Usability Evaluation of An Electronic Medication Administration Record (eMAR) Application

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Keywords

Interfaces and usability, Human-computer interaction, Medication administration records, Electronic health record, Testing and evaluation

Summary

Background: Electronic medication administration records (eMARs) have been widely used in recent years. However, formal usability evaluations are not yet available for these vendor applications, especially from the perspective of nurses, the largest group of eMAR users.
Objective: To conduct a formal usability evaluation of an implemented eMAR.
Methods: Four evaluators examined a commercial vendor eMAR using heuristic evaluation techniques. The evaluators defined seven tasks typical of eMAR use and independently evaluated the application. Consensus techniques were used to obtain 100% agreement of identified usability problems and severity ratings. Findings were reviewed with 5 clinical staff nurses and the Director of Clinical Informatics who verified findings with a small group of clinical nurses.
Results: Evaluators found 60 usability problems categorized into 233 heuristic violations. Match, Error, and Visibility heuristics were the most frequently violated. Administer Medication and Order and Modify Medications tasks had the highest number of heuristic violations and usability problems rated as major or catastrophic.
Conclusion: The high number of usability problems could impact the effectiveness, efficiency and satisfaction of nurses' medication administration activities and may include concerns about patient safety. Usability is a joint responsibility between sites and vendors. We offer a call to action for usability evaluations at all sites and eMAR application redesign as necessary to improve the user experience and promote patient safety.

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Introduction

Now widely implemented, electronic medication administration records (eMARs) are used to support medication management to reduce medication errors, promote patient safety and improve workflow efficiency [1–3]. Nurses represent the greatest numbers of eMAR users and are recognized as the "last line of defense" in preventing medication errors in acute care settings [4]. Therefore, eMARs must facilitate nurses' medication activities without requiring "workarounds", difficult application navigation or other usability problems [5, 6].

Whether with electronic or paper records, nurses must accomplish a series of sequential tasks to complete crucial medication administration activities. Errors can occur in these activities due to human factors and usability issues. Distractions, interruptions, and human factor issues can negatively influence a nurse's ability to stay focused on medication activities [7]. A recent MEDMARX® report indicated that 35.4% of medication errors were attributed to workplace distractions [8]. MEDMARX® is a national internet-accessible anonymous adverse drug reporting registry program aimed to help healthcare facilities better understanding contributing factors to medication errors [8]. Usability issues such as poorly designed user interfaces can impact nurses' activities and result in poor outcomes [9].

Recent white papers from the Agency of Healthcare Research and Quality (AHRQ) stressed the need for usability evaluations of vendors' electronic health records (EHRs) [10, 11]. No published usability evaluations of any commercial vendor eMAR are yet available despite the common use of eMARs in acute care settings. Only one usability study of an eMAR was located, a descriptive study about nurses' satisfaction with a novel eMAR design [12]. In fact, few usability and design evaluations exist for electronic tools nurses use. Given the volume of nurses worldwide and their increasing use of eMARs, a formal usability evaluation of an eMAR is in critical need as well as a timely research topic. An evaluation at a single site, like the one here, may not typically be generalizable, but is important for two reasons. First, the study can serve as a methodological guide for evaluations at other sites with other vendors' products and second, this particular vendor has sites worldwide. Thus, similar usability issues may exist at hundreds of sites around the globe.

eMARs and Patient Safety

Broad studies are beginning to be available about nurses' use of EHRs. Recently, authors in Taiwan examined nurses' use of EHRs [13], although specific findings about eMAR use were not outlined. Beauscart-Zephir and colleagues [14] found that communication among physicians and nurses in French hospitals was impacted when computerized physician order entry (CPOE) was installed. These authors performed a usability assessment discovering that when physicians entered medication orders, the system-generated electronic time schedules were ambiguous to nurses. Interestingly, numerous studies are published on CPOE [15–22] a process that involves nurses. However, Weir, Staggers and Phansalkar [23] completed a systematic review of CPOE studies and found that nurses were not a population of interest for studies published in refereed journals. Also, in the 46 relevant studies, none of the CPOE authors mentioned evaluating eMARs as part of their research, although eMARs may have been an available application [23].

The role and impact of information technology (IT) has a direct link to patient safety in the healthcare setting [24–26]. A difficult-to-use interface in the clinical setting may hamper efficiency, clinical productivity, and increase the probability of human error, ultimately compromising patient safety [27]. For example, adverse drug events (ADEs) are a leading cause of medical injuries, morbidity, and mortality in hospital patients [28, 29]. Preventable ADEs can occur at any stage of the medication process, but do so most frequently at the prescription and administration stages [30]. One report estimates that when all types of errors are accounted for, every hospitalized patient can expect on average one type of medication error per day [30]. Additionally, the authors provided a conservative annual estimate of 380,000–450,000 ADEs in hospital settings. Estimated costs for these ADEs are $8,750 (in 2006) per hospital stay or a total of over 3.5 billion for 400,000 cases [31]. Preventing or decreasing medication-related error is clearly both a financial and patient safety issue.

Studies have been conducted on ordering systems, bar-coded medication administration and the extent to which ADEs are prevented [31–33]. A void exists in research about eMARs in general and

design implications specifically for the primary users of eMARs: nurses. Anecdotal information suggests that sub-optimal eMAR designs can interfere with nurse effectiveness and efficiency.

Ideally, eMARs should be designed to support nursing workflow processes to ensure efficiency and effectiveness, especially when compared to traditional paper-based medication administration records. Features of an eMAR to maximize patient safety, reduce ADEs and enable nursing processes include:

1. Access to the most recent drug information, hospital policies and procedures related to medication administration;
2. Access to context-specific patient clinical results;
3. Methods to facilitate communication between nurses and pharmacists; and
4. Automated verification of the "five rights" (right patient, right drug, right dose, right route, and right time) [34].

Usability

Usability is a subset of human factors engineering and originates from cognitive science [35]. The International Standards Organization (ISO) defines usability as, "the extent to which a product can be used by specified users to achieve goals with effectiveness, efficiency, and satisfaction in a specified context of use" [36]. Usability examines the fit between systems, tasks, and users in a given environment and involves multiple concepts: learnability, efficiency, ease of recall, low error generation, and satisfaction [37, 38]. Usability evaluations are one way to assure complex applications, such as eMARs, fit nurses' cognitive and behavioral requirements, and are efficient, effective, and positively impact patient safety.

Healthcare delivery, especially in clinical settings, brings unique constraints to IT design – considerations for the distributed nature of work, multidisciplinary interactions and life-critical impacts to patient safety. These elements require accurate information and highly usable computer interface designs. Healthcare software applications do not often undergo usability testing [39]. Yet, these evaluations are imperative for safe and reliable healthcare applications. Recently the AHRQ recommended that usability studies be conducted on EHRs to foster application effectiveness and efficiency [10, 11]. These kinds of usability evaluations can be conducted using a variety of methods, such as heuristics evaluation, cognitive walkthrough, and think aloud [38].

Objective

In this study the usability of a vendor's eMAR was assessed from a nursing perspective using a heuristic evaluation technique. Nursing perspective means that the heuristic evaluation was done from the point of view of nurses as the end users of the eMAR system; that is, nursing practice and workflow are considered in determining the compliance of the eMAR with recognized usability principles. The tasks performed in the application are more comprehensive compared to other healthcare disciplines using the application; for example, pharmacists and physicians enter medications into the eMAR but do not administer medications to patients. Nurses perform both tasks.

Methods

Setting

The University of Utah Healthcare system operates three hospitals (University Hospital, Huntsman Cancer Hospital, and University Neuropsychiatric Institute), in addition to 80 general and specialty clinics. The hospitals and clinics employ over 900 board-certified physicians, 1000 full-time equivalent nurses and provide 850,000 inpatient and outpatient episodes and visits annually [40]. This medical system uses an inpatient EHR supplied by a major EHR vendor having installations worldwide. Overall, the site is at Level 4 on the HIMSS 8-level EMR Adoption model [41]. Installed functions include: Computerized Provider Order Entry (CPOE), nursing documentation, results review

and integrated ancillary applications in pharmacy, laboratory and radiology. Pharmacy processes are completely computerized to include supply chain management.

The inpatient EHR was implemented over an 8-year period, beginning with results review in 2001, nursing documentation in 2007, and CPOE with the integrated eMAR in May 2009. Medication bar-coding is not yet installed; however, its project funding is anticipated for 2011. Tailoring for the eMAR was jointly completed among representative clinical users, informaticists assigned to the IT department and the vendor's personnel. The organization mandated use of CPOE and the associated eMAR. The facility provided formal classes on CPOE, eMAR, and related documentation. Implementation processes included the use of executive champions, an extensive network of superusers to support staff and mandatory training for the eMAR. This evaluation was conducted beginning spring 2010, approximately 9 months post-CPOE and eMAR implementation and extended through December 2010.

Heuristic Evaluation

Heuristic evaluation is a systematic inspection of an application interface by independent evaluators, who are usability experts, who compare the design and interactions against a list of established usability principles (heuristics) [35, 42]. The method relies on the established heuristics plus the knowledge and experience of the evaluators. The ideal number of experts to conduct a heuristic evaluation of an application is three to five [43]. During the process, the evaluators define and use tasks typical for users of the application called the "dialogue" by Nielsen [44]. Evaluators uncover usability issues, categorize them using the heuristics and rate the severity of the usability issues.

The evaluators for this study were four registered nurses with clinical experience who are also doctoral nursing informatics students trained in heuristic evaluation. The eMAR application was initially evaluated using the training application having functionality thought to be congruent with the production system in active use. Subsequently, the findings were confirmed with clinical staff nurses and the Director of Clinical Informatics using the production system. Both training and production systems were version 2010.01. The evaluators used the 14 usability heuristics from Zhang et al. [42] (▶Table 1), a set of heuristics derived from earlier works and adapted to healthcare applications. Zhang et al. developed their heuristics by combining previous work by Nielsen's 10 heuristics [44] and Shneiderman's eight "golden rules" [45]. The severity rating scale for this study was also based upon Zhang et al. [42] (original severity rating scale from Nielsen [44], but adapted for medication management activities [▶Table 2]). In addition to Zhang's severity definitions the following elements were added to the definitions: impact on patient safety, nursing workflow, and workaround (▶Table 2).

Defining Typical eMAR Tasks and Use of Specific eMAR Screens

The evaluators identified seven primary nursing task categories that reflect common, sequential nursing practice for medication administration and using the eMAR. The tasks were identified prior to performing the evaluation. The nursing tasks include:

1. *Log into the System:* gaining secure access into the system using a username and password;
2. *Order and modify medication:* entering and/or modifying medication orders, e.g., in some settings nurses receive verbal medication orders via telephone; it should be noted that the doctor will need to review and sign these type of orders within the system;
3. *Verify medication orders:* reviewing and verifying medication orders such as an electronic signature or having clear indication of order already verified;
4. *Access drug references:* gaining access to an electronic drug reference guide while within the eMAR system;
5. *Administer medication:* viewing medication schedule and documenting medication administration in the eMAR system, e.g., time, route, dose, reasons for medication being held;
6. *Edit eMAR:* ability to edit medication documentation, e.g., change administration time or reschedule medication due times;
7. *Generate reports and review eMAR:* ability to generate and review reports related to medication administration, such as a missed medication or PRN effectiveness.

The tasks were matched to their respective eMAR functions in the application. Four pertinent EHR screens were evaluated to assess eMAR application: login/password (task 1), orders (task 2), eMAR (task 3–6), and eMAR summary (task 7).

Procedure

The study was approved by the institutional review board. The four evaluators were trained in heuristic evaluation methodology and attended a formal eMAR training session to become familiar with the software before conducting the evaluation. Each evaluator independently identified usability problems and heuristics violated using predefined tasks as suggested by Nielsen (1994) [46], in this case nursing medication administration tasks using the eMAR.

The independently identified usability problems and heuristic violations were combined across the four evaluators to create a master list of uniquely identified usability problems. The severity ratings for the usability problems were then rated by each evaluator. The pre-consensus Cohen's Kappa for inter-rater reliability was calculated using a pairwise comparison for severity ratings across evaluators (average = 0.86, range = 0.81–0.94). A consensus process was then used to resolve discrepancies in severity ratings to reach 100% agreement.

The findings were reviewed for accuracy with 5 staff nurses and the Director of Clinical Informatics who also reviewed results with a separate, small group of clinical nurses. The evaluators met with each of the 5 staff nurses individually and asked them to perform the defined tasks while being observed. The nurses verbalized and discussed their thoughts with the evaluators as they performed the tasks.

For example, one nurse stated "some error messages are not understandable or even applicable". She demonstrated what she meant by documenting a medication (task 5 – administer medication) that generated an error stating "the task was not completed – contact the systems administrator". Another nurse performed task 2 (order and modify medication), with an insulin order and received an error message stating "pharmacy reject". She commented "…this is not clear to me, what does it mean, why was the order rejected? It is unclear to me if I need to call the doctor or pharmacy". During the validation process: (1) four new usability problems were added (see results); (2) one was deleted (unable to view the ordered insulin sliding scale while in the eMAR screen where administration is documented) because this issue was corrected in an eMAR application upgrade; and (3) wording for the entire list of usability problems was refined for clarity.

Data Analysis

Descriptive statistics were used to determine the frequencies of usability heuristics and severity ratings, and the averages of severity ratings and number of heuristics violated per usability problems. Cohen's Kappa statistic was calculated to examine the interrater reliability. These analyses were performed using SPSS statistical software (SPSS 17.0 for Windows, Chicago, IL, USA) and Microsoft® Excel 2007.

Results

The evaluators found 60 unique usability problems (number of usability problems identified per evaluator: JG: 31, SI: 23, SK: 22, and SP: 32) which were categorized into 233 heuristic violations (▶Table 3). Of the 60 usability problems, four were identified during the validation process. These include:

1. Difficult to discern medication actions at a glance, e.g., small text, actions appear in a different location, no highlighting or color coding, entire text and box disappears for medication due (*Administer medication*);
2. There is no free text option for "Site", e.g., nurses select "body" and use the comment box for specific information (*Administer medication*);
3. The orders screen must be manually updated by clicking "As Of" icon (*Order and modify medication*); and

4. Unverified orders can be missed using the "PAL" screen view that nurses commonly use to view orders (*Verify medication orders*).

Usability problems occurred in each of the seven medication administration tasks while using this eMAR application, with the exception of login to the system. On average, each usability problem had four heuristic violations. The majority of usability problems were identified for *Order and modify medication* (n = 20) and *Administer medication* (n = 19) tasks. The highest average severity ratings were for the same two tasks, plus verify medication orders and generate reports and review eMAR, which although had similar average severity ratings, had fewer identified usability problems (▶Table 3).

Usability Problem Identification

The eMAR usability problems, corresponding heuristic violations and severity ratings are displayed in ▶Table 4. One usability problem is once a medication is charted its location changes from the medication order description row to the single line below the full description (▶Fig. 1). Information about the medication administration route and site is dropped, making it difficult to discern medication actions at a glance because of the small text, actions appear in a different location, no highlighting or color coding, and that the entire text and medication due box disappears (▶Fig. 1). This problem was scored as a severity rating of 4 (usability catastrophe) because it significantly hinders workflow in that users may spend a significant amount of time discerning medication actions, especially if they are new users to the application. Additionally, there is no workaround for this process as is appropriate because of its implications to patient safety; however, this issue can be problematic especially in fast-paced patient care environments. There is a high potential of missing important information, e.g., nurses can easily miss when a medication was given especially with non-scheduled medications such as narcotics, which could significantly impact patient safety especially in emergency situation.

Other examples include: icons which are not intuitive, (e.g., the icon for a patient's care plan is a yellow square with colored dots [▶Fig. 2]); the system-generated list of medication administration routes was not tailored to the particular medication (e.g., a topical medication could be ordered and charted as being administered intravenously [IV]); and that a narcotic PRN (as needed) medication could be charted as given before the minimum time interval for administration of the next dose had elapsed. Furthermore, the application did not produce an alert indicating that the medication was being given too soon. Multiple doses of the narcotic could be given and charted within a timeframe outside of the ordered range. Additionally, the eMAR screen truncates messages as may be seen in ▶Figure 2. Lastly, in the *Verify medication orders* task, a medication could be administered and documented even if it was not yet verified by a pharmacist, nurse, or other clinical provider.

Severity Rating Evaluation

Severity ratings for the seven tasks are located in ▶Figure 3. The evaluators found nine usability issues rated as catastrophic (severity = 4) across all tasks, 23 rated as major (severity = 3), 27 rated as minor (severity = 2), one rated as cosmetic (severity = 1). The *Order and modify medication* task had the highest number of problems rated catastrophic (n = 4) and minor (n = 8), while the *Administer medication* task had the highest number of problems rates major (n = 9).

Heuristic Evaluation Categories

In this study, the greatest number of violations occurred in the match heuristic category (n = 48, ▶Fig. 4) and the least in the undo (n = 1) category. An example of a match violation is that a list or report of overdue or missed medications, a very common task for nurses, cannot be generated. To identify missed or overdue medications, nurses needed to scroll back and forth and up and down in each individual patient's eMAR. As may be seen in ▶Figure 2, the extensive white space in the eMAR precludes easy identification of medications, especially those outside the current field of view.

The second highest number of violations occurred in the visibility heuristic category (n = 33). An example is the extremely small icon for ordering an insulin sliding scale (▶Fig. 5). Moreover, the icon is non-intuitive as indicating an insulin sliding scale.

The third highest number of violations occurred in the error heuristic category (n = 29). An example of this violation is the "As Of" icon (▶Fig. 2). During eMAR training, the evaluators learned that the "As Of" icon must be clicked during an EHR session of any kind to retrieve the latest data. If users forget to click this icon, they could make clinical decisions based on outdated information or administer discontinued medications.

Another example of an error violation was that the eMAR data is not integrated with other modules; therefore, nurses must search in other EHR modules for vital signs, laboratory values or other information pertinent to medications. For example, if nurses are giving digoxin, they must record an apical pulse. A capability exists to enter the apical pulse as free text in a temporary notation. The notation appears as an icon on the eMAR (▶Fig. 2). However, the value in the notation is not visible unless nurses take an extra step to click on the icon. Because the notation is free text, critical values are not clearly highlighted and could be easily missed by other clinicians. Nurses must still chart the pulse in the vital signs application or as a comment that is also hidden unless another step is taken to open the comment box.

Discussion

This study revealed a high number of heuristic violations and high severity ratings for this vendor's eMAR. The application is in use by over 1,000 nurses in three hospitals in Utah and, more importantly, it is available worldwide from this vendor. To our knowledge, the study is a first formal usability evaluation of a vendor eMAR application in active use at a site.

Heuristic Evaluation Method

The heuristic evaluation technique proved very useful in identifying usability issues with the eMAR application. In fact, a heuristic evaluation approach can be a method for identifying usability issues with clinical system applications that span a range of sources, including interoperability, site and vendor issues. In this evaluation, interoperability issues created usability problems for nurse users. Without integration between modules, nurses had to move from one application (eMAR) to another (vital signs, intake and output) to synthesize critical information for medication administration activities. Thus, the heuristic evaluation technique adapted to nursing medication tasks was able to uncover more typical usability issues such as icon design, but it also revealed issues that spanned interoperability, site built decisions and hard-coded vendor programming.

In the future, researchers could analyze the source of the issue and work with sites and vendors to address them. This is not a simple process once the application is implemented. Preferably, usability evaluations would be completed much earlier in the systems lifecycle to avoid having to analyze the origin of issues as is the case for this eMAR. Instead, critical issues could be identified and corrected well before the application is programmed.

An eMAR application is interdisciplinary, highly used by nurses, pharmacists, respiratory therapists and physicians, respectively. This evaluation addressed the perspective of nurse users, the largest eMAR user population. When evaluators perform usability assessments on complex products in the future, especially early the systems lifecycle, they will want to assume the perspective of all interdisciplinary users of the applications. The identified usability issues in this study have implications for each of the published usability goals: effectiveness (safety, accuracy, fit with workflow), efficiency (productivity), and satisfaction [10, 11, 37].

Impact on Effectiveness

The high number of identified usability problems could impact the effectiveness of medication administration tasks. The accuracy of nurses' medication administration may become impaired, resulting in patient safety issues. In particular, the inability in being able to discern missed, overdue and

administered medications at a glance could result in patient over- or under-dosing. That is, the eMAR has substantial white space, meaning that nurses must scroll both horizontally and vertically and side to side to locate overdue and missed medications both time consuming and potentially inaccurate processes.

Additionally, no indicators are displayed to indicate if overdue or missed medications exist outside of the selected field of view (nurses may select the time range to be displayed, e.g., 4, 8 or 12 hour view). Being able to document (administer) narcotics and other medications before they are due could lead to inadvertent overdoses. Adverse drug events could occur especially when nurses are under time pressures typical of acute care settings. Nurses have high cognitive loads with frequent distractions and interruptions in the clinical workplace [7]. Usability issues with eMARs, in addition to the typical interruptions in acute care, could exacerbate patient safety concerns during medication-related tasks.

The high number of heuristic violations in the Match category indicates that this eMAR application does not fit well with nurses' work design and thought processes. The mismatch could lead to missteps, workarounds to the "5-rights" medication administration process and potential bypassing known safety procedures leading to medication errors. Likewise, issues with the visibility of system actions could impede nurses' abilities to detect critical information in the eMAR.

Impact on Efficiency

The identified usability issues could also impact nurses' efficiency. Nurses' productivity is negatively impacted when they have to search for information across disparate applications, such as moving away from the eMAR to other screens to locate vital signs or laboratory values pertinent to medications being administered. This is especially crucial because nurses spend approximately 25% of their time in acute care settings performing medication-related activities [34]. Inefficient eMAR activities could then lead to delays in medication administration or other care activities.

Informaticists might argue that usability issues could be alleviated through expanded training. However, dependence upon even comprehensive, standardized training is time-consuming at best and risk-prone at worst. The evaluators experienced this first-hand. For example, the standardized training did not include material about how to access the insulin sliding scale within the eMAR perhaps because the function was not available in the training system.

Only after validating this issue with staff nurses did they learn that the scale was available in the production system by hovering over the insulin order to retrieve the information. Moreover, training time impacts clinician productivity and the quality of training varies among trainers. Last, an extensive training burden impacts efficiency individually and organizationally. There is a ratio between system usability and training. The more usability problems with an application, the longer time and more resources a site must devote to training to demonstrate system "workarounds", application "quirks" and workflow management issues. Also, clinicians can be employed by more than one institution, requiring users to learn and remember various systems. Training time is an economic burden for the organization. The training issues identified are all related to the overall efficiency and usability of systems.

Impact on Satisfaction

Issues with efficiency and effectiveness also impact user satisfaction with a product [45, 47]. The myriad of usability issues can result in user frustration, sub-optimal use of the product and even sub-optimal adoption of the EHR as a whole. Anecdotally, the Director of Clinical Informatics at the site acknowledged that nurses' satisfaction with the application was poor due to issues with effectiveness and efficiency and, in fact, recommended the application to the authors as one in need of a usability evaluation.

Responsibilities for eMAR Designs

It is tempting to attribute the high number of eMAR usability issues to the vendor's product [45, 47]. However, this eMAR is not atypical of current EHR designs. More important, responsibility for ad-

equate usability rests jointly with the vendor and the site. Clearly, the basic design of the product is created and coded by the vendor. Currently, evidence is available that most vendors do not employ usability principles including user-centered design in development processes nor do they routinely conduct usability tests [39]. Sites do have some discretion about features in the completed application as they tailor the product. For example, this site chose to allow medications to be documented without verification by a pharmacist, nurse or physician. This decision was made to allow urgent medication administration during emergencies. Unfortunately, this decision has a crucial impact on non-urgent medications as well. The vendor product did not allow tailoring to verify options by unit, medication or other more granular elements.

Another factor impacting usability is the current version of software installed at a site. A site may decline to install the most current upgrade, even if it contains fixes to the issues at hand, because upgrades are costly and time-consuming to configure and install and may require additional training. Also, upgrades may have multiple features only some of which a site may choose to install. All of these factors contribute to the current usability of the implemented product. At this particular site, an upgrade after 18 months of initial eMAR implementation addressed only 2 of the 60 issues found in this study. The two issues were that vendor grayed out the small icon for insulin sliding scale and added a feature to right-click on a medication to reschedule its timing. While these improvements are helpful, the product has continuing usability issues.

The sub-optimal usability of this particular eMAR might be related to a lack of informatics sophistication or sound implementation processes at the site. However, this site has a long-standing reputation of excellence in IT and informatics. The CPOE implementation process was multi-faceted and consistent with known implementation guidelines. Like most other sites, however, usability principles and usability testing were not employed during product tailoring or the implementation process.

Other sites, especially rural or community hospitals may have even fewer resources dedicated to application tailoring and implementation processes. With the vast numbers of EHRs with embedded eMARs being hurriedly deployed in the United States under the American Recovery and Reinvestment Act (ARRA) funding, the potential for sub-optimal EHR usability is great. At this site, study findings were relayed to information technology administrators. The process for fixing these issues is, unfortunately, complex and no short-term solution is available. Rebuilding software at the site is not a high priority compared to implementing new projects. Also, the vendor's priority in recoding the application is negatively balanced with coding new projects.

A Call for eMAR Re-design and Ubiquitous Usability Evaluations

An eMAR application is expected to promote effective medication administration practices, decrease errors, and reduce inefficiencies. A high level of usability issues with eMARs, like the ones found here, can critically impact the user experience, patient outcomes, and even the overall success of a clinical information system [9, 48]. To improve the user experience and promote patient safety, a combination of actions is needed across vendor application design processes, vendor/site best practices for tailoring products and site usability testing.

As the 2010 report from AHRQ noted, vendors need to improve design processes by incorporating known usability principles and practices into products [39]. User-centered design, iterative prototyping and systematic assessments are basic to usable and safe applications. Fundamental design improvements for this particular eMAR include reducing the whitespace in the eMAR to allow medications to be viewed at a glance without the need to scroll extensively and include provisions for a report of missed, overdue and administered medications. Displaying integrated information pertinent to medication administration tasks is critical, e.g., being able to concurrently view and document the patient's blood glucose or apical pulse.

System tailoring and usability evaluations are highly dependent upon the skill of the vendor's representatives assigned to the site as well as the availability of site personnel educated in informatics and usability. To decrease the variability of skills from vendor representatives, best practices for tailoring could be compiled and communicated across sites without extra charges for services. The consequences of sub-optimal design choices can be emphasized. For instance, without medication bar-coding software or basic alerts, inappropriate medication doses are possible in this eMAR. Sites

may still choose to not implement a best practice but having impacts of decisions compiled and communicated would make these site decisions explicit and more transparent.

Commonly, sites are responsible for system and integration testing of applications, but they rarely complete usability testing after tailoring a product. This choice can be due to time pressures, lack of resources or lack of knowledge about usability. In the future, we recommend that all sites complete usability testing for clinical applications, especially for critical products like eMARs. Usability evaluations can be built into project management timelines. Usability testing could have uncovered the major and catastrophic errors before the eMAR was deployed at this site, prevented workarounds and created a safer environment for patients. For those new to the concept of usability, guides are available [35, 38, 42, 49].

Study Limitations and Future Research

This study evaluated an eMAR from one vendor and one site, thus the results may not be comparable to other vendors and sites. However, this particular vendor eMAR is distributed worldwide and has a large and growing user base. The site does have informatics expertise available, although other sites might make different choices, more or less optimal, during the tailoring process.

As noted earlier, the site does not yet have medication bar-coding in place. Some findings might be different if this application was in place or if a newer version of software were available and installed. Nevertheless, the fact is that the application was deployed without bar-coding and with a current version of software, making the identified usability issues pertinent. This site is likely not atypical. A usability evaluation after a product is available for nine months might initially appear as a limitation; however, it is not for this eMAR. The application is used many thousands of times each shift across the facility and changes to the software did not occur as they might with a homegrown system. By nine months post-implementation, the application had been used hundreds of thousands of times and was very stable.

Future research is suggested to compare various eMAR designs on effectiveness and efficiency outcomes, e.g., accuracy in information management and human performance times and errors. Observations in naturalistic settings could be completed to capture actual errors and near-misses with deployed eMARs across products and settings.

We also recommend that usability evaluations of clinical products include a validation step with practicing clinicians. While not a usual component of heuristic evaluations, typically completed by usability experts, including clinicians is worthwhile for evaluating complex tools like EHRs. The authors learned this first-hand. They were concerned that despite training and practice with the eMAR, they might not be aware of all its functions.

They also discovered that despite having congruent software version numbers for training and production systems, the training application was not as robust as the production product for several functions. Thus, a verification step was warranted. Non-clinical usability experts in particular need to consult with clinical users to verify the list of initial usability problems. This can be easily accomplished by conferring with clinicians about potential problems to assure they exist before labeling the issues with the known heuristic categories.

This validation step adds to the available usability techniques and is distinct from other methods such as think aloud. Users of established applications could be adapted to usability issues and likely would not mention the problems if Think Aloud techniques were used. Also, while a Cooperative Evaluation technique might be used, clinicians will not participate in lengthy evaluation sessions. Therefore, having usability experts identify usability issues and then validating the issues with clinicians maximizes the potential for clinician participation.

Conclusions

In this study, four evaluators used a heuristic evaluation method to evaluate the usability of a major vendor's eMAR application from the perspective of nurses, the most frequent users of these applications. A significant number of usability issues were identified, approximately half of which were rated as catastrophic or major in severity. These usability issues are an imperative or high priority, re-

spectively, to address before implementing. The high number and severity of usability issues could impact nurses' effectiveness, efficiency and satisfaction with medication activities, potentially negatively impacting patient safety. Preventing usability issues is a joint responsibility between sites and vendors. We offer a call to action for eMAR redesign, incorporating best practices into the tailoring process and assuring that sites complete usability testing after tailoring.

Implications of Results for Practitioners and/or Consumers

In summary, this study has implications for patient safety, for clinician productivity and for vendors. When eMARs have major and catastrophic usability problems, patient safety could be compromised. Clinician productivity can be impacted by eMAR designs, e.g., having to scroll to determine missed or overdue medications. Informaticists and vendor implications include the need to incorporate usability principles and practices into development processes. Sites and vendors both have a responsibility to conduct usability testing to determine the effectiveness and efficiency of eMAR designs.

Conflict of Interest

None of the authors have actual or potential conflicts of interest to disclose.

Human Subjects Protections

The University of Utah Institutional Review Board approved this project, rating it as exempt.

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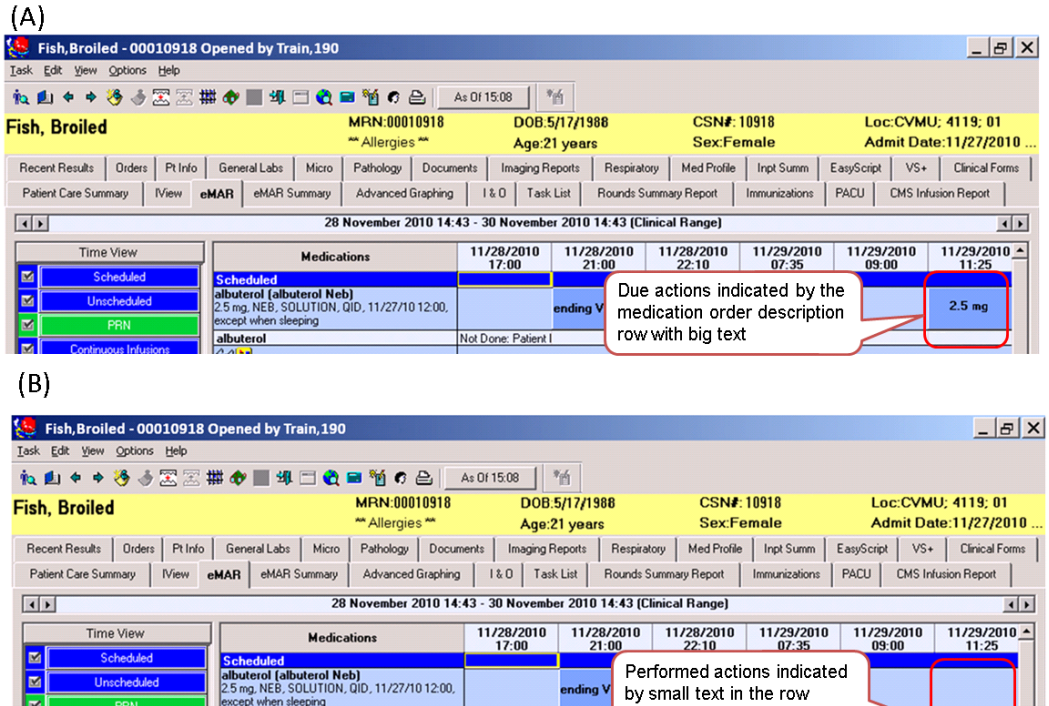

Fig. 1 Screenshots of (A) before charting medication administration and (B) after charting medication administration.

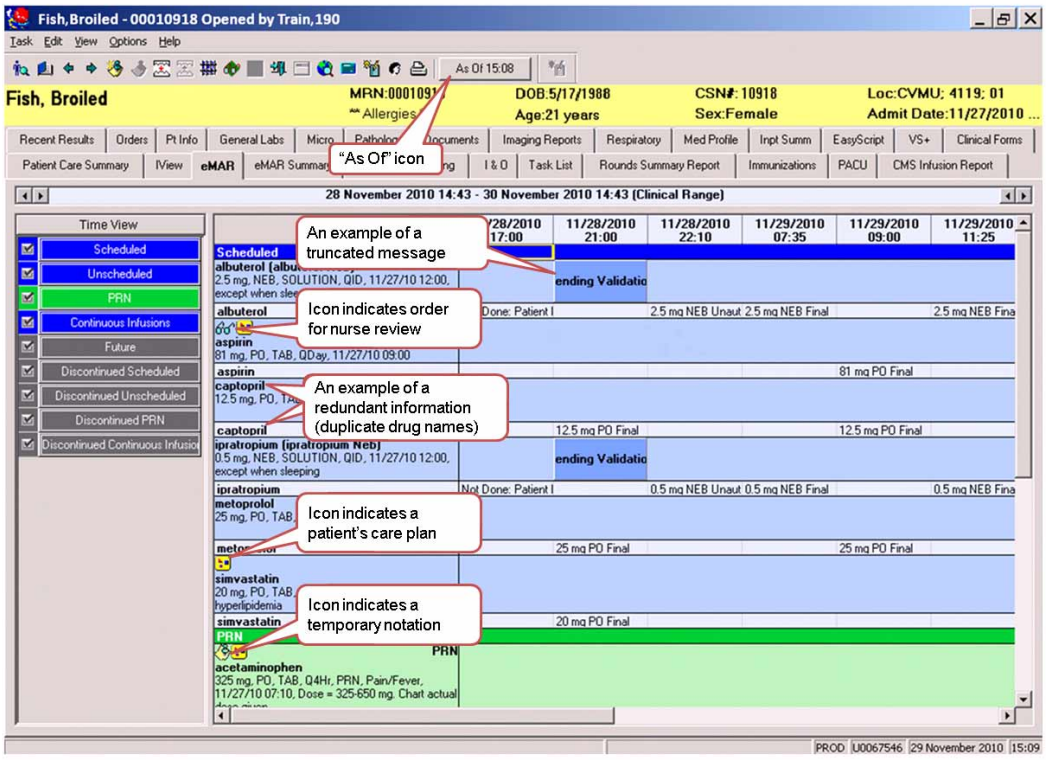

Fig. 2 A screenshot of the substantial white space in eMAR, non-intuitive icons, truncated messages, redundant information, and "As Of" icon.

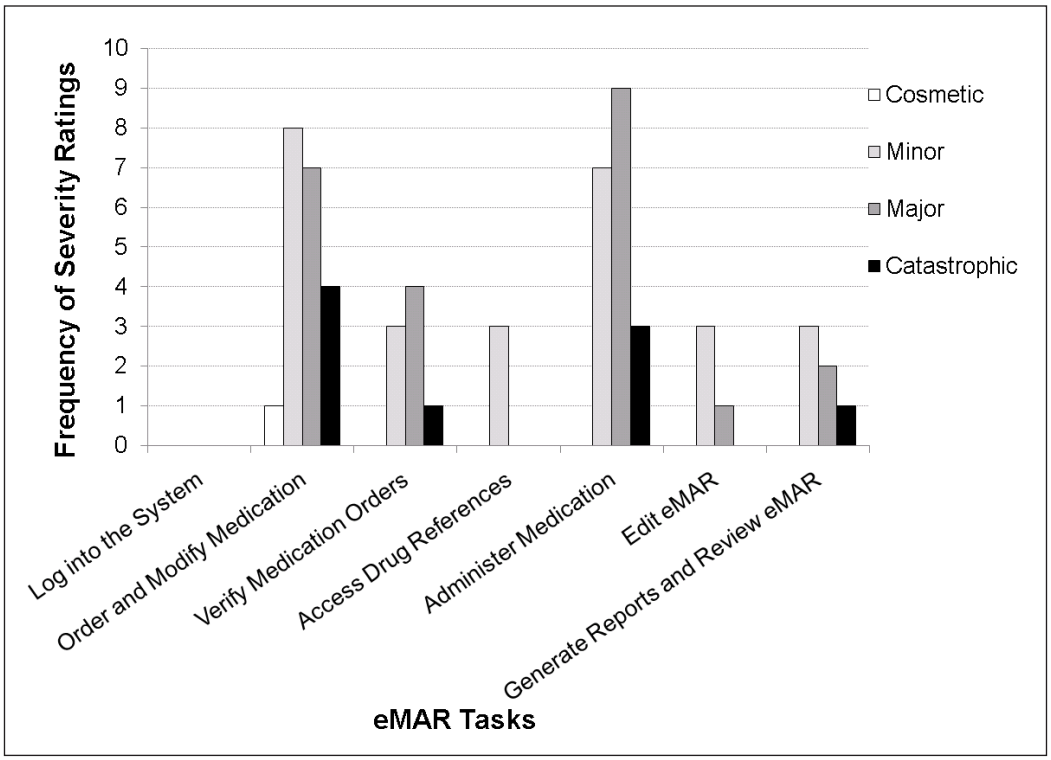

Fig. 3 Severity rating by eMAR tasks (N = 60).

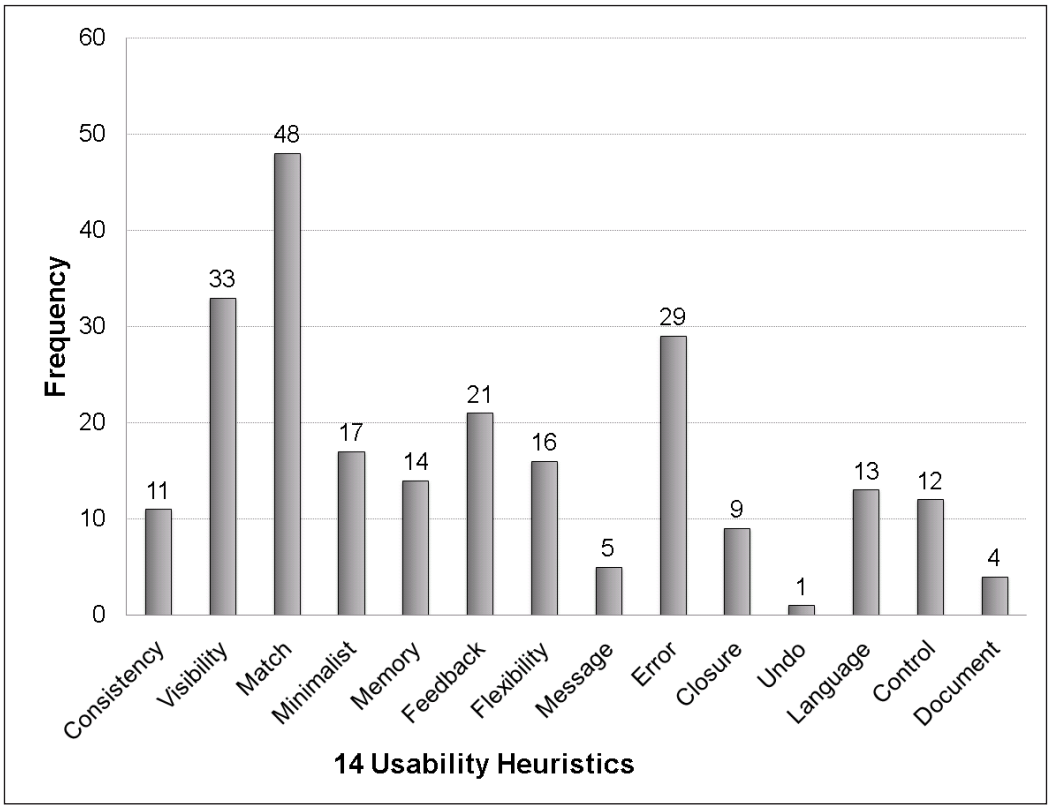

Fig. 4 Frequency of usability heuristics violated (N = 233).

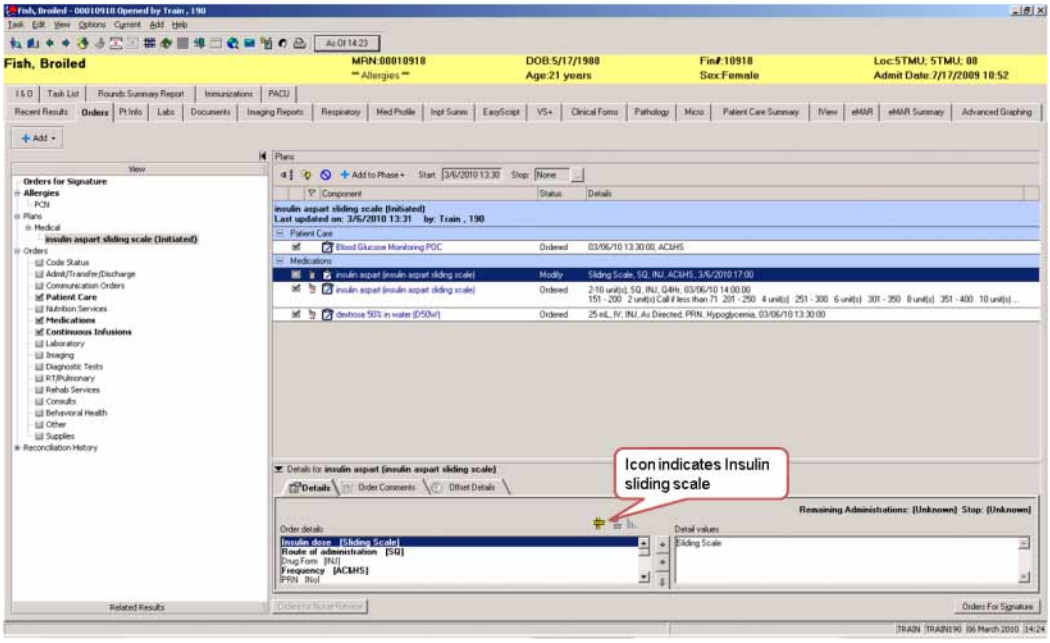

Fig. 5 A screenshot showing the small, non-intuitive icon for the insulin sliding scale.

Table 1 Fourteen usability heuristics (adapted from Zhang et al.[42])

Heuristic	Criteria
Consistency	There should be no confusion or uncertainty about the meanings of different words, situations, or actions by users. Standards and conventions should be applied in product design.
Visibility	Appropriate feedback and display of information should be used to inform users of what is going on in the system.
Match	Match between system and world. The model should match the image of the system perceived by users.
Minimalist	Less is more. The system should contain only pertinent information and extraneous information should be avoided to prevent distraction and a slow-down.
Memory	Minimize memory load. The system should not require the user to memorize a lot of information in order to carry out tasks. Capacity to carry out main tasks is affected by memory load.
Feedback	Informative feedback. There should be prompt and informative feedback given for users' actions in the system.
Flexibility	Flexibility and efficiency. The system should allow users to customize and utilize shortcuts in order to accelerate their performance.
Message	Good error messages. Error messages should be clear and informative, such that users' can easily interpret, learn, and recover from the errors.
Error	Prevent error. The system should have measures that prevent error from happening.
Closure	Clear closure. Users' should be able to know when a task is completed.
Undo	Reversible actions. The system should allow users' to recover from errors and prevent serious errors.
Language	Use users' language. Language that is understandable by the intended user should always be utilized.
Control	User in control. Users' should feel that they are in control of the system rather than controlled by the system.
Document	Help and documentation. The system should provide help for users' when needed.

Table 2 Severity rating scale. (adapted from Zhang et al.[42])

Score	Rating Scale	Description
0	No problem	Not a usability problem.
1	Cosmetic problem only	Does not need fixing unless extra time is available.
2	Minor usability problem	Fixing given low priority. Quantified by no anticipated impact on patient safety. May require workaround resulting in minor workflow hindrance.
3	Major usability problem	High priority to fix. Qualified by impact on patient safety and nurse productivity with difficult workarounds required.
4	Usability catastrophe	Imperative to fix. Quantified by potential for severe patient safety and productivity issues. Significantly hinders workflow.

Table 3 eMAR heuristic evaluation summary.

eMAR Task	Usability Problems	Heuristics Violated	Average Number of Heuristics Violated per Usability Problems	Average Severity Rating
Log into the system	0	0	–	–
Order and modify medication	20	83	4.2	2.7
Verify medication orders	8	28	3.5	2.8
Access drug references	3	9	3.0	2.0
Administer medication	19	73	3.8	2.8
Edit eMAR	4	11	2.8	2.3
Generate reports and review eMAR	6	29	4.8	2.7
Total	**60**	**233**	**4.2**	**2.7**

Table 4 List of identified usability problems, severity rating, and heuristics violated.

eMAR Task	Usability Problem Description	Heuristics Violated	Severity Rating
Order and Modify Medication	Lacks spatial consistency, e.g., multiple screens to complete order, small print, difficult to read, must scroll to view entire list of order details.	• Consistency • Visibility • Match • Minimalist • Error	3
	No feedback to indicate when orders have been transferred to "Plan" screen.	• Visibility • Match • Feedback	2
	Process to create or modify an order is confusing and inconsistent across sections of the order screen, e.g., the orders, "Order Detail" and "Detail Values" fields are in separate sections of the screen.	• Consistency • Visibility • Match • Minimalist • Memory • Feedback • Error • Closure	3
	Headings such as "Order Detail" and "Detail Values" are meaningless to clinicians.	• Consistency • Match • Memory • Language	2
	Unclear what the bold items in the "Order Detail" field mean.	• Visibility • Match • Language	2
	Unclear how to add an order value, e.g., two separate sections of the screen ("Order" and "Order Detail") must be selected first before the "Detail Value" can be entered.	• Consistency • Visibility • Match • Flexibility	3
	Icons/Navigation tools do not adhere to known design standards (e.g., consistent color and format across application) and are not easily visible, e.g., the insulin sliding scale icon is not intuitive, miniscule, and difficult to locate.	• Consistency • Visibility • Match • Memory • Language	3

Table 4 (Continued)

eMAR Task	Usability Problem Description	Heuristics Violated	Severity Rating
Order and Modify Medication	No feedback when searching for orders not in the database, e.g., PCA, the result window appears blank, rather than displaying a message that a particular order was not found.	• Visibility • Feedback • Closure	3
	Labels/definitions are missing when users hover over icons.	• Visibility • Match • Memory • Feedback • Language • Document	2
	Screen space is too small to display pertinent "Frequency" and "Detail" fields (must scroll to find data or complete order detail).	• Visibility • Match • Control	2
	Order details for power plans are inaccessible (unable to modify power plans).	• Visibility • Match • Flexibility • Control	3
	Multiple non-intuitive steps required to enter insulin sliding scale, e.g., enter order, click "Insulin dose" under "Order Detail", click insulin icon, and enter scale values manually.	• Visibility • Match • Flexibility • Error • Closure • Document	4
	Pop-up screens that appear during the ordering process obscure the newly created order. Users must move pop-up screens to view new order in progress.	• Visibility • Match • Message • Closure	2
	Unnecessary redundancy in patient information, such as the duplicate screen banner.	• Minimalist	2
	Unclear error messages.	• Message • Error • Language • Feedback	2
	Allows multiple orders of the same medication without an alert (by site choice).	• Match • Feedback • Error	3
	Inconsistent labels, e.g., drug information is called "Reference Information" in the Order screen, but it is called "Reference Manual" in the eMAR screen.	• Consistency • Match • Language	1
	"Order Detail" includes entire list of possible routes rather than being tailored to the medication; potentially incorrect routes can be ordered.	• Visibility • Match • Minimalist • Flexibility • Error • Control	4
	Users must sign in two places to activate orders. No notification if one signature is missing. Order appears to be active without the second signature.	• Visibility • Match • Feedback • Error • Closure	4

Table 4 (Continued)

eMAR Task	Usability Problem Description	Heuristics Violated	Severity Rating
Order and Modify Medication	The orders screen must be manually updated by clicking "As Of" icon (see Figure 2).	• Match • Memory • Error	4
Verify Medication Orders	Medications may be administered without order verification from pharmacy or nurse (by site choice).	• Visibility • Match • Feedback • Error	3
	Unverified orders in the eMAR are indicated by a non-intuitive icon (eye glasses).	• Visibility • Match • Language	3
	No way to see a list of unverified orders unless nurses navigate to a separate application called "PAL".	• Visibility • Match • Feedback • Error • Closure	3
	Inconsistent terminology, "Orders for Nurse Review" is actually order verification.	• Consistency • Match • Language	2
	Have to navigate to a separate application called "PAL" to find who verified the order.	• Visibility • Match • Memory	2
	Order to be verified difficult to read, e.g., route, dose, administration time in small print and listed together rather than in distinct columns.	• Visibility • Match • Flexibility • Error	3
	Drug name listed twice, two separate lines and different color.	• Consistency • Minimalist	2
	Unverified orders can be missed using the "PAL" screen view that nurses commonly use to view orders.	• Match • Minimalist • Memory • Error	4
Access Drug References	No actual picture of medication on "Drug Reference" to prevent medication errors.	• Visibility • Match • Error	2
	Data dense screen; lacks progressive disclosure for levels of detail.	• Visibility • Minimalist • Flexibility • Control	2
	Lacks style guide (consistency in color and font).	• Consistency • Memory	2
Administer Medication	Redundant information crowds the screen and compromises readability, e.g., duplicate patient banner and duplicate drug names (see Figure 2).	• Consistency • Visibility • Minimalist	3
	When administration schedule is altered, system does not automatically prompt to reschedule next dose, or require user to chart reason for alteration in schedule.	• Feedback • Error • Closure	3

Table 4 (Continued)

eMAR Task	Usability Problem Description	Heuristics Violated	Severity Rating
Administer Medication	eMAR is not integrated with pertinent applications such as labs or vital signs.	• Visibility • Match • Memory • Feedback • Error	3
	Icons are non-intuitive, e.g., yellow square with dots (see Figure 2).	• Match • Memory • Language	2
	Labels/definitions are missing when users hover over icons.	• Match • Feedback • Message • Language • Document	2
	eMAR lacks capability to record name of second RN verifying high alert medications.	• Match • Error • Control	3
	Unclear definition of prompts such as "Pending".	• Match • Feedback • Language	2
	Finding missed or overdue medications requires scrolling vertically and horizontally with the potential to easily miss medications and/or create errors.	• Visibility • Match • Minimalist • Flexibility • Error	3
	Cumbersome process to chart medication if not given because of patient absence. Requires full "Unchart".	• Visibility • Match • Minimalist • Memory • Flexibility • Undo	3
	No alert when vital signs are outside of safe range for applicable medications, e.g., Digoxin administration during bradycardic episode.	• Feedback • Error • Match	3
	List of medication administration routes is long and easily allows inappropriate route to be selected e.g., topical, by mouth, sublingual can be charted as IM. It should be tailored to specific medication.	• Consistency • Visibility • Match • Minimalist • Error	4
	Unclear error messages.	• Feedback • Message • Language • Error	2
	Lacks reminder if the medication order expires, e.g., if a medication has been ordered for only 6 doses.	• Match • Feedback • Closure • Error	4

Table 4 (Continued)

eMAR Task	Usability Problem Description	Heuristics Violated	Severity Rating
Administer Medication	Allows users to chart repeated administrations of PRN medications outside of scheduled dosing without an alert (by site choice).	• Feedback • Error	3
	Modifying times for medication administration cumbersome to enter.	• Match • Minimalist • Memory • Flexibility	2
	No option to document start and stop times for critical medications in eMAR, e.g., chemotherapy drugs.	• Match • Control	3
	No pain scale rating within eMAR system on PRN or scheduled analgesics. Must navigate to vital signs application.	• Visibility • Match • Minimalist • Memory • Closure	2
	Difficult to discern medication actions at a glance e.g., small text, actions appear in a different location, no highlighting or color coding, entire text and box disappears for medication due.	• Visibility • Match • Minimalist • Memory • Error	4
	There is no free text option for "Site", e.g., nurses select "Body" and use the comment box for specific information.	• Match • Flexibility • Control	2
Edit eMAR	No free text capability to document reason for changing medication time if the medication has not been given.	• Match • Flexibility • Control	2
	If date and time are entered incorrectly when rescheduling no correct format is provided.	• Feedback • Document • Error	2
	If scheduled dose is altered no prompt is issued by system.	• Feedback • Error	2
	Insulin order and the sliding scale text runs together. Difficult to discern the correct dosage. Insulin sliding scale icon difficult to locate and not intuitive.	• Visibility • Match • Minimalist	3
Generate Reports and Review eMAR	Data dense screen; lacks progressive disclosure levels of detail.	• Visibility • Match • Minimalist • Flexibility • Error	2
	Difficult to assess at a glance which medications were charted. Potential to overlook missed medications.	• Visibility • Match • Minimalist • Flexibility • Error • Control	3

Table 4 (Continued)

eMAR Task	Usability Problem Description	Heuristics Violated	Severity Rating
Generate Reports and Review eMAR	eMAR summary lacks detailed information for nurses, e.g., the dose given is not shown.	• Visibility • Match • Feedback • Flexibility • Error • Control	3
	No capability to filter eMAR summary for specific medications for individual patients or across patients, e.g., missed doses, PRN medications.	• Visibility • Match • Flexibility • Error • Control	4
	The term "Overdue Pending Doses" is unclear.	• Match • Feedback • Message • Language	2
	Lacks basic formats for printing, uses Excel printing format including white space, e.g., one page could list only one drug.	• Match • Flexibility • Control	2

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