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Emily M. Hayden

Ambrose H. Wong

Jeremy Ackerman

Margaret K. Sande

Charles Lei

See next page for additional authors

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Authors

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Human Factors and Simulation in Emergency Medicine

Emily M. Hayden, MD, MHPE, Ambrose H. Wong, MD, MSHPEd, Jeremy Ackerman, MD, PhD, Margaret K. Sande, MD, MS, MSHPEd, Charles Lei, MD, Leo Kobayashi, MD, Michael Cassara, DO, MSED, Dylan D. Cooper, MD, Kimberly Perry, William E. Lewandowski, MS, and Mark W. Scerbo, PhD

ABSTRACT

This consensus group from the 2017 *Academic Emergency Medicine* Consensus Conference "Catalyzing System Change through Health Care Simulation: Systems, Competency, and Outcomes" held in Orlando, Florida, on May 16, 2017, focused on the use of human factors (HF) and simulation in the field of emergency medicine (EM). The HF discipline is often underutilized within EM but has significant potential in improving the interface between technologies and individuals in the field. The discussion explored the domain of HF, its benefits in medicine, how simulation can be a catalyst for HF work in EM, and how EM can collaborate with HF professionals to effect change. Implementing HF in EM through health care simulation will require a demonstration of clinical and safety outcomes, advocacy to stakeholders and administrators, and establishment of structured collaborations between HF professionals and EM, such as in this breakout group.

The use of novel technologies and systems has improved the efficiency and patient-centeredness of the contemporary practice of emergency medicine (EM). Patients receive effective and safe care when human characteristics are taken into account in the design of technologies and systems that involve people, tools and technology, and work environments. The field of human factors (HF) seeks to address this directly, critically analyzing physical demands, mental workload, team dynamics, work environments, and device design required to complete a task optimally and improve safety and effectiveness.

Patient simulation has been used extensively in health care training and assessment. HF researchers and designers also use simulation in an iterative process to design, engineer, and troubleshoot evolving technologies and techniques prior to their widespread production, deployment, and integration into everyday practice. A clear extension of this approach is HF work that emphasizes providers, devices, systems, and institutions, to identify and mitigate actual and latent patient safety threats.

During the 2017 *Academic Emergency Medicine* Consensus Conference, the Human Factors and Simulation in Emergency Medicine breakout group presented their findings of the current state of the topic as well as gaps in research and understanding. This article serves to document the breakout group's findings.

HF: AN OVERVIEW OF THE FIELD

In 2000, the International Ergonomics Association proposed its consensus-based definition for HF as

"the scientific discipline concerned with the understanding of the interactions among humans and the other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance."[1] This definition is the most widely cited and serves as a basis for consensus building on the topic of HF and simulation in EM. Ergonomics is often used interchangeably with HF; however, ergonomics in the United States emphasizes human physical work (physical fatigue, biomechanics, tool design, etc.). Also potentially confused with HF, systems engineering psychology focuses on the characteristics of the human mind that inform the design process and is similar but distinct to HF.[2] While HF has emerged as its own academic discipline, it is important to recognize that members of a wide range of disciplines perform HF analyses, including psychologists, engineering subspecialists, computer scientists, and architects.

While the integration of HF with EM may seem novel or underutilized, HF-centered approaches have been applied to a variety of industries, cultures, and other work-associated endeavors including those in the military, commercial aviation and aerospace, agriculture, construction, information technology, and service sectors. Multiple modern design methodologies, such as design thinking[3] and human centered design,[4] heavily leverage both prior knowledge derived from the study of HF as well as techniques used to identify and predict behavior and failure points as part of the design process.

HF IN MEDICINE

Modern HF research and design was an outgrowth of World War II, when formal laboratories were established in the Unites States and Great Britain to better understand why highly trained and motivated military personnel remained susceptible to errors. It was not until the early 1960s that HF researchers began to examine potential problems within hospital environments. Formal programs of health care–related research were not initiated until the 1980s.

The medical literature provides examples of studies using HF analyses (HFAs) to evaluate device performance, clinician–device interactions, and patient–device interactions. For an example of how HFAs are used in device design, consider the study by Yin and colleagues[5] who redesigned a hospital trolley-bed tray table using HFA methods. They recognized that

emergency department (ED) patients were frequently moved between locations during their admission, creating a risk that items might be misplaced. They identified the items most often placed on their trolley-bed trays including small inexpensive items (e.g., hand sanitizer) and large expensive equipment (e.g., vital signs monitor). They then generated several design ideas, such as an expandable tabletop, a trough with a table to place small objects, hooks under the tray table to hang heavy equipment, and a translucent document pocket to hold frequently accessed paperwork. The investigators built a small-scale prototype to generate additional suggestions and refinements and then a crude, but full-scale, working prototype. This prototype was evaluated through a series of simulation scenarios. Ultimately, the results of the simulation tests validated many of their design ideas.

Several studies have demonstrated the use of HFA in evaluating clinician–device interactions, such as with infusion pumps,[6,7] defibrillators,[8] telerobotic endoscopic surgical equipment,[9] and high-acuity alarms.[10,11] The Food and Drug Administration (FDA) has developed HF guidelines to assist with the design and development of medical devices.[12] Kobayashi et al.[13] studied the addition of an automatic external defibrillator (AED) to standard defibrillator-based response systems using simulated in situ cases. They found similar defibrillation delivery and an improvement in time to compressions by the group utilizing the AED-integrated device. However, the AED group performed more inappropriate compressions as a result of misalignment of AED prompt programming.

Human factors analyses have been used to evaluate and improve medical equipment interactions with patients, including positive airway pressure devices, a novel naloxone autoinjector,[14,15] and prescription warnings.[16]

HF IN EM

The clinical environment of the ED and the field of EM are ripe for HF application.[17–19] Investigators have applied HF principles to the study of trauma resuscitation, cardiac arrest, and other areas of emergency care.[13,20–29] In particular, HF methods have been used to examine aspects of individual performance, such as task switching exhibited by EM residents[28,30] and clinical decision-making for medical students, paramedics, and nurses.[31–35] Human factor methods have also been used to examine EM team

performance, such as communication in trauma settings[36,37] and task saturation for those involved in rapid response and critical care transport.[38,39] The importance of HF in preventing adverse events and improving patient safety in the ED have become widely acknowledged.[40–42]

Clinically active EM researchers have applied HF principles to the evaluation and improvement of systems of emergency care.[43] These investigations have led to insights into HF issues that affect vital ED processes and tasks, including patient transportation,[44] disaster response,[45,46] and the acquisition of essential clinical supplies.[47] Patient telemetry monitoring, a complex clinical process, exemplifies an active area of HF-based research, with a focus on alarm fatigue[48] and the timely detection of life-threatening arrhythmias.[11] There is growing interest in understanding how ED clinicians interact with their work environment through ergonomic and safety analyses of the ED[49–51] and through the study of health information technology systems such as patient tracking boards[52,53] and electronic health records.[54] HF has been used in device design within the ED to create a work surface to replace the Mayo stand.[55] Additionally, investigators have begun to explore the effects of HF on measures of ED operations, including patient flow,[56] boarding,[57] and surge capacity.[58] Indeed, this diversity of opportunities provides a unique environment in EM for HF practitioners to observe and address needs in the larger landscape of health care.

In parallel with its use in medical device design, HFA methods are being successfully applied to procedural skills training and competency within EM. At the previous *Academic Emergency Medicine* Consensus Conference on simulation in 2008, convened groups described the simultaneous need for and difficulty in setting competency standards for the technical skills required of an emergency provider.[59] Although not explicitly stated, the procedural skill breakout group recommended using simulation and task analyses in designing procedural skill education.[60] More recently, educators are using HF more overtly in addressing procedures[61] and also indirectly through the measurement of learner cognitive load during the training process.[29,30] Investigators have utilized HFA to approach simulation-based training and assessment of procedures, including intraosseous line insertion,[62] epistaxis management,[63] bag-valve-mask ventilation,[64] intravenous catheter insertion,[65] emergency ultrasound technique,[66] and central venous catheter placement.[67,68]

HF METHODS

A primary goal of HF is to build systems that are more efficient, comfortable, and safe. Although a full account of HF methods and techniques is beyond the scope of this paper, several methods are particularly important to the design and use of tools and technologies.

Human factors specialists use hierarchical task analysis (HTA) to understand a task that needs to be accomplished.[69] The goal of an HTA is to generate a complete description of what individuals must do to carry out their objectives. This method is used across many domains including aviation, air traffic control, power plant operations, and product design.[70]

A task is defined by observing performers, surveying subject matter experts, and reviewing standard operating procedures. The task is then broken down into subgoals, and then descriptions of how to accomplish each goal and subgoal are created. The Consensus group discussed the use of an HTA for defibrillator design. Figure 1A shows a portion of an HTA for defibrillating a patient. Plan 0 indicates the main goal and the primary subgoals. Figure 1B drills down to the next level of subgoal 3, Attach Pads. The end product of the HTA process is a description of the physical activities required to perform a task.

Human factors specialists often use HTA together with a cognitive task analysis (CTA). The goal of CTA is to describe the decision making that influences the observable activities of the performer.[71] Like HTA, there are a wide variety of CTA methods. The process begins with establishing the purpose of the analysis, such as defining training requirements. The work domain and tasks are analyzed, probe questions are designed to elicit pertinent information regarding the decision-making process, and subject matter experts are interviewed. The resulting information is organized into a critical decision-making table.

The HTA and CTA processes should be followed with a method for identifying the errors that performers might make. Human error identification (HEI) analysis and prediction methods help pinpoint potential sources of error. Similar to task analysis methods, there are several methods of HEI and prediction. Possible errors for each step are described along with the consequences, recovery potential, probability, criticality,
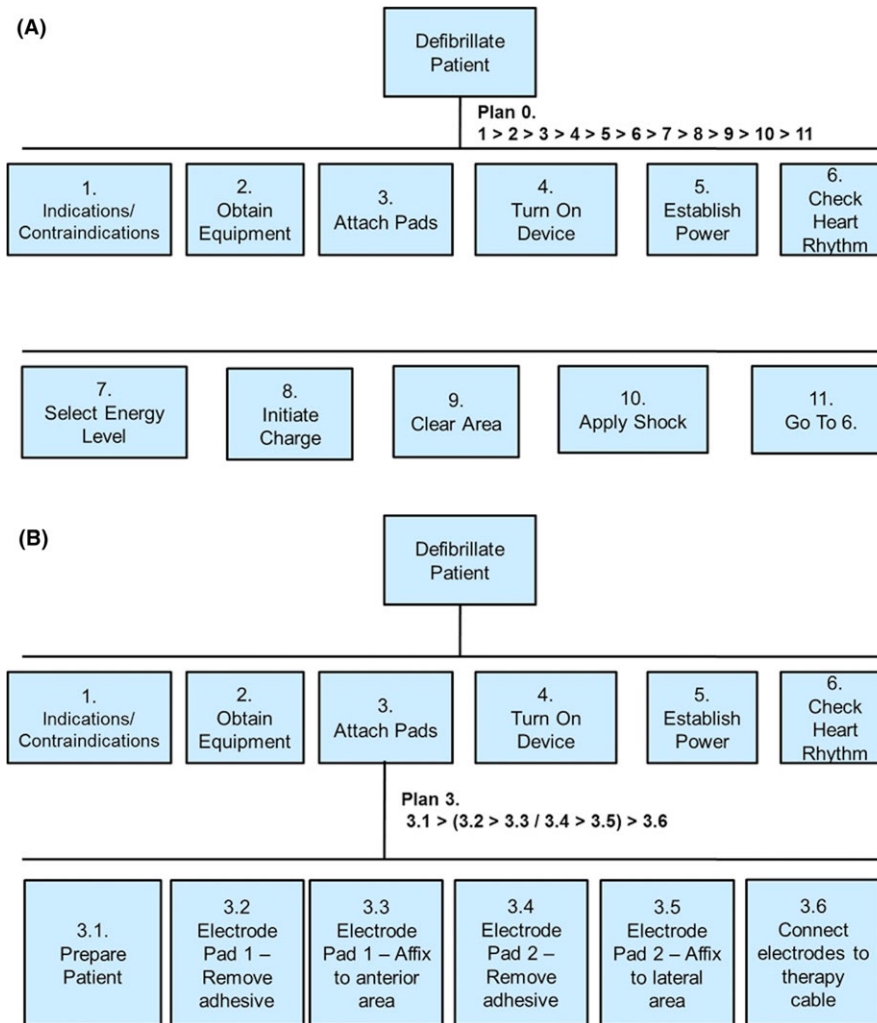
Figure 1. A) A portion of an HTA for defibrillating a patient. Plan 0 indicates the main goal and the primary subgoals. The notation (1 > 2 > 3 —) indicates that each subgoal is performed in sequence. B) The next level of subgoal 3, Attach Pads. The notation (3.1 > (3.2 > 3.3 / 3.4 > 3.5) > 3.6) indicates that each subgoal is performed in sequence with the exception of 3.2 > 3.3 and 3.4 > 3.5. These pairs of subgoals can be done in either order. HTA = hierarchical task analysis.

and remedial strategy. Figure 2 shows a sample HEI table for a portion of the HTA for defibrillating a patient (subgoals 7–8). The first column indicates the fundamental error categories. The next column lists the consequence of each type of error. The detection latency column provides an estimate of how long it would take to notice the error. The next two columns indicate estimates for the probability that the error would occur and how critical the error would be if not corrected. Thus, for subgoal 7.1, press the ENERGY SELECT button; if the operator fails to perform this step, the device will not charge. It is estimated that this error would be noticed after a slight delay and that it does not occur very often; however, failing to correct the error would be a low criticality event because it would only delay delivering the charge by a few seconds.

Another HF method is usability testing,[72,73] which evaluates how well an individual can use a product. The key to this approach is setting metrics for various characteristics of usability. Suppose one wants to know how: 1) easy it is to learn a new system, 2) to customize an existing system, or 3) users like a system. Target goals for each of these characteristics are established. For example, a new user must be able to successfully accomplish three fundamental tasks in under 1 hour. A sample of users performs the tasks and data are measured against the target goals. Failure to meet the goals indicates the system is not usable and requires modification or redesign. Careful consideration must be given to target goals, because goals cannot be redefined to meet users' results.

Human factors professionals often use simulation technologies and techniques with each of these

	Problem(s) A = Action S = Selection Ch = Check R = Retrieval C = Communication	Consequence	Detection Latency I = Immediate S = Slight delay D = Delayed	Probability H = High M = Moderate L = Low	Criticality (higher values – more critical) 0 - 9
Subgoal 7: **Select** **Energy Level**					
Subgoal 7.1: Press ENERGY SELECT button	(A 1) Fail to execute	Will not charge	S	L	5
	(A 8) Right action – wrong object (Charge)	Charge initiated	S	L	7
	(Ch1) Omitted	Charge to default value	I	L	2
Subgoal 7.1: Set Joule level; Press Up/Down arrow buttons	(S2) Wrong direction	Incorrect level	I	L	5
	(S2) Wrong setting	Incorrect level	I	M	5
	(Ch1) Omitted	Charge to default value	S	L	1
Subgoal 8: **Initiate** **Charge**					
Subgoal 8.1: Press CHARGE button	(A 1) Fail to execute	Will not charge	S	L	5
	(A 8) Right action – wrong object	Will not charge	I	L	5
	(Ch1) Omitted	Cannot shock	S	L	5

Figure 2. Sample HEI methods table for a portion of the HTA for defibrillating a patient (subgoals 7–8). For each subgoal, the types of problem, consequences, detection latency, and ratings for probability and criticality are shown. HEI = human error identification; HTA = hierarchical task analysis.

methods, especially when safety or patient privacy are potential concerns. In a simulated environment, users can interact with actual production devices and systems to inform an HTA or CTA. HF professionals can embed prototypes or fully functional products within simulation scenarios to evaluate products within the context they will be used. For example, a product that meets usability target goals in a laboratory setting may fail when measured within the context of a user's environment and workload.

BARRIERS TO USE OF HF AND SIMULATION IN EM

Several cultural and organizational factors create barriers to incorporating HF. First, emergency physicians "have been trained to feel that, if [they] were just alert enough, smart enough, and dedicated enough, [they] should have been able to overcome whatever ergonomic impediments [they] encountered."[49] However, HF professionals recognize that highly trained and motivated individuals cannot always overcome poor design. Second, rarely are there dedicated resources for the use of HF in health care organizations. Finally, the lack of a central, unifying organization to coordinate improvement projects creates scenarios with narrowly focused goals that do not translate or interface with other specialties and groups.

Institutional barriers exist impeding the engagement of HF personnel into clinical settings. Privacy concerns, infectious disease control concerns, and local credentialing requirements frequently necessitate explicit procedures as well as standing legal agreements between the health care institution and the employer of HF personnel. These agreements may be needed even when HF personnel are employees of the same university or institution. Additional concerns include the handling of proprietary information, including the potential for publication of information that may impact an institution's or vendor's reputation and business, as well as the need to clarify the ownership of intellectual property that might come from the work. Addressing these barriers takes institutional knowledge and support which may be beyond the scope of many emergency physicians.

HF AND SIMULATION IN EM SYSTEMS

Decades ago, Moray[74] argued that errors in health care represent a systemic problem. From the micro to the macro level, each of the following factors contributes to errors: design of physical devices, ergonomics of the clinical environment and equipment, individual performance, team performance, organizational policies, legal and regulatory issues, and societal

and cultural pressures. As noted throughout this article, the field of HF aims to improve systems via many of these factors. Through simulation, EM professionals can demonstrate how HF methods can be used to repeatedly test a system to identify new patient safety threats.

DISCUSSION AND HF BREAKOUT SESSION POSITION STATEMENTS

Through the consensus group's literature reviews and discussions with HF professionals in conjunction with discussions amongst the 2017 Consensus Conference participants, several knowledge and research gaps were identified for the application of HF and simulation in EM.

How do we demonstrate the value of HF for patient safety and patient outcomes?

High-reliability organizations in domains such as the military and aviation recognize the value of HF for optimizing human–systems interactions and preventing adverse outcomes. The health care industry, including the specialty of EM, has been slower to integrate and utilize HFA to improve patient safety and outcomes. Reasons likely include EM unfamiliarity and lack of expertise with HF and the methodologies required to integrate HF in a meaningful way. Convincing stakeholders to invest limited resources to support partnerships between experts in HF and EM requires outcomes that demonstrate the value of such partnerships. Simulation-based research should examine the associations between HF, EM, and patient-centered outcomes to explicitly quantify the return on investment in clinically oriented terms. EM simulation experts should identify and prioritize design opportunities where HF have the most significant impact on patient safety and clinical outcomes. These opportunities include high-stakes events in EM, such as trauma resuscitations or the management of cardiac arrest, in which the rates and consequences of adverse events are the best studied and the prospects for HF-based improvements are the greatest.

> **Position:** *Application of HF in EM should focus on demonstrable outcomes in patient safety and clinical outcomes that should be disseminated widely to all stakeholders (e.g., the public, policy makers, payers).*

How do we use the relationships between HF professionals and EM to effect change?

The field of HF has great potential to influence the implementation and improvement of devices and systems in emergency care. Health care simulation provides a safe and convenient bridge between HF and EM given that both fields share an interest in the integration of technology to support the clinical environment and improve safety, particularly in high-stakes situations. EM simulation experts can help close this gap by pioneering and advocating the implementation of HF approaches in future research to educate colleagues and stakeholders about the benefits. In addition, efforts need to be made to facilitate collaborations between EM and HF professionals through networking and joint research opportunities at the local, regional, and national levels. Health care simulation centers can be convenient geographical and academic hubs to colocate EM and HF professionals and their programmatic efforts.

> **Position:** *Emergency medicine simulation should promote the use of HF approaches to address emergency care by educating their stakeholders and colleagues as well as leading successful collaborations that lead to improved safety and outcomes.*

How should EM, simulation, and HF interface?

Many universities have departments of HF. Individual faculty and students who have knowledge and skills in HF exist within numerous other academic disciplines, e.g., engineering, design, architecture, computer science, psychology, and business. Individuals in these programs may have expertise in architecture or biomedical engineering and may be interested in problems concerning patient flow or equipment compatibility within a health care facility. Students may be a good resource for developing long-term collaborations among clinical and academic faculty advisors.

Human factors professionals can be identified through several professional societies. In the United States, the primary professional organization is the Human Factors & Ergonomics Society (www.hfes.org). HFES has 24 technical groups or subdivisions with one focused on health care (hctg.wordpress.com). There are also 23 local chapters of HFES across the United States and many universities and geographical regions have student chapters. The HFES website has a link to HFES design standards and a consultant's directory. The American Psychological Association also

has a group, Division 21 - Applied Experimental & Engineering Psychology (http://www.apa.org/about/division/div21.aspx), that emphasizes the psychological side of HF. The largest international professional HF society is the International Ergonomics Association (www.iea.cc), which has federated societies in 50 countries or global regions.

Position: *Collaborative and structured relationships should be fostered and established between EM simulation and HF professionals using existing academic structures at the local, regional, and national levels.*

CONCLUSION

In summary, implementation of human factors in emergency medicine via health care simulation has significant potential gains in improving the interface between technologies and individuals. Accomplishing this goal will require demonstrable clinical and safety outcome, advocacy of human factors to stakeholders and administrators, and establishment of formal collaborations between human factors professionals and emergency medicine.

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