure 5), across all tasks, were face-to-face physician communication (47.5%, N = 144), face-to-face nursing communications (21.1%, N = 64), and phone calls (13.5%, N=41). Face-to-face physician interruptions most frequently interrupted charting (29.2%, N = 42), eWB interaction (22.2%, N = 32), and exchanging patient information tasks (11.8%, N = 17). Face-to-face nursing interruptions most frequently interrupted exchanging patient information tasks (23.4%, N = 15), eWB interactions (21.9%, N = 14) and charting (15.6%, N = 10). Phone interruptions most frequently interrupted exchanging patient information tasks (22.0%, N = 9), direct patient care (17.1%, N = 7), and charting (14.6%, N =6). The distributions of observed interruptions were consistent in regards to frequency and duration (Figure 5). That is, the interruptions that occurred the most consumed the most clinical time.

Use of the electronic whiteboard

Physician viewing of and interaction with the eWB (i.e., touch-screen or networked computers) represented 19.3 percent (N = 396) of all clinical tasks observed. Faculty physicians and PGY-2 residents viewed the eWB 9 times and interacted with it 10 times per observational session. PGY-3 residents viewed the eWB 5 times and interacted with it 14 times per session. The tasks that most frequently preceded eWB viewing or interaction were (Figure 6):

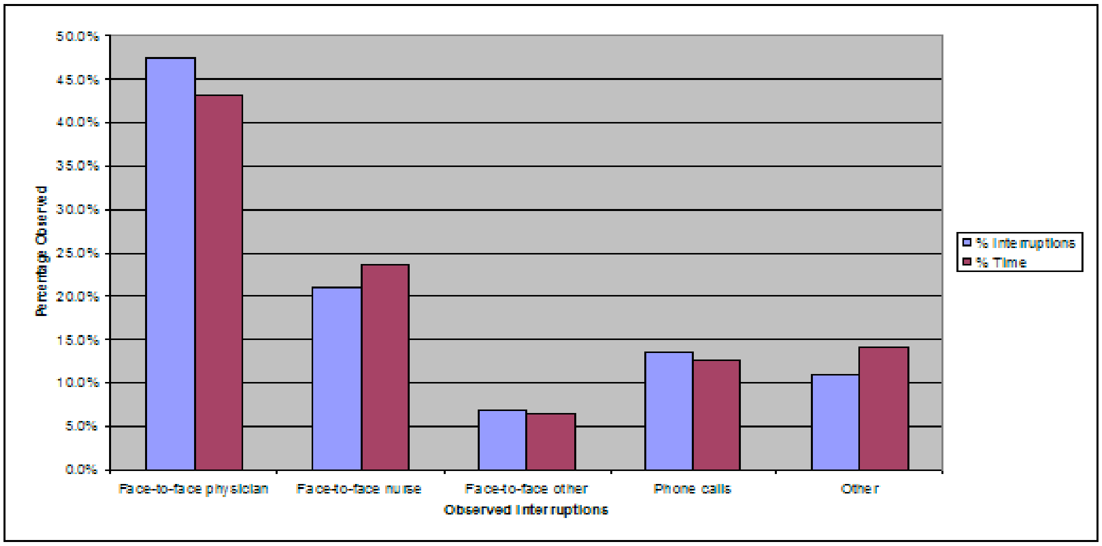

Figure 5. Distributions of Interruptions Observed - Frequency and Duration

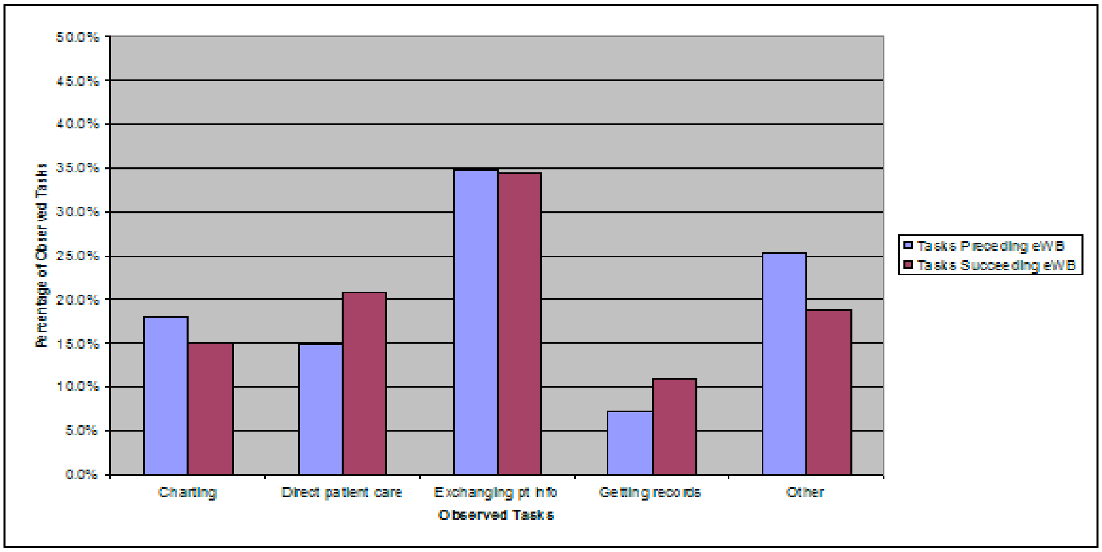

Figure 6. Distribution of Tasks Preceding and Succeeding

Physician Electronic Whiteboard Activity (Viewing or Interaction)

exchanging patient information (34.8%), miscellaneous other tasks (25.3%), charting (18.0%), and direct patient care (14.8%). Exchanging patient information (34.5%), direct patient care (20.8%), and charting (15.0%) most frequently succeeded eWB viewing or interaction.

Physician patient load, physical activity, and subjective workload

Faculty and PGY-3 resident physicians managed approximately twice as many patients (i.e., 12 patients) per observational session than did PGY-2 residents (i.e., 6 patients). No differences were found in the mean distance each physician group walked (i.e., 0.8 miles) per observational period (Table 4). Faculty physicians exhibited lower subject workload scores than residents for all tasks, except supervising (Table 5). Residents performed only one supervisory task during the observational period. PGY-3 residents reported a mean workload score of 71.8 ± 8.9 for patient care tasks, which represented the highest mean workload score reported for all groups. PGY-3 residents also scored for exchanging patient information tasks higher than either faculty or PGY-2 resident physicians. PGY-2 residents assigned their highest workload score (67.5 ± 11.5) to charting, a task they spent more observed time (20%) performing than any other group.

Table 4. Summary Statistics from EM Physician Observations

	Attending (N = 10)	PGY-3 (N = 5)	PGY-2 (N = 5)
Total Time Observed (hours:minutes:seconds)	25:28:42	12:54:19	11:53:48
Counts of ED System Workload Metrics (mean and standard deviation)			
Total # of Patients Seen	11.4 ± 5.3	12.6 ± 2.7	6.4 ± 5.0
Maximum # of Patients Simultaneously Managed	9.8 ± 4.0	10.8 ± 1.6	5.6 ± 4.3
Acuity of Patients Seen	2.6 ± 0.2	2.1 ± 0.2	2.2 ± 0.2
Patient LOS (hours)	5.9 ± 2.2	9.8 ± 0.9	6.4 ± 3.7
ED Occupancy (%)	92.7 ± 3.8	94.8 ± 11.7	92.0 ± 6.5
Counts of Tasks and Interruptions (mean and standard deviation)			
Tasks	102.4 ± 23	108.0 ± 10	97.8 ± 13
End Tasks	86.4 ± 24.0	90.4 ± 14.6	86.8 ± 12.0
Break in Tasks	5.3 ± 3.8	5.6 ± 3.0	2.4 ± 1.8
Temporary Interrupted	10.7 ± 2.9	12.0 ± 7.9	8.6 ± 2.1
# of Interruptions	16.0 ± 3.4	17.6 ± 5.5	11.0 ± 2.0
Time between Interruptions (min)	9.6	8.8	13.0
Duration of Tasks and Interruptions (mean and standard deviation)			
Uninterrupted Task	1:22 ± 1:56	1:17 ± 2:03	1:23 ± 2:16
Broken Tasks	0:54 + 0:52	1:21 ± 1:44	0:56 ± 0:52
Interrupted Tasks (excluding duration of interruption)	2:09 ± 1:42	2:03 ± 1:57	1:48 ± 1:35
Task Duration Preceding Temporary Interruption	1:00 ± 1:10	0:57 ± 0:59	0:53 ± 0:56
Temporary Interruptions	0:33 ± 0:40	0:29 ± 0:32	0:24 ± 0:19
Distance Walked (mean and standard deviation)			
Distance Walked (miles)	0.8 ± 0.4	0.8 ± 0.3	0.7 ± 0.3

Table 5. Mean Subjective Workload Scores by Task and Training Level

Task	**Attending (N = 10)**	**PGY-3 (N = 5)**	**PGY-2 (N = 5)**
Answering EMS	26.0 ± 18.9	39.6 ± 25.8	28.5 ± 22.9
Charting	52.7 ± 15.7	59.8 ± 13.5	67.5 ± 11.5
Direct Patient Care	53.7 ± 18.8	71.8 ± 8.9	61.5 ± 13.5
Electronic Whiteboard Interaction	35.5 ± 18.2	42.0 ± 19.7	48.8 ± 4.6
Exchanging Patient Information	53.8 ± 11.7	66.2 ± 22.4	58.8 ± 13.3
Getting Old Records	30.2 ± 25.2	46.2 ± 32.6	40.8 ± 28.7
Phone Call/Consults	51.0 ± 15.4	65.2 ± 21.4	65.8 ± 13.6
Supervising	54.8 ± 12.8	41.3 ± 25.5	20.5 ± 41.0
Teaching/Learning	54.6 ± 11.9	55.6 ± 15.9	57.5 ± 19.0
Viewing Diagnostic Results	43.6 ± 20.9	52.8 ± 15.1	54.0 ± 20.0

Analysis of the six dimensions of subjective workload revealed relatively balanced scoring behaviors across physician training levels (Table 6). However, two dimensions – temporal demand (TD) and frustration - drove the mean weighted workload scores approximately 10 percent higher for residents than faculty physicians.

Table 6. Mean Subjective Workload Scores by Dimension and Training Level

Workload Dimension	**Attending (N = 10)**	**PGY-3 (N = 5)**	**PGY-2 (N = 5)**
Mental Demand	56.3 ± 19.5	59.9 ± 19.8	44.9 ± 17.2
Physical Demand	24.8 ± 12.9	20.4 ± 17.9	46.2 ± 15.2
Temporal Demand	62.8 ± 17.7	74.4 ± 13.2	63.5 ± 25.8
Effort	50.8 ± 22.0	61.1 ± 22.7	63.8 ± 5.6
Performance	45.6 ± 20.9	41.4 ± 19.8	45.8 ± 14.1
Frustration	45.3 ± 14.2	65.8 ± 18.1	61.2 ± 18.9
Weighted Workload	**50.6 ±12.7**	**61.9 ± 12.8**	**61.0 ± 7.7**

These dimensional differences between faculty and residents were statistically significant (frustration: $p = 0.02$; TD: $p = 0.05$). Nearly 40 percent of all physicians observed scored TD as the highest overall contributor to workload. The majority (86%) of physicians had an average TD workload score that exceeded their overall weighted workload score. Physicians ranked TD the strongest contributor to workload for the following tasks: direct patient care, charting, exchanging patient information, and eWB interaction. For the study period, these tasks represented 68.2 percent of all tasks performed and 78.4 percent of all clinical time observed.

Discussion

This study replicated and expanded the methodology of several previously published observational studies in the ED and other clinical areas to gain some insight on the effects of implementing an integrated eWB on physician work, communication, and workload in the ED. The results of this study would have been greatly strengthened by using an increased sample size and a pre-post (i.e., before and after eWB implementation) study design. These changes were not feasible for this study due to various organizational and resource constraints. Despite these limitations, a number of important insights have been gained regarding the behavior of physicians in a complex clinical setting supported by an advanced informatics infrastructure. Information garnered from the study provides some important feedback regarding the benefits of the eWB and future improvements.

The most striking differences in our results compared to previously published results relate to work efficiency and interruption rates in the ED. The EM physicians representing our study sample performed 102.6 ± 19.0 tasks and were interrupted 14.9 ± 3.6 times per 180-minute observational period. Chisholm et al. reported that EM physicians performed 67.6 ± 15 tasks and experienced 30.9 ± 9.7 interruptions per 180-minute period in a conventional ED.[20] Similarly, EM physicians in our study were interrupted every 9.5 minutes, or 6.3 times per hour. Chisholm and Coiera reported interruption rates of 9.7 and 11.5 interruptions per hour, respectively.[19-21] However, Hymel and Severyn reported a lower rate (4.8 interruption per hour) in an urban teaching ED.[74] Finally, our pooled EM physician group spent approximately 40 percent of all observed time on direct patient care. This result is 10 percent higher than previously reported by Hollingsworth et al. who studied a similar sample in a city teaching hospital.[73] Although unproven by our study, the results suggest that distributed and accessible clinical information improves work and communication efficiency.

Our results are consistent with those previously reported by Hollingsworth regarding the time faculty and residents allocate to different tasks.[73] Faculty, PGY-3, and PGY-2 physicians each spent the greatest percentage of their clinical time on direct patient care. Similarly, we found that resident physicians perform the majority of charting tasks in the ED. PGY-3 resident physicians were determined to be the workhorses of the ED in our study, performing the most tasks and experiencing the most interruptions. Our results did not support

Hollingsworth's finding that faculty walked less than resident physicians. [73] We found no difference in the distance walked between our physician groups.

As previously reported by Chisholm, we found temporary interruptions occurred at nearly twice the rate that breaks-in-tasks occurred.[20,21] We also found that tasks temporarily interrupted, excluding the duration of the interruption, were approximately 40 seconds longer in duration than uninterrupted tasks. This has important implications for ED efficiency and patient safety. The results suggest that physicians do not simply resume the task they were performing from the point of an interruption, but actually either re-start the task or take considerable time to re-collect their thoughts and concentration before proceeding. Interruptions test the limits of human memory and information processing and represent serious threats to patient safety.

Overall, 14.8 percent of all observed tasks were interrupted (e.g. temporary or breaks-in-tasks). Coiera previously reported 30.8 percent of all communication events were interruptions.[19] Face-to-face interruptions, by physician or nurse, were determined to be the most common type of interruption (68.6%) in our study. Although interruption rates appear to be reduced in an ED equipped with an eWB, it is clear that such synchronous communications are still commonplace. This is not a surprising or unsatisfactory result since the ED is a dynamic, team-oriented environment. These results tend to support Coiera's earlier conclusion that "excessive emphasis on communication technology may be misguided since much may be gained from information exchange through information technology".[18]

Only 9 percent of all interruptions directly interrupted patient care. Therefore, safety interventions, such as crew resource management, that focus on provide-provider interactions outside the patient's room may produce the greatest improvements in patient safety outcomes. The results support or encourage a dual approach to clinical improvement in complex environments, one that finds a balance between information technology and team training (e.g. crew resource management, Med-Teams, etc). It is hypothesized that the safest, most efficient and reliable socio-technological systems will find this balance between human-human and human-technology interaction. That is, information technology solutions will facilitate the efficient and safe communication of clinical data to all members of a care team.

The eWB appeared to function as the command and control center of the ED. One-fifth of all clinical activities recorded in our study were either eWB viewing or interaction. Provider-to-provider communication (i.e., exchanging patient information) was the most common task preceding and succeeding eWB activity. This result re-emphasizes the importance of team communication and feedback in the ED. Only direct patient care and retrieving records occurred more often after eWB activity than before. Although resident physicians reported higher overall workload scores and workload scores across most tasks, including eWB usage, than faculty physicians, the workload scores were well distributed. The workload differences observed across physician training level suggest that physicians with more experience have acclimated to the work environment and have achieved a greater sense of control over job demands. This is supported by the finding that residents ranked frustration as a major contributor to their workload while faculty physicians did not. All physicians ranked temporal demands and mental demands as major contributing factors to workload, a result that is expected in the fast-paced ED environment.

These results appear to have important human factors and safety implications. The eWB appears to be used by the ED team to evenly distribute workload among team members and to anchor provider situational awareness. The relatively even distribution of NASA-TLX scores across training levels and the increase in direct patient care tasks after eWB activity, respectively, support this view. Futures studies must examine the relationship among task load factors, communication factors, and information technology factors with patient and provider safety outcomes. Research methodologies from human factors engineering may be best to elucidate the conditions and circumstances in which errors and adverse events occur and how these relate to the physical and psychological state of the EM providers. Finally, observational studies must be continued in the ED, but extended to provider teams rather than isolated EM providers.

CHAPTER IV

TRACKING WORKLOAD IN THE EMERGENCY DEPARTMENT

Introduction

The State of Emergency Medicine

Modern EM is currently in a state of assessment due to a variety of inter-dependent perils that have been recently discovered and substantiated. ED overcrowding, efficiency and patient and provider safety are at the forefront of many issues that the EM community is addressing. Data published in the Centers for Disease Control and Prevention’s 2004 report *National Hospital Ambulatory Medical Care Survey: 2002 Emergency Department Summary* indicate that EDs in the U.S. are approaching a boiling point in terms of increasing patient demand and shrinking bed capacity.[43] Just prior to this report the Institute of Medicine (IOM) released *To Err is Human: Building a Safer Health System*, which estimated that between 44,000 and 98,000 patients die of iatrogenic injury annually. Accompanying these reports are numerous research studies capturing the negative effects of the ED environment on physicians, nurses and patients.[78-88] Despite these ominous circumstances EDs continue to be effective, which is easily attributable to the scores of ED staff that painstakingly do their job well.

The nature of EM contributes to a rather unfavorable ED setting for both the patients and providers. The ED is notorious for being a stressful, chaotic and unpredictable environment within the hospital. The more fluctuant nature of the ED is then coupled with punctuations of high-risk time-critical activities that may result in serious consequences for both the patients and providers. For this reason, it is equally important to study the effects of this volatile surrounding on ED providers as it is to assess patient safety. It is hopeful that further understanding about how ED physicians interact with their environment will conjure evidence supporting ED system changes linking provider wellness, job satisfaction and efficiency to a higher quality of patient care.

Impact on Emergency Department Providers

Currently, the situation for ED providers remains hectic. Occupational stress and depression in EM physicians are extremely high in comparison to other medical specialties.[83] The term "burnout" has been utilized quite frequently in this setting. Burnout is defined as feelings of emotional exhaustion, depersonalization, depression and reduced personal accomplishment.[84] A study of Canadian EM physicians used the Maslach Burnout Inventory scales to discover that 46 percent of the sample experienced medium to high levels of emotional exhaustion, 93 percent fell in the medium to high range for depersonalization, and 79 percent were within the medium to low range for personal accomplishment.[85] High rates of burnout and stress are known to support the relatively high levels of projected attrition within the specialty. [86] In a population of Pediatric Emergency Medicine (PEM) physicians from 37 separate departments, it was found that only 22 percent believed they could practice PEM after the age of 50.[87] This environment is having a similar effect on the nursing and clerical staff as well.[88] It is a clear and general consensus that the ED setting has a profoundly negative impact on workers that are exposed to it constantly.

Although it is agreed upon that ED physicians tend to be more stressed and burn-out, there is less of a consensus on the source of these stressors. A study conducted in 1988 listed time pressure, critical decisions, provider-patient dissonance, and patient stress as the majors sources of stress for doctors and nurses in the ED.[89] Keller and Koenig questioned 104 EM physicians at 24 separate hospitals in the greater Los Angeles area to conclude that; (1) patient load, (2) interaction with patients and families, and (3) lack of administrative support were the major contributors to stress in the ED. High patient loads, high patient mortality, peer competition, long hours and lack of sleep were noted to be major stressors among ED residents.[90] A report in 2000, *Wellness Issues and the Emergency Resident*, Houry, et al. concluded that the most common stressors in the ED involved long shift work, the disruption of circadian rhythms, chemical dependence, women's issues, interpersonal relationships and personal safety. Workload also claimed its stake as among the top stressors in the ED.[81] Forty-six percent of PEM physicians believed that clinical workload was excessive and that total work hours was the most common reason for this excess.[87] Although some discrepancies exist, it is quite clear that many of the factors mentioned aggregate to create a stressful work environment that is conducive to burnout.

Impact on Emergency Department Patients

The current ED conditions may sacrifice the quality of patient care. Compared with non-burned out residents, burned out residents are more likely to say they “discharged patients early to make their work manageable, did not fully discuss treatment options or answer a patient’s questions, or made medical errors.”[91] The stressful, chaotic environment is advantageous for the occurrence of errors. A study of an ED in western Massachusetts found that an error was reported 18 times in every 100 registered patients. However, 98 percent of these errors did not result in a significant adverse patient outcome.[92] Often times, these errors are caught or blocked before affecting the patient by system safeguards or provider adaptation. However, there are also times when these errors result in poor patient outcomes. The ED has been specifically identified as a location where adverse events are highly likely to be attributable to error. Studies estimate that the proportion of ED adverse events deemed preventable are between 53 and 83 percent in comparison to the overall estimates of 27 to 51 percent for hospital-based events.[92]

There are several theories as to why errors are more prevalent and hazardous in EM than in other specialties. A wide variety of task complexity, uncertainty, unpredictability, continuous multi-tasking and production pressures all may contribute to the higher risk for error found in EM.[93] Communication patterns and interruptions have been suggested as a source of error production.[18] High levels of workload and stress have also been recognized as a contributor to high error rates. Human reliability analysis has demonstrated that high stress levels can increase human error probability by factors up to 10 in less experienced personnel during the most routine tasks.[94] The concept that excessively high levels of workload can lead to human error and system error is fundamental.[95] In addition to this, excess loads of the entire health care delivery are passed directly to and through the ED, adding to the complexity and strain that is already being experienced.[93] These factors intermingle to create an EM system that is prone to error production and susceptible to adverse events.

Studying Workload

The impending issues that EM is facing cries out for researchers to chip away at these problems. It is obvious that one solution will not suffice. The combined effect of research from different disciplines focusing on different aspects of the ED will allow for a holistic improvement of the system so that it may be able to better cope with the heavy demands it faces. The HFE approach taken in this report focuses on the measurement and dissection of ED physicians' workload. It seems that workload has been the "golden yardstick" in the human factors community, which is constantly a topic of study and debate. In medicine, the ability to measure and characterize workload has been studied in various settings ranging from the operating room to the pharmacy; however, limited research has been conducted in highly mobile work environments such as the ED. Furthermore, inadequate research has been performed to characterize or model changes in workload over time.

ED system and individual workload is becoming a more ubiquitous issue due to overcrowding. Many EDs in use today were not designed to handle the patient volume that they are now seeing. Technological advancements, notably in communications and medical record access, have improved the situation; however the workforce is still feeling the brunt of this problem. Currently, the worsening conditions of excessive workload in the ED raise concerns about the direction that EM must take in order to cope. The wealth of knowledge in the human factors domain concerning human performance under various levels of workload proves to have relevant application. In addition, advances in biomedical informatics are enabling new ways to collect information focusing on the relationships between provider work activity, clinical workload, and other healthcare system factors.

Research Objective

The primary objective of this study was to create a methodology for measuring physician workload in a highly dynamic, interrupt-driven clinical work setting such as the ED. The study used four distinct measurement techniques to characterize physician workload in the ED: (1) observational task analysis, (2) subjective workload assessment, (3) objective workload assessment, and (4) physiological workload assessment. Data collected using these techniques were synchronized, integrated and analyzed. A new methodology for measuring subjective and objective workload in the ED was implemented. The measurement methods continuously monitored physician workload over finite time periods using both subjective and objective measures. The subjective measurement overlays NASA-TLX workload scores with a formal procedural time-motion task analysis. The objective measure integrates two aspects that are involved in characterizing the productivity of an individual physician. Both measurements allow for the creation of two separate workload profiles for individual physicians during the measurement period. These profiles may be used to model changes in physician workload in these providers.

Methods

Participants

The study was performed at the Vanderbilt University Medical Center Adult ED between September 8, 2003 and May 14, 2004. This ED is a Level I trauma center in a large urban tertiary care hospital in Nashville, Tennessee. The department receives approximately 43,000 visits per year. The population observed consisted of a convenience sample of 10 faculty (Attending) physicians, 5 third-year (PGY-3) residents and 5 second-year (PGY-2) residents. The Vanderbilt University Internal Review Board approved the study and all participants gave appropriate verbal consent prior to their observation.

Study Design

A time-motion, primary task analysis was conducted on each of the 20 participants. The observational study consisted of a trained observer following a single ED provider for a 180-minute interval. The observer used a standardized data collection form to continuously record the type and duration of all primary tasks and work interruptions. The form incorporated Chisholm's method of categorizing task outcomes and interruptions.[20] The form was installed on a wireless handheld computer to facilitate mobile data collection. The physician was shadowed throughout the duration of the observational period except when privacy for patient care or other personal reasons was requested. Several observers were used to complete all of the observations. In order to ensure precise data collection from each of the observers, a pilot study testing inter-rater reliability was conducted. For two 3-hour observation sessions, two observers shadowed the same physician achieving an inter-rater reliability of .81 (Kappa statistic).

The NASA – TLX was administered to all study participants immediately following the expiration of the observational time period. This method of test administration proved to be more feasible in a live ED setting. It was desirable to minimize the amount of occasions in which the observer must interfere with the physician. This retrospective evaluation method has proven to be superior in that it enables the subject to make more relative judgments of each task after all tasks have been experienced.[96] The test focused on each of the 11 primary task categories that were recorded during the observation.

The Vanderbilt ED information system stores time stamped patient and provider data in history tables continuously via an electronic whiteboard. Provider level information concerning the number patients being cared for simultaneously and those patients' acuity levels were extracted from this database. An acuity scale is a means of ranking patients based upon severity of injury and need for hospitalization.

Each physician observed was equipped with body worn devices to take minute-by-minute physiological measurements. A SenseWear^{TM} Wireless armband monitor recorded galvanic skin response (GSR), skin temperature, upper body motion and upper body energy expenditure.[97] A three-dimensional accelerometer was clipped at the waste to the physician. This monitor recorded lower body movement and lower body energy expenditure.

Descriptive statistics (i.e., mean ± standard deviation) were used to characterize physician work activity, interruption patterns and several types of workload in the ED. Mann-Whitney U tests were used to compare continuous variables between EM faculty and resident physicians (i.e., PGY-3 and PGY-2 pooled). A significance level of .05 was used for all analyses.

Workload Profile Creation

Two unique workload metrics were calculated for each physician. The first measurement represents the physician's subjective self-assessment of workload over their observational time period. The second metric represents the actual workload of the physician over this same time frame. Both these measures spawn two separate workload profiles for a particular physician that represent their subjective and objective workload.

The subjective measurement integrates the observational task analysis with the work scores generated for each task from the NASA-TLX. The work score is placed at the stop time (t) of its corresponding task during the observation. That work score is then multiplied by the duration of that particular task to render a workload density (W) profile. The workload density profile can be seen in Figure 7. This graphical depiction consists of peaks, which represent times of high workload as characterized by that particular physician. However, the erratic nature of the profile does not accurately signify how the effects of previous work task influence a provider's current subjective workload score. For this reason a smoothing algorithm is run on the workload density profile. The transform is displayed below and the smoothed workload density (S) curve can also be seen in Figure 7.

$$S_t = S_{t-1} + \alpha * [W_t - \mu(W)] \qquad (1)$$

The (α) coefficient can be chosen based upon the degree of change desired in the profile. However, changing the coefficient will never change the shape of the curve. An (α) of .1 was selected for this study.

The objective metric incorporates two critical aspects that help define the actual workload a physician is experiencing. This involves the number of patients being managed simultaneously (P) by a physician and the severity of injury or acuities for those patients.

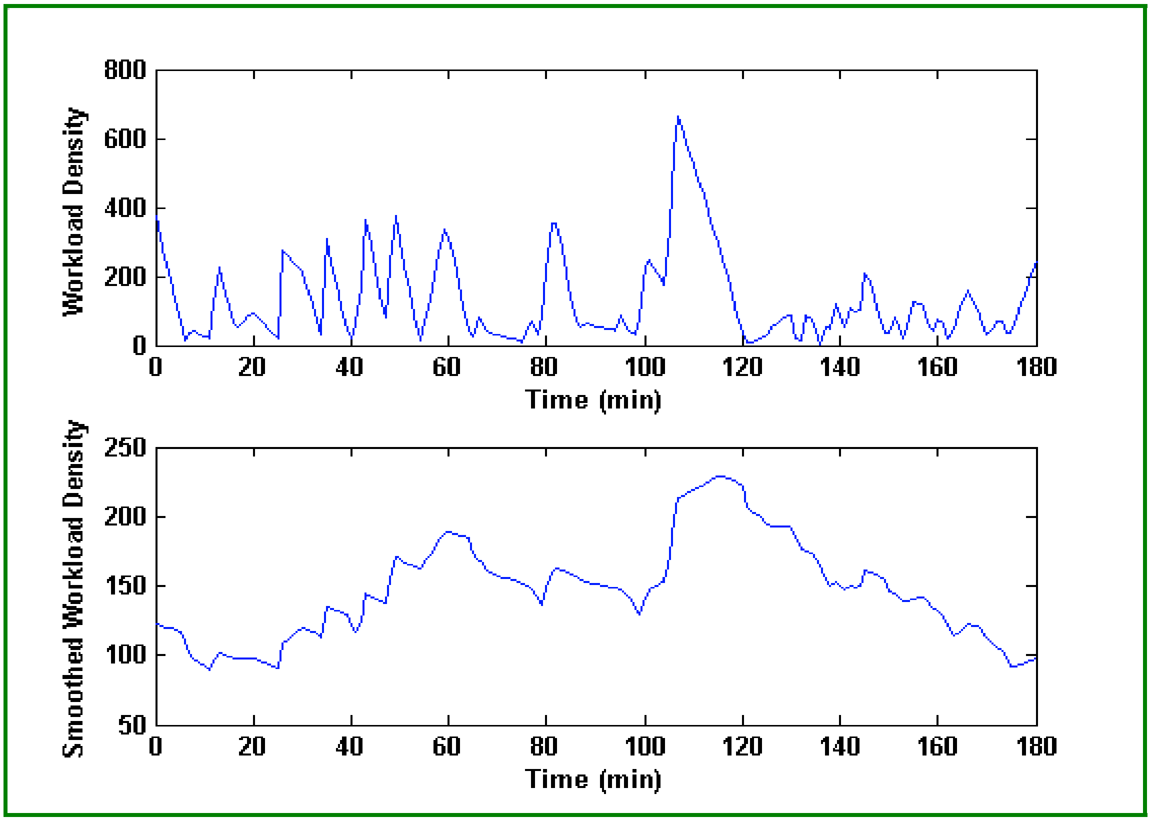

Figure 7. Example workload density profile and corresponding smoothed workload density profile

An acuity level is an integer from 1 to 4, where 1 is considered most severe. The average acuity (A) of all patients seen simultaneously by a physician is used.

Thus, a measurement designated patient load (L) is constructed over time:

$$L_t = [\ P / \mu(P)\ ] * [\ \mu(A) / \ (A)\ ] \qquad (2)$$

$*\ \mu(P)$ = average simultaneous patients managed across all physicians observed
$*\ \mu(A)$ = average acuity for all patients across all physicians observed

The subjective metric (S_t) and objective metric (L_t) can then be created for every physician observed.

Results

Task Analysis

The three observers recorded a total of 50hours of work activity. Physicians performed an average of 103 ± 19 tasks and were interrupted 14.9 ± 3.6 times per 180-minute period. The distribution of tasks based upon frequency and duration can be seen in Figure 8. The Vanderbilt University Medical Center (VUMC) ED utilizes an electronic whiteboard, which functions as central control center. Whiteboard information is networked to all computers within the department for easy access. The system provides physicians with integral information and tools assisting health care delivery. A recent by-product of this study illustrates the effects of the whiteboard on physicians' behavior and workload.[98] Results of the task analysis and concurrent information collected from the whiteboard is summarized in this paper.[98]

When calculating the objective workload metric the number of simultaneous patients managed across all physicians was (μ(P) = 6.75). The average acuity for all patients across all physicians observed was (μ(A) = 2.28). These values were used for all subsequent objective workload calculations.

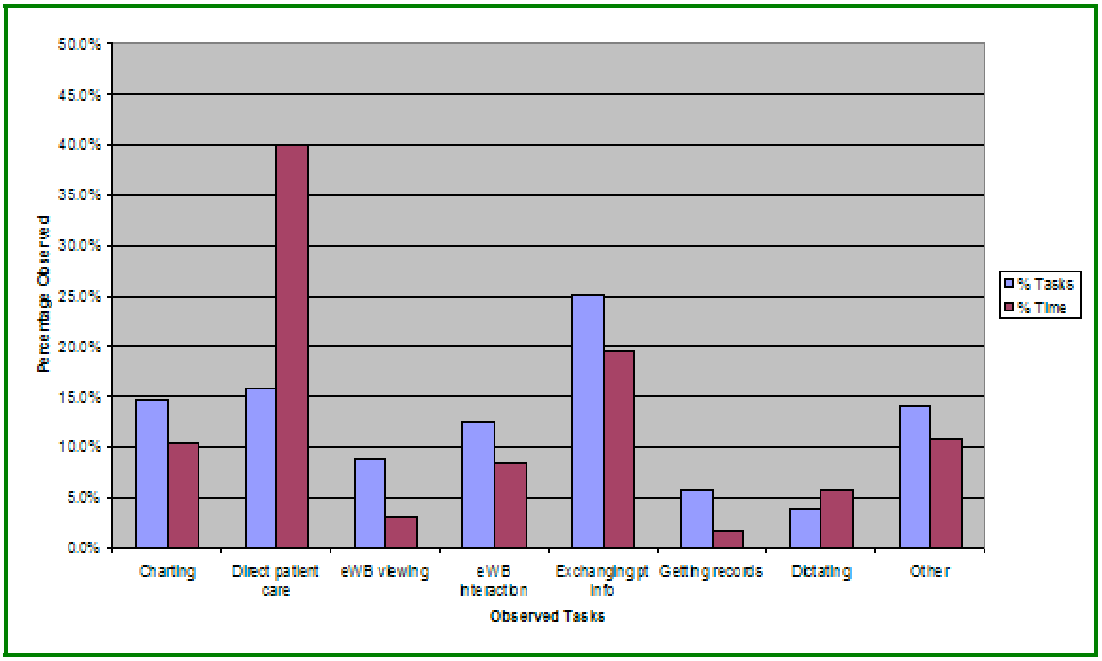

Figure 8. Distribution of tasks observed based upon frequency and duration[98]

Workload

In analyzing workload data provided by the NASA-TLX and the ED information system we were able to better understand the characteristics of different physicians' workloads. Summary statistics of NASA-TLX scores showed that TD was on average the dimension that contributed the most to a physicians' self-assessment of workload. Forty percent of physicians ranked TD the highest contributor to overall workload and 86 percent of physicians had an average TD workload score that exceeded their average overall weighted workload score. The average dimensional scores for each type of physician in the ED can be seen in Table 7.[98]

Table 7. Mean Subjective Workload Scores by Dimension and Training Level[97]

Workload Dimension	**Attending (N = 10)**	**PGY-3 (N = 5)**	**PGY-2 (N = 5)**
Mental Demand	56.3 ± 19.5	59.9 ± 19.8	44.9 ± 17.2
Physical Demand	24.8 ± 12.9	20.4 ± 17.9	46.2 ± 15.2
Temporal Demand*	62.8 ± 17.7	74.4 ± 13.2	63.5 ± 25.8
Effort	50.8 ± 22.0	61.1 ± 22.7	63.8 ± 5.6
Performance	45.6 ± 20.9	41.4 ± 19.8	45.8 ± 14.1
Frustration*	45.3 ± 14.2	65.8 ± 18.1	61.2 ± 18.9
Weighted Workload	**50.6 ±12.7**	**61.9 ± 12.8**	**61.0 ± 7.7**

There was a substantial difference seen in frustration scores between the various physician training levels. Residents seemed to be significantly more frustrated in their work environment than faculty physicians (p = .02). PGY-3 residents proved to be the workhorses of the ED. On average, they cared for the most patients, completed the most tasks, experienced the most interruptions and slightly edged out PGY-2 residents in recording the highest average work scores.

Continuous measurements for subjective workload (S_t) and objective workload (L_t) were synchronized for each physician observed. An example of these metrics calculated over time for one physician is overlaid in Figure 9. Corresponding measurements of GSR and skin temperature for the same physician can be seen in Figure 10. A variety of vantage points for measuring

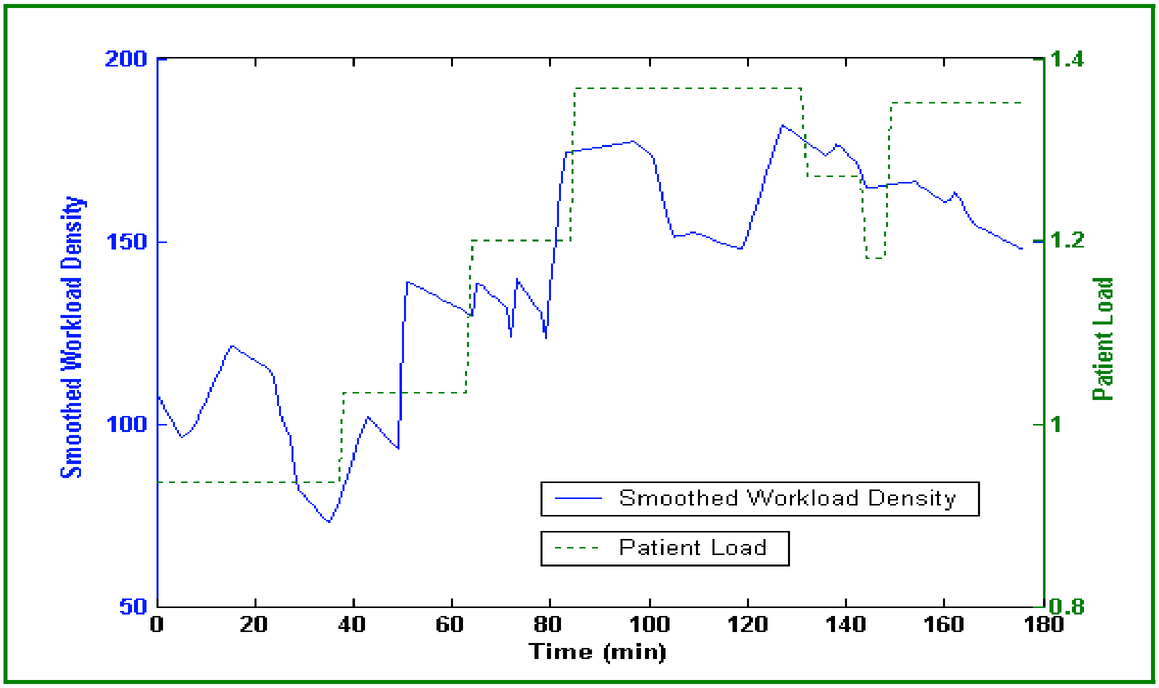

Figure 9. Smoothed Workload Density (S_t) and Patient Load (L_t) aligned and tracked over the length of the observation

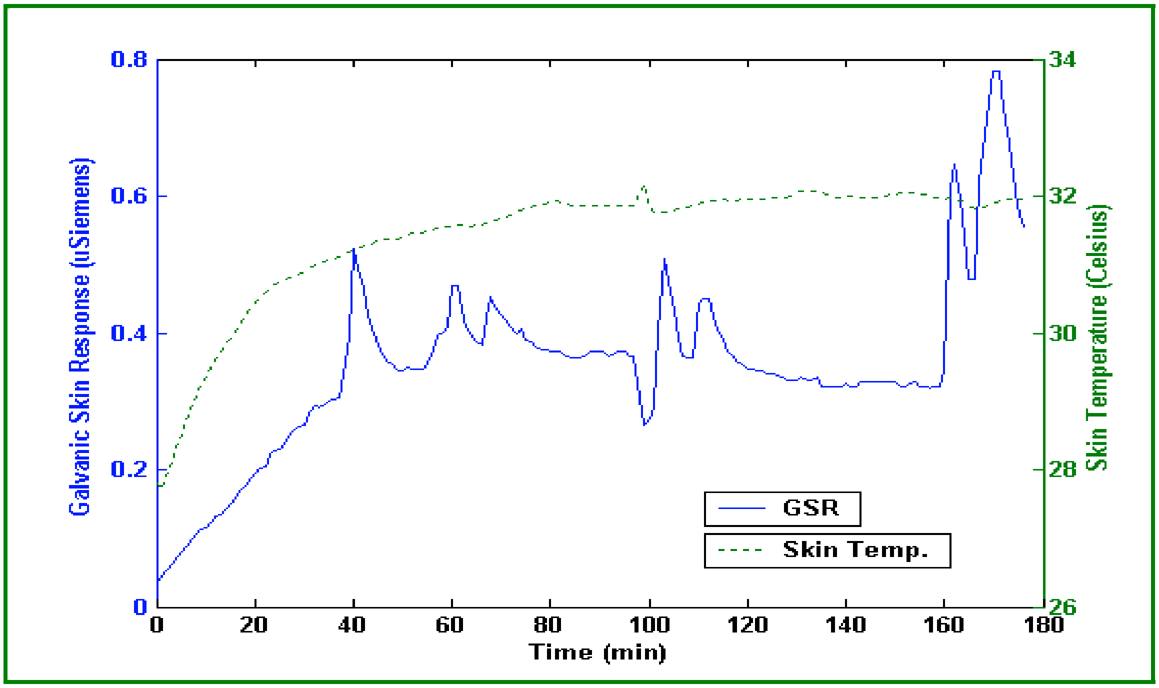

Figure 10. Galvanic Skin Response and Skin Temperature aligned and measured over the length of the observation

workload in the ED were used. Subjective, objective and physiological measures were used to track ED physicians over time.

These measurements were synchronized and plotted together to facilitate comparative analysis.

Discussion

The measurement of physician workload in the ED using a variety of techniques has proven to be a complex task. The non-deterministic nature of physician workflow, rapidly changing clinical demands, and the interactive nature of EM makes measuring workload difficult in this setting. However, these are the very factors creating the unsafe conditions that patients and providers are experiencing in the ED. Static measures of workload (i.e. summary statistics such as mean and median) cannot adequately characterize workload in the ED and do not provide information about the multiple time varying factors and conditions that increase the likelihood of adverse events.

The concurrent uses of subjective, objective and physiological measures have raised discrepancies, but simultaneously provided insight on the workload experienced by physicians in the ED. In tracking workload over time, the creation of a workload density (W) profile for each physician allows an investigator to pinpoint finite periods of high or low workload. However, this profile becomes hard to compare to other measures and lacks in its ability to realistically characterize changes in workload over time. The smoothing algorithm implemented considers workload density scores of past tasks in creating the new measure at time point (t). A current smoothed workload density (S_t) score is affected by past scores that are closest to the time point (t). The effect of past tasks decreases exponentially as the time difference to (t) increases. The more planate changes in workload for the smoothed workload density profile (S_t) create a more sensible curve that is feasible to compare with other workload measures over time. The objective measure of patient load (L) utilized can be considered a fundamental measure of how much work the physician is performing at a given time point. A team of researchers assigned to the task of developing measures of workflow in EDs designated 38 potentially effective measurements (15 input, 9 throughput and 14 output).[99] ED workload was characterized as the, "demand and complexity of patient care that is undertaken by the ED within a given period."[99] A throughput measure of a particular physician's workload was defined as a function of the number of patients treated and those patients' acuities for a particular period of time during a shift.[99] This is represented in the patient load (L) metric.

We found it difficult to make qualitative comparisons between the subjective, physiological and objective measures over time. Several subjects' curves seemed to correlate well with one another, however for many physicians there was no agreement. Psychological and physiological measurements showed low correlation, which is consistent with other studies of workload performed on clinicians.[100,101] However, skin temperature has been significantly correlated with stress scores over an entire shift.[102] The correspondence between the subjective and objective measures was low as well. This seems akin to a large portion of studies finding comparable results.[103] The evaluation of the physiological versus objective measures produced similar results.

Several constraints and inherent limitations of the techniques used in this study may have produced these low correlations. For one, the sample size of 20 physicians confined the study. We will increase our sample size to 60 physicians for our second study in the Adult and Pediatric EDs. Larger sample sizes will enable the application of quantitative analysis techniques, such as linear mixed effects modeling. Linear mixed effects modeling will be used to perform multivariate analysis on our repeated measures data to determine which factors contribute, and with what magnitude, to changes in physician workload. The NASA-TLX scores were fairly definitive, however some differences across subjects may be a result of the context of effects.[104] The retrospective use of the NASA-TLX was thought to suppress the variance associated with context. Although several limitations exist in this study, the development and analysis of the work metrics used were valuable in characterizing the workload of ED physicians.

The methods used in this research may have relevant application in managing ED physicians during normal working conditions. The physiological and subjective measures must be created prior to a given time period, however the patient load (L) measure can be created in real time. This measure can be tracked for all physicians simultaneously and used to generate alerts guiding physicians' decisions about whether or not to take on another patient. These alerts would ideally distribute patient load equally across all physicians on staff.

Other alerts simply warning physicians that they are entering a high workload time period may also be effective. This being said, it still may be necessary to study how the ED interacts with other departments within and outside the hospital before interventions like this are actually implemented. Information generated from this research could also be used in workload projection. The major principle in scheduling theory is that time pressure is the primary source of cognitive workload.[105] The diagnostic results from NASA-TLX suggest that scheduling theory may be applicable to the ED. This becomes more complex in a medical environment because of its unpredictable nature; however, it may be possible to utilize during normal operating conditions.

The introduction of HFE techniques to the ED setting is a unique and complex task. The chaotic nature of this environment makes it difficult to capture and describe using human factors methodologies. The current trend in researching quality in the ED focuses on medical errors. Kyriacou and Coben described three major research categories on error: (1) research summarizing the magnitude of errors, (2) research identifying casual factors behind these errors, and (3) research evaluating interventions that are meant to reduce errors.[106] Studies falling within these categories have made had an impact on quality in EM. However, the study of human performance within an ED is a rare occurrence. James Reason's contention is that, "correct performance and systematic errors are two sides of the same coin."[6] Human factors methods concerning human performance and human errors will fill a void in EM research that may be able to improve the conditions for all who set foot through ED doorways. Studying human performance and analyzing how physicians function and interact with the normal ED environment seems to be the key in justifying system changes that will improve the EM delivery system for both the patients and the providers.

CHAPTER V

CONCLUSION

Presently, healthcare is in a suspended state, aware that change must be made, but unsure which direction to take. Evidence warranting improvement has received mainstream attention. This serves as an important first step. It is now the duty of all who work in the healthcare community to progress in a safe and effective manner. Recently, goals leading toward advancements in medical technologies and drug treatments seem to overwhelm the medical research domain. Although these areas are of utmost importance, it seems that they have stunted much of the research that is necessary regarding the process of delivering healthcare. A reason for this may be the more ambiguous nature of studying the HDS in efforts to improve it. It seems quite challenging to tackle all aspects of healthcare delivery; however, it is hopeful that research efforts can independently take small steps to shape a new and improved system.

The focus on errors in medicine is leading the surge. The alarming frequency and sobering impact of medical errors causing adverse events must be addressed immediately. The ED in particular continues to be a good host for these occurrences for reasons aforementioned. Most of the errors occurring within the system are a result of human interaction. Human error and more specifically, latent errors are known to be the major contributor to preventable adverse events. The personal and systems approach are the two vantage points from which the problem can and has been attacked. The systems approach has been advocated and has proven to work in other high-risk technologies. The incongruity in correcting for human error with system solutions has been discussed. The path of creating systems solutions to defend against human error runs through HFE.

Studying human performance and understanding how healthcare workers truly interact with their environment will lead to smart solutions and more robust defenses. Learning from mishaps in the past by methods such as root cause analysis has proven to be useful; however, shortcomings exist regarding generalization. Focus should be placed on the normal operating conditions of the system. Channeling attention toward human performance in the system, not just errors, is a means of killing two birds with one stone. Studying healthcare staff in their normal environment will provide insights into how errors occur and how these errors may be transformed into adverse events. When studying human factors, a presumption is that humans inherently err. The goal is to create or change an aspect of the healthcare system so that: (1) human error is not induced and (2) latent human error is prevented from creating an adverse event. Although it is simply stated, the means of achieving this have thus far been daunting. The increasing complexity of the HDS has been a fundamental reason for this. There has been insufficient research to determine how technology and increasing complexity is affecting providers. "Complexity not in harmony with the organism tends to induce error."[3] The interdisciplinary nature of human factors attempts to pull knowledge on human behavior and communication from cognitive psychology and integrate it harmoniously with technical factors from engineering as well as organizational factors in management. HFE is an area that has potential to facilitate this harmony.

This report focused on the VUMC ED and serves as another example of human factors research in medicine. The effort to characterize and describe the ED environment is an initial step in the process. The methods used to study the affects of a technological advancement (eWB) on physicians prove to be valuable in understanding this human-system interface. Results can be analyzed and compared to similar research in other settings. The further attempts to measure workload continuously in a live ED are useful due to the impending circumstances EDs are facing. The use of several techniques to characterize a physician's transient workload level may be useful in the management of ED staff. Continuous research efforts similar to those conducted in this report will better characterize these work environments. The aggregation of numerous human factors studies has potential to create a profoundly positive impact on the way healthcare is delivered. This junction of human and system seems to be the perpetrator of many of the quality issues healthcare is facing. It is at this human-system interface where problems can be studied and corrected at the source.

APPENDIX

WORKLOAD PROFILE – MATLAB SOURCE CODE

Individual Provider Analysis – Example ---

```
close all; clear;

% COMPILING WORKLOAD DATA
[times,tasks] = xlsread('training_level','racfid');
taskscores = xlsread('taskscores','racfid')
% generating continuous workload
ContWork = Workload(times,tasks,taskscores);
% workload curves vs. observation time
start = ContWork(:,5);
workscore = ContWork(:,1);
smworkscore = ContWork(:,2);
density = ContWork(:,3);
smdensity = ContWork(:,4);

%COMPILING PHYSIOLOGICAL DATA
phys = xlsread('Physiodata','racfid');
ptimes = phys(:,1);
skintemp = phys(:,7);
armtrans = phys(:,12);
armlong = phys(:,13);
VMrt3 = phys(:,22);
    mov = sqrt(armtrans.^2 + armlong.^2) + VMrt3; %upper + lower
gsr = phys(:,15);
EEarm = phys(:,20);
EErt3 = phys(:,21);
   EE = EEarm + EErt3; %upper + lower

%COMPILING WHITEBOARD DATA
changetimes = [135];% time patients arrive/discharged
ps = [2 1]; % number of patients
changetimes = changetimes+1;
patients = zeros(length(ptimes),1);

% creating # of patients curve
patients = zeros(length(ptimes),1);
patients(1:changetimes(1)-1) = ps(1);
for i = 1:length(changetimes)-1;
```

```
 patients(changetimes(i):changetimes(i+1)-1) = ps(i+1);
end;
patients(changetimes(length(changetimes)):length(patients)) = ps(length(ps));

% creating avg acuity curve
acuity = zeros(length(ps),1);
acuity(1) = mean([2 2]);
acuity(2) = mean([2]);
pacuity = zeros(length(ptimes),1);
pacuity(1:changetimes(1)-1) = acuity(1);
for i = 1:length(changetimes)-1;
  pacuity(changetimes(i):changetimes(i+1)-1) = acuity(i+1);
end;
pacuity(changetimes(length(changetimes)):length(pacuity)) =
acuity(length(acuity));

% calculating whiteboard metric
wbmetric = (patients/(max(patients))).*(pacuity/(max(pacuity)));

% creating hospital occupancy
occpt = 25;
occpts = [occpt+1 occpt+61 occpt+121];
perocc = [113 108 113];

%INTERPOLATING WORKLOAD DATA
intworkscore = interp1(start, workscore, ptimes,'linear','extrap');
intsmworkscore = interp1(start, smworkscore, ptimes,'linear','extrap');
intdensity = interp1(start, density, ptimes,'linear','extrap');
intsmdensity = interp1(start, smdensity, ptimes,'linear','extrap');

Master = zeros(length(ptimes),11);
Master(:,1)  = ptimes;
Master(:,2)  = intdensity;
Master(:,3)  = intsmdensity;
Master(:,4)  = intworkscore;
Master(:,5)  = skintemp;
Master(:,6)  = mov;
Master(:,7)  = gsr;
Master(:,8)  = EE;
Master(:,9)  = patients;
Master(:,10) = pacuity;
Master(:,11) = wbmetric;

% creating plots

%WORKLOAD
```

```
figure(1);
subplot(2,2,1); plot(ptimes,intdensity);
title('Workload Density')
subplot(2,2,2); plot(ptimes,intsmdensity);
title('Smoothed Workload Density')
subplot(2,2,3); plot(ptimes, intworkscore);
title('Workscore');
subplot(2,2,4); plot(ptimes, intsmworkscore);
title('Smoothed Workscore');

%PHYSIOLOGY
figure(2);
subplot(2,2,1); plot(ptimes,skintemp);
title('Skin Temp. Celcius');
subplot(2,2,2); plot(ptimes,mov);
title('Movement');
subplot(2,2,3); plot(ptimes,gsr);
title('GSR uSiemens');
subplot(2,2,4); plot(ptimes,EE);
title('EE');

%WHITEBOARD

figure(3)
subplot(2,2,1); plot(ptimes, patients);
title('# of Patients');
subplot(2,2,2); plot(ptimes, pacuity);
title('Avg. Patient Acuity');
subplot(2,2,3); plot(ptimes,wbmetric);
title('Patient/Acuity Metric');
subplot(2,2,4); plot(occpts,perocc);
title('% ED Occupancy');
```

Curve Creation --

```
function ContWork = Workload(times,tasks,taskscores);

[C,taskmap] = xlsread('taskmap');

% sorting vectors
tasks = tasks(:,1);
start = times(:,3);
stop = times(:,4);
map = taskmap(:,1);
```

```
% formatting arrays
workscore = zeros(length(tasks),1);
tasks = char(tasks);
tasks1 = double(tasks);
map = char(map);
map1 = double(map);

% assigning workload scores to tasks
for i = 1:length(tasks);

if tasks1(i,:) == map1(1,:);
   workscore(i) = taskscores(1);
elseif tasks1(i,:) == map1(2,:);
   workscore(i) = taskscores(2);
elseif tasks1(i,:) == map1(3,:);
   workscore(i) = taskscores(3);
elseif tasks1(i,:) == map1(4,:);
   workscore(i) = taskscores(4);
elseif tasks1(i,:) == map1(5,:);
   workscore(i) = taskscores(5);
elseif tasks1(i,:) == map1(6,:);
   workscore(i) = taskscores(6);
elseif tasks1(i,:) == map1(7,:);
   workscore(i) = taskscores(7);
elseif tasks1(i,:) == map1(8,:);
   workscore(i) = taskscores(8);
elseif tasks1(i,:) == map1(9,:);
   workscore(i) = taskscores(9);
elseif tasks1(i,:) == map1(10,:);
   workscore(i) = taskscores(10);
end;
end;
workscore;
x = find(workscore);

% assigned workload scores
work = workscore(x);
% workload density
density = work.*(stop(x)-start(x));
% smoothed workload
smwork = zeros(length(work),1);
mu = mean(work);
smwork(1) = mu + .25*(work(1) - mu);
for k = 2:length(work);
    smwork(k) = smwork(k-1)+.25*(work(k) - mu);
```

```
end;
smwork;
% smoothed workload density
smdensity = zeros(length(density),1);
mu = mean(density);
smdensity(1) = mu + .25*(density(1) - mu);
for k = 2:length(density);
    smdensity(k) = smdensity(k-1)+.25*(density(k) - mu);
end;
smdensity;


ContWork = zeros(length(x),6);
ContWork(:,5) = start(x); ContWork(:,6) = stop(x);
ContWork(:,1) = work; ContWork(:,2) = smwork;
ContWork(:,3) = density; ContWork(:,4) = smdensity;
```

REFERENCES

1. Cook, R. Woods, D. Miller, C. *A Tale of Two Stories: Contrasting Views of Patient Safety.* Chicago*:* National Patient Safety Foundation, 1998.

2. Perrow, C. Organizing to Reduce the Vulnerabilities of Complexity. *Journal of Contingencies and Crisis Management.* September 1999 1999;7(3):1450 - 59.

3. Bogner, S. *Misadventures in Health Care: Inside Stories*. Hillsdale, NJ: Lawrence Erlbaum Associates Inc, 2003.

4. *To Err is Human: Building A Safer Health System*. Washington, D.C.: National Academy Press, 1999.

5. Cooper, J. Newbower, R. Long, C. Preventable anesthesia mishaps: a study of human factors. *Aneshtesiology.* 1978;49:339-406.

6. Reason J. *Human Error.* Cambridge: Cambridge University Press, 1990.

7. Brennan, A. Leape, L. Laird, M., et al. Incidence of adverse events and negligence in hospitalized patients: Results of the Harvard Medical Practice Study I. *N Engl J Med.* 1991;324:370–76.

8. Thomas, E. Studdert, D. Burstin, H., et al. Incidence and Types of Adverse Events and Negligent Care in Utah and Colorado. *Med Care* 2000.

9. HealthGrades Inc. *HealthGrades Quality Study: Patient Safety in American Hospitals.* HealthGrades Inc, 2004.

10. Rasmussen, J. Jensen, A. Mental procedures in real life tasks: a case study of electronic trouble shooting. *Ergonomics*. 1974;17:293-307.

11. Leap, L. Error in Medicine. *Journal of the American Medical Association*. 1994;272(23):1851-57.

12. Reason J. Human Error: Model Management. *British Medical Journal.* 2000;320:768-70.

13. *Crossing the Quality Chiasm: A New Health System for the 21st Century.*. Washington, D.C.: National Academy Press, 2001.

14. Perrow, C. Organizing to Reduce the Vulnerabilities of Complexity. *Journal of Contingencies and Crisis Management.* 1999;7(3):1550-56.

15. Engineering the Delivery of Healthcare: Priorities for Application and Research:National Academy of Engineering and The Institute of Medicine, 2002:C1-7.

16. Weinger, M. Slagle, J. Human Factors Research in Anesthesiology. *Journal American Medical Informatics Association.* 2002;9(6):S58-S61

17. Gosbee. Introduction to the Human Factors Engineering Series. *Joint Commission Journal on Quality and Safety.* 2004;30(4).

18. Coiera, E. Tombs V. Communication behaviours in a hospital setting: an observational study. *Bmj* 1998;316(132):673-676.

19. Coiera, W, Jayasuriya, R, Hardy J, Bannan, A, Thorpe, M. Communication loads on clinical staff in the emergency department. *Med J Aust* 2002;176(9):415-18.

20. Chisholm, CD. Collison, EK. Nelson, DR. Cordell WH. Emergency department workplace interruptions: are emergency physicians "interrupt-driven" and "multitasking"? *Acad Emerg Med* 2000;7(11):1239-43.

21. Chisholm, CD. Dornfeld, AM. Nelson, DR. Cordell, WH. Work interrupted: a comparison of workplace interruptions in emergency departments and primary care offices. *Ann Emerg Med* 2001;38(2):146-51.

22. Graff LG, Wolf S, Dinwoodie R, Buono D, Mucci D. Emergency physician workload: a time study. *Ann Emerg Med* 1993;22(7):1156-63.

23. Mackenzie, C. Hu, P. Horst, R. An audio-video system for automated data acquisition in the clinical environment. LOTAS Group. *J Clin Monit* 1995;11(5):335-41.

24. Gaba M. Human error in anesthetic mishaps. *Int Anesthesiol Clin* 1989;27(3):137-147.

25. Gaba, D. Lee, T. Measuring the Workload of the Anesthesiologist. *Anesth Analg.* 1990;71:354-61.

26. Howard, S. Gaba, D. Fish, K. Yang, G. Sarnquist, F. Anesthesia crisis resource management training: teaching anesthesiologists to handle critical incidents. *Aviat Space Environ Med* 1992;63(9):763-70.

27. Cooper, J. Newbower, R. Long, C. McPeek, B. Preventable anesthesia mishaps: a study of human factors. *Anesthesiology* 1978;49:339-406.

28. Cooper, J. Long, C. Newbower, R. Philip, J. Critical incidents associated with intraoperative exchanges of anesthesia personnel. *Anesthesiology* 1982;56(6):456-61.

29. Cooper JB, Newbower RS, Kitz RJ. An analysis of major errors and equipment failures in anesthesia management: considerations for prevention and detection. *Anesthesiology* 1984;60(1):34-42.

30. Cook RI, Potter, S.S., Woods, D.D., McDonald, J.S. Evaluating the human engineering of microprocessor-controlled operating room devices. *Journal Clin. Monit.* 1991;7(3):217-26.

31. Cook RI, Woods, D.D. Adapting to new technologies in the operating room. *Human Factors* 1996;38(4):593-613.

32. Weinger MB, Englund CE. Ergonomic and human factors affecting anesthetic vigilance and monitoring performance in the operating room environment. *Anesthesiology* 1990;73(5):995-1021.

33. Weinger MB, Herndon OW, Zornow MH, Paulus MP, Gaba DM, Dallen LT. An objective methodology for task analysis and workload assessment in anesthesia providers. *Anesthesiology* 1994;80(1):77-92.

34. Howard, S. Rosenkind, M. Katz, J. Berry, A. Fatigue in Anesthesia. *Anesthesiology.* 2002;97:1281-1294.

35. Donchin Y, Gopher D, Olin M, Badihi Y, Biesky M, Sprung CL, et al. A look into the nature and causes of human errors in the intensive care unit. 1995. *Qual Saf Health Care* 2003;12(2):143-7; discussion 147-148.

36. Wears RL, Perry SJ. Human factors and ergonomics in the emergency department. *Ann Emerg Med* 2002;40(2):206-12.

37. Gosbee J, Anderson, T. Human factors engineering design demonstrations can enlighten your RCA team. *Qual Saf Health Care* 2003;12:119-121.

38. Gosbee J, Human Factors Engineering is the Basis for a Practical Error-in-Medicine Curriculum. Human Error and Clinical Systems; 1999; Glasgow.

39. Flynn EA, Barker KN, Gibson JT, Pearson RE, Smith LA, Berger BA. Relationships between ambient sounds and the accuracy of pharmacists' prescription-filling performance. *Human Factors.* 1996;38(4):614-622.

40. Gertman, D. Blackman, H. *Human Reliability & Safety Analysis Data Handbook.* New York, NY. Wiley-Interscience. 1994.

41. Grabowski, M. Roberts, K. Human and Organizational Error in Large Scale Systems. *IEEE Transactions on Systems, Man and Cybernetics.* 1996;26(1):2-16.

42. Perrow, C. Accidents in High-Risk Systems. *Technology Studies.* 1994;1(1)1-38.

43. L. McCraig, Burt, CW, "National Hospital Ambulatory Medical Care Survey: 2002 Emergency Department Summary," National Center for Health Statistics, Hyattsville, MD, Advance Data 340, March 2004.

44. S. Trzeciak, E. P. Rivers, et al.,"Emergency department overcrowding in the United States: an emerging threat to patient safety and public health. *Emerg Med J*. 2003;20402-405.

45. A. Forster, Stiell, I., Wells, G., Lee, AJ., van Walraven, C., "The effect of hospital occupancy on emergency department length of stay and patient disposition," *Acad Emerg Med*. 2003;10:127-33.

46. "Reasons for crowded EDs vary among hopsital, communities, GAO says," *Qual Letter Healtc Lead*. 2003;15:12-3.

47. F. Zwemer, "Emergency department overcrowding," *Ann Emerg Med*. 2000;36:279-80.

48. J. Appleby, "ER Conditions: Critical," in *USA Today*. Crystal City, 2001.

49. J. Fordyce, Blank, F.S., Pekow, P., Smithline, H.A., Ritter, G., Gehlbach, G., Benjamin, E., Henneman, P.L., "Errors in a Busy Emergency Department," *Annals of Emergency Medicine*. 2003;42:324-33.

50. D. M. Taylor, R. Wolfe, and P. A. Cameron, "Complaints from emergency department patients largely result from treatment and communication problems," *Emerg Med (Fremantle)*. 2002;14:43-9.

51. J. Vinen, "Doctors beware: why a patient complains is not always what it seems," *Emerg Med (Fremantle)*. 2002;14:9-11.

52. L. R. Schwartz and D. T. Overton, "Emergency department complaints: a one-year analysis," *Ann Emerg Med*. 1987;16:857-61.

53. E. D. Boudreaux, C. V. Mandry, and K. Wood, "Patient satisfaction data as a quality indicator: a tale of two emergency departments," *Acad Emerg Med*. 2003;10:261-8.

54. J. G. Adams and J. S. Bohan, "System contributions to error," *Acad Emerg Med*. 2000;7:1189-93.

55. J. Allard, J. Carthey, J. Cope, M. Pitt, and S. Woodward, "Medication errors: Causes, prevention and reduction," *British Journal of Haematology*. 2002;116:255-65.

56. T. Hamilton, "Communication in the emergency department," *Med J Aust*. 2002;177:334; author reply 334-5.

57. R. Knopp, S. Rosenzweig, E. Bernstein, and V. Totten, "Physician-patient communication in the emergency department, part 1," *Acad Emerg Med*. 1996;3:1065-9.

58. C. A. Vincent and R. L. Wears, "Communication in the emergency department: separating the signal from the noise," *Med J Aust*. 2002;176:409-10.

59. S. Williams, J. Weinman, and J. Dale, "Doctor-patient communication and patient satisfaction: a review," *Fam Pract*. 1998;15:480-92.

60. D. T. Risser, M. M. Rice, M. L. Salisbury, R. Simon, G. D. Jay, and S. D. Berns, "The potential for improved teamwork to reduce medical errors in the emergency department. The MedTeams Research Consortium," *Ann Emerg Med*. 1999;34:373-83.

61. P. Bennett, Lowe, R., Matthews, V., Dourali, M., Tatersall, A., "Stress in nurse: coping, managerial support and work demand," *Stress and Health*. 2001;17:55-63.

62. V. Cassar and A. Tattersall, "Occupational stress and negative affectivity in Maltese nurses: testing moderating influences," *Work and Stress*. 1998;12:85-94.

63. J. M. Laposa, L. E. Alden, and L. M. Fullerton, "Work stress and posttraumatic stress disorder in ED nurses/personnel," *J Emerg Nurs*. 2003;29:23-8.

64. M. Levitt, "An evaluation of physiological stress in the emergency department," *Am J Emerg Med*. 1991;9:217-9.

65. J. Losek, "Characteristics, workload, and job satisfaction of attending physicians from pediatric emergency medicine fellowship programs.," *Pediatric Emerg Care*. 1994;10:256-9.

66. S. D. Loyd S, Shannon S., "Burnout, depression, life and job satisfaction among Canadian emergency physicians," *J Emerg Med*. 1994;12:559-65.

67. G. Lum, Goldberg, RM, Mallon, WK., Lew, B., Margulies, J., "A survey of wellness issues in emergency medicine (part 2)," *Ann Emerg Med*. 1995;25:242-248.

68. M. Reinhart, Munger, BS, Rund, DA, "American Board of Emergency Medicine Longitudinal Study of Emergency Physicians," *Ann Emerg Med*. 1999;33:22-32.

69. A. Whitley TW, EJ Gallery ME, Heyworth J, Cockington RA, Gaudry P, Revicki, DA, "Work-related stress and depression among physicians pursuing postgraduate training in emergency medicine: an international study," *Ann Emerg Med*. 1991;20:992-6.

70. S. Williams, J. Dale, E. Glucksman, and A. Wellesley, "Senior house officers' work related stressors, psychological distress, and confidence in performing clinical tasks in accident and emergency: a questionnaire study," *Bmj*. 1997;314:713-8.

71. G. M. Whitley TW, Allison EJ Jr, Revicki, DA, "Factors associated with stress among emergency medicine residents," *Ann Emerg Med*. 1989;18:1157-61.

72. J. Zautcke, Neylan, VD, Hart, RG, "Stress in the emergency department clerical staff," *J Emerg Med*. 1996;14:279-9.

73. J. C. Hollingsworth, C. D. Chisholm, B. K. Giles, W. H. Cordell, and D. R. Nelson, "How do physicians and nurses spend their time in the emergency department?," *Ann Emerg Med*. 1998;31:87-91.

74. G. Hymel, Severyn, F., "Typical shiftwork interruptions faced by supervising EM faculty in an EM residency setting," presented at Society for Academic Emergency Medicine Midwest Regional Meeting, Ann Arbor, Michigan, 1999.

75. Y. Xiao, Lasome, C., Moss, J., Mackenzie, CF, Faraj, S., "Cognitive Properties of a Whiteboard: A Case Study in a Trauma Centre," presented at Seventh European Conference on Computer-Supported Cooperative Work, Bonn, Germany, 2001.

76. "NASA Task Load Index (TLX) V 1.0 Users Manual," Human Systems Information Analysis Center, 1988.

77. S. G. Hart and L. E. Staveland, "Development of NASA-TLX (Task Load Index): Results of experimental and theoretical research," in *Human Mental Workload*, P. A. Hancock and N. Meshkati, Eds. Amsterdam:: North Holland, 1988:139-183.

78. Whitley, T. Gallery, M. Allison, E. et,. al. Work-related stress and depression among physicians pursing postgraduate training in emergency medicine: an international study. 1991;20(9):992-6

79. Golberg, R. Boss, R. et,.al. Burnout and its correlates in emergency physicians: four years' experience with a wellness booth. *Acad Emerg Med.* 1996;3(12):1156-64.

80. Wyatt, J. Weber, J. Chudnofsky, C. The work of the American emergency physician. *J Accid Emerg Med.* 1998;15(3):170-4.

81. Houry, D. Shockley, L, Markovchick, V. Wellness Issues and the Emergency medicine resident. *Ann Emerg Med.* 2000;35:394-396.

82. Forster, A. Stiell, I. et,.al. The Effect of Hospital Occupancy on Emergency Department Length of Stay and Patient Disposition. *Acad Emerg Med.* 2003;10(2):127-33.

83. Whitley, T. Gallery, M. Allison, E. Revicki, D. Factors associated with stress among emergency medicine residents. *Ann Emerg Med.* 1989;18(11):1248-9.

84. Kalemoglu, M. Keskin, O. Evaluation of stress factors and burnout in the emergency department staff. *Ulvas Travma Derg.* 2002;8(4):215-9.

85. Lloyd, S. Streiner, D. Shannon, S. Burnout, depression, life and job satisfaction among Canadian emergency physicians. *J Emerg Med.* 1994;12(4):559-65.

86. Doan-Wiggins, L. Zun, L. Cooper, M. Meyers, D. Chen, E. Practice satisfaction, occupational stress, and attrition of emergency physicians. Wellness Task Force, Illinoise College of Emergency Physicians. *Acad Emerg Med.* 1995;2(6):556-63.

87. Losek, J. Characteristics, workload, and job satisfaction of attending physicians from pediatric emergency medicine fellowship programs.

Pediatric Emergency Medicine Collaborative Research Committee. *Pediatric Emerg Care.* 1994;10(5):256-9.

88. Zautcke, J. Neylan, V. Hart, R. Stress in the emergency department clerical staff. *J Emerg Med.* 1996;14(2):247-9.

89. Phipps L: Stress among doctors and nurses in the emergency department of a general hospital. *Can Med Assoc J.* 1988;139:375-376.

90. Schwartz, L. Overton, D. Emergency department complaints: a one-year analysis. *Ann Emerg Med.* 1987;16:857-61.

91. Bradley, KA. Wipf, JE. Back, AL. Burnout and Self-Reported Patient Care in an Internal Medicine Residency Program. *Annals of Internal Medicine.* 2002;136:358-67.

92. Fordyce, J. Blank, F. Pekow, P. et., al. Errors in a Busy Emergency Department. *Annals of Emergency Medicine*. 2003;42(3):324-33.

93. Wears, R. Errors in Emergency Medicine: A Call to Action. *Academic Emergency Medicine.* 2000;7(11);1173-79.

94. *Handbook of Human Factors and Ergonomics*. New York: John Wiley & Sons, 1997.

95. Braby, D. Harris, D. Muir, H. A Psychophysiological Approach to the Assessment of Work Underload. *Ergonomics.* 1993;2(4):271-280.

96. Tsang, P. Vidulich, M. The Roles of Immediacy and Redundancy in Relative Subjective Workload Assessment. *Human Factors.* 1994;36(3):503-513.

97. Liden, B. Wolowicz, M. et,.al. Characterization and Implications of the Sensors Incorporated in the SenseWear^{TM} Armband of Energy Expenditure and Activity Detection. Sensewear Incorporated.

98. France, D. Levin, S. Emergency Physician's Behaviors and Workload in the Presence of an Electronic Whiteboard. 2004 (under review)

99. Solberg, L. Aspilin, B. Weinick, R. Magid, D. Emergency Department Crowding: Consenus Development of Potential Measures. *Annals of Emergency Medicine.* 2003;42(6):824-34.

100. Reddy, S. Slagle, J. Weinger, B. et.,al. Physiological, Psychological, and Procedural Measures of Clinical Workload. *Anesthesia. 2001*

101. Charlton, S. "Chapter 10: Mental Workload Test and Evaluation". *Mental Workload. 1991;10:180-199.*

102. Levitt. An evaluation of physiological parameters of stress in the emergency department. *J Emerg Med.* 1989;7:293-299.

103. Charlton, S. "Chapter 41: Workload an Examination of the Concept". *Human Peformance. 1991;41:1-27.*

104. Colle, H. Context effects in subjective mental workload ratings. *Human Factors.* 1998;40(4):1-6.

105. Moray, N. Dessouky, M. Kijowski, B. Adapthya, R. Strategic Behavior, workload, and performance in task scheduling. *Human Factors*. 1991;33:607-629.

106. Kyriacou, D. Coben, J. Errors in Emergency Medicine: Research Strategies. *Academic Emergency Medicine.* 2000;7(11):1201-03.