Improving Patient Safety and Clinician Cognitive Support through eMAR Redesign

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Inclusive Dates of Project: 7/01/2018-4/30/2024

Federal Project Officer: Christine Dymek

This work was supported by a grant from the Agency for Healthcare Research and Quality.

Grant Award Number: R01 HS25136

Structured Abstract

Purpose: The purpose of this research was to (1) identify health information technology usability issues during the medication process that contribute to patient safety, (2) analyze these issues to identify specific usability aspects that should be addressed, and (3) determine what usability measures and specific usability issues are identified in the literature and whether they are aligned with our findings.

Scope: This research focused on health information technology used to support the medication process in inpatient settings at two large healthcare systems. We focused on usability of these technologies and how these usability issues can impact patient safety and provider burden.

Methods: Several different methods were utilized including qualitative analysis of patient safety event reports, interviews with clinicians, and usability testing methods.

Results: The analysis of patient safety event reports revealed that most health IT issues associated with medication errors are due to usability and nearly half of these issues reach the patient. The interviews identified several specific usability issues that were aligned with those found during the analysis of patient safety event reports. These included issues with visual display, alerting, and workflow. The scoping review also aligned with the interviews and safety reports. A systematic review of usability measures found that most measures were qualitative in nature and that most measurement was focused on effectiveness and satisfaction rather than efficiency.

Key Words: medication processes, usability, patient safety

Purpose

Objectives of Study

The original objectives of the study were to:

1. Analyze a diverse set of over 1.7 million medication related patient safety event reports to identify specific problematic aspects of CPOE-eMAR-BCMA activities that contribute to medication errors.
   a. Analyze two different datasets to identify CPOE- eMAR-BCMA related usability and safety hazards using an innovative natural language processing (NLP) and active learning approach.
   b. Develop a detailed taxonomy of error types and associated usability hazards across the continuum of medication ordering and administration.

2. Conduct multi-method usability evaluations of current eMAR-related processes for physicians, nurses and pharmacists to identify usability, medication information flow, and communication challenges.
   a. Screen for eMAR pain points, conduct heuristic evaluations, semi-structured interviews, and cognitive walk-throughs using think- aloud protocol and contextual inquiry observations.
   b. Determine eMAR usability gaps in the current process; create comprehensive test scenarios of the CPOE-eMAR-BCMA medication process.

3. Iteratively design, develop, test, and disseminate eMAR wireframes and prototypes, working with Cerner, to better support clinician communication and information flow.
   a. Develop eMAR design documents, wireframes and prototypes and test in simulation.
   b. Disseminate materials to government agencies, EHR vendors, and healthcare providers.

Modifications to the Original Objectives

As with most multi-year grants, modifications to the original objectives were made given changing health information technology (health IT) use and other contextual factors that can impact research. In Aim 2, we modified some of our methods for screening for eMAR pain points. In Aim 3, we conducted usability evaluations, but we did not design, develop, test, and disseminate eMAR wireframes since our research team, as well as others, have not been able to encourage electronic health record (EHR) developers to adopt these. Thus, we determine this was a not a good use of resources and we used those resources to further our analysis of current systems so that we could continue to highlight the significant usability and safety challenges.

Scope

Background

While new medication assistive technologies, such as computerized provider order entry (CPOE), electronic medication administration records (eMAR), and barcode medication administration (BCMA) have been developed to support the medication process there continue to be both usability and safety issues. These issues have led to new patient safety threats as well as workforce frustration and burden that also impacts patient safety.

Context

Addressing these usability and safety issues requires a deeper understanding of the specific design issues that are contributing to patient safety threats, an analysis of how clinicians currently use these technologies, and the ideal workflows and information displays to appropriately support clinical use, as well as specific recommendations for improvements. We sought to provide this foundational knowledge through the course of this multi-year grant.

Settings

This research effort took place at two large healthcare systems in the United States, one on the East coast and one on the West coast. The research was focused on health information technology (IT) and medication processes in the inpatient environment. Two different EHRs are used across these healthcare systems: Oracle Cerner and Epic.

Participants

The participants in this study were clinicians including physicians, nurses, and pharmacists.

Incidence

Medication errors occur across healthcare settings and can have a significant impact on patients, including harm and death. With most healthcare facilities using an EHR, and adopting other medication assistive technologies, the incidence of health IT related medication issues is increasing.

Prevalence

Medication errors are one of the most frequent types of error impacting patients. With the widespread use of health IT in the medication process it is likely that a large percent of medication errors can be attributed to health IT. However, few studies have defined prevalence, and this is one aspect we examine as part of this research effort.

Methods

Given the numerous analyses performed under this multi-year grant, we segmented the methods by specific grant aims.

Specific Aim 1

To identify safety issues associated with health information technology (health IT) during the medication process, we applied a previously developed natural language processing algorithm to a database of over 2.3 million patient safety event (PSE) reports from 595 healthcare facilities in a single state and then conducted keyword search to focus on medication-related events. A random sample of PSEs that were likely health IT related and contained at least one medication related keyword were then manually reviewed by a team of subject matter experts, including a physician, pharmacist, nurse, and human factors and systems engineer. The free-text of the reports were analyzed to identify: (1) events associated with health information technology (health IT) intended to support the medication process, including computerized provider order entry (CPOE), electronic medication administration record (eMAR), and barcode medication administration (BCMA); and (2) usability issues associated with eMAR. Analyses focused on determining: (1) the type of medication error, medication process stage, and health IT usability issue; and (2) specific types of eMAR-related usability challenges that contributed to the PSE.

Specific Aim 2

We used multiple approaches in Aim 2 to investigate eMAR usability, including interviews, conducting a systematic review, and Markov modeling.

Interviews: We interviewed 32 nurses practicing at two urban, health systems (one on the East coast and one on the West coast of the United States) to explore hazards and inefficiencies in the medication process. One health system used the Oracle Cerner electronic health record (EHR) and the other used Epic. Qualitative analysis using inductive and deductive coding included consensus discussion, iterative review, and coding structure revision. We abstracted hazards and inefficiencies through the lens of risks to patient safety and the cognitive Perception-Action Cycle (PAC). We also conducted scenario-based semi-structured interviews with eight physicians and eight nurses to explore risks associated with using free-text orders to communicate medication information since this was previously identified as an area of specific risk in past research. Interview responses were analyzed and grouped into common themes.

Systematic review: We conducted a systematic review of the literature to identify the measures of eMAR and BCMA usability, operationally defined as efficiency, effectiveness, and satisfaction. We retrieved peer-reviewed journal articles on BCMA and eMAR quantitative usability measures from PsycInfo, MEDLINE, and EMBASE (1976 – October 23, 2019). Following Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines, we screened articles, extracted and categorized data into the usability categories of effectiveness, efficiency, and satisfaction, and evaluated article quality.

Markov modeling: We modeled and estimated the frequency of automated dispensing cabinet (ADC) discrepancy safety events across three different data sources: ADC transaction logs, user ADC discrepancy reports, and user reports to a patient safety event (PSE) reporting

system. Data were collected over a 1-month period and a Markov model was used to categorize ADC transactions.

Aim 3

We used two methods to develop and test eMAR designs to improve usability: a scoping review and a usability assessment.

Scoping review: We conducted a scoping review to identify functional requirements of eMAR and BCMA. In collaboration with medical librarians, we searched PubMed, MEDLINE, and Google Scholar to retrieve peer-reviewed journal articles, conference proceedings, and gray literature on BCMA and eMAR functional requirements from scientific databases. We retrieved 118 records. After title, abstract, and full-text review, we retained 10 articles for data extraction. Data categories were extracted based on the criteria that best exemplified the medication administration stage where the functional requirement existed (i.e. planning, dispensing, administration, monitoring). These results were then categorized based on the usability issue where the functional requirement would impact a nurse's work (i.e. data entry, alerting, interoperability, visual display, availability of information, system automation and defaults, workflow support). Functional requirements related to eMAR and BCMA workflow interactions were categorized into a distinct medication stage in the nursing workflow (i.e., planning, dispensing, administration, or monitoring), and then narrative findings were mapped to specific usability categories of data entry, alerting, interoperability, visual display, availability of information, system automation and defaults, or workflow support.

Usability assessment: The research team developed scenarios that nurses completed using a simulated electronic health record. Data was qualitatively analyzed using the reflexive thematic analysis method. Three female medical-surgical nurses participated in the study.

Results

Principal Findings

Results are summarized by specific aims and reference outputs in terms of publications and conference presentations.

Aim 1:

An inter-disciplinary team manually reviewed 2700 patient safety event reports associated with health IT in the medication process, including CPOE, eMAR, and BCMA. These reports were from more than 595 healthcare facilities entered between January 2013 and September 2018. The facilities span urban, rural, and suburban geographies. Of the 2700 events, 1508 (55.9%) described a medication error that was associated with health IT use and 750 (49.7%) reached the patient. Improper dose errors were frequent (1214 of 1508, 80.5%) with most errors during ordering (673 of 1508, 44.6%) and reviewing medications (639 of 1508, 42.4%). Most health IT-associated medication error reports described usability issues (n = 1468 of 1508, 97.3%) including data entry, workflow support, and alerting. eMAR contributed to 473 PSEs. More detailed information can be found in Publication 6 in peer-reviewed journal articles.

eMAR was the point of origin for 84 (17.8% of 473) PSEs. Usability challenge categories included Workflow support (n = 52, 11.0%) and Display/Visual clutter (n = 30, 6.3%). eMAR contributed down- stream from the point of origin in 389 (82.2% of 473) PSEs, with errors stemming primarily from Pharmacy IT and CPOE. Prominent secondary eMAR–associated usability challenges included Display/Visual clutter (n = 327, 69.1%) and Alerting (n = 32, 6.8%). More detailed information can be found in Publication 6 in peer-reviewed journal articles.

Aim 2

We present findings about eMAR usability from interviews, a systematic review, and Markov modeling.

Interviews: Persistent safety hazards and inefficiencies related to eMAR and BCMA included:

1) Compatibility constraints create information silos;
2) Missing action cues;
3) Intermittent communication flow between safety monitoring systems and nurses;
4) Occlusion of important alerts by other, less helpful alerts;
5) Dispersed information: Information required for tasks is not co-located;
6) Inconsistent data organization: Mismatch of the display and the user's mental model;
7) Hidden medication assistive technology (MAT) limitations: Inaccurate beliefs about MAT functionality contribute to over-reliance on the technology;
8) Software rigidity caused workarounds;
9) Cumbersome dependencies between technology and the physical environment;
10) Technology breakdowns require adaptive actions.

Thus, errors might persist in medication administration despite successful BCMA and eMAR deployment for reducing errors. Opportunities to improve MAT require a deeper understanding of high-level reasoning in medication administration, including control over the information space, collaboration tools, and decision support. More detailed information can be found in Publication 1 in peer-reviewed journal articles.

In the second interview study, which was scenario-based and focused on use of free-text medication orders, we found that physicians primarily used this functionality because of poor usability of structured order entry, including reduced efficiency and limited functionality. Common risks to using free-text orders for medication communication included the increased likelihood of missing orders and the increased workload on nurses responsible for executing orders. To encourage the safe communication of medication information between clinicians, the EHR's structured order entry must be redesigned to support clinicians' cognitive, and workflow needs that are currently unsupported and driving clinicians to use free-text orders. More detailed information can be found in Publication 5 in peer-reviewed journal articles.

Systematic review: We identified 1,922 articles and extracted data from 41 articles. Twenty-four articles (58.5%) investigated BCMA only, 10 (24.4%) eMAR only, and seven (17.1%) both BCMA and eMAR. Twenty-four (58.5%) articles measured effectiveness, eight (19.5%) efficiency, and 17 (41.5%) satisfaction. Study designs included randomized control trial (n = 1; 2.4%), interrupted time series (n = 1; 2.4%), pretest/posttest (n = 21; 51.2%), posttest only (n =

14; 34.1%), and pretest/posttest and posttest only for different DVs (n = 4; 9.8%). Data collection occurred through observations (n = 19, 46.3%), surveys (n = 17, 41.5%), patient safety event reports (n = 9, 22.0%), surveillance (n = 6, 14.6%), and audits (n = 3, 7.3%). Of the 100 measures across the 41 articles, implementing BCMA and/or eMAR broadly resulted in an increase in measures of effectiveness (n = 23, 52.3%) and satisfaction (n = 28, 62.2%) compared to measures of efficiency (n = 3, 27.3%). Future research should focus on eMAR efficiency measures, utilize rigorous study designs, and generate specific design requirements. More detailed information can be found in Publication 2 in peer-reviewed journal articles.

Markov modeling: A total of 1,989,443 ADC transactions were recorded. Of these, 18,943 (0.95%) had a discrepancy difference; of these, 1163 (6.1%) had a user report. In total, 17 (0.09% of 18,943) ADC discrepancy PSEs had discrepancy user reports and appeared in the transaction logs. However, 1146 of 1163 (98.5%) discrepancy user reports did not have an associated PSE report. In addition, 1914 of 3077 of the identified discrepancy events (62.2%) did not have a discrepancy user report or a PSE report. The study findings illustrate how PSE reports are only the tip of the iceberg, capturing less than 0.6% of possible ADC discrepancy events. This work can be leveraged to better understand both safety hazards and the effectiveness of interventions. More detailed information can be found in Publication 3 in peer-reviewed journal articles.

Aim 3

We present findings about eMAR redesign based on the scoping review and usability assessment.

Scoping review: We found 32 distinct functional requirements across the stages of the medication administration cycle, with the highest in Administration (n=18) and Planning (n=10), and fewer in Dispensing (n=3) and Monitoring (n=1). In terms of usability, Workflow Support (n=13), Alerting (n=7), and Visual Display (n=6) were among the highest requirements, Availability of Information (n=2), System Automation and Defaults (n=2), and Data Entry (n=2) had fewer requirements.

Key usability challenges in the planning stage included alerting (about allergies and duplicate orders), visual display (poor organization of medications and medication screen design), availability of information (mismatch of administration times for medications that should be taken with meals and actual patient mealtimes), and workflow support (poor organization of medications, lack of decision support for novice users, poor planning support across patients).

Key usability challenges in the dispensing stage included data entry (missed documentation alerting), alerts (medication orders with pending discontinuation), and visual display containing color-coded home medications.

Key usability challenges in the administration stage included:

- Data entry, such as functional requirements related to data being buried under multiple clicks.
- Alerting, such as repeated, low-utility alerts being perceived to be of low value and contributing to alert fatigue.

- Visual display, such as visual clutter and issues where the most important information is not salient.
- System automation and defaults, such as some orders may automatically be removed or dropped from a list.
- Workflow, such as missing action cues to indicate what to do next in a sequential task, documentation fields not being available on the screen when needed, and BCMA work arounds to address issues with barcodes.

Within the monitoring medication stage, usability challenges related to availability of information (cognitive workload of monitoring medication effects and adverse events). In summary, across all medication stages, planning (n=10) and administration (n=18) had the highest number of functional requirements listed. The lowest number of functional requirements was found within the monitoring (n=1) medication stage. This large discrepancy found between these stages could be related to the higher number of cognitive and physical tasks required for planning and administering medications among nurses. This is clear within the 'workflow support' usability category, as the number of functional requirements within this category was greater in both planning and administration.

Usability assessment: We identified five themes in our usability assessment of the eMAR:
1) essential information exists outside of the eMAR,
2) unable to view future medications,
3) information lost with unit transfer,
4) unable to document home medications,
5) certain medications delay sequential orders.

Future usability evaluations of the eMAR should continue to look for poor usability, identify solutions, and consider the process for how individual hospitals can apply these usability evaluations to their own eMARs.

Conclusions

Health IT related medication errors, analyzed as part of Aim 1, occur most commonly during ordering and reviewing of medications and most frequently result in improper doses. Nearly half of health IT related medication errors are reaching the patient. Nearly all the health IT medication-related safety issues described usability as an aspect of the issue underscoring the criticality of usability. The interviews, conducted in Aim 2, revealed similar patterns to the analysis of patient safety event reports and contribute additional contextual information that cannot be derived from the reports alone. Nurses found many of the medication assistive technologies to lack appropriate considerations for their workflow, be burdensome to use, and be designed in ways that increase cognitive load.

The systematic review, conducted in Aim 2, focused on the types of usability measures in the literature which may provide insights on where shortcomings in usability measurement exist so that the gaps can be filled. The review identified two major areas for future focus. One is the need for more rigorous usability studies and measures with many studies relying on qualitative assessments. Part of the reason for this is that most measures of usability are qualitative in nature. The other area for future focus in measures of efficiency which tended to be lacking in the literature.

The scoping review, conducted in Aim 3, provides specific areas for usability improvements by medication stage. This information also aligns with the findings from the interviews conducted as part of Aim 2 and should be a focus of future optimization and new design efforts.

Significance

There are several significant aspects to this research. First, the research underscores the criticality of usability of health IT in the medication process with most safety issues related to usability. Second, there are clear common usability issues that emerged from the analysis of PSEs, the interviews, and the scoping review. Third, the scoping review pinpoints immediate changes that should be made to these technologies, and the broader work system to address the identified usability and patient safety issues. These insights, also describe below, have been raised to the stakeholders and partners that can support implementation.

Implications

This research has implications for multiple stakeholders:

Health IT developers should prioritize improvements to their medication-related technologies based on the findings from our research. There are clear areas of importance and optimization efforts should be focused on these areas with rigorous iterative testing as design improvements are made. Further, health IT developers should conduct both proactive and retrospective analyses to identify usability and patient safety issues to drive their future development efforts.

Policymakers and federal agencies, such as the Office of the National Coordinator for Health Information Technology (ONC), should promote usability and safety by encouraging health IT developers to address the issues identified in this research. To achieve this, the ONC can include usability and safety test cases as part of their certification program under the safety enhanced design provision. Further, they can include usability assessments in their real-world testing provision. Finally, they can establish clear pathways for healthcare facilities to report usability and safety issues so that the ONC can better understand these issues and inform future policies based on these data.

Healthcare facilities should use the knowledge generated from this grant to conduct risk assessments of their existing health IT that is part of the medication process. Where high-risk areas are identified, risk mitigation plans and actions should be put in place. Healthcare facilities can also develop test cases to evaluate their health IT systems for the types of medication issues identified here. Finally, when considering new health IT to support the medication process, these technologies should be assessed, prior to purchase, for usability and safety.

Limitations

There are several limitations to our study. Our analysis of patient safety event reports is limited to the description entered by the frontline reporter. There was no opportunity to independently verify any of the details or to do any analyses beyond what was provided by the reporter. There also may be reporter bias. The analyses we performed using the interview data are limited by the experiences of the participants that were interviewed. Most participants used either the Oracle

Cerner or Epic electronic health record. Thus, our results may not generalize to all electronic health records.

List of Publications and Products

(Bibliography of Published Works and Electronic Resources from Study—Use AHRQ Citation Style for Reference Lists).

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