

Article type : Consensus Conference

HUMAN FACTORS AND SIMULATION IN EMERGENCY MEDICINE

Proceedings from Academic Emergency Medicine Consensus Conference:

Catalyzing System Change through Health Care Simulation: Systems, Competency, and Outcomes

Emily M. Hayden, MD, MHPE¹; Ambrose H. Wong, MD, MSHPEd²; Jeremy Ackerman, MD, PhD^{3,4}; Margaret K. Sande, MD, MS, MSHPEd^{5,6}; Charles Lei, MD⁷; Leo Kobayashi, MD⁸; Michael Cassara, DO, MSED⁹; Dylan D. Cooper, MD¹⁰; Kimberly Perry, BS¹¹; William E. Lewandowski, MS¹²; Mark W. Scerbo, PhD¹¹

¹Department of Emergency Medicine, Massachusetts General Hospital, Boston, MA; ²Department of Emergency Medicine, Yale-New Haven Hospital, New Haven, CT; ³Department of Emergency Medicine, Emory University School of Medicine, Atlanta, GA; ⁴Department of Biomedical Engineering, Emory University/Georgia Institute of Technology; ⁵Centra Health, Fairfax, VA; ⁶Department of Emergency Medicine, University of Colorado School of Medicine, Denver, CO; ⁷Department of Emergency Medicine, Vanderbilt University Medical Center, Nashville, TN; ⁸Department of Emergency Medicine, Alpert Medical School of Brown University, Providence, RI; ⁹Department of Emergency Medicine, Northwell Health, Manhassat, NY; ¹⁰Department of Emergency Medicine, Indiana University School of Medicine, Indianapolis, IN; ¹¹Department of Psychology, Old Dominion University, Norfolk, VA; ¹²3D Systems Healthcare, Littleton, CO

Corresponding author: Emily M. Hayden, emhayden@mgh.harvard.edu.

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 and simulation in the field of emergency medicine. The human factors discipline is often underutilized within emergency

This is the author's manuscript of the article published in final edited form as:

Hayden, E. M., Wong, A. H., Ackerman, J., Sande, M. K., Lei, C., Kobayashi, L., Cassara, M., Cooper, D. D., Perry, K., Lewandowski, W. E. and Scerbo, M. W. (2017), Human factors and simulation in emergency medicine. Acad Emerg Med. Accepted Author Manuscript. <http://dx.doi.org/10.1111/acem.13315>

Accepted Article

medicine but has significant potential in improving the interface between technologies and individuals in the field. The discussion explored the domain of human factors, its benefits in medicine, how simulation can be a catalyst for human factors work in emergency medicine, and how emergency medicine can collaborate with human factors professionals to affect change. Implementing human factors in emergency medicine through healthcare simulation will require a demonstration of clinical and safety outcomes, advocacy to stakeholders and administrators, and establishment of structured collaborations between human factors professionals and emergency medicine, such as in this breakout group.

Introduction

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. Human factors 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.

Accepted Article

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.

Human Factors: 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 emergency medicine. 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 under-utilized, 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 Thinking³ and Human Centered Design⁴, 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.

Human Factors in Medicine

Modern HF research and design was an outgrowth of World War II, when formal laboratories were established in the United 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 healthcare-related research were not initiated until the 1980s.

The medical literature provides examples of studies using human factors analyses (HFA) 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 who redesigned a hospital trolley-bed tray table using HFA methods.⁵ They recognized that emergency department 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. 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.¹³ 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 auto-injector,^{14,15} and prescription warnings.¹⁶

Human Factors in Emergency Medicine

The clinical environment of the emergency department (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 fatigue⁴⁸ 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 ED⁴⁹⁻⁵¹ and through the study of health information technology systems such as patient tracking boards^{52,53} and electronic health records.⁵⁴ Human factors 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 procedures⁶¹ and also indirectly through the measurement of learner cognitive load during the training process.^{30,62} Investigators have utilized HFA to approach simulation-based training and assessment of procedures, including intraosseous line insertion,⁶³ epistaxis management,⁶⁴ bag-valve mask ventilation,⁶⁵ intravenous catheter insertion,⁶⁶ emergency ultrasound technique,⁶⁷ and central venous catheter placement.^{68,69}

Human Factors 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.⁷⁰ 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.⁷¹

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.⁷² Like HTA, there is 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 human error identification and prediction. Possible errors for each step are described along with the

consequences, recovery potential, probability, criticality, 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 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**^{73,74} 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) customize an existing system, or 3) how 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 one 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 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. Human factors 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 Human Factors and Simulation in Emergency Medicine

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".⁷⁵ 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 healthcare 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.

Human Factors and Simulation in Emergency Medicine Systems

Decades ago, Moray⁷⁶ argued that errors in healthcare 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 emergency medicine.

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 healthcare 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

Accepted Article

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 emergency medicine 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, etc.).*

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

The field of HF has great potential to influence the implementation and improvement of devices and systems in emergency care. Healthcare 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. Healthcare simulation centers can be convenient geographical and academic hubs to co-locate EM and HF professionals and their programmatic efforts.

Position: *Emergency medicine simulation should promote the use of human factors 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 human factors. 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 healthcare 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 healthcare (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 (www.apa21.org), 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 emergency medicine simulation and HF professionals using existing academic structures at the local, regional and national levels.*

Conclusion

In summary, implementation of HF in emergency medicine via healthcare 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 HF to stakeholders and administrators, and establishment of formal collaborations between HF professionals and emergency medicine.

References

1. Association IE. What is ergonomics. <http://www.iea.cc/whats>. Published 2000. Accessed March 3, 2017.
2. Wickens C, Lee J, Liu Y, Gordon-Becker S. *Introduction to Human Factors Engineering*. 2nd ed. Upper Saddle River, NJ: Pearson; 2004.
3. Design Thinking for Educators. <https://designthinkingforeducators.com/>.
4. Cowan D, Yi Luen Do E, Margolis M, Zimring C AJ. The ED of the Future: an Interdisciplinary Graduate Course in Healthcare Design. *Acad Emerg Med*. 2009;16:S277.
5. Yin S, Siew JJH, Ng SBI, Putra AS, Ang A. Functional Redesign of the Hospital Trolley-Bed Tray Table. *Ergon Des Q Hum Factors Appl*. 2016;24(4):20-26. doi:10.1177/1064804616630692.
6. Ginsburg G. Human factors engineering: A tool for medical device evaluation in hospital procurement decision-making. *J Biomed Inform*. 2005;38(3):213-219. doi:10.1016/j.jbi.2004.11.008.
7. Lin L, Vicente KJ, Doyle DJJ. Patient Safety, Potential Adverse Drug Events, and Medical Device Design: A Human Factors Engineering Approach. *J Biomed Inform*. 2001;34(4):274-284. doi:10.1006/jbin.2001.1028.
8. Fidler R, Johnson M. Human Factors Approach to Comparative Usability of Hospital Manual Defibrillators. *Resuscitation*. 2016;101:71-76. doi:10.1016/j.resuscitation.2016.01.029.
9. Lee EC, Rafiq A, Merrell R, Ackerman R, Dennerlein JT. Ergonomics and human factors in endoscopic surgery: A comparison of manual vs telerobotic simulation systems. *Surg Endosc Other Interv Tech*. 2005;19(8):1064-1070. doi:10.1007/s00464-004-8213-6.
10. Cvach M, Rothwell KJ, Cullen AM, Nayden MG, Cvach N, Pham JC. Effect of altering alarm settings: a randomized controlled study. *Biomed Instrum Technol*. 2015;49(3):214-222. doi:10.2345/0899-8205-49.3.214.

11. Kobayashi L, Parchuri R, Gardiner FG, et al. Use of in situ simulation and human factors engineering to assess and improve emergency department clinical systems for timely telemetry-based detection of life-threatening arrhythmias. *BMJ Qual Saf.* 2012;72-83. doi:10.1136/bmjqs-2012-001134.
12. Premarket Information-Device Design and Documentation Processes. <https://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/HumanFactors/ucm119190.htm>. Accessed January 5, 2017.
13. Kobayashi L, Dunbar-Viveiros JA, Sheahan BA, et al. In Situ Simulation Comparing In-Hospital First Responder Sudden Cardiac Arrest Resuscitation Using Semiautomated Defibrillators and Automated External Defibrillators. *Simul Healthc.* 2010;5(2):82-90. doi:10.1097/SIH.0b013e3181ccd75c.
14. Raffa RB, Taylor R, Pergolizzi J V, Nalamachu S, Edwards ES, Edwards ET. Application of human factors engineering (HFE) to the design of a naloxone auto-injector for the treatment of opioid emergencies. *Drug Deliv Transl Res.* 2017;7(1):1-10. doi:10.1007/s13346-016-0323-x.
15. Fung C, Igodan U, Alessi C, Al E. Human factors/usability barriers to home medical devices among individuals with disabling conditions: in-depth interviews with positive airway pressure device users. *Disabil Heal J.* 2015;8:86-92.
16. Russ AL, Zillich AJ, Melton BL, et al. Applying human factors principles to alert design increases efficiency and reduces prescribing errors in a scenario-based simulation. *J Am Med Inform Assoc.* 2014;1-10. doi:10.1136/amiajnl-2013-002045.
17. Ornato JP, Peberdy MA. Applying lessons from commercial aviation safety and operations to resuscitation. *Resuscitation.* 2014;85(2):173-176. doi:10.1016/j.resuscitation.2013.10.029.
18. Petrosioniak A, Hicks CM. Beyond crisis resource management. *Curr Opin Anaesthesiol.* 2013;26(6):699-706. doi:10.1097/ACO.0000000000000007.
19. Timmons S, Baxendale B, Buttery A, Miles G, Roe B, Browes S. Implementing human factors in clinical practice. *Emerg Med J.* 2015;32(5):368-372. doi:10.1136/emered-2013-203203.
20. Gjeraa K, Møller TP, Østergaard D. Efficacy of simulation-based trauma team training of non-technical skills. A systematic review. *Acta Anaesthesiol Scand.* 2014;58(7):775-787. doi:10.1111/aas.12336.
21. Wisborg T, Brattebø G, Brinchmann-Hansen Å, Hansen K. Mannequin or standardized patient: participants' assessment of two training modalities in trauma team simulation. *Scand J Trauma Resusc Emerg Med.* 2009;17(1):59. doi:10.1186/1757-7241-17-59.
22. Stratton A, Furey A, Hogan M. The Effect of Sleep Deprivation on a Resident's Situational Awareness in a Trauma Scenario. *J Orthop Trauma.* 2014;28(7):e160-e163. doi:10.1097/BOT.0000000000000003.

23. Clarke S, Carolina Apesoa-Varano E, Barton J. Code Blue: methodology for a qualitative study of teamwork during simulated cardiac arrest: Table 1. *BMJ Open*. 2016;6(1):e009259. doi:10.1136/bmjopen-2015-009259.
24. Donoghue A, Ventre K, Boulet J, et al. Design, Implementation, and Psychometric Analysis of a Scoring Instrument for Simulated Pediatric Resuscitation: A Report from the EXPRESS Pediatric Investigators. *Simul Healthc J Soc Simul Healthc*. 2011;6(2):71-77. doi:10.1097/SIH.0b013e31820c44da.
25. Griffin P, Cooper C, Glick J, Terndrup TE. Immediate and 1-year chest compression quality: effect of instantaneous feedback in simulated cardiac arrest. *Simul Healthc*. 2014;9(4):264-269. doi:10.1097/SIH.0000000000000030.
26. Lemke DS, Fielder EK, Hsu DC, Doughty CB. Improved Team Performance During Pediatric Resuscitations After Rapid Cycle Deliberate Practice Compared With Traditional Debriefing: A Pilot Study. *Pediatr Emerg Care*. October 2016. doi:10.1097/PEC.0000000000000940.
27. Fernandez R, Compton S, Jones KA, Velilla MA. The presence of a family witness impacts physician performance during simulated medical codes. *Crit Care Med*. 2009;37(6):1956-1960. doi:10.1097/CCM.0b013e3181a00818.
28. Smith D, Miller DG, Cukor J. Can Simulation Measure Differences in Task-Switching Ability Between Junior and Senior Emergency Medicine Residents? *West J Emerg Med*. 2016;17(2):149-152. doi:10.5811/westjem.2015.12.28269.
29. Haji FA, Rojas D, Childs R, de Ribaupierre S, Dubrowski A. Measuring cognitive load: performance, mental effort and simulation task complexity. *Med Educ*. 2015;49(8):815-827. doi:10.1111/medu.12773.
30. Haji FA, Khan R, Regehr G, Drake J, de Ribaupierre S, Dubrowski A. Measuring cognitive load during simulation-based psychomotor skills training: sensitivity of secondary-task performance and subjective ratings. *Adv Heal Sci Educ*. 2015;20(5):1237-1253. doi:10.1007/s10459-015-9599-8.
31. Schubert CC, Denmark TK, Crandall B, Grome A, Pappas J. Characterizing Novice-Expert Differences in Macrocognition: An Exploratory Study of Cognitive Work in the Emergency Department. *Ann Emerg Med*. 2013;61(1):96-109. doi:10.1016/j.annemergmed.2012.08.034.
32. Ten Eyck RP, Tews M, Ballester JM, Hamilton GC. Improved Fourth-Year Medical Student Clinical Decision-Making Performance as a Resuscitation Team Leader After a Simulation-Based Curriculum. *Simul Healthc J Soc Simul Healthc*. 2010;5(3):139-145. doi:10.1097/SIH.0b013e3181cca544.
33. Smith MW, Bentley MA, Fernandez AR, Gibson G, Schweikhart SB, Woods DD. Performance of Experienced Versus Less Experienced Paramedics in Managing Challenging Scenarios: A Cognitive Task Analysis Study. *Ann Emerg Med*. 2013;62(4):367-379. doi:10.1016/j.annemergmed.2013.04.026.

34. Yang H, Thompson C, Bland M. The effect of clinical experience, judgment task difficulty and time pressure on nurses' confidence calibration in a high fidelity clinical simulation. *BMC Med Inform Decis Mak.* 2012;12(1):113. doi:10.1186/1472-6947-12-113.
35. Bond W, Kuhn G, Binstadt E, et al. The Use of Simulation in the Development of Individual Cognitive Expertise in Emergency Medicine. *Acad Emerg Med.* 2008;15(11):1037-1045. doi:10.1111/j.1553-2712.2008.00229.x.
36. Fernandez R, Kozlowski SWJ, Shapiro MJ, Salas E. Toward a Definition of Teamwork in Emergency Medicine. *Acad Emerg Med.* 2008;15(11):1104-1112. doi:10.1111/j.1553-2712.2008.00250.x.
37. Lazzara EH, Benishek LE, Patzer B, et al. Utilizing Telemedicine in the Trauma Intensive Care Unit: Does It Impact Teamwork? *Telemed e-Health.* 2015;21(8):670-676. doi:10.1089/tmj.2014.0074.
38. Davis B, Welch K, Walsh-Hart S, et al. Effective teamwork and communication mitigate task saturation in simulated critical care air transport team missions. *Mil Med.* 2014;179(8 Suppl):19-23. doi:10.7205/MILMED-D-13-00240.
39. Beebe P, Bawel-Brinkley K, O'Leary-Kelley C. Observed and Self-Perceived Teamwork in a Rapid Response Team. *J Nurses Staff Dev.* 2012;28(4):191-197. doi:10.1097/NND.0b013e31825e63d7.
40. Bleetman A, Sanusi S, Dale T, Brace S. Human factors and error prevention in emergency medicine. *Emerg Med J.* 2012;29(5):389-393. doi:10.1136/emj.2010.107698.
41. Bashkin O, Caspi S, Swissa A, Amedi A. Human Factors and Quality Improvement in the Emergency Department : Reducing Potential Errors in Blood Collection. 2016;0(0):1-5.
42. Fan M, Petrosoniak A, Pinkney S, et al. Study protocol for a framework analysis using video review to identify latent safety threats: trauma resuscitation using in situ simulation team training (TRUST). *BMJ Open.* 2016;6(11):e013683. doi:10.1136/bmjopen-2016-013683.
43. Kobayashi L, Overly FL, Fairbanks RJ, et al. Advanced Medical Simulation Applications for Emergency Medicine Microsystems Evaluation and Training. *Acad Emerg Med.* 2008;15(11):1058-1070. doi:10.1111/j.1553-2712.2008.00247.x.
44. Segev D, Levi R, Dunn PF, Sandberg WS. Modeling the impact of changing patient transportation systems on peri-operative process performance in a large hospital: insights from a computer simulation study. *Health Care Manag Sci.* 2012;15(2):155-169. doi:10.1007/s10729-012-9191-1.
45. Ohta S, Yoda I, Takeda M, et al. Evidence-based Effective Triage Operation During Disaster: Application of Human-trajectory Data to Triage Drill Sessions. *Prehosp Disaster Med.* 2015;30(1):102-109. doi:10.1017/S1049023X14001381.
46. Wilkerson W, Avstreich D, Gruppen L, Beier K-P, Woolliscroft J. Using Immersive Simulation for Training First Responders for Mass Casualty Incidents. *Acad Emerg Med.* 2008;15(11):1152-1159. doi:10.1111/j.1553-2712.2008.00223.x.

47. Richardson DM, Rupp VA, Long KR, et al. Using lean methodology to decrease wasted RN time in seeking supplies in emergency departments. *J Nurs Adm.* 2014;44(11):606-611. doi:10.1097/NNA.0000000000000133.
48. Kobayashi L, Gosbee JW, Merck DL. Development and Application of a Clinical Microsystem Simulation Methodology for Human Factors-Based Research of Alarm Fatigue. *HERD Heal Environ Res Des J.* 2016;1-14. doi:10.1177/1937586716673829.
49. Wears RL, Perry SJ. Human factors and ergonomics in the emergency department. *Ann Emerg Med.* 2002;40(2):206-212. <http://www.ncbi.nlm.nih.gov/pubmed/12140500>. Accessed February 14, 2017.
50. Kobayashi L, Shapiro MJ, Sucov A, et al. Portable Advanced Medical Simulation for New Emergency Department Testing and Orientation. *Acad Emerg Med.* 2006. doi:10.1197/j.aem.2006.01.023.
51. Geis GL, Pio B, Pendergrass TL, Moyer MR, Patterson MD. Simulation to Assess the Safety of New Healthcare Teams and New Facilities. *Simul Healthc J Soc Simul Healthc.* 2011;6(3):125-133. doi:10.1097/SIH.0b013e31820dff30.
52. McGeorge N, Hegde S, Berg RL, et al. Assessment of Innovative Emergency Department Information Displays in a Clinical Simulation Center. *J Cogn Eng Decis Mak.* 2015;9(4):329-346. doi:10.1177/1555343415613723.
53. Pennathur PR, Cao D, Sui Z, et al. Development of a Simulation Environment to Study Emergency Department Information Technology. *Simul Healthc J Soc Simul Healthc.* 2010;5(2):103-111. doi:10.1097/SIH.0b013e3181c82c0a.
54. Zhou Y, Ancker JS, Upahdye M, et al. The impact of interoperability of electronic health records on ambulatory physician practices: a discrete-event simulation study. *Inform Prim Care.* 2014;21(1):21-29. doi:10.14236/jhi.v21i1.36.
55. Zhang XC, Bermudez AM, Reddy PM, et al. Interdisciplinary Development of an Improved Emergency Department Procedural Work Surface Through Iterative Design and Use Testing in Simulated and Clinical Environments. *Ann Emerg Med.* November 2016. doi:10.1016/j.annemergmed.2016.08.436.
56. Laskowski M, McLeod RD, Friesen MR, Podaima BW, Alfa AS. Models of Emergency Departments for Reducing Patient Waiting Times. Morty RE, ed. *PLoS One.* 2009;4(7):e6127. doi:10.1371/journal.pone.0006127.
57. Levin SR, Dittus R, Aronsky D, et al. Optimizing cardiology capacity to reduce emergency department boarding: A systems engineering approach. *Am Heart J.* 2008;156(6):1202-1209. doi:10.1016/j.ahj.2008.07.007.
58. Franc JM, Ingrassia PL, Verde M, Colombo D, Della Corte F. A Simple Graphical Method for Quantification of Disaster Management Surge Capacity Using Computer Simulation and Process-control Tools. *Prehosp Disaster Med.* 2015;30(1):9-15. doi:10.1017/S1049023X1400123X.
59. Lammers RL, Davenport M, Korley F, et al. Teaching and Assessing Procedural Skills

- Using Simulation: Metrics and Methodology. *Acad Emerg Med*. 2008;15(11):1079-1087. doi:10.1111/j.1553-2712.2008.00233.x.
60. Wang EE, Quinones J, Fitch MT, et al. Developing Technical Expertise in Emergency Medicine-The Role of Simulation in Procedural Skill Acquisition. *Acad Emerg Med*. 2008;15(11):1046-1057. doi:10.1111/j.1553-2712.2008.00218.x.
 61. Clark RE, Pugh CM, Yates KA, Inaba K, Green DJ, Sullivan ME. The Use of Cognitive Task Analysis to Improve Instructional Descriptions of Procedures. *J Surg Res*. 2012;173(1):e37-e42. doi:10.1016/j.jss.2011.09.003.
 62. Haji FA, Rojas D, Childs R, de Ribaupierre S, Dubrowski A. Measuring cognitive load: performance, mental effort and simulation task complexity. *Med Educ*. 2015;49(8):815-827. doi:10.1111/medu.12773.
 63. Oriot D, Darrieux E, Boureau-Voultoury A, Ragot S, Scépi M. Validation of a Performance Assessment Scale for Simulated Intraosseous Access. *Simul Healthc J Soc Simul Healthc*. 2012;7(3):171-175. doi:10.1097/SIH.0b013e31824a5c20.
 64. Lammers RL. Learning and Retention Rates after Training in Posterior Epistaxis Management. *Acad Emerg Med*. 2008;15(11):1181-1189. doi:10.1111/j.1553-2712.2008.00220.x.
 65. Marjanovic N, Le Floch S, Jaffrelot M, L'Her E. Evaluation of manual and automatic manually triggered ventilation performance and ergonomics using a simulation model. *Respir Care*. 2014;59(5):735-742. doi:10.4187/respcare.02557.
 66. Adhikari S, Schmier C, Marx J. Focused simulation training: emergency department nurses' confidence and comfort level in performing ultrasound-guided vascular access. *J Vasc Access*. 2015;16(6):515-520. doi:10.5301/jva.5000436.
 67. Chung GKWK, Gyllenhammer RG, Baker EL, Savitsky E. Effects of Simulation-Based Practice on Focused Assessment With Sonography for Trauma (FAST) Window Identification, Acquisition, and Diagnosis. *Mil Med*. 2013;178(10S):87-97. doi:10.7205/MILMED-D-13-00208.
 68. Clinkard D, Holden M, Ungi T, et al. The Development and Validation of Hand Motion Analysis to Evaluate Competency in Central Line Catheterization. Burton J, ed. *Acad Emerg Med*. 2015;22(2):212-218. doi:10.1111/acem.12590.
 69. Thomas SM, Burch W, Kuehnle SE, Flood RG, Scalzo AJ, Gerard JM. Simulation Training for Pediatric Residents on Central Venous Catheter Placement. *Pediatr Crit Care Med*. 2013;14(9):e416-e423. doi:10.1097/PCC.0b013e31829f5eda.
 70. Annett J, Stanton N, eds. *Task Analysis*. 1st ed. London, United Kingdom: Taylor and Francis; 2000.
 71. Diaper D, Stanton N. *Handbook of Task Analysis in Human-Computer Interaction*. 1st ed. Mahwah, NJ: Erlbaum; 2004.
 72. Militello L, Hutton J. Applied Cognitive Task Analysis (ACTA): A practitioner's toolkit for

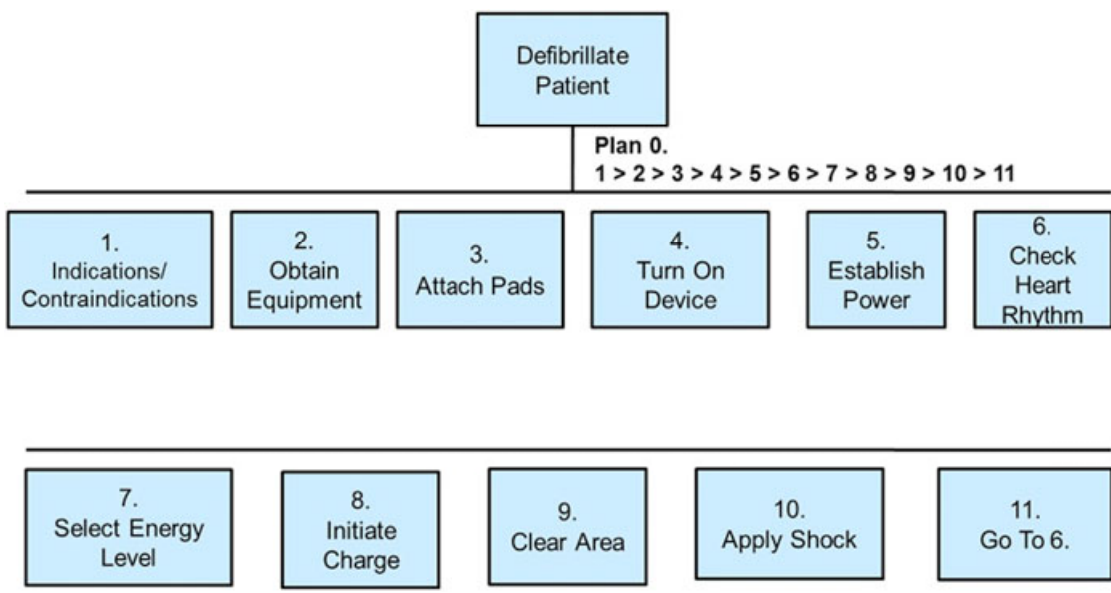
understanding cognitive task demands. In: Annett J, Stanton N, eds. *Task Analysis*. London, United Kingdom; 2000.

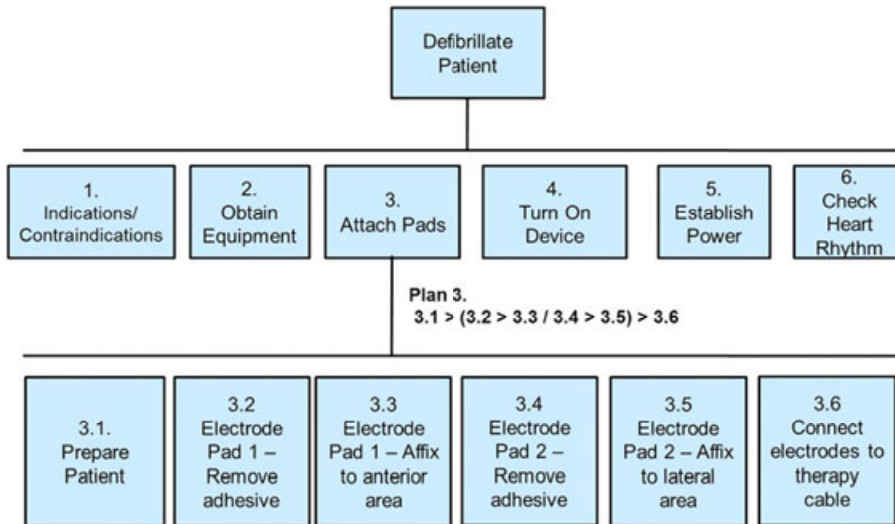
73. Scerbo M. Usability testing. In: Weimer J, ed. *Research Techniques in Human Engineering*. Englewood Cliffs, NJ: Prentice-Hall; 1995:72-111.

74. Wiklund M, Kendler J, Strohlic A. *Usability Testing of Medical Devices*. 2nd ed. Boca Raton, FL: CRC Press; 2016.

75. Wears RL, Perry SJ. Human factors and ergonomics in the emergency department. *Ann Emerg Med*. 2002;40(2):206-212. doi:10.1067/mem.2002.124900.

76. Moray N. *Human Error in Medicine*. (MS B, ed.). Hillsdale, NJ: Erlbaum; 1994.





	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	(A1) Fail to execute	Will not charge	S	L	5
	(A8) 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	(A1) Fail to execute	Will not charge	S	L	5
	(A8) Right action – wrong object	Will not charge	I	L	5
	(Ch1) Omitted	Cannot shock	S	L	5

	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	(A1) Fail to execute	Will not charge	S	L	5
	(A8) 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	(A1) Fail to execute	Will not charge	S	L	5
	(A8) Right action – wrong object	Will not charge	I	L	5
	(Ch1) Omitted	Cannot shock	S	L	5