The Joint Commission
Journal on Quality and Patient Safety®

Improvement from
Front Office to Front Line

March 2013
Volume 39 Number 3

Photo courtesy of Virginia Mason Medical Center

"When an error was discovered by the operating room staff, a signal (via text page) was sent to the sterile processing leadership team, which would immediately go to the operating room to investigate the potential error."

—"Applying Lean Methods to Improve Quality and Safety in Surgical Sterile Instrument Processing" (p. 101)

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Bringing Lean to Surgical Instrument Processing

Features

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Information Technology

Enhancing Electronic Health Record Usability in Pediatric Patient Care: A Scenario-Based Approach

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Although hospitals, clinics, and small-group medical practices are accelerating their adoption of electronic health records (EHRs),[1] there has been a slower adoption rate in pediatric care.[2] Anecdotal reports also suggest that these systems often are not ideal for supporting children's health care needs. Moreover, unintended consequences with the use of systems primarily designed for adult populations to provide care to children is documented in the literature.[3] Pediatric care differs substantially from adult care because of differences in age representations, developmental status, size, and the measurements used to convey this type of information, and the ability to communicate. These differences make the selection and arrangement of information displays, definition of "normal" ranges, and thresholds for alerts more challenging than for EHR use with adult populations. Technical guidance for stakeholders in the EHR design and implementation process has therefore been identified as a national need to improve the design of EHRs for pediatric patients, in particular, to enhance EHR usefulness, usability, and patient safety.

Given the importance of developing technical guidance, in November 2011, the National Institute of Standards and Technology (NIST) invited experts [the authors] in human factors engineering (HFE), usability, informatics, and pediatrics in ambulatory care and pediatric intensive care to participate in an effort to generate consensus recommendations. The focus of this effort was not on all aspects of EHR design but rather on those that are part of "critical user interactions," defined as interactions "between a user, such as a physician, nurse, pharmacist, caregiver, or patient, and the EHR, which can potentially lead to errors, work-arounds, or adverse events that are associated with patient harm." Several of the experts had also participated in previous efforts funded and coordinated by the NIST Information Technology Laboratory, including the development of a guideline to evaluate, test, and validate[4] the usability of EHRs and to document the results from summative usability testing.[5] The current effort was informed by previously published recommendations made to improve the usefulness,[6–9] patient safety,[6,10,11]

Article-at-a-Glance

Background: Usability of electronic health records (EHRs) is an important factor affecting patient safety and the EHR adoption rate for both adult and pediatric care providers. A panel of interdisciplinary experts (the authors) was convened by the National Institute of Standards and Technology to generate consensus recommendations to improve EHR usefulness, usability, and patient safety when supporting pediatric care, with a focus on critical user interactions.

Methods: The panel members represented expertise in the disciplines of human factors engineering (HFE), usability, informatics, and pediatrics in ambulatory care and pediatric intensive care. An iterative, scenario-based approach was used to identify unique considerations in pediatric care and relevant human factors concepts. A draft of the recommendations were reviewed by invited experts in pediatric informatics, emergency medicine, neonatology, pediatrics, HFE, nursing, usability engineering, and software development and implementation.

Recommendations: Recommendations for EHR developers, small-group pediatric medical practices, and children's hospitals were identified out of the original 54 recommendations, in terms of nine critical user interaction categories: patient identification, medications, alerts, growth chart, vaccinations, labs, newborn care, privacy, and radiology.

Conclusion: Pediatric patient care has unique dimensions, with great complexity and high stakes for adverse events. The recommendations are anticipated to increase the rate of EHR adoption by pediatric care providers and improve patient safety for pediatric patients. The described methodology might be useful for accelerating adoption and increasing safety in a variety of clinical areas where the adoption of EHRs is lagging or usability issues are believed to reduce potential patient safety, efficiency, and quality benefits.

interoperability,[12] and ability to conduct research[13] of EHRs for pediatric patients and previous recommendations made to enhance usability and patient safety with the use of health information technology for all patient populations.[14]

In relation to this focused work, on July 11, 2012, a technical report, *A Human Factors Guide to Enhance EHR Usability of Critical Care Interactions When Supporting Pediatric Patient Care* (NISTIR 7865),[15] was published. This report provided 54 detailed recommendations to improve critical user interactions with an EHR when providing pediatric care and described their relation to concepts in the human factors and usability literature. The recommendations were grouped into the nine themes of patient identification, medications, alerts, growth chart, vaccinations, labs, newborn care, privacy, and radiology. In addition, 14 areas for innovation were suggested as useful EHR features for supporting the provision of pediatric care. Finally, four clinical scenarios that highlight unique risks for pediatric patients and human factors concepts were provided in NISTIR 7865 via an appendix for use in formative user-centered design processes or summative usability evaluations.

In this article, we summarize the methods and findings from NISTIR 7865 and then suggest how the specific recommendations could be translated into practice. In addition, we reflect on how to translate the methodologies to similar efforts in a variety of other areas where EHRs are being designed and implemented. Specifically, we summarize the methodology employed to generate the recommendations that are provided, and include one of the four representative, fictional clinical scenarios that was used to identify unique pediatric needs and the related human factors concepts[15] (Appendix 1, available in online article).

We also highlight a small number of selected recommendations for three specific stakeholder groups—EHR vendors and developers, small-group pediatric medical practices, and children's hospitals—to aid in implementation of these insights as quickly as possible into the work setting. Finally, we discuss reflections on the process of partnering human factors experts with clinical experts to identify the unique needs of pediatric patients in the quest to reduce the risks of unintended consequences from the use of a generalist EHR for pediatric populations.

Methods

Meetings

To derive the critical user interactions and associated recommendations and to gain group consensus, we conducted a series of one-hour teleconferences during a six-month period (February–July 2012). The effort included all-group meetings, meetings between the human factors experts and individual clinical experts, and subgroup meetings regarding particular scenarios and recommendations. We conducted a literature review for existing recommendations published in pediatrics and informatics journals, which we referenced in the report[15] and used during the consensus process. We also conducted iterative discussions with pediatric clinical experts and in-depth reviews of the human factors literature. In addition, we obtained extensive peer review of the recommendations from experts in pediatric informatics, emergency medicine, neonatology, pediatrics, HFE, usability engineering, and software development and implementation (see the acknowledgments, pages 134–135).

Clinical Expertise: Special Considerations for Pediatric Patients. Insights from the clinical experts whom we consulted regarding special considerations for providing pediatric care using an EHR were as follows:

- High variability in physiology and disease states on the basis of age and weight generates unique requirements for information displays and alarm and alert thresholds.
- Deviations from standardized vaccination schedules are extremely complex because of interactions among events and would benefit from automated decision support and reminders.
- Growth charts are centrally important in providing care—they require a standardized display and easy access to allow physicians to employ expert strategies to detect patterns that indicate potential abnormalities.
- Limited ability to communicate with pediatric patients increases the reliance on the EHR to accurately identify patients, detect erroneous assumptions, discover symptoms, and access historical information.
- Increased options for medication orders need to be supported, including weight-based dosing, alternative medication formats, combined prescriptions, and sophisticated rounding strategies for dosing.

Human Factors Expertise: Relevant Concepts from Human Factors Engineering. A number of concepts in HFE were distilled and presented by human factors experts to the authors as particularly relevant to the area for recommendations. These distilled human factors concepts were as follows:

- Methods for conducting risk assessments of the potential for human error in a given setting, such as human reliability analysis (HRA)[16]
- Strategies to reduce mode errors, which are actions performed in one mode that were intended for another mode[17]
- Signal detection theory and the associated phenomenon of "alert fatigue," in which alerts, reminders, and warnings tend to be overridden about 90% of the time[18]
- The contextualized nature of expertise and the related "rep-

resentation effect," in which specialized knowledge is difficult to apply when information is not represented in the way in which professionals are trained to use it[19]

■ The relation of increased complexity in a scheduling task with more interdependencies among tasks, often referred to as *task coupling*[20]

■ The importance of providing information displays that accommodate distinct work flows for high-stakes tasks

The expertise derived from the clinical providers and the human factors experts among the authors, combined with support from the literature, provided a foundation for the deeper exploration of the unique challenges inherent in use of the EHR in pediatric populations. This foundation was used as the panel began to compile and analyze scenarios that captured unique challenges of providing pediatric care with an EHR and to generate and group recommendations to address these challenges.

Scenario-Based Analysis of Unique Clinical Considerations and Human Factors Concepts

We collected relevant case experiences as a series of miniscenarios in a "corpus of cases" approach, similar to Flanagan's critical incident technique.[21] We drew on the miniscenarios, each of which described use of an EHR in the provision of care for pediatric patients, and identified emerging themes. We combined these miniscenarios into related, integrated longer scenarios. For example, the three miniscenarios from our corpus of cases related to the theme of patient identification were as follows:

1. Twin newborn patients are admitted to a neonatal ICU. When the physician reviews the chart, the name of each patient does not appear on all screens, and the physician confuses the patients, resulting in Twin A's medications being listed in Twin B's chart.

2. Unrelated and unnamed infants in a newborn nursery share the same birth date and the same name. For example, Baby Girl Smith DOB (date of birth) 1/1/2011 is used for three different babies from three different families being cared for at the same time in a single newborn nursery. In several cultures, a small number of last names are identical. The EHR listed patients by last name and date of birth.

3. The simultaneous treatment of siblings, particularly multiple birth children with the same last name and same birth date, has resulted in numerous unintended actions. Filing reports in the correct chart, ordering specific treatments and medications, and administering the proper therapies have a heightened risk of not being done correctly in this situation. The level of risk is heightened as patients move through the system, are transferred to other units, or are taken to external departments for therapy.

Human factors concepts relevant to patient identification were identified. In the three miniscenarios, the human factors concept of mode error,[17] in which patient care or documentation intended for patient A is done for patient B, was relevant.

Subsequent steps included the compilation of a variety of miniscenarios, each demonstrating one or more human factors concepts, into four larger, integrated scenarios and the determination of the human factors elements that emerged. This assembly allowed the panel to fully frame and understand the problem and arrive at a consensus on recommendations for action in the scenario, "Newborn with Sepsis Treated by the Emergency Department," as adapted from NISTIR 7865[15] (Appendix 1). The human factors concepts are provided at the end of each sequence.

The "Newborn with Sepsis" scenario serves as an example of (1) the potential areas of error for pediatric patients when an EHR is being used and (2) the human factors–based guidance for recommendations likely to improve the system. As we generated recommendations and linked them to guidance provided by the human factors literature, we continually reviewed the corpus of cases and their relation to human factors concepts to clarify the issues and potential solutions. These scenarios were particularly helpful in identifying when more than one issue was being covered by a single recommendation and where it would be better to separate the concerns. We formulated the recommendations provided in the next section on the basis of the cases represented by the four scenarios, the human factors identified, and consultation with the reviewers and other experts.

Recommendations

For the purpose of this article, we identified three stakeholder groups as particularly relevant to facilitate rapid translation into practice: EHR developers, small-group pediatric medical practices, and children's hospitals. We then selected and tailored a maximum of 6 recommendations for each stakeholder group from the original 54 recommendations.[15]

Recommendations for EHR Developers

1. Avoid Truncating Information. Display information in menu items and on charts/graphs without truncating critical information; the full name of the medication and dose should be viewable without actively selecting an item. For limited space displays, rollover interactions that show the full text when the user moves the mouse or other input device over the items can be used.

2. One-Click Growth Chart. Support one-click access to the growth chart in the standard format (that is, the World Health

Organization international growth chart for patients between the ages of 0 and 24 months and the Centers for Disease Control and Prevention clinical growth chart for patients older than 2 years of age).[22]

3. No Automated Changes to Default Dose. Eliminate automated changes to adult dose defaults for medication orders for patients under the age of 18 years; automatically employing defaults for standard doses in the event of what appears to be an erroneous dose entry is extremely risky for low-weight patients.

4. Protect Against Mode Errors. Add protections against ordering medications in the wrong units; mode errors have been reported because of the confusion in prescribing a medication when the volume is specified in milliliters (mL) rather than milligrams (mg). Because of this type of mode error, 10-fold iatrogenic overdoses for young children receiving intravenous acetaminophen for pain relief have been publicly reported.[23]

5. Support High-Precision Dosing for Low-Weight Patients. Low-weight patients can experience toxicity if medications are rounded to the nearest digit.[24] In particular, medications with narrow therapeutic indices such as digoxin or insulin have a great potential for adverse consequences if dosed improperly. For example, for a 575-gram (20.28-ounce) infant, kilogram units need to be accommodated to three decimal places.

6. Allow Data Entry for Vaccinations Given at Other Institutions. In the event that systems are not completely integrated across institutions, at a minimum, it should be possible to document vaccinations given at other institutions. Similarly, printouts of vaccination records should incorporate data from all institutions where vaccinations are given. This ability would reduce the risk of double vaccinations.

Recommendations for Small-Group Pediatric Medical Practices

Although small-group pediatric medical practices typically purchase EHR software from vendors, there are often degrees of freedom during the implementation and customization processes to increase EHR usefulness, usability, and patient safety.

1. Minimize Displayed Options for Medication Orders in Menus. With most paper-based ordering systems, medications are ordered by physicians without the specificity used in pharmacies. When pharmacy-specific information is displayed to physicians, there can be as many as 17 choices for a common medication, creating complexity that can lead to erroneous selection of medications. For children, medications are often given together or with complex dosing regimens, thereby increasing the number of potential ordering options. Practices could either create an interdisciplinary committee (consisting of, for example, one or two physicians, a nurse, and an information technology staffperson) or work with other practices to have a local committee (as with a Health Information Exchange), which would determine the displayed options to be used, as well as medication options that can be ordered but not shown on a primary display.

2. Display Normal Ranges for Medication Doses and Lab Values. Normal ranges can be based on weight, height, body surface area, body mass index, and age information, while also differing on the basis of information source (adult normal, pediatric normal, weight-based normal, age-based normal, body surface area normal). Even in cases in which EHRs do not have normal ranges for medications based on weight and age information available, the practice could incorporate this additional information and display it.

3. Do Not Permit Automated Changes to Measurement Systems. Measurement systems (for example, lb versus kg) should not automatically change. For infants, it is common in the United States to use the English pound measurement system for data collection and then convert to the metric system when ordering medications. To reduce mode error risks from working in different measurement systems, displays should not automatically default to a different measurement system. In addition, displaying units of measure along with data values reduces risks for confusion about the current measurement system and scale.

4. Annotate Corrections to Plotted Data Directly on Chart. There are a number of reasons why plotted data, such as weight, may be inaccurate and need to be corrected to aid decision making, such as when a premature infant's chronologic age is evaluated on the basis of a younger age group. One technique is to "move back" data points by a time period (for example, two months) to assess growth, given the premature birth. Data quality issues might also arise on the basis of where measurements were taken, how the data were collected, and errors in data entry. Annotating corrections to plotted data needs to be done such that the next user accessing the information can see them easily.

5. Support Managing Privacy Settings. Particularly for small-group practices, complex distinctions in privacy settings access to areas of EHR might not be needed and could be avoided either during purchase or when the settings are defined locally. Many levels of confidentiality for different notes can make it difficult for users to understand what privileges are provided with each level, particularly if the distinctions are not well defined in the online help documentation. For example, systems can have confidential notes, sticky notes, private notes, and internal notes, each of which has different definitions regarding access for viewing and transferring to other systems. On the other hand, features with different privacy settings with relation to patients

and their family members may be needed. Access issues are particularly complicated for adolescent patients based on age, assent status, and nontraditional caregiving arrangements.

6. Support Physicians' Timely Access to Specialized Radiologic Expertise When Ordering Diagnostic Imaging. It is important for pediatricians and radiologists to directly communicate whenever possible to clarify in real time which scan variation to order for high-stakes sedation and intubation procedures. Radiology is a particularly important specialty in pediatric care. Knowing which test to order is an important decision because the risk associated with exposure to radioactivity is particularly high for infant patients whose cell division is very active and whose cumulative lifetime exposure is just beginning. Sedation, intubation, and radiation for pediatric patients are much higher-risk activities than for adult patients. Having multiple scans because of inaccurate selection of correct procedures can have many negative clinical implications.

Recommendations for Children's Hospitals

Although children's hospitals and pediatric wards in adult hospitals typically purchase EHR software from vendors, there are often degrees of freedom during the contracting, implementation, and customization processes to increase usefulness, usability and patient safety.

1. Unit-Specific Banners. On the basis of the unit's population, the following variables might be included: name, gender, weight, age, gestational age, postconceptual age, and date of birth. For pediatric patients, it is common practice for family members with the same last name to be cared for by the same providers and/or same organizations during the same appointment. To prevent "wrong patient" errors, constant-identification banner headers should include gender, weight (in kilograms), and age as well as the units for age, which can range from "days of life" to "months" to "years" in scale. Note that for same-age siblings due to multiple births, first name, medical record number, and unique medical events, such as birth time in minutes, can be the main distinguishing elements and therefore should be easily accessible if not included on the banner header.

2. Specialized Threshold Settings. Support flexibility in unit-based settings for alerts, reminders, and warnings based on weight, height, body surface area, body mass index, and age. Specialized units focusing on pediatric care, including pediatric ICUs, pediatric emergency departments, labor and delivery, and pediatric outpatient clinics, need to be able to adapt threshold settings appropriate for their patient demographics, particularly with respect to weight and age. A committee is recommended to be responsible for determining these settings for groups rather than for individuals in collaboration with staff members, including pharmacists, physicians, nurses, and administrators, and with periodic updates to thresholds and underlying logic.

3. Soft Stops for Adult Dose. Dosages should be capped at the standard adult dose while allowing overrides with justification (such as for the ordering of medications for obese adolescents). When an order is entered for a child younger than 14 years of age that exceeds the standard adult dose, provide a real-time and visible alert that the adult dose has been exceeded. Alerts should not be "hard stops" in that they should be allowed to be overridden with a justification.

4. Support Communications to Change Inaccurate Normal Ranges. It is recommended that one contact person be designated to receive requests in regard to inaccurate normal ranges for medications and labs. Notification of errors in ranges is recommended to be facilitated by EHR features, which automatically directs the notice to the designated person or group.

5. Support "Break the Glass" Privacy Law Violations for Urgent Care Situations. In urgent care scenarios, it might be necessary to access critical health information that is available in an EHR yet restricted for privacy or security purposes. In the event that this is needed, the system should support access as long as a detailed audit trail with rationale is documented.

6. Monitor Cumulative Radiation Exposure over Time. A listing in one location of all radiology tests, done at any location, for each patient would help to monitor and reduce exposure to ionizing radiation. The use of computed tomography, which delivers approximately 100 times the radiation dose as a traditional x-ray,[25,26] has increased more than 20-fold in the United States since 1975.[27] For newborn patients, it is possible that new sources of radiation will emerge in future decades, further raising the cumulative exposure over a lifetime. High cumulative radiation exposures create cancer and other undesirable consequences. Therefore, The Joint Commission has recommended capturing "dose information in the patient's electronic medical record."[27] It would be useful for physicians, nurses, radiologists, and, ideally, caregivers and patients if the EHR provided a cumulative plot of radiation exposure over time.

Discussion

We selected a maximum of 6 recommendations each for EHR developers, small-group pediatric medical practices, and children's hospitals out of 54 consensus recommendations. For EHR developers, we generated recommendations that are sensitive to specialized patient safety risks for low-weight patients and unique patient safety concerns when ordering medications for young children. For small-group pediatric physician practices,

we created recommendations primarily to reduce complexity, increase efficiency, and reduce the chances of displaying inaccurate information. For hospitals, we created recommendations to primarily increase flexibility in how the elements of the EHR are implemented in a pediatric unit.

We suggest that EHR vendors developing systems for children's hospitals and medical practice clinics consider rapidly implementing these recommendations to enhance the usefulness, usability, and safety of their products when providing care to pediatric patients. In December 2012 the Office of the National Coordinator (ONC) added a new requirement for safety-enhanced design to achieve certification of EHR technology.[28] Hospitals will be required to have certified EHRs by 2014 to meet meaningful use Stage 2 criteria. Therefore, an additional potential benefit of implementing these recommendations is to meet this new requirement. In addition, the ONC certification requirement stipulates that vendors document their quality management systems.[28] Our experience with one another and the reviewers and other experts suggests that human factors, informatics, and usability specialists are important team members in a quality management system. The nonclinical experts on the panel brought important knowledge to bear in terms of problematic design elements in other complex, sociotechnical settings; efficient identification of relevant human factors concepts; a synthesis of lessons learned that are not concisely or usefully conveyed in the published literature; and, in collaboration with the clinical experts, valid, useful scenarios for formative design and usability evaluation.

In addition to the application of human factors expertise, we feel that there are potential lessons learned for a quality management system. We generated these recommendations by consensus during a series of remote one-hour meetings held in a six-month period. Notable elements of the process included the collection of miniscenario incidents and near misses; collection of the miniscenarios, which were created on the basis of clinical experience, and abstracted into emerging themes; and integrating miniscenarios into longer, more elaborate scenarios that could be useful for design and evaluation efforts. Draft recommendations were generated by individual panel members, and debate continued until consensus was reached on a final recommendation. Finally, extensive peer review was provided by experts in pediatric informatics, emergency medicine, neonatology, pediatrics, HFE, usability engineering, and software development and implementation. The peer review process identified potential disagreements with aspects of the recommendations, recognized the need to clarify the description of particular issues, and revealed previously unknown best-practice design and implementation strategies for avoiding issues.

There are limitations to this effort. Most notably, none of the recommendations have yet been validated to improve patient safety or usability. Following all of these recommendations is unlikely to guarantee that all important patient safety or usability aspects have been addressed or that adoption of EHRs would be accelerated for all providers of pediatric care. In particular, the following topics were outside the scope of this effort: challenges associated with supporting collaborative work and shared situation awareness among interdisciplinary panel members, transitions across care settings, interoperability between systems, integration with bar code point of care and other medical devices, quality improvement and research using data pulled from EHRs, integration with social media and handheld devices, and software designed exclusively for use by caregivers or nontraditional health care providers.

Conclusion

Usability of EHR systems has been identified as an important factor in patient safety. The adoption of EHRs by providers specializing in pediatric patient care has lagged behind adoption for general population providers. Pediatric patient care has unique features, and many aspects of care are exceedingly complex and have significantly lower margins for error. In this article, we highlighted unique critical user interactions important for providing pediatric care with the support of an EHR. We also provided specific guidance distilled from the human factors literature to increase the usefulness, usability, and patient safety of an EHR for three relevant stakeholder groups when designing, purchasing, customizing, or implementing EHRs. J

This research was funded by the National Institute of Standards and Technology (NISTIR 7865). The views expressed in this article do not necessarily represent the views of NIST or the US Department of Commerce. The authors gratefully acknowledge the intellectual contributions from the following reviewers of an earlier draft of the report from which part of this article was adapted: Anne Bobb, RPh, Children's Memorial Hospital, Chicago; Joseph Cafazzo, PhD, PEng, Healthcare Human Factors, University Health Network, Toronto; Willa Drummond, MD, University of Florida College of Medicine, Gainesville; Daniel Essin, MA, MD, University of Southern California Keck School of Medicine, Los Angeles; Scott Finley, MD, MPH, Westat, Rockville, Maryland, and Office of Health Information, Veterans Health Administration, US Department of Veterans Affairs, Washington D.C.; Anne B. Francis, MD, Elmwood Pediatric Group, Rochester, New York; Ayse Gurses, PhD, Johns Hopkins University, Baltimore; Marta Hernanz-Schulman, MD, Vanderbilt Children's Hospital, Vanderbilt, Tennessee; Kevin Jones, MS, Ohio State University, Columbus; Dean Karavite, MS, Children's Hospital of Philadelphia; Ben-Tzion Karsh, PhD (deceased), University of Wisconsin, Madison; Yiannis L. Katsogridakis, MD, MPH, Children's Memorial Hospital, Chicago; Rainu Kaushal, MD, MPH, Weill Cornell Medical College, New York City; George Kim, MD, Johns Hopkins University Children's Center, Baltimore; Nancy F. Krebs, MD, MS, University of Colorado School of Medicine, Denver; David Kreda, Social Research Corporation, Wyncote, Pennsylvania; Andrew Kroger, MD, MPH, National Center for Immunization and Respiratory Diseases, Atlanta; Herschel R. Lessin MD, The Children's Medical Group, Poughkeepsie, New York; Eugenia Marcus, MD, Pediatric Health Care at Newton Wellesley, Newton, Massachusetts; Colleen McLaughlin, MPH, PhD, Patient Safety Center, New York State Department of Health, New York City; Deepa Menon, MD, Johns

Hopkins University; Mary Patterson, MD, MEd, Akron Children's Hospital, Ohio; Sean Petty, RN, Jacobi Medical Center, Bronx, New York; Debora Simmons, PhD, RN, CCNS, St. Luke's Episcopal Health System, Houston; Dean Sittig, PhD, University of Texas Houston; Arthur Smerling, MD, Columbia University College of Physicians and Surgeons, New York City; S. Andrew Spooner, MD, MS, Cincinnati Children's Hospital Medical Center; Jennifer Stinson, RN, PhD, Hospital for Sick Children, Toronto; Susan Torrey, MD, NYU Langone Medical Center, New York City; Michael S. Victoroff, MD, University of Colorado School of Medicine; Robert Wears, MD, PhD, University of Florida Health Center, Jacksonville.

Online-Only Content

See the online version of this article for

Appendix 1. Integrated Scenario with Human Factors Concepts Highlighted: Newborn with Sepsis Treated by Emergency Department

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References

1. Jha AK, et al. Use of electronic health records in U.S. hospitals. *N Engl J Med.* 2009 Apr 16;360(16):1628–1638.
2. Nakamura MM, et al. Electronic health record adoption by children's hospitals in the United States. *Arch Pediatr Adolesc Med*. 2010;164(12):1145–1151.
3. Hales JW, et al. Pediatric safety risks from unintended consequences of the use of EMRs designed for adults. In *Proceedings of the 36th Annual Symposium of the American Medical Informatics Association.* Bethesda, MD: AMIA, 2012, 1512–1513. Accessed Jan 30, 2013. http://proceedings.amia.org/2p94pp/2p94pp/1.
4. Lowry SZ, et al. *NISTIR 7804. Technical Evaluation, Testing, and Validation of the Usability of Electronic Health Records.* Gaithersburg, MD: National Institute of Standards and Technology, Feb 2012. Accessed Jan 30, 2013. http://www.nist.gov/healthcare/usability/upload/EUP_WERB_Version _2_23_12-Final-2.pdf.
5. Schumacher RM, Lowry SZ, et al. *NISTIR 7742. Customized Common Industry Format Template for Electronic Health Record Usability Testing*. Gaithersburg, MD: National Institute of Standards and Technology, 2011. Accessed Jan 30, 2013. http://www.nist.gov/customcf/get_pdf.cfm?pub_id=907312.
6. Spooner SA, et al. Special requirements of electronic health record systems in pediatrics. *Pediatrics.* 2007;119(3):631–637.
7. Shiffman RN, et al. Information technology for children's health and health care: Report on the Information Technology in Children's Health Care Expert Meeting, Sep 21-22, 2000. *J Am Med Inform Assoc.* 2001;8(6):546–551.
8. Healthcare Information and Management Systems Society (HIMSS). Model Children's EHR Format. Grace E, Kahn J, Finley S. HIMSS 2011 Annual Conference. Feb 23, 2011. Accessed Jan 30, 2013. http://www.himss.org/content/files/proceedings/2011/149.pdf.
9. United States Pharmacopoeia. Error-Avoidance Recommendations for Medications Used in Pediatric Populations. 2011. Accessed Mar 22, 2011 (no longer available). http://www.usp.org/hqi/patientSafety/resources/pedRecommnds2003-01-22 .html.
10. Scanlon MC, Bauer P. Human factors and ergonomics in pediatrics. In Carayon P, editor: *Handbook of Human Factors and Ergonomics in Health Care and Patient Safety*. Mahwah, NJ: Lawrence Erlbaum, 2007, 723–742.
11. Scanlon MC, Karsh BT, Densmore EM. Human factors engineering and patient safety. *Pediatr Clin North Am.* 2006;53(6):1105–1119.
12. Hinman AR, Davidson AJ. Linking children's health information systems: Clinical care, public health, emergency medical systems, and schools. *Pediatrics.* 2009;123 Suppl 2:S67–73.
13. Stiles PG, et al. Ethically using administrative data in research: Medicaid administrators' current practices and best practice recommendations. *Administration & Society.* 2011;43(2):171–192.
14. Committee on Patient Safety and Health Information Technology, Institute of Medicine. *Health IT and Patient Safety: Building Better Systems for Better Care.* Washington, DC: National Academies Press, 2012.
15. Lowry SZ, et al. *NISTIR 7865. A Human Factors Guide to Enhance EHR Usability of Critical Care Interactions When Supporting Pediatric Patient Care*. Gaithersburg, MD: National Institute of Standards and Technology, Jun 2012. Accessed Jan 30, 2013. http://www.nist.gov/healthcare/usability/upload/NISTIR-7865.pdf.
16. Lyons M, et al. Human reliability analysis in healthcare: A review of techniques. *International Journal of Risk & Safety in Medicine.* 2004;16(4):223–237.
17. Sarter NB, Woods DD. How in the world did we ever get into that mode? Mode error and awareness in supervisory control. *Hum Factors.* 1995;37(1): 5–19.
18. Isaac T, et al. Overrides of medication alerts in ambulatory care. *Arch Intern Med*. 2009 Feb 9;169(3):305–311.
19. Woods DD, Roth EM. Cognitive engineering: Human problem solving with tools. *Hum Factors*. 1988;30(4):415–430.
20. de Snoo C, van Wezel W. Coordination and task interdependence during schedule adaptation. *Human Factors and Ergonomics in Manufacturing & Service Industries.* Dec 12, 2001. DOI: 10.1002/hfm.20363.
21. Flanagan JC. The critical incident technique. *Psychol Bull.* 1954;51(4): 327–358.
22. Grummer-Strawn LM, Reinold C, Krebs NF; Centers for Disease Control and Prevention (CDC). Use of World Health Organization and CDC growth charts for children aged 0–59 months in the United States. *MMWR Recomm Rep.* 2010 Sep 10;59(RR-9):1–15. Erratum in: *MMWR Recomm Rep*. 2010 Sep 17;59(36):1184.
23. Cooper WO, et al. ADHD drugs and serious cardiovascular events in children and young adults. *N Engl J Med*. 2011 Nov 17;365(20):1896–1904.
24. Johnson KB, et al. Automated dose-rounding recommendations for pediatric medications. *Pediatrics*. 2011;128(2):e422–428.
25. Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology. *Br J Radiol*. 2008;81(965):362–378.
26. Berrington de González A, Darby S. Risk of cancer from diagnostic x-rays: Estimates for the UK and 14 other countries. *Lancet.* 2004 Jan 31;363(9406): 345–351.
27. The Joint Commission. Radiation Risks of Diagnostic Imaging. *Sentinel Event Alert.* No. 47. Aug 24, 2011. Accessed Feb 13, 2012. http://www.jointcommission.org/assets/1/18/SEA_47.pdf.
28. Office of the National Coordinator for Health Information Technology. 2014 Edition S&CC Final Rule for Meaningful Use Stage 2. Accessed Jan 30, 2013. http://www.healthit.gov/policy-researchers-implementers/meaningfuluse-stage-2-0.

Online-Only Content

Appendix 1. Integrated Scenario with Human Factors Concepts Highlighted: Newborn with Sepsis Treated by Emergency Department*

A six-day old infant is brought to the emergency department (ED) by his mother (Anna Smith), who reports that he has a fever. At triage, he is very irritable, has a rectal temperature of 102°F (38.9°C) and a bulging anterior fontanel. By ED protocol, he is brought to a treatment room immediately to be seen by a physician. The infant's history is significant for being the Twin A of a term pregnancy delivered by a scheduled cesarean section (in the same hospital). Twin B is reported to be well at home with the father. The physician's assessment is that the infant may have sepsis/meningitis and requires a workup. On examination, the physician observes respiratory distress and determines that a chest x-ray is indicated.

The mother does not know the hospital assigned a medical record number, so the registrar in the ED asks for the Social Security number. As is characteristic with newborns, the Social Security number has not been issued yet. A search on "Baby Smith" retrieves many different records. The registrar searches on and successfully finds the mother's electronic chart, which includes a note from the newborn nursery with medical record numbers for both children. Using the medical record number, the physician is then able to successfully pull up the chart. The physician clicks the "sepsis bundle" quick order set on the EHR interface. The system retrieves the standard adult doses for these medications, which are far too large, as well as an inappropriate procedure for inserting a central line. The physician notes the mismatch and cancels the set of orders.

Human Factors Concepts Identified

- **Potential for mode error (wrong patient):** Lack of a Social Security number results in issues with retrieving the patient's information in a reliable and expedient fashion.
- **Potential for automation surprise:** Unexpected default to standard adult dose

The physician then calls up a feature that supports weight-based dosing. He estimates that the patient weighs 8 pounds and types the number 8 in the weight box entry. The physician does not realize that the system records the weight as 8 kg, a system default feature that, unfortunately, does not display the unit of measurement in the data entry field. The alert that is issued because the weight falls outside the normal value range is located on the "face sheet" screen, not on the screen where the dose is entered, and therefore it is missed by the clinician. At the time of administration of the medication, the ordered dose is not what the nurse expects, and she catches the mistake. She realizes that the weight was entered in pounds, not kilograms, and that the calculated dosage is therefore significantly incorrect. The nurse informs the physician of the errors in the documented weight and calculated dosage.

Human Factors Concepts Identified

- **Potential for mode error (wrong measurement system):** Defaulting to the metric measurement system is not always expected in pediatric care for the weights for young children.
- **Potential for missed information:** The alert for a high weight is unlikely to be viewed because it is not displayed on the same screen as where the medication dose is entered.

The nurse informs the physician that the exact weight is 4.1 kg (9.0 pounds). The physician remembers that the appropriate dose for the antibiotic is 10 mg/kg/dose, and calculates in his head that the appropriate dose is 41 mg. He accesses the EHR and types in the order for 41 mg of a brand-name antibiotic for the patient. The system automatically changes the dose of 41 mg to the typical adult dose of 2,000 mg and changes the form of the medication from the brand name that was ordered to the generic form of the medication available in the formulary. The clinician then cancels the order. He consults with the nurse to learn how to override the automated changes in the order, enters an order with the intended dose and form, and confirms his order by printing his order sheet to paper.

Human Factors Concepts Identified

- **Complexity:** Potential for mode error, calculation mistakes, occurring within a prescribing episode with weight-based dosing
- **Potential for automation surprise:** The unexpected change to dose and form of the medication could be easily missed and result in a patient receiving a medication in an unintended form and/or receiving a significantly lower or higher drug dosage.

The physician needs broad antimicrobial coverage and decides to start a second antibiotic. The physician then enters an order for the second medication in the EHR. The dose and frequency of administration for this particular medication are dependent on the gestational age of the patient, the actual age, the weight, and the renal function. This medication is administered intravenously, so the options available for ordering are reported in mL, but the information regarding concentrations (based on mg/kg) are truncated on the ordering display. In some of the EHR systems that the physician uses, this medication is ordered in mg/kg/day, and in others it is ordered by mg/kg/dose, so the physician has to intently focus on the units of measurement. He clicks on each of the options, until he finds the correct concentration. He calculates the amount of medication needed in his head and orders it. When he reviews the order, the system has automatically rounded the dose amount to the nearest regular dose, which is too high and would be potentially harmful to the child if administered. He cancels the order and manually corrects the dosage in the EHR.

(continued on page AP2)

Online-Only Content

Appendix 1. Integrated Scenario with Human Factors Concepts Highlighted: Newborn with Sepsis Treated by Emergency Department* (continued)

Human Factors Concepts Identified

- **Potential for mode error (wrong dose):** Complexity, truncation of critical information, and inconsistent conventions increase the likelihood of selecting an inappropriate dose.
- **Potential for automation surprise:** Rounding a dose to the nearest unit or standard dose amount could have unique unintended clinical consequences for low-weight pediatric patients.

The physician then returns to assess the patient and informs the mother that antibiotics have been ordered. He learns that the patient's twin is at home with the father and queries the mother for the first name as a safety check. When he looks at the EHR again, he now realizes that he had ordered the medications for the "wrong" twin. He informs the mother that because this is an emergency situation, he will not correct the mistake now but will make a note in both charts. He writes in the progress note that because of an error in patient identification, the order for the sepsis medication was made for the wrong twin, even if the "right" twin received the administered medication. He includes a note in the right twin's chart that he has discussed this with the mother and that he will add the correct information to both twins' charts.

Human Factors Concepts Identified

- **Potential for work-flow mismatch:** Difficult for subsequent providers, such as the nurse documenting medication administration, to document actions in the proper location.
- Difficult to change inaccuracies in documentation after the event, even when documentation is often delayed until after care is provided.

The physician then observes an acute change in the neurological status of the infant and orders a computed tomography (CT) scan in the EHR. There are 24 available options for CT scans, taking into account the potential implications of size-based parameters and sedation techniques. Choosing the appropriate test would be difficult for a less experienced physician without consulting with a radiologist. Because the radiologist does not have access to the EHR or the EHR's data until the morning of the procedure, it is not possible for the radiologist to audit and correct orders in advance.

Human Factors Concepts Identified

- **Potential for responsibility-authority double bind:** Although physicians are responsible for ordering CT scans, radiology expertise is often needed to know exactly which CT scan is best to order.

* The scenario is fictional. Adapted from Lowry SZ, et al. *NISTIR 7865. A Human Factors Guide to Enhance EHR Usability of Critical Care Interactions When Supporting Pediatric Patient Care.* Gaithersburg, MD: National Institute of Standards and Technology, 2012. Accessed Jan 30, 2013. http://www.nist.gov/healthcare/usability/upload/NIST-IR-7865.pdf.