Original Article

Proactive Safety Management in Trauma Care: Applying the Human Factors Analysis and Classification System

Tara N. Cohen • Jennifer S. Cabrera • Tracy L. Litzinger • Kevin A. Captain • Michael A. Fabian • Steven G. Miles • Scott T. Reeves • Scott A. Shappell • Albert J. Boquet

ABSTRACT

Introduction: This article examines the reliability of the Human Factors Analysis and Classification System (HFACS) for classifying observational human factors data collected prospectively in a trauma resuscitation center.

Methods: Three trained human factors analysts individually categorized 1,137 workflow disruptions identified in a previously collected data set involving 65 observed trauma care cases using the HFACS framework.

Results: Results revealed that the framework was substantially reliable overall ($\kappa = 0.680$); agreement increased when only the preconditions for unsafe acts were investigated ($\kappa = 0.757$). Findings of the analysis also revealed that the preconditions for unsafe acts category was most highly populated (91.95%), consisting mainly of failures involving communication, coordination, and planning.

Conclusion: This study helps validate the use of HFACS as a tool for classifying observational data in a variety of medical domains. By identifying preconditions for unsafe acts, health care professionals may be able to construct a more robust safety management system that may provide a better understanding of the types of threats that can impact patient safety.

Keywords: human factors engineering, patient safety, emergencies

Introduction

Like early efforts in aviation, attempts to address human error in health care have largely been reactive in nature.[1] Historically, the medical community has focused most of its efforts on identifying and mitigating human error by the analysis of sentinel events. While reactive approaches are oftentimes effective in identifying and rectifying issues related to the "low hanging fruit" in terms of accidents and incidents, they lack a systemic understanding of how error is generated within a complex system. To this end, it is incumbent upon health care professionals to adopt a more proactive approach in dealing with system failure to see lasting advances in addressing the problem of human or system error.

Rather than focusing on active failures (i.e., faults that are directly linked to an accident) the authors propose to explore latent failures and how they contribute to system inefficiencies. Latent failures represent areas of systemic weakness, and although they do not have an immediate consequence, they may lie dormant for days, months, or even years before an accident occurs. Thus, health care may be better served by addressing latent failures, which would represent a more proactive approach to patient safety.

Sarcavic explains that trauma resuscitation is unpredictable and occurs in a fast-paced, dynamic environment where health care professionals must proficiently evaluate and diagnose severe patient cases. This process is information laden and team dependent, relying heavily not only on clinical skill, but also on the efficiency of the system.[2]

The American College of Surgeons explain that the general size and composition of the team may vary based on the hospital size, severity of injury, and the corresponding level of trauma team activation. Traditionally, a high-level response to a severely injured patient includes a general surgeon, emergency physician, surgical and emergency residents, emergency department nurses, laboratory technician, radiology technician, critical care nurse, anesthesiologist, operating room nurse, security officers,

Journal for Healthcare Quality, Vol. 40, No. 2, pp. 89–96

The authors declare no conflicts of interest.

For more information on this article, contact Tara N. Cohen at tara@flyawayhome.biz.

DOI: 10.1097/JHQ.0000000000000094

chaplain, and scribe. However, a low-level response to a less critical patient usually consists of an emergency physician and the emergency department nurses until the general surgeon arrives.[3]

Given the nature of trauma care, it is imperative that health care professionals have a standardized system to classify latent failures, thus providing a means to both understand and target those failures. This may then form the cornerstone of a true safety management system which will allow the system to evolve into one that provides an appropriate level of redundancy and resiliency to accommodate the inevitable latent failures that are part of all complex systems.

To this end, the Human Factors Analysis and Classification System (HFACS), which began as an accident investigation tool in aviation, was applied in health care settings. The HFACS methodology, created by Shappell and Wiegmann, was built on James Reason's "Swiss cheese" model of accident causation. Reason's model consists of 4 layers that act as barriers to protect a system. Shappell and Wiegmann expanded on Reason's model by describing failures at each of the 4 layers. Within these layers (also called tiers) exist 19 causal categories to allow classification and further analysis of human factors associated with accidents.

As preconditions for unsafe acts are most easily observable and central to this study, this tier of HFACS is described in more detail. This tier of HFACS captures failures associated with the individual and the general working environment and includes three overarching categories (i.e., environmental factors, conditions of the operator, and personnel factors), which can be further broken down into seven distinct categories. Physical environment refers to factors in the operational and ambient environment that can make it difficult for the individual to complete their task. Technological environment includes traditional usability issues associated with equipment, software, and several forms of documentation (e.g., checklists and procedures). Adverse mental states are mental conditions of operators that may affect performance such as distraction, inattention, and mental fatigue, as well as personality traits and attitudes such as anger, overconfidence, and frustration. Adverse physiological states refer to medical or physiological conditions that may preclude safe operations such as illness or fatigue. Physical/mental limitations include those instances when operational requirements exceed the capabilities of the individual. With respect to personnel factors, communication, coordination, and planning accounts for occurrences of poor communication or coordination among team members while fitness for duty includes activities that are performed off the job that influence an individual's ability to perform on the job (see Table 1 for a full description).[4,5]

Cohen et al explored the utilization and the reliability of HFACS for the classification of observational data in the cardiovascular operating room (CVOR).[6] The authors applied HFACS to two separate data sets collected from different CVORs and found that HFACS was not only reliable, but it could also be used to detect differences identified between the two hospitals. The results of the study are important because they demonstrate the utility of HFACS as a proactive tool for investigating observational human factors data in the cardiac operating room. However, it has not been determined if HFACS can reliably be used in other medical domains outside the CVOR.

To test the applicability of HFACS outside a predictable environment like the CVOR, the current investigation applied the taxonomy to data that had been previously collected in the trauma setting. Based on previous findings, it is predicted that the HFACS framework can be reliably applied to trauma care. The results will provide new information regarding those process inefficiencies that may contribute to systemic problems within a trauma center.

Methods

Data Collection

The data set used for this study was originally collected to identify workflow disruptions during trauma cases observed at a Level II trauma center. Data were collected from an East Central Florida community hospital and approved by the hospital's Institutional Review Board. During each case, data were collected from the time the patient arrived in the resuscitation bay and continued through imaging (if needed), until disposition to surgery, the medical floor unit, or the emergency department for further assessment. Specifically, case observation occurred in two parts: (1) observation of the team in the resuscitation bay (the area used to stabilize patients) and (2) observation of the team in imaging (the area that houses the computed tomography scanner for in-depth images). Researchers observed and recorded workflow disruptions during both phases (if applicable), as well as the amount of time spent in each observation area.

Table 1. Description of HFACS Categories

Organizational influences
Organizational climate: Prevailing atmosphere/vision within the organization, including such things as policies, command structure, and culture.
Operational process: Formal process by which the vision of an organization is performed including operations, procedures, and oversight, among others.
Resource management: How human, monetary, and equipment resources necessary to carry out the vision are managed.
Unsafe supervision
Inadequate supervision: Oversight and management of personnel and resources, including training, professional guidance, and operational leadership, among other aspects.
Planned inappropriate operations: Management and assignment of work, including aspects of risk management, crew pairing, operational tempo, etc.
Failed to correct known problems: Those instances in which deficiencies among individuals, equipment, training, or other related safety areas are “known” to the supervisor yet are allowed to continue uncorrected.
Supervisory violations: The willful disregard for existing rules, regulations, instructions, or standard operating procedures by managers during the course of their duties.
Preconditions for unsafe acts
Environmental factors
Technological environment: This category encompasses a variety of issues, including the design of equipment and controls, display/interface characteristics, checklist layouts, task factors, and automation.
Physical environment: Included are both the operational setting (e.g., weather, altitude, terrain) and the ambient environment (e.g., as heat, vibration, lighting, toxins).
Condition of the operator
Adverse mental states: Acute psychological and/or mental conditions that negatively affect performance, such as mental fatigue, pernicious attitudes, and misplaced motivation.
Adverse physiological states: Acute medical and/or physiological conditions that preclude safe operations, such as illness, intoxication, and the myriad pharmacological and medical abnormalities known to affect performance.
Physical/mental limitations: Permanent physical/mental disabilities that may adversely impact performance, such as poor vision, lack of physical strength, mental aptitude, general knowledge, and a variety of other chronic mental illnesses.
Personnel factors
Crew resource management: Includes a variety of communication, coordination, and teamwork issues that impact performance.
Personal readiness: Off-duty activities required to perform optimally on the job, such as adhering to crew rest requirements, alcohol restrictions, and other off-duty mandates.
Unsafe acts
Errors
Decision errors: These “thinking” errors represent conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation. These errors typically manifest as poorly executed procedures, improper choices, or simply the misinterpretation and/or misuse of relevant information.

Table 1. Description of HFACS Categories *(Continued)*
Skill-based errors: Highly practiced behavior that occurs with little or no conscious thought. These "doing" errors frequently appear as breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgotten intentions, and omitted items in checklists. Even the manner or technique with which one performs a task is included.
Perceptual errors: These errors arise when sensory input is degraded, as is often the case when flying at night, in poor weather, or in otherwise visually impoverished environments. Faced with acting on imperfect or incomplete information, aircrew run the risk of misjudging distances, altitude, and descent rates, as well as of responding incorrectly to a variety of visual/vestibular illusions.
Violations
Routine violations: Often referred as "bending the rules," this type of violation tends to be habitual by nature and is often enabled by a system of supervision and management that tolerates such departures from the rules.
Exceptional violations: Isolated departures from authority, neither typical of the individual nor condoned by management.

Coder Training

Three human factors graduate students classified events using the HFACS taxonomy. Notably, coders were not associated with the data collection effort explained above. An expert in HFACS provided coders with 2 days of training, including a summary of human factors, an overview of HFACS, and a discussion of each causal category, including examples of each. After HFACS training, coders were given more detailed instruction on specific trauma care topics, including emergency medicine terminology, trauma team roles and responsibilities, and common procedures and equipment.

Data Coding/Classification

To standardize the coding process, all 3 raters classified 50 randomly selected events from the observational data set into the HFACS framework as a group with supervision and guidance from the researchers. After this period, each rater independently classified 100 additional events to practice coding on their own. The researcher and 3 raters reviewed any disagreements to be sure that all raters had a shared mental model for classifying the events. Following, the raters individually coded the remainder of the data and later returned to independently code the original 150 practice observations. To include as many events as possible in the analysis, these 150 recoded events were combined with the other (nontraining) events for use in this study.

Data Inclusion and Reliability

Data inclusion was determined based on 3 analytical methods: unanimous agreement, majority agreement, and reconciled agreement. Unanimous agreement included the total percentage of events in which all 3 coders agreed on the allocation of an event into HFACS. Majority agreement was based on the percentage of events in which at least 2 raters agreed on the appropriate HFACS code. Finally, reconciled agreement is a subsequent version of majority agreement where raters reconciled and came to consensus for those events which they originally disagreed on. For all 3 methodologies, percent agreement could range from 0% to 100%, with agreement of 70% or higher being considered reliable, 60%–69% being moderately reliable, and below 60% being unreliable.

For reporting interrater reliability, a more stringent measure of Fleiss Kappa (κ) was applied with alpha set at $p \leq .05$. Fleiss' Kappa is used in place of Cohen's Kappa to assess interrater reliability when more than 2 raters are used. This metric measures nominal data on a scale of 0.0–1.0 where values between 0.40 and 0.60 are considered moderately reliable, values between 0.60 and 0.80 are considered substantially reliable, and values above 0.80 are reliable.[7]

Results

Data Inclusion

Results produced 1,137 events associated with 65 observed cases (2,468 patient contact minutes) to be classified using HFACS. This was done using 3 methods as previously described; unanimous, majority, and reconciled. In the unanimous agreement method, of the 1,137 original observations, all 3 coders agreed that 993 events could be coded using HFACS. Of these 993 "codable" events, all coders agreed on the allocation of 929 events at the tier level

Table 2. Methodology Comparisons at the Tier and Category Levels for 1,137 Observations

	Unanimous (3/3 agree)	Majority (2/3 agree)	Reconciled (majority + consensus)
Total events that could be coded using HFACS	993	1,068	1,068
Tier agreement	929 (93.55%)	1,057 (98.97%)	1,057 + 0 = 1,057 (98.97%)
Category agreement	742 (74.72%)	1,012 (94.75%)	1,012 + 45 = 1,057 (98.97%)
Breakdown of HFACS categories			
Preconditions for unsafe acts	697 (93.94%)	939 (92.79%)	939 + 33 = 972 (91.96%)
Unsafe acts	44 (5.93%)	71 (7.01%)	71 + 12 = 83 (7.75%)
Organizational influences	1 (0.13%)	2 (0.18%)	2 + 0 = 2 (0.18%)

HFACS = Human Factors Analysis and Classification System.

of HFACS (i.e., whether an observation belonged in unsafe acts, preconditions for unsafe acts, unsafe supervision, or organizational influences). Of the 993 total codable events, 742 (74.8%) were unanimously agreed on at the category level.

In terms of majority agreement, at least 2 of 3 raters agreed that 1,068 of the events could be coded using HFACS. Of these "codable" events, 1,057 were allocated into the appropriate tier. Subsequently, 1,012 observations were allocated into the appropriate category. Thirty-three events that were initially disagreed on during the majority agreement were reconciled during consensus coding. Of note here is that most of the events were coded as preconditions (Table 2).

Reliability

Two Fleiss' Kappa values were calculated depending on the amount of data included. First, an overall Fleiss' Kappa was calculated to investigate interrater reliability for all potential events (n = 1,137). This first method investigates how well the 3 raters agreed on the allocation of an event into any of the 19 causal categories represented in HFACS. Here, Fleiss' Kappa showed substantial agreement (κ = 0.680 [95% confidence interval, CI, 0.662 to 0.698], p = .000).

Because an overwhelming majority of the data was considered preconditions for unsafe acts, Kappa was also calculated based on those events that all raters unanimously agreed were "codable" at the preconditions for unsafe acts tier (n = 876). This second method investigates how well the 3 raters agreed on the allocation of an event into the 7 preconditions for unsafe acts categories represented in HFACS. In this case, Fleiss' Kappa also showed substantial agreement (κ = 0.757 [95% CI, 0.731–0.784], p = .000).

Findings

Overall, 697 events (93.8%) and 939 events (92.7%) (for unanimous and majority agreement methods, respectively) were coded as a precondition for unsafe acts. As such, a more fine-grained analysis was performed to investigate the types of preconditions for unsafe acts identified. Figure 1 depicts the populated preconditions for unsafe acts categories based on the results from the unanimous agreement method, the majority agreement method, and a reconciled version of the majority agreement method, which includes an additional 33 reconciled preconditions events.

Regardless of the reliability method used, there are no differences in the populated preconditions for unsafe acts categories (Figure 1). As a result, only the reconciled precondition data (n = 972) are discussed. Most failures involved communication, coordination, and planning (59.77%). These events involved ineffective communication, lack of response, personnel not available, and teamwork issues. This was followed by adverse mental state (24.28%), comprised mainly of distractions such as phone calls, pages, and text messages. Physical environment represented 10.91% of the data and involved inadequate space, and furniture/equipment repositioning. Less populated categories included issues with the technological environment (3.09%) (e.g., general usability, charting/documentation issues), and physical/mental

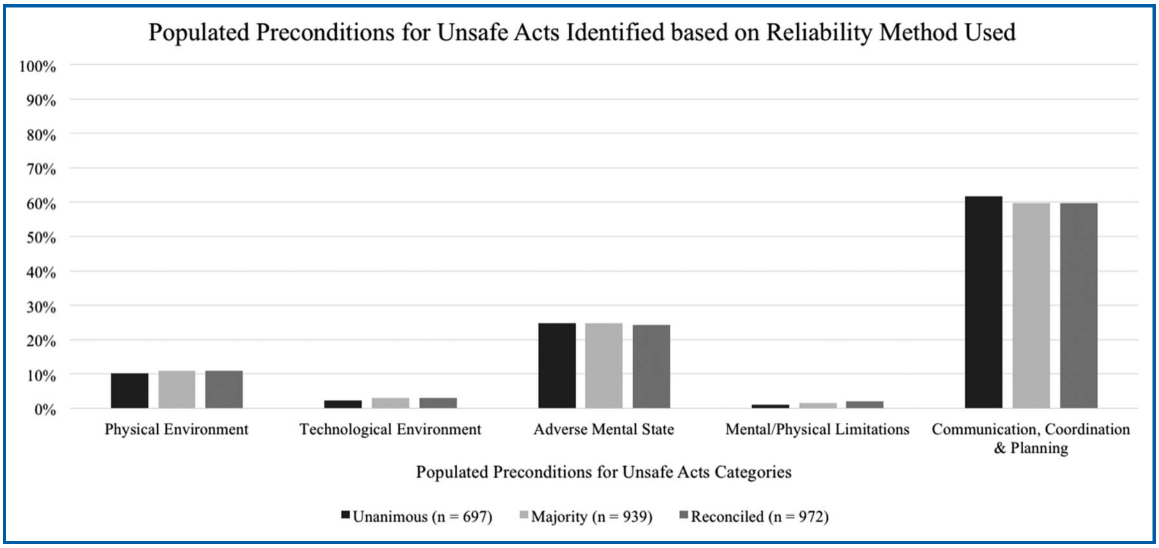

Figure 1. Unanimous versus majority versus reconciled preconditions for unsafe acts.

limitations (1.95%) (e.g., lacking strength to complete a task).

Limitations

The data used for classification were collected with the intention of analyzing workflow disruptions and were not collected with the HFACS framework in mind. Subsequently, the coders were not involved with data collection. This could explain why reliability may have been low at the category level when using the unanimous method. Furthermore, although utilization of HFACS resulted in 7.75% of the data being coded as unsafe acts, this number is probably compressed in terms of the number of unsafe acts that occur in a trauma care facility. Because the data were not collected with the intention of identifying HFACS categories specifically, it is possible that some errors or violations were not recorded, as they may not have been workflow disruptions.

Discussion

Overall, given the results of the above analyses, HFACS can be reliably used to categorize observations in trauma care. Findings are discussed below based on the results of the reconciled agreement method to include as much data as possible. Of the 1068 events that were indicated as "codable" during majority agreement, 11 events were ultimately deemed "uncodable" when coders discussed differences during the reconciled agreement phase. Most of the remaining 1057 events that were ultimately coded in HFACS, were preconditions for unsafe acts (972 events, 91.95%) followed by unsafe acts (83 events, 7.75%) and organizational influences (2 events, 0.18%).

A relatively small percentage (7.75%) of unsafe acts was identified. This category captures active failures of operators that may, ultimately, lead to an unintended outcome. The identification of unsafe acts is not surprising considering the fast-paced nature of resuscitation. This finding speaks to the concept of the speed-accuracy trade off that occurs during response execution, the notion that when an individual must speed up their processes, their accuracy declines, potentially leading to unforgiving errors.[8]

Although Cohen et al (2016) identified relatively few active failures during their investigation of the use of HFACS in the CVOR, there are inherent differences in trauma care as opposed to cardiac care that bear consideration. As opposed to other patient care domains which are scheduled and planned, traumatic injury happens unexpectedly, resulting in the need for trauma care at all hours. Barach and Weinger explain that sleep deprivation and fatigue are common among trauma team members who work regularly on recurring call or night shifts and "a sleep deprived or fatigued trauma team will make more errors, be less likely to recover from these errors, and provide lower quality care than a well-rested team" (p. 104).[9]

Events classified as preconditions for unsafe acts typically involve latent failures that are associated with the individual and the general working environment. Not surprisingly, the category that made up the largest proportion of preconditions for unsafe acts was communication, coordination, and planning (n = 581, 59.77%). This category captured issues involving ineffective and ambiguous communication, ineffective teamwork, poor planning, and other coordination issues echoing the findings of others.[1,10–14]

Treatment in a Level II trauma center is further complicated by the fact that the team is not intact. One of the challenges most trauma teams face are ad hoc teams that work together for short periods in a fast-paced, dynamic environment.[15] Roberts et al[16] explain that because of the constraints placed on the trauma team by the very nature of trauma care, ideal communication and coordination is difficult to achieve.

The next most populated preconditions for unsafe acts were adverse mental state and physical environment. Adverse mental state issues included general interruptions that were oftentimes brief, yet served as distractions that may break the concentration of individual team members and make it difficult to keep "their head in the game." Physical environment failures resulted from inadequate space, misplaced items, organizing of wires and tubing, and architectural issues. Findings are consistent with Boquet et al which indicated that interruptions and layout issues were responsible for 24% and 16% of workflow disruptions, respectively, in a Level II trauma center. The combination of equipment necessary and the various health care disciplines involved oftentimes produce an overcrowded space susceptible to disruptions.

Conclusions

This study helps to validate the use of HFACS as a tool for classifying observational data from a variety of medical domains and provides support for the use of HFACS as a proactive tool for identifying failures in the health care industry. Most importantly, by identifying preconditions, it may be possible to disrupt the chain of events that lead to errors and ultimately prevent errors from occurring in the first place.

Implications

By understanding the chain of events that has the potential to lead to errors, health care professionals may be able to construct a more robust safety management system that may provide a better understanding of the types of threats that may impact patient safety. Most importantly, tools such as HFACS allow for proactive safety management rather than reactive. As opposed to traditional models for safety, where interventions are put in place after the occurrence of an adverse event, this method allows for the potential disruption of the "accident chain" before the occurrence of an adverse event. Finally, by classifying these events, professionals can develop targeted interventions which allow for the potential mitigation of threats to patient safety.

Acknowledgments

The authors thank Emily Anania (BS), Victoria Lew (BS), and Austin Yazel (BS) for their help in coding and preparing the data for publication.

Authors' Biographies

Tara N. Cohen, PhD, recently earned her doctorate at Embry-Riddle Aeronautical University in Daytona Beach, FL. As the first author, she took the lead in collecting the data, managed the coding of the data, and contributed to a majority of the manuscript writing.

Jennifer S. Cabrera, MS, is from Embry-Riddle Aeronautical University in Daytona Beach, FL. Her roles included data collection and manuscript editing.

Tracy L. Litzinger, MS, is a doctoral candidate at Embry-Riddle Aeronautical University in Daytona Beach, FL. She collected data, participated in the coding of the data and editing the manuscript.

Kevin A. Captain, RN, is at Memorial Hospital in Jacksonville, FL. He contributed substantially to the conception and formulation of the manuscript as well as editing of the document.

Michael A. Fabian, MD, is at Halifax Health Medical Center in Daytona Beach, FL. He contributed substantially to the conception and formulation of the manuscript as well as editing of the document.

Steven G. Miles, MD, is at Halifax Health Medical Center in Daytona Beach, FL. He contributed substantially to the conception and formulation of the manuscript as well as editing of the document.

Scott T. Reeves, MD, MBA, is the chair of the Department of Anesthesia at the Medical University of South Carolina in Charleston, SC. He played a substantial role in the formulation, drafting, and revision of the manuscript.

Scott A. Shappell, PhD, is the chair of the Human Factors Department at Embry-Riddle Aeronautical University in Daytona Beach, FL. He played a substantial role in the conception of the project and formulation of the manuscript.

Albert J. Boquet, PhD, is a professor in the Human Factors Department at Embry-Riddle Aeronautical University in Daytona Beach, FL. He played a substantial role in the conception of the project, formulation, drafting, and revising of the manuscript.

References

1. Boquet A, Cohen T, Cabrera J, et al. Using broken windows theory as the backdrop for a proactive approach to threat identification in healthcare. *J Patient Saf.* Advance online publication. doi: 10.1097/PTS.0000000000000328.
2. Sarcevic A. A study of collaborative information behavior in trauma resuscitation. presented at the AMC GROUP 2009

Workshop "Collaborative Information Behavior (CIB)," Sanibel Island, Florida, May 10, 2009.

3. American College of Surgeons: Committee on Trauma. *Resources for the Optimal Care of the Injured Patient*. 6th ed. Chicago, IL: American College of Surgeons, 2014.
4. Shappell S, Wiegmann D. Applying reason: The human factors analysis and classification system (HFACS). *Hum Factors Aerospace Saf.* 2001;1:59-86.
5. Reason J. *Human Error*. New York, NY: Cambridge University Press; 1990.
6. Cohen T, Wiegmann D, Reeves S, et al. Coding human factors observations in surgery. *Am J Med Qual.* Advance online publication. doi: https://doi.org/10.1177/1062860616675230.
7. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33: 159-174.
8. Wickens CD, Gordon SE, Liu Y, et al. *An introduction to human factors engineering*. Chicago, IL: Pearson Education, Inc; 2004.
9. Barach P, Weinger MB. Trauma team performance. In: *Trauma: Resuscitation, Perioperative Management, and Critical Care*. Boca Raton, FL: Taylor & Francis Group; 2007: 101-111.
10. Blocker R, Duff S, Wiegmann D, et al. Flow disruptions in trauma surgery: Type, impact, and affect. *Proc Hum Fact Ergon Soc Annu Meet.* 2012;56:811-815.
11. Blocker R, Shouhed D, Gangi A, et al. Barriers to trauma patient care associated with CT scanning. *J Am Coll Surg.* 2013;217: 135-143.
12. Catchpole K, Gangi A, Blocker R, et al. Flow disruptions in trauma care handoffs. *J Surg Res.* 2013;184:586-591.
13. Shouhed D, Blocker R, Gangi A, et al. Flow disruptions during trauma care. *World J Surg.* 2014;38:314-321.
14. Catchpole K, Ley E, Wiegmann D, et al. Human factors subsystems in trauma care. *JAMA Surg.* 2014;49:962-968.
15. Manser T. Teamwork and patient safety in dynamic domains of healthcare: A review of the literature. *Acta Anaesthesiol Scand.* 2009;53:143-151.
16. Roberts NK, Williams RG, Schwind CJ, et al. The impact of brief team communication, leadership and team behavior training on ad hoc team performance in trauma care settings. *Am J Surg.* 2014;207:170-178.