

Usability and Safety in Electronic Medical Records Interface Design: A Review of Recent Literature and Guideline Formulation

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Objective: The objectives of this study were to (a) review electronic medical record (EMR) and related electronic health record (EHR) interface usability issues, (b) review how EMRs have been evaluated with safety analysis techniques along with any hazard recognition, and (c) formulate design guidelines and a concept for enhanced EMR interfaces with a focus on diagnosis and documentation processes.

Background: A major impact of information technology in health care has been the introduction of EMRs. Although numerous studies indicate use of EMRs to increase health care quality, there remain concerns with usability issues and safety.

Method: A literature search was conducted using Compendex, PubMed, CINAHL, and Web of Science databases to find EMR research published since 2000. Inclusion criteria included relevant English-language papers with subsets of keywords and any studies (manually) identified with a focus on EMR usability.

Results: Fifty studies met the inclusion criteria. Results revealed EMR and EHR usability problems to include violations of natural dialog, control consistency, effective use of language, effective information presentation, and customization principles as well as a lack of error prevention, minimization of cognitive load, and feedback. Studies focusing on EMR system safety made no objective assessments and applied only inductive reasoning methods for hazard recognition.

Conclusion: On the basis of the identified usability problems and structure of safety analysis techniques, we provide EMR design guidelines and a design concept focused on the diagnosis process and documentation.

Application: The design guidelines and new interface concept can be used for prototyping and testing enhanced EMRs.

Keywords: electronic medical records, electronic health records, interface design, usability, systems safety, literature review

INTRODUCTION

The introduction of information technology in the health care industry has led to a number of changes. One of the most impactful has been the replacement of paper-based medical records with electronic medical records (EMRs). The Office of the National Coordinator for Health Information Technology (ONC) defines an EMR as a digital version of paper charts in a clinician's office that contain the medical and treatment history of patients in one practice (Garrett & Seidman, 2011). However, the information contained in the EMR does not travel easily out of the practice. The terms *EMR* and *electronic health record* (EHR) are sometimes used interchangeably. However, these terms actually refer to different aspects. The ONC differentiates between the definitions of EMR and EHR by saying that EHRs are designed to reach out beyond the health organization that originally collects and compiles the information, and they focus on the total health of the patient. In addition, according to Garets and Davis (2006), an EMR is a legal record created in hospitals and ambulatory environments and is the source of data for the EHR. An EHR is a broader technology that provides the capability to share medical information among health care stakeholders. It also supports the flow of patient information through various modalities of care engaged by the individual.

The focus of the present review was to identify usability issues and use of safety analysis techniques related to EMRs; however, we also reviewed specific studies of EHRs, as the usability or safety problems identified were also relevant to EMRs. Optimally, an EMR should contain the most up-to-date information on a patient, it should be capable of supporting documentation of patient states as well as physician condition

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diagnosis, and it should be equipped with computerized physician order entry (CPOE) capability. The majority of the literature reviewed in this paper focused on physician use of EMRs and their requirements for task performance; consequently, the design guidelines that we have formulated, as well as a concept for enhanced EMR interface design, focus on physician diagnosis and documentation processes. There are many other functions that EMRs support, including patient appointment scheduling, billing, and so on. These functions are typically used by other health care professionals, including secretaries, nurses, and pharmacists. Consideration of EMR interface design for such functions also requires a focused review of literature and analysis of context of use to identify specific user task requirements and guidelines.

Edmund, Ramaiah, and Gulla (2009) observed that the use of EMRs has led to some improvements in health care, such as increased information exchange among providers. Moreover, Kalogriopoulos, Baran, Nimunkar, and Webster (2009); Chin and Sakuda (2012); Chaudhry et al. (2006); and Bates and Gawande (2003) all identified implementation of EMRs to have resulted in increased quality of health care systems, decreased errors by health care workers (HCWs), and savings in time and money. In addition, McGuire et al. (2013) found that EMRs, if designed and implemented properly, may promote safety culture in primary care providers. They observed EMR implementation to lead to improvements in HCW attitudes toward safety, perceived job satisfaction, perception of executive and local management, perceived safety climate, teamwork climate, and working condition.

Although many researchers have concentrated on the benefits of implementing EMRs, there remain concerns with the technology's potential for increasing likelihood of new types of errors and creating safety issues that could lead to patient harm (Ammenwerth & Shaw, 2004). Several case studies have been published on patient overdose as a result of flaws in EMR human-system interface design and errors in the use of CPOE systems (e.g., Caudill-Slosberg & Weeks 2005; Weber-Jahnke & Mason-Blakley 2012). In addition, some researchers have observed safety issues or hazards to be associated with certain EMR implementations

(e.g., Caudill-Slosberg & Weeks 2005; Kumar and Aldrich 2010). Ammenwerth and Shaw (2004) observed that although EMRs may be used frequently in health care, they may cause unintended safety risks and such risks need to be systematically identified and addressed through effective interface and system design. The frequency of user and patient risk exposure, as well as the severity of outcomes, may be reduced through enhanced EMR design guidelines and concepts. Related to these usability and safety issues, Jha et al. (2009) found that the use of EMRs in hospitals and clinics is not as great as the adoption of information technology for similar purposes (i.e., process documentation and decision making) as in other industries. One of the main causes of the low usage rate in health care might be poor usability and efficiency of system designs.

On this basis, we reviewed research regarding usability issues in EMR and related EHR interface design as well as the use of safety engineering techniques to identify hazards associated with systems. The identification of EMR usability issues and recognition of associated hazards for patients provides a problem basis for formulation of design recommendations or controls to mitigate user performance issues and potential patient safety hazards. Although some prior reviews have been conducted on health information technology (e.g., Yen & Bakken, 2012), such reviews have been broad in scope and EHRs were only one of a number of systems covered. Furthermore, the Yen and Bakken (2012) review focused on identification of usability study methodologies with application to health information technology and not usability issues in existing designs of EMRs. Some other technical reports have been published regarding the usability and safety of EHRs, such as Lowry et al. (2012). This report briefly addresses usability principles in information technology design but focuses on procedures for design evaluation and user performance testing with EHRs. With this literature in mind, we further perceived a need for an accounting of current EMR and EHR usability and safety as bases for enhanced system design approaches.

Consequently, the objectives of the present study were to (a) identify EMR and EHR interface usability issues revealed by prior research,

TABLE 1: Literature Search Results on Electronic Medical Records by Engine and Keywords

Engine	Keyword <i>Electronic Medical Record</i> +							
	Safety		Interface Design		Errors		Usability	
	Initial	Refined	Initial	Refined	Initial	Refined	Initial	Refined
CINAHL	243	2	49	4	75	1	35	2
Compendex	263	2	377	2	928	3	181	10
PubMed	1,186	4	219	5	298	1	258	9
Web of Science	726	2	140	8	535	8	149	8

(b) identify how EMRs have been evaluated through use of safety analysis techniques along with recognition of any hazards, and (c) formulate a set of design guidelines as well as a design concept for enhanced EMR interfaces with a focus on diagnosis and documentation processes.

METHOD

A literature search was conducted using Compendex, PubMed, CINAHL, and Web of Science databases in order to find relevant research published since 2000. (It is important to note that all of these indices, save PubMed, allow for specification of exact date ranges for searches. PubMed supports searches on the previous 10 years of literature.) Manual searches were also performed of lists of references (largely from highly cited articles) concerning usability issues in EMR and EHR design. Search terminology submitted to the databases included *electronic medical records* and *electronic health records* combined with *interface design*, *usability*, *safety*, and *errors*. Inclusion criteria for the literature review included relevant English-language papers with subsets of the keywords as well as any research studies (manually) identified with a focus on EMR and EHR usability. (Articles appearing in databases without abstracts were excluded.) The initial hit counts were obtained in 2014. Although these counts were high, we reviewed for relevance the title (and often the abstract) of each and every hit obtained through the databases. Subsequently, the abstracts of all related papers identified based on the defined search strategy were read and assessed for relevance. Full texts

of articles considered relevant to the research objectives were obtained and reviewed.

Details on the initial numbers of articles found in each database by using the identified search terms are presented in Table 1 and Table 2. The tables also present the numbers of abstracts meeting the inclusion criteria and articles considered relevant for further review. The label *initial* refers to the count of articles found on the first search with an engine. The label *refined* refers to the count of articles after application of the inclusion criteria.

RESULTS

In total, 50 unique studies were found to meet the inclusion criteria after accounting for overlap of hits across search engines. These studies were subsequently reviewed by three expert ergonomists in order to confirm relevance to the present research and to summarize any EMR and EHR usability and safety findings. An annotated bibliography was developed with a structured format, including the following subsections: (a) citation information, (b) study objective, (c) research methodology, (d) significant results, and (e) conclusions. On the basis of the bibliography, studies were categorized into one of two major classifications: (a) usability problems related to EMR and EHR interface design or (b) application of safety techniques for EMR hazard identification and control. Within these classifications, several subclassifications were identified based on usability problem types or types of system safety analysis. Subcategories within usability problems were based on the usability principles that Molich and Nielsen (1990) developed as a part of their heuristic

TABLE 2: Literature Search Results on Electronic Health Records by Engine and Keywords

Engine	Keyword <i>Electronic Health Record</i> +							
	Safety		Interface Design		Errors		Usability	
	Initial	Refined	Initial	Refined	Initial	Refined	Initial	Refined
CINAHL	2,671	4	48	4	865	2	235	1
Compendex	410	3	259	5	374	6	180	8
PubMed	1,466	7	233	11	323	4	291	12
Web of Science	995	5	176	8	651	13	249	8

analysis methodology for usability evaluation of interactive systems. Table 3 presents the list of studies on EMR and EHR usability problems, and Table 4 shows those studies applying safety analysis techniques to EMRs. Here, it is important to note that some of the EMR safety studies did not make application of inductive or deductive systems safety analysis techniques for hazard recognition and control, and therefore, those studies were not categorized in Table 4. In general, there were more studies concerned with usability issues (46) than with associated safety hazards (6).

REVIEW FINDINGS ON EMR AND EHR USABILITY

Usability is a general term concerning the effectiveness, efficiency, and satisfaction with which users achieve goals with an interface (International Organization for Standardization, 1998). There are many principles of usability identified in the literature (e.g., Dix, Finlay, Abowd, & Bealle, 2004), including interface learnability, flexibility, robustness in functionality, capability for error recovery, and so on. On the basis of field research in five health clinics, Hollin, Griffin, and Kachnowski (2012) identified eight aspects of usability relevant to EMR design. These aspects include the nature of user–software interaction, learnability of software, facilitation of user cognition, degree of user control and software flexibility, degree of matching of system structure and content to that of real-world tasks, design of graphics, system navigation, and editing capability and consistency among interfaces. Hollin et al. used an online software usability questionnaire to conduct qualitative and quantitative analyses of

EMR use to identify relevant usability issues. They generally observed that graphical interface design improved EMR usability but that changes still need to be made in terms of certain system capabilities. (The Hollin et al. study is not listed in Table 3 because they did not identify violations of usability principles; in fact, their fieldwork indicated positive user attitudes toward specific aspects of usability in EMR design. See Naturalness subsection.)

In addition, in a review of human–computer interaction issues with EHRs, Clarke et al. (2013) identified four common problems, including poor display of information, cognitive overload, navigation issues, and workflow issues. They found that these issues frustrated physicians, caused errors, compromised patient–physician interaction, and ultimately limited user acceptance of EHRs. Some of the recommendations they provided to address these issues included applying human-centered design, capturing relevant information that physicians need, simplifying information presentation, and designing systems to use as few clicks as possible. Viitanen, Kuusisto, and Nykänen (2011) identified another classification of usability issues related to electronic nursing record systems. They conducted an empirical study on nurses in Finland and used contextual inquiry as well as expert review of usability heuristics. Results revealed problems in five usability attributes, including fluency of reporting practices, accuracy of documentation, learnability, exploitation of documented information, and support for collaborative care. Some specific problems that users had included complicated interaction sequences, unnecessary interaction, not following

TABLE 3: Relevant Studies Focused on EMR and EHR Usability

Reference	Natural-ness	Consistency	Prevent Errors	Minimize Cognitive Overload	Efficient Interaction	Forgiveness and Feedback	Effective Language Use	Effective Information Presentation	Customizability/Flexibility
1. Rodriguez, Borges, Murillo, Ortiz, & Sands (2002)				*					
2. Weir et al. (2003)		*	*					*	
3. Caudill-Slosberg & Weeks (2005)			*					*	
4. Rose et al. (2005)				*				*	*
5. Reuss, Naef, Keller, & Norrie (2007)									*
6. Thielke, Hammond, & Helbig (2007)			*						
7. Zheng, Padman, & Johnson (2007)					*				
8. Edwards, Moloney, Jacko, & Sainfort (2008)		*	*		*			*	
9. Graham et al. (2008)						*			
10. Jaspers, Peute, Lauteslager, & Bakker (2008)					*			*	
11. Tasa, Ozcan, Yantac, & Unluer (2008)								*	
12. Wu, Orr, Chignell, & Straus (2008)									*
13. Indrani, Wyatt, & Li (2009)					*				
14. Nakano & Tohyama (2009)		*							
15. O'Donnell et al. (2009)			*						
16. Shachak, Hadas-Dayagi, Ziv, & Reis (2009)			*						
17. Craig & Farrell (2010)					*				
18. Saitwal, Feng, Wajji, Patel, & Zhang (2010)	*				*				
19. Schumacher, Berkowitz, Abramson, & Liebovitz (2010)	*		*	*	*				
20. Ahmed, Chandra, Herasevich, Gajic, & Pickering (2011)				*					
21. Chen & Akay (2011)									*
22. Hagstedt, Rudebeck, & Petersson (2011)			*		*				
23. Harrington, Kennerly, & Johnson (2011)	*								
24. Harrington, Wood, et al. (2011)				*					
25. Harrington, Porch, Acosta, & Wilkens (2011)	*								
26. Ventura et al. (2011)						*			

(continued)

TABLE 3: (continued)

Reference	Natural-ness	Consistency	Prevent Errors	Minimize Cognitive Overload	Efficient Interaction	Forgiveness and Feedback	Effective Language Use	Information Presentation	Customizability/Flexibility
27. Wilcox, Chen, & Hripcsak (2011)			*					*	*
28. Zhang & Walji (2011)	*	*	*	*	*	*	*	*	*
29. Zopf-Herling (2011)	*			*			*		
30. Abramson et al. (2012)			*	*	*				
31. Hyman, Laire, Redmond, & Kaplan (2012)			*						
32. Kuqi, Eveleigh, Holzer, & Sarkani (2012)				*					
33. Méndez & Ren (2012)			*						
34. Pereira et al. (2012)	*					*			*
35. Sittig & Singh (2012)				*			*		*
36. Weber-Jahnke & Mason-Blakley (2012)				*		*	*		*
37. Bouamrane & Mair (2013)				*	*				
38. Bowman (2013)			*						
39. Clarke et al. (2013)	*			*	*			*	*
40. Rogers, Sockolow, Bowles, Hand, & George (2013)	*		*	*	*	*		*	*
41. Suebnukarn et al. (2013)				*				*	*
42. Walji et al. (2013)								*	*
43. Lowry et al. (2014)			*		*			*	*
44. Vatnøy, Vabo, & Fossum (2014)					*		*	*	*
45. Weis and Levy (2014)			*		*		*	*	*
46. Yamamoto (2014)			*					*	*

Note. EMR = electronic medical record; EHR = electronic health record.

TABLE 4: Relevant Studies Focused on EMR and EHR Safety

Reference	Safety Technique	
	Inductive Reasoning	Deductive Reasoning
1. Singh, Servoss, Kalsman, Fox, & Singh (2004)	P-FMEA (preliminary failure modes and effects analysis)	N/A
2. Win et al. (2004)	FMEA	N/A
3. Caudill-Slosberg & Weeks (2005)	Cause and effect/fishbone analysis	N/A
4. Belden, Grayson, & Barnes (2009)	FMEA, topological risk analysis	N/A
5. Kumar & Aldrich (2010)	Fishbone analysis	N/A
6. Weber-Jahnke & Mason-Blakley (2012)	STAMP (systems-theoretic accident model and process)	N/A

Note. EMR = electronic medical record; EHR = electronic health record.

nurses' mental models, lack of automatic transfer of information, and difficulty in searching for information.

Our review of EMR and EHR usability studies revealed nine major types of problems. All of these problems except lack of customization represent violations of the usability principles Molich and Nielsen (1990) developed as a part of their heuristic analysis methodology for usability evaluation of interactive systems. These usability principles include simple and natural dialogue, speaking the user's language, minimization of user's memory load, consistency in design, providing feedback, providing clearly marked exits, providing shortcuts, providing good error messages, and error prevention. Related to Molich and Nielsen's study, some prior reviews of EMR studies have also been conducted to identify usability issues in design (e.g., Belden, Grayson, & Barnes, 2009). The current review is similar to Belden et al.'s (2009) work in terms of the categories of usability issues identified, but Belden et al. did not focus on violations of usability principles in designs. In addition, the literature we cover is contemporary and completely different from the studies covered by Belden et al. The present review also provides an additional focus on safety implications of EMRs and some system safety analysis techniques that have been used to identify hazards in this domain. (This information will be discussed in the next subsection.)

Furthermore, Belden et al. (2009) did not identify any principle related to customization and/or

flexibility of EMRs. Although a lack of customization was one of the 14 usability principles that Zhang and Walji (2011) identified as an EMR issue, there are few studies that have focused on this issue. Consequently, the usability problems identified in this review include violations of natural dialog, control design consistency, error prevention, minimization of cognitive load, efficiency in interaction, forgiveness and feedback, efficient use of language, effective information presentation, and customizability principles. These usability principle violations are discussed in detail next.

Naturalness

All information in the display should appear in a natural order. *Naturalness* also refers to how familiar and easy an application is to use and to what extent it follows the "natural" workflow of the system. In the field study that Hollin, Griffin, and Kachnowski (2012) conducted, users indicated neutral-to-positive attitudes toward this aspect of EMR interfaces; however, authors of other studies have identified violations of naturalness in EMR interfaces. Harrington, Porch, Acosta, and Wilkens (2011) conducted an empirical study that used heuristic analysis to evaluate EMR designs in terms of 14 usability design principles. By monitoring staff nurses working with EMRs, they found that one of the most frequently violated usability principles was a lack of matching between user work flow in the real health care operations and using an EMR. They recommended improvements in EMR design based on the heuristic

analysis but did not specify methods by which to achieve new designs. Zopf-Herling (2011) conducted a comprehensive analysis of EMR usability by reviewing information displays that were shared by hospitals. On the basis of this empirical study, the author offered that interface design should support effective communication of data. The author suggested logically ordering interface content based on work flow and highlighting task-critical information. Zopf-Herling also offered that considering user characteristics in EMR interface design could promote usability and encourage more frequent use of EMRs.

Beyond the aforementioned work, authors of other studies have identified violations of naturalness as part of EMR or EHR usability evaluation. For example, Pereira et al. (2012) found that the principle was violated in one EHR form. They recommended that the position of interface buttons be changed in order to achieve the natural work flow of actual hospital tasks. In another study, Craig and Farrell (2010) identified information recording and navigation as the two tasks suffering from usability issues in EMR systems. Focusing on information entry, they said that EMR interface design should make entry processes as natural as possible for physicians. In order to address this issue, they designed a new interface that allowed users to enter data in a free-text format (vs. using templates or selecting terminology/labels). The expected outcome was reduced disruptions between clinicians and patients during consultations. In addition, Schumacher, Berkowitz, Abramson, and Liebovitz (2010) found physicians to perceive mismatches between EHR work flow and actual clinical processes. They concluded that EHRs should not hinder physician performance but should allow them to work "smarter" and faster by leveraging real task work flows in design.

In their review of EMR technology, Harrington, Kennerly, and Johnson (2011) assessed performance with three components of EMRs, including CPOE systems, clinical decision support systems (CDSS), and bar-coded medication administration systems. Based on several studies, they concluded that CPOE systems could be a new source for errors in EMR use that might lead to adverse patient consequences or even mortality. They attributed the potential for such

errors, in part, to poor EMR interface design. Some safety issues identified by Harrington, Kennerly, et al. included changes in work flow and task interruptions posed by EMRs. They suggested that effective planning and design of CPOE systems is critical for reducing unintended consequences. Finally, in a more recent study, Rogers, Sockolow, Bowles, Hand, and George (2013) identified violations of the naturalness principle as a part of a usability analysis of a nursing information system (NIS), which was one of the modules of an EHR system used in a hospital. In an empirical study of nurses in two hospitals, and application of a scenario-based evaluation technique (think-aloud) as well as usability heuristic evaluation, the authors found that NIS screen inputs did not match clinical practices. For example, the order of data entries was not based on the usual order during a physical exam. The researchers said this problem would lead to nurse frustration and reduced productivity.

Summary. All of the preceding reviewed studies focusing on violations or naturalness included the recommendation that EMR interfaces be designed to follow the natural work flow of health care systems. The primary objective of these recommendations is to reduce task interruptions for physicians and other HCWs.

Consistency

This principal basically means that knowing one part of an interface should be relevant for use of other parts. A particular system action should always be achievable by one particular user action (Molich & Nielson, 1990). More consistent systems also require less learning, which ultimately leads to fewer errors in task performance. Related to this definition of consistency, Dix et al.'s (2004) categorization also defined consistency as a subset of system learnability.

In our review, there were very few studies in which lack of consistency was identified as the main usability problem related to EMRs. Nakano and Tohyama (2009) evaluated an EMR system between 2005 and 2006 and focused on nonfunctional characteristics. Their results revealed a significant problem in lack of system design consistency, including colors, the meaning of colors, and

layout. They also identified a lack of unified operating procedures and lack of consistency from one screen to another, even within one EMR product. The authors mentioned some causes of inconsistency in the EMR system, including various situations occurring in the development process, local design rules, and requirements for specific additional functions. In order to prevent these errors, they provided recommendations in three major categories of unified design, unified operation, and improved operability. Some of their specific recommendations included using specific basic colors and unified layouts of forms, applying unified design to buttons that have similar functions, and designing entry areas based on emphasis and simplification principles. After formulating a design guideline, they were able to upgrade their EMR system and eliminate the inconsistency problems.

Edwards, Moloney, Jacko, and Sainfort (2008) also identified violation of the consistency principle in their usability evaluation of a commercial EHR in a pediatric hospital system. They used the heuristic walk-through method to evaluate the system in a case study. Users of the EHR system consisted of physicians, nurses, pharmacists, therapists, other clinicians, and support staff. Results showed that 15% of issues were related to consistency. For example, they found that the *close* button was not always in a consistent place. However, they provided some general recommendations to address usability issues, which included immediate changes in system configurations and training material, and sharing evaluation results with vendors in order to improve usability in future releases.

Some other authors mentioned a lack of consistency as part of other EMR design problems. For example, Weir et al. (2003) reported that inconsistent text format requirements (e.g., “mm/dd/yyyy”) was an issue leading to frequent data entry errors in EMR use. In addition, they suggested that since EMRs are typically reviewed by physicians using a “skimming” process, the interfaces should be designed in a consistent and familiar format in order to reduce learnability and increase speed of task performance. However, Hollin et al. (2012) found that users have neutral-to-positive attitudes toward consistency in EMR design.

Summary. Our review of literature indicated that very few authors identified the violations of consistency in EMR interface design. Some recommendations to address this issue included using basic colors and unified form layouts. However, according to the human-computer interaction literature, consistency is an important usability principle that should be considered in interactive systems interface design in order to reduce learnability and increase task efficiency.

Preventing Errors

Interactive system interfaces should be designed in a way that prevents errors from happening in the first place (Molich & Nielson, 1990). Schumacher et al. (2010) observed that EMR interfaces should anticipate the next steps of users and prevent potential mistakes in task performance. Related to this observation, Edwards et al. (2008) found that users may not know what to do in the next step. For example, there was a required data entry field for which users did not know the value to enter at a specific stage of system use. This situation resulted in data entry errors. To address the problem, the authors recommended changing the required field to a nonrequired field or instituting a policy on how the system should respond when the user is uncertain about a required value. Related to this problem, Rogers et al. (2013) mentioned that some functions of the NIS were unclear to nurses and they could not predict what would happen if they clicked them. To address this issue, Rogers et al. recommended that an NIS should support the ability for users to predict when memory of information would be required in EMR work and to provide prompts to cue data entry.

In our review of literature, there were several studies in which authors identified violations of the error prevention principle in providing copying and pasting (C/P) functions for data entry as part of the documentation process. For example, Weir et al. (2003) analyzed notes made in EMRs as part of inpatient admissions and observed that C/P functions, object insertion, and electronic signatures were the main causes of data entry errors. To solve these problems and prevent future errors, they recommended enhancements to EMR design, including structured C/P functions and reducing

the use of templates for data entry. Regarding C/P function use, Thielke, Hammond, and Helbig (2007) explored the prevalence of use in EMRs and the effect on medical errors by using an automated text categorization algorithm. They conducted an analytical study of patient records and found C/P of exam results to increase errors in records. The authors recommended altogether removing C/P functions from EMR software or presenting copied and noncopied texts in different colors for user awareness.

Related to this finding, O'Donnell et al. (2009) also noted inconsistencies and outdated information as a result of C/P function use in patient notes. They conducted a cross-sectional survey of resident and faculty physicians in two medical centers. Although most of the physicians identified errors from using C/P functions, the majority of them wanted to continue to use the functions. To resolve this issue, some users agreed with recommendations, such as having C/P text more identifiable (highlighted or italicized), adding alerts to notify users when notes are similar, and placing restrictions on C/P of parts of notes (e.g., physical exam information). The use of C/P functions resulting in EMR content errors was also one of the interface design problems identified by Caudill-Slosberg and Weeks (2005). They also said that ensuring the availability of readable documents as well as elimination of C/P functions would reduce the distribution of inaccurate data and improve overall patient safety.

In a more recent study, Weis and Levy (2014) identified benefits and risks of content-importing technologies (CIT), such as C/P functions in EHRs. Despite CIT advantages, such as saving time, these technologies may cause risks that compromise patient safety. In their review of literature, Weis and Levy found CIT tools to lead to inconsistency and repetition of expired information and to create difficulties for users in identifying new information. To address these problems and prevent errors, the authors summarized controls from the literature, including copying information from one record to another, copying chief complaints, reviewing systems and physical examination information, copying entire sections of documents and reports, copying subjective data, and so on. They also provided a list of "best

practices" for EHR interface design. They recommended clearly identifying all copied information and including attributions to sources of information (e.g., date, time, and original author) in copied text or data.

Hyman, Laire, Redmond, and Kaplan (2012) identified errors in placement of orders in patient EMRs. They observed that orders were often made for the wrong patient or the wrong order was made for a patient. In order to address this problem, they made changes to a current EMR interface used in a large hospital, including an order verification dialog with a patient photograph. This dialog was presented directly before final electronic signature of orders. They compared the number of reported incidents in care between the existing and new systems and found that order verification significantly reduced the frequency of unintended documentation in patient EMRs. As with orders being incorrectly filed for patients, Wilcox, Chen, and Hripcsak (2011) identified "patient-note mismatch" as a common type of EMR data entry error. They observed that documents were often added to EMRs without confirmation of patient names and numbers and so on. They designed a new interface, adding a pop-up window to show patient identification before confirmation of a new record submission. In this way, the interface interrupted user action and required review of patient identification before a system upload. By comparing the rate of patient-note mismatches before and after the new intervention, they found that the error reduction rate was significant. The authors also observed the interface to make correct patient information more accessible to the user.

Shachak, Hadas-Dayagi, Ziv, and Reis (2009) also observed that EMR use can lead to additional medical errors, such as patient-note mismatch and typos. By conducting a cognitive task analysis using semistructured interviews, as well as field observations of primary care physicians, they found system automaticity to be the main factor that could lead to errors. Although their findings indicated a fine balance between the benefits and risks of EMR use, on the negative side, they found that users accidentally added information to the wrong patient's chart and selected wrong items from scroll-down lists

located above or below desired items. They also mentioned that when a list of patient names appeared by typing part of a name, physicians unintentionally selected the wrong name. The authors said that providing the capability for physicians to double-check prescriptions before signing them would serve as a safety mechanism in order to prevent such errors.

In a more recent study, Yamamoto (2014) conducted a survey of emergency department clinicians to assess the frequency of errors in patient notes in EMRs. They found that almost all clinicians made wrong patient EMR errors. In order to prevent these errors, they improved the information display by adding patient room numbers as watermarks in an EMR to display, with automatic and passive presentation. The author said that other methods to prevent patient-note mismatch, such as adding a confirmation page (e.g., Wilcox et al., 2011), would result in additional burden on clinicians. By displaying patient identifiers (such as room number) as watermarks, EMRs can prevent errors in a passive and more automated way.

Bowman (2013), in studying EHRs, observed that the complexity of interfaces contributes to user confusion and can cause errors. In her literature review, she identified the main causes of documentation errors to include C/P function use, use of templates, use of standard phrases and paragraphs, and automatic insertion. With respect to templates, Bowman observed that default data entries or prior field fill-ins led to identification of patient characteristics not representative of actual conditions. She also observed a lack of consistency in the design of data fields from one template to another, making detection of such default entry errors difficult for users. Beyond this finding, Bowman found that errors were often committed in template use as a result of adjacency of features and fields (i.e., confusing one field for another). The author provided recommendations to address these issues, such as monitoring the C/P process to ensure appropriate case content and implementing EHR content design standards and guidelines.

In the most recent study, Lowry et al. (2014) used two human factors modeling methods (process mapping and goal-means decomposition

diagrams) to improve EHR work flow integration in a larger clinical work flow. They considered using EHRs in different stages of the health care process (before the patient visit, during the visit, physician encounters, discharge, documentation). In the physician encounters and documentation stages of the process, physicians identified several usability issues regarding the use of EHRs. These issues included reduced user vigilance and increased error rates in use of many C/P functions, use of many templates for data entry, and inaccurate or difficult modification of diagnosis lists. The recommendations they suggested to address these problems included the use of color-coding methods to differentiate between copied and new information, providing the capability to label diagnoses with degrees-of-certainty information, and providing an *unknown* option to be selected from a diagnosis list.

Finally, Méndez and Ren (2012) found that, in general, reading and entering, for example, the vital signs of patients in an EMR is an error-prone and time consuming process. To address this issue, they proposed a prototype design of an electronic interface for the EMR system to automatically acquire and store data for other networked systems and databases. In our review of literature, there were other studies in which authors found violations of error prevention as part of their analysis. For example, Abramson et al. (2012) found that having a default value for dosage fields is error prone (especially for residents) because users often accept computer-generated doses without checking accuracy. In addition, Hagstedt, Rudebeck, and Petersson (2011) found that entering dosage values as free text may result in different interpretations at a pharmacy and ultimately increase the risk that a drug will be prescribed with the incorrect dosage. The authors said that an improvement in the dosage function of CPOEs is necessary.

Summary. Our review showed that one of the main issues that can lead to an increase in the number of errors in EMR use is C/P functions supported through interfaces. Some of the recommendations to address this problem include using structured C/P functions, color coding, or removing C/P functions from data entry and documentation processes. In addition, data entry

errors can be prevented by automatic data entry, adding verification dialogs or confirmation windows, and adding patient identifiers as watermarks in displays. We also found that EMR template design is considered critical to error prevention and that data field formatting needs to be consistent along with placement that prevents field misselection and elimination of use of default field values leading to patient state mischaracterization.

Minimizing Cognitive Load

Human short-term memory is limited in capacity (Miller, 1956). Interfaces should be designed in a way to reduce mental workload for users. Users should not have to memorize system information or database content (Molich & Neilsen, 1990). Information overload is a problem that occurs when perceptuo-cognitive capacity is exceeded by the quantity of data presented via an interface to the extent that errors occur in user information processing. Authors of several studies we reviewed identified violations of the minimization-of-cognitive-load principle in EMR interface design. For example, Kuqi, Eveleigh, Holzer, and Sarkani (2012) evaluated usability issues in EMR use and observed that poor design leads to user information overload. They proposed an approach to analyze dependencies among display information elements called the design structure matrix (DSM). They applied the DSM to a case study of ambulatory-based EMR system use and formulated interface design changes that minimized the number of steps to complete a task. The authors offered that the reduced task steps served to minimize user cognitive load. In another study, Ahmed, Chandra, Herasevich, Gajic, and Pickering (2011) identified user errors in EMR use due to information load and prototyped a new interface design that ranked data in terms of importance to a case and presented only highly ranked items on the screen for clinicians. The authors compared the new interface design to a standard design and measured information processing load using the NASA Task Load Index. Through this empirical study, Ahmed et al. found the new interface to reduce errors and task completion time and to facilitate efficient information navigation.

Through an analytical study, Harrington, Wood, et al. (2011) also identified information overload as a major EMR usability issue. They observed that EMRs typically include many objects on screen and that several may not be relevant to a user's work domain. They found that such designs create (cognitive) "overhead" for users and that the amount of domain-related content needs to be increased in interfaces. They also found that reductions in the overall information content and complexity of EMRs could promote task efficiency and ease of use. They redesigned a system interface with the goal of reducing user cognitive processing. The redesign reduced the number of screens and dialogs used to present similar information. They also modified "confusing" dialog boxes by limiting options to those considered "important" to case processing and by removing "unimportant" options. Widgets were, however, provided to guide users to hidden information. They also suggested that direct manipulation methods for modifying interface content could lead to reductions in the number of steps and time for performing tasks. They employed the task analysis, user analysis, representational analysis, and functional analysis (TURF) method to evaluate the usability of the existing interface and redesign and found the redesign to achieve the design goal.

In a more recent study, Suebnukarn et al. (2013) found mental workload to be a major usability issue in using EHRs. They analyzed an EHR interface used in a comprehensive dental clinic by applying the cognitive task analysis method "goals, operators, methods, and selection rules" as well as keystroke level modeling. Results revealed mental operations to be the majority of steps in interface use, and more than half of user time was spent on performing mental tasks, which can result in fatigue over the long run. The authors wrote that designers can simplify interfaces and improve organization by combining related information and using fewer screens. In addition, the authors mentioned that providing information reminders and recognition-based assistance can reduce mental workload. Other suggestions included use of different colors to classify each main menu in order to reduce mental recall and improve user-friendliness of interfaces.

Cognitive overload has also been identified as an EMR usability problem in evaluations conducted as part of some other studies. For example, Rose et al. (2005) suggested that when the amount of information presented in an interface increases, user attention is divided, as in multiple-task performance, and the probability of errors increases. They identified “close” screen elements as an example interface design problem. To address this issue, they recommended presenting related items near each other (based on the proximity-compatibility principle described by Wickens and Carswell, 1995, according to which displays with relevance to a common task or mental operation should be rendered close together in perceptual space). Rose et al. also suggested presenting only certain test results on displays rather than presenting all notes. In addition, Rogers et al. (2013) found that most users felt they had to remember actions already completed as well as what they had to do next, which the authors contended causes a high memory load. To address the problem, they recommended making status information more visible in the NIS module of EHRs.

In another study, Schumacher et al. (2010) assessed EHR usability, including interface information content. They conducted an empirical study, including interviews with physicians, in order to identify usability problems and potential solutions. They also found EHR content to cause information overload for physicians as well as “alert fatigue.” Related to this finding, they concluded that EMRs should present essential information and that there is a need to eliminate irrelevant interface options. Alerting overload was also a usability and safety issue identified by Bouamrane and Mair (2013), Abramson et al. (2012), and Sittig and Singh (2012). Last but not least, minimizing cognitive overload was also identified as an EMR design rule of thumb by Zopf-Herling (2011). The author suggested reducing redundant information, reducing the number of dialog options, providing information summary screens, and carrying critical patient data forward from one mode of operation to another in order to address cognitive overload problems.

Although authors of a number of prior studies have recommended reducing the amount of

information presented in EMR interfaces, Weber-Jahnke and Mason-Blakley (2012) observed that some EMR screens did not present critical patient information, including current infusions or identification of current lab test results. They applied a systems safety analysis approach (reviewed later) in order to identify hazards or safety issues associated with EMR design. However, they did not provide recommendations to solve the specific information presentation problems. Finally, in Hollin et al.’s (2012) study, the authors found that users have neutral-to-positive attitudes about the level of cognitive load imposed by EMR interfaces.

Summary. User information overload is one of the most common usability problems identified in the literature. Some of the main recommendations for EMR design to address this problem include presenting only the most important information for concurrent tasks, reducing the number of screens with similar information, and using the proximity-compatibility principle for display layout in EMR screens.

Efficient Interaction

Human-computer interaction should be designed for efficiency by minimizing the number of steps to complete a task or providing shortcuts for users (Belden et al., 2009). Molich and Nielsen (1990) recommended using shortcuts in order to make the system easy to use for all users. Belden et al. (2009) also identified reducing the amount of visual search for information and minimizing cursor travel distance as other objectives of efficient interaction.

Craig and Farrell (2010) focused on assessment of EMR interface navigation, function accessibility and flexibility, and recording patient information. They observed existing interface designs to inflate the number of steps to perform a task and that displays failed to maintain an overview of information for users. They also noted the presence of many “modal” dialogs, or interfaces requiring a user response before any other system information could be accessed. They presented a new interface design by reducing conventional interface elements to improve the navigation process and physicians’ work flow. However, at the time of their publication, the EMR prototype was under development and

usability evaluation had yet to be conducted. Related to Craig and Farrell's study, Saitwal, Feng, Walji, Patel, and Zhang (2010) examined the usability of the Armed Forces Health Longitudinal Technology Application EHR system by using cognitive task analysis. They found the current interface design to require a large number of steps to complete tasks. They argued that this situation represented an interface navigation problem and that it posed high mental demands for operators with the potential for information overload. The authors recommended reducing the number of steps and menus required to perform system functions and to ensure that interfaces presented task-critical information to reduce the level of difficulty for users.

Minimizing the number of user control actions to access functions was also one of the usability rules of thumb identified by Zopf-Herling (2011). She also suggested the use of check boxes instead of drop-down boxes in order to reduce the number of clicks for completing a task. Related to this finding, Hagstedt et al. (2011) compared the usability of different CPOEs used in EHRs in primary care. By developing an evaluation model and conducting interviews with physicians, they found that one of the most prominent issues was nonintuitive interface design. They observed that many mouse clicks were required to make a prescription. Although some of the required steps were mandatory due to patient safety issues, the authors wrote that a balance should be achieved between simplicity and patient safety and that more intuitive systems should be developed.

Zheng, Padman, and Johnson (2007) conducted an analytical study of the organization of EMR content and the potential impact on user task efficiency by using sequential pattern analysis. They analyzed user activity sequences with EMRs in order to identify patterns in navigation of features. On the basis of this analysis, they found that many features with high frequencies of use were not prominently located. Conversely, they noted that less frequently used items often occupied salient interface spaces. They also observed that many related information items were not colocated or adjacent to each other. They recommended that EMR features be relocated based on frequency of use and organized

according to functional relationships. They also observed that usable EMR interface design could be facilitated by analyzing actual user everyday usage patterns for inefficiency.

Rose et al. (2005) sought to identify usability deficiencies in EMR design, including feature navigation. The authors conducted two qualitative empirical studies, including a user task analysis and ethnographic observations (patterns of group behavior with interfaces). The studies were focused on primary care practices and revealed that user alerts and process guideline dialogs did not appear at prominent EMR screen positions. They also observed that accessibility to EMR functions could be substantially improved by adding function controls presented as graphics at the bottom of display screens. Related to this finding, Rodriguez, Borges, Murillo, Ortiz, and Sands (2002) compared a graphics-based electronic patient record (EPR) with a text-based record in terms of the usability attributes of learnability, task efficiency, and user satisfaction. They conducted a lab study and asked users (internal medicine resident physicians) to perform the same tasks with both interfaces. They recorded performance times and found the average time for completing tasks to be significantly less when using the graphics-based interface prototype; that is, the efficiency of interaction was greater as compared with the text-based interface.

Jaspers, Peute, Lauteslager, and Bakker (2008) compared a newer version of an EMR system with a previous one in order to understand if the redesigned system improved the satisfaction of users. The authors administered usability questionnaires to clinicians. Results showed that although users were generally satisfied with the new EMR system, screen design and navigational structure were less easy to work with. Regarding navigational issues, the authors said that there was too much information on a single screen, which made it difficult for users to complete tasks. They recommended that EMR systems should be designed in a consistent manner, functions should have one-to-one correspondence with user goals, and the order of information presentation should match the order of information processing in a user's mind. These recommendations are also in line with the design guidelines for minimizing cognitive load.

Indrani, Wyatt, and Li (2009) developed an EHR training tool called iCare and assessed tool usability by applying Molich and Nielsen's (1990) heuristic analysis method. Nursing faculties and students evaluated the interface based on questionnaires. The main usability issue was related to use of the keyboard. The authors found that the user interface mainly consisted of check boxes and radio buttons. They believed not having free-text boxes presented a usability issue. In order to solve this problem, the authors added a check box labeled *other*. When the check box was selected, a text box appeared for entry of free-text values.

Abramson et al. (2012) also found violations of efficient interaction in their comparison of new versus old versions of an EHR system. In a case study, including field observations and semistructured interviews of internal medicine faculty members, they identified usability as one of six major design issues. Related to this finding, the authors found that most physicians described the new EHR as "overengineered." They mentioned that the new interface supported too many ways for doing tasks, which was confusing for users. In addition, there were many steps to complete tasks, and it was difficult for users to find certain information. Related to this issue, the authors recommended simplifying the interface and its functions. They also mentioned that if additional steps were required in use for safety purposes, real-time feedback should be provided in order for users to understand the advantages of these new steps.

Bouamrane and Mair (2013) assessed general practitioners' (GP) ideas on using an EMR system and found navigation to be one of the main usability issues. They conducted semistructured and open-ended interviews to collect GP views on information management in a patient surgical flow in a major medical system in Scotland. Although many practitioners believed that the EMR system was beneficial to their work, they expressed some usability concerns, including unnecessary steps (a lot of clicking), extra keystrokes, a busy "front page," and difficulty in visualizing the flow of patient consultation through the system. They recommended that iterative user-centered improvements and additional training in using the technology would solve these issues.

In a more recent study, Vatnøy, Vabo, and Fossum (2014) also identified navigation as a main usability challenge of EHRs. The authors conducted an empirical study with registered nurses and used the cognitive walk-through approach to identify usability issues related to the graphical user interface of an EHR. Results revealed finding information where it was expected to be found was rated low by participants. In addition, users could not find the information easily when they were looking for it. This situation was primarily due to functions not being organized in a logical way. Another issue with navigation of the system was that it was not intuitive where information could be found, and none of the participants were certain as to where to look next. The authors recommended that education, training, and support are necessary for using EHR systems. In addition, they offered that standardization of format, content, and terminology is needed to improve EHR functionalities.

Violation of the efficient interaction principle was also identified as a problem in some other usability assessments of EMR interfaces. For example, although Walji et al. (2013) primarily focused on display terminology problems (discussed later), they also found other navigation problems, such as limited accessibility of functions or time-consuming processes to select functions, illogical organization of options and terms, and inconsistent positioning of controls for functions. In another study, Schumacher et al. (2010) also observed interface navigation problems, specifically, excessive clicking to access functions, resulting in physician frustration. Rogers et al. (2013) said that nurses also complained about navigation issues in the NIS module of EHRs. However, their recommendation, which was increasing observability of work processes, did not directly address the usability problem. Last but not least, Edwards et al. (2008) said that users had to reenter the same information for each new order, which violates the principle of efficiency in task completion. To address this issue, the authors recommended that the system be designed in a way to inherit information from previously completed forms.

Summary. Lack of efficient user interaction with EMR systems, especially navigation problems, has been identified frequently in the

literature. Some of the main recommendations to address this issue include reducing conventional interface elements, presenting task-critical information on screens, placing important features in salient places, and use of shortcuts.

Forgiveness and Feedback

Molich and Nielson (1990) wrote that interactive systems should provide feedback in real time in order to keep the user informed about what is currently going on. Appropriate feedback should also inform users about the consequence of actions they are going to make (Belden et al., 2009). In general, feedback is critical for facilitating user error recovery and presenting future errors. Related to this issue, Ventura et al. (2011) suggested that EMR systems should be equipped with CPOE dialogs in order to increase efficiency in use; however, they also noted that without patient and order verification dialogs, such systems could lead to prescription errors. After an analysis of the data from a 10-year EMR usage study, the authors' main conclusion was that the success of EMRs is highly dependent on user involvement in the system design and development phases for conveying feedback requirements. With respect to their specific EMR interface design, Ventura et al. recommended integration of an "alarm" into the system to inform users whenever an erroneous entry was made in a prescription.

No clear feedback or delayed feedback on an action are usability issues that were also identified in several other studies (e.g., Pereira et al. 2012; Weber-Jahnke & Mason-Blakley, 2012). Graham et al. (2008) offered that when there is no feedback to identify incomplete order entries (under high workload conditions), users often fail to recognize the oversight. In a more recent study, Rogers et al. (2013) identified lack of feedback as a violation of visibility of system status. They said that because of no feedback in the NIS module, users did not know if others saw their documentation. In addition, users had no idea where the data went in the system after they entered it. Their recommendation regarding this issue was to provide status information to users, especially making system changes more visible.

Summary. Lack of feedback is a usability problem that can lead to data entry errors in

EMR systems. Authors of the studies reviewed suggested the use of data entry confirmation dialogs and/or visual and auditory warnings/alarms to address this issue.

Effective Use of Language

Molich and Nielson (1990) wrote that all dialogs should be presented with clear words and phrases that are familiar to users. In the health care domain, there are many terms and abbreviations that may be familiar to specific users but may be meaningless to others. Belden et al. (2009) also mentioned that abbreviations and acronyms should be used in EMR interfaces only when they are completely understandable and meaningful to all users.

Walji et al. (2013) evaluated the usability of an EHR interface in order to identify some high-priority problems that could deteriorate user ability to perform tasks. They conducted a field study that included user testing, interviews, and direct observations from dental providers for problem identification. They also focused on the organization and identification of data fields and options in the interface. They observed that confusing labeling of controls and excessive use of abbreviations created the potential for user errors. They found that the terms used in the EHR interface were not optimal for users, and they had difficulty in understanding the meaning of some categories and concepts. They concluded that HCW success in use of EHRs is critically dependent upon interface usability.

Graham et al. (2008) also studied usability issues of CDSS, including data field design and entry. A CDSS is any electronic or nonelectronic system that helps decision making and uses specific information to generate assessments or recommendations that can be presented to clinicians for their consideration. The methods Graham et al. used to identify usability issues included automated screen captures combined with analysis based on usability engineering techniques. They observed, for example, that the absence of desired terminology in menus or dialogs often led to user selection of similar options but not exactly correct choices (in order to avoid leaving fields blank). They said that the identified usability problems could lead to adverse medical events. Graham et al. also suggested

that usability problems need to be solved early in the system design phase of the product life cycle in order to be cost-effective and to prevent the potential for negative patient outcomes.

Weber-Jahnke and Mason-Blakley (2012) suggested that deteriorating quality of terminology and data in EMR documentation represented a hazard for patients. By analyzing a case study of EMR safety issues, they observed manual entry of text, in the absence of user menu-based selection of terminology, to increase data entry and documentation errors. They found that when users could not find appropriate terminology in menus, manual entry was error prone. This situation creates data quality problems over time, such as misspellings of terms or the use of incorrect terms for medical conditions, depending on the background of the health care worker. Finally, they suggested that without embedded system controls to prevent or account for such data entry errors, a general reduction in EMR data quality and patient safety would ultimately occur. There is a need to provide HCWs with medical terminology reference tools in the use of EMRs.

Finally, Sittig and Singh (2012) also identified the need for structured and coded data in EHRs. On the basis of a literature review, they proposed a three-phase framework for development of EHR patient safety goals. In addition to alert fatigue, the authors identified a lack of structured data as contributing to failure in appropriate use of EHRs and creating safety concerns. The authors argued that this issue might prevent users from correct interpretation of system states, which could lead to errors. Some interface design recommendations for solving this problem included use of structured clinical vocabularies and developing order entry templates. Authors of other studies also referred to violations of the effective use of language principle in EMR design as a part of their usability evaluation (e.g., Indranoi et al., 2009; Vatnøy et al., 2014; Zopf-Herling, 2011).

Summary. Authors of studies concerning effective use of language in EMR design identify poor labeling, use of acronyms, and lack of consistent terminology in options as usability issues. General suggestions that can help to promote effective use of language include meaningful labeling and

adding medical terminology reference tools to systems. Such tools increase user access to specific terminology options and can reduce the number of blank data entry fields in records.

Effective Information Presentation

The design of EMR interfaces, in terms of the amount, type, and organization of information, influences complexity and usability from a user perspective. Caudill-Slosberg and Weeks (2005) observed that interface templates are typically used in EMRs for standardization and elimination of extra details. Although templates may have been developed to improve user efficiency, the authors found that such interfaces often prevent users from recognizing most relevant pieces of information for a specific task. In some cases, templates were observed to create visual barriers to search for relevant information. Caudill-Slosberg and Weeks conducted an analytical study (using a fishbone analysis technique) and showed that template use could lead to errors in medication orders, inaccurate HCW interpretation of orders, drug overdoses, and so on. They recommended that the design of templates account for the system understanding of different users in order to enhance patient safety.

Readability was another aspect of effective information presentation that Belden et al. (2009) identified. Lack of visibility of options in EMR interfaces was also identified as a usability problem by Walji et al. (2013). Wu, Orr, Chignell, and Straus (2008) observed HCWs to have difficulty in reading information from EMR screens and in data entry, specifically with mobile systems. They conducted qualitative evaluations of HCW performance and found that display visibility and creation of new records were the most frequent challenges with mobile EMRs. However, the recommendations that they provided basically address customization and flexibility issues. They said that in order to eliminate user errors and increase EMR usability, HCWs need to be provided with flexible, fast, and time-saving methods. They recommended integrating new technologies in EMR systems, such as speech recognition. Related to visibility of options, usability issues regarding the size of letters, text, and buttons were identified by Vatnøy et al. (2014).

Tasa, Ozcan, Yantac, and Unluer (2008) suggested that icons be used in EMRs to promote user readability and task efficiency. They conducted an empirical study and administered questionnaires to hospital users in order to identify relevant metaphors for various health care operations. They wrote that previous studies had focused on user “mental models” for overall interface design and navigation issues but not on metaphors for information presentation. They designed icons for EMR interfaces and found prototype interfaces to improve readability. In line with the larger body of human-computer interaction research, they concluded that icon-based design is preferable to textual interface design.

Violation of effective information presentation has been identified as a usability issue as part of some other studies. More specifically, Rose et al. (2005) identified screen contrast as an important feature of EMR user interface designs. They recommended that screens be designed with higher resolutions and to incorporate soft colors to improve feature contrast for promoting readability. In another study, Edwards et al. (2008) found that 13% of users did not notice how to complete the task based on information presented to them. For example, some hyperlink texts were not underlined or highlighted in different colors, or some clickable icons did not appear as buttons. Jaspers et al. (2008) also found that the layout of information presentation in a new EMR system was less usable in comparison to an old version. They said that reorganization of information was somewhat more difficult to work with for clinicians. In order to solve this issue, they recommended clustering related information on the screen, which can also reduce mental load of users.

Summary. Our review of literature revealed that use of templates can reduce effective information presentation. However, icon-based interfaces and use of higher-resolution displays can increase HCW task efficiency.

Customizability/Flexibility

Customization is the capability of an EMR interface to be modified based on the needs of each health care provider. Flexibility, or the

capacity of an interactive system to be customized, is one of the 14 usability principles identified by Zhang and Walji (2011) in their research toward developing a unified framework of EMR usability. However, there are few studies in which customization is identified as an EMR usability issue. As previously mentioned, a prior report by the Health Information and Management Systems Society (Belden et al., 2009) did not include customization as a principle for EMR usability evaluation.

Chen and Akay (2011) identified a lack of interface customizability as a major issue in EMR system use in developing countries. To address this problem, they proposed use of database software (FileMaker) to allow clinics to easily change the information content delivered to an EMR interface based on specific needs. Rose et al. (2005) also identified use of predefined interface templates as a lack-of-customization issue in EMR design. They observed that many physicians prefer to use a free format in preparing letters and that templates did not support such preference. The literature reveals a need to provide flexible templates that allow users to import test results and letters in various formats in order to address diagnosis problems.

Pereira et al. (2012) identified lack of customization for users with different levels of expertise as a usability issue. They conducted a usability evaluation of an EHR in a Portuguese hospital by applying a usability inspection method and heuristic walk-through. They noted a lack of customizability for expert users, such as the amount of information revealed in notifications and error messages as well as access to shortcuts (e.g., hot-key sequences) to accelerate task performance. On the basis of this evaluation, the authors concluded that there is a need for new methods of information organization as well as control design to improve EHR usability. For example, Pereira et al. recommended adding “accelerators” to EHR systems to increase flexibility of use for different users.

In an empirical investigation of physician and nurse practices in recording information with EPRs, Reuss, Naef, Keller, and Norrie (2007) found the majority of HCWs to identify a lack of flexible ways for entering information to be a usability issue. They conducted interviews with

the HCWs and found a desire for entry methods, including drawing sketches, annotating documents, or highlighting relevant data fields. They also noted that most of physicians and nurses could not record complete information in records due to the absence of suitable forms and elements, such as data entry fields that were very small. Based on these findings, they recommended that a shortcut and/or context menu should be provided for record annotation (marking specific information) and that any annotations should be displayed at the same time as the original EPR in order to increase system usability (efficiency of use). They also suggested that HCWs be supported in making independent entries and that all messages, questions, and so on should be managed in terms of the HCW's role.

Lack of customization based on user's role was also a problem identified by Lowry et al. (2014). They posited that EHR users want to see different views of patient information based on their role. For example, the data that are important for a physician might not be critical for a specialist, and the physician may prefer other information to be displayed on the screen. Lowry et al. recommended the use of multiple views for different physicians based on their role and adding a feature for viewing notes from the perspectives of other roles in order to ensure entered information meets the needs of other users.

Last, authors of some other studies mentioned an inability to reorganize interface content as a lack of customization. For example, Walji et al. (2013) observed reordering of concepts in an EHR to be a problem in their usability evaluation.

Summary. Our review of literature revealed a lack of customizability to be a critical issue in EHR/EMR/EPR design for HCWs. Study results reveal that changing information content based on a clinic's needs, flexible templates, shortcuts, and multiple views based on a user's role can all be effectively used to address lack-of-customization problems.

REVIEW FINDINGS ON EMR SAFETY

Beyond the aforementioned usability problems with EMRs and EHRs, several previous studies have linked interface design issues with safety incidents (e.g., Ammenwerth & Shaw,

2004; Caudill-Slosberg & Weeks 2005; Weber-Jahnke & Mason-Blakley 2012). On this basis, we briefly summarize those studies that made use of safety analysis techniques to identify potential hazards in EMR use. In any investigation applying such techniques, one makes the assumption that implementation of EMRs may lead to hazards for patients. As mentioned in regard to Table 4, all of the articles reviewed involved the use of inductive and qualitative methods for EMR analysis. In general, the EMR safety issues identified with these methods include (a) delayed feedback in response to control actions, (b) disruptions in HCW and patient interaction due to EMR use, (c) EMR failure to provide accurate and up-to-date patient information, and (d) failure to detect or warn HCWs of conflicts in drug interactions.

Weber-Jahnke and Mason-Blakley (2012) conducted an analytical study using the systems-theoretic accident model and process (STAMP) approach to evaluate an EMR system. In STAMP, systems are considered as interrelated components that are maintained in a state of dynamic equilibrium by feedback loops of information and control (Leveson, 2004). The authors contended that use of event-based safety analysis techniques, such as fault trees and event trees, may not be successful in complex socio-technical systems, such as EMRs. However, no additional objective justification was provided for this contention. The STAMP approach was considered useful in that it allows one to consider nontechnical as well as technical factors when assessing system safety. The authors applied STAMP to an EMR case study. Some types of hazards they identified included inconsistent, incomplete, or incorrect process models (as compared to physician internal models) and delayed feedback on control actions. Related to their special case study, the authors recommended controls such as allowing EMR pharmacy order dialogs to enforce limits on maximum dosages of medications, EMR injection order controls enforcing limits on volumes entered by physicians, EMR displays highlighting out-of-range order values, and providing warnings to users about "stale" results or the requirement for active drip infusions as well as providing feedback on order administration.

Singh, Servoss, Kalsman, Fox, and Singh (2004) applied failure modes and effects analysis (FMEA) for evaluating safety issues in EMR use. FMEA is an engineering technique used to define, identify, and eliminate known and/or potential problems, errors, and so on from the system, design, process, and/or service before they reach the customer (American Society for Quality Control Statistics Division, 1983; Omdahl, 1988). On the basis of their FMEA, Singh et al. observed that EMRs may introduce new hazards to patient safety (over the use of conventional paper-based systems) as a result of changes in physician, nurse, and patient interactions. Hazards that they identified included multiple primary care errors in 12 different domains, such as physician-chart interaction, nurse-physician interaction, nurse-chart interaction, and so on. They said that FMEA applied to specific practices can be used to identify changes related to EMR implementation, such as disruptions in doctor-patient communication when EMRs are being used.

In their review of literature, Belden et al. (2009) also identified FMEA as an appropriate risk analysis approach for evaluating the effectiveness of EMRs. In addition to FMEA, they identified another risk assessment technique called topological risk analysis (TRA). They wrote that this method is used to describe the processes in an in-depth manner, define a process layout (topology), and identify risk elements, such as "single-point" failures and "common-mode" failures. Subsequent to risk identification, detailed analysis and control efforts can be concentrated on these points. Having reviewed Belden et al.'s work, we feel it is important to note that the TRA methodology is not commonly identified or detailed in system safety analysis references (e.g., Bahr, 1997). Win et al. (2004) also used the FMEA technique to identify potential failure modes in a health information system. They wrote that techniques such as fault-tree analysis allow one to identify sources of errors after the event; however, with FMEA, failure modes can be predicted. In a case study at the Simpson Centre for Health Services, the authors identified possible failure modes from processes. Based on the FMEA, the most hazardous failure modes included forms not being

marked appropriately (leading to incomplete data), missing forms, identical medical record numbers for different patients, and mismatches in data.

Caudill-Slosberg and Weeks (2005) suggested that hazards associated with EMR use could also be identified by using techniques such as cause-and-effect diagrams or fishbone analysis. A cause-and-effect diagram is a tool that helps one to identify, sort, and display possible causes of a specific problem or quality characteristic (Ben-Daya, 2009). They said that such methods could even be applied before EMR system implementation to project types of hazards. In their analysis of a specific health care operation, they identified four entities contributing to hazards, including patients, clinicians, pharmacy, and EMRs. For example, hazards related to EMRs included failure to present "clean and relevant" information, up-to-date and accurate patient information, coherent presentation of information, accurate information, and medication data entry. It was shown that an EMR failure could lead to negative health care outcomes for patients.

In a similar study, Kumar and Aldrich (2010) analyzed a case of failure in health care due to EMR system failure. They also used fishbone analysis to identify major contributing factors and specific conditions leading to negative patient outcomes. The analysis revealed EMR design, implementation strategy, and HCW errors in use to all be causes of overall system failure. Specific hazards in technology design included alerts that could not be overridden, conflicts in drug interactions, too many fields for data entry, and no flexibility for custom entries.

Guidelines based on the foregoing review are captured in Table 5. Here we make a few points regarding how these safety guidelines can be related to usability issues of EMR systems. As mentioned earlier, Weber-Jahnke and Mason-Blakley (2012) recommended highlighting out-of-range values in EMR displays and providing warnings about "stale" results. These recommendations are in line with the forgiveness and feedback principles of Molich and Nielsen (1990), as they would keep users informed about what is going on with the system in real time. In addition, the recommendations by Caudill-Slosberg and

TABLE 5: Summary of Usability Guidelines for EMR and EHR Interfaces Based on Literature Review

Usability Issue	Guideline	Reference
Naturalness	1. Ensure task or work flow with EHR corresponds to manual clinical process work flow.	Schumacher, Berkowitz, Abramson, & Liebovitz (2010); Zopf-Herling (2011)
Consistency	2. Design a “natural” work flow. 1. Use basic but specific color coding and unified form layouts, apply unified design to buttons that have similar functions, and design entry areas based on emphasis and simplification principles.	Belden, Grayson, & Barnes (2009) Nakano & Tohyama (2009)
Preventing errors	1. Reduce complexity of interfaces and ensure consistency in data field design. 2. Remove C/P functions from EMR interfaces or color the information based on status and provide structured C/P functions. 3. Do not allow copying of all types of notes. 4. Add alerts to indicate similar notes. 5. Monitor use of C/P functions in record preparation and limit use of “boilerplate” content across records. 6. Add patient identifiers (e.g., room numbers) as watermarks in EMR display screens. 7. EMR systems should automatically capture patient data from other electronic systems.	Bowman (2013) Thielke, Hammond, & Helbig (2007); Caudill-Slosberg & Weeks (2005); Lowry et al. (2014); Weis & Levy (2014); O'Donnell et al. (2009) O'Donnell et al. (2009) O'Donnell et al. (2009) Bowman (2013)
Minimizing cognitive overload	8. Integrate order verification dialogs in EMRs. 9. Allow <i>unknown</i> option to be selected from a diagnosis list. 10. Provide the capability to label each diagnosis with certainty information. 11. Require patient identification confirmation before permitting new record uploads or entries. 12. Reduce the use of templates for data entry. 13. Provide the capability to predict when users may require input prompts. 14. Provide the capability to double-check patient prescriptions before signing. 15. Change required fields to non-required fields when users do not have enough information on content. Otherwise, institute a policy regarding what to do when a value for data entry is not known. 1. Reduce the amount of information on EHR displays; eliminate redundant display information. 2. Provide information summary screens. 3. Carry data forward from one mode to another; allow for modeless entry of data.	Yamamoto (2014) Mendez and Ren (2012) Hyman et al. (2012) Lowry et al. (2014) Lowry et al. (2014) Wilcox, Chen, & Hripcsak (2011) Weir et al. (2003) Rogers, Sockolow, Bowles, Hand, & George (2013) Shachak, Hadas-Dayagi, Ziv, & Reis (2009) Edwards, Moloney, Jacko, & Sainfort (2008) Schumacher et al. (2010); Craig & Farrell (2010); Zopf-Herling (2011); Clarke et al. (2013) Zopf-Herling (2011) Zopf-Herling (2011); Craig & Farrell (2010)

(continued)

TABLE 5: (continued)

Usability Issue	Guideline	Reference
	4. Strive for “transparency” in display design and do not create too many intrusive stimuli for users.	Belden et al. (2009)
	5. Reduce display density by providing views of data at a summary level before facilitating drill-down to detail.	Belden et al. (2009)
	6. Apply the proximity-compatibility principle in layout of interface elements.	Rose et al. (2005)
	7. Ensure that the EMR interface presents all patient medication information as well as dates of records entered into the system.	Weber-Jahnke & Mason-Blakley (2012)
	8. Rank data in terms of importance and reduce amount of information presented.	Ahmed, Chandra, Herasevich, Gajic, & Pickering (2011)
	9. Reduce number of screens presenting similar data and present only critical options in dialogs.	Harrington, Wood, et al. (2011)
	10. Reduce the number of interface elements and/or increase the number of task-relevant pieces of information.	Harrington, Wood, et al. (2011)
	11. Consider dependencies among interface items and minimize the number of task steps.	Kuij, Eveleigh, Holzer, & Sarkani (2012)
	12. Make status information more visible.	Rogers et al. (2013)
	13. Improve data organization by integrating relevant information and data using fewer screens; provide information reminders and recognition-based assistance; use different colors.	Suebnuarn et al. (2013)
	14. Simplify the interface.	Suebnuarn et al. (2013); Clarke et al. (2013)
Efficient interaction	1. Minimize steps to complete a task by providing shortcuts; limit mouse use in accessing information.	Zhang (2010); Zopf-Herling (2011); Clarke et al. (2013)
	2. Ensure accessibility of functions.	Walji et al. (2013); Rose et al. (2005); Schumacher et al. (2010)
	3. Present frequently used information in salient positions; present alerts and guidelines in prominent display locations.	Zheng, Padman, & Johnson (2007); Rose et al. (2005)
	4. Colocate features that are used in a sequential manner; collocate related pieces of information; ensure logical ordering of terms.	Zheng et al. (2007); Walji et al. (2013); Zopf-Herling (2011)
	5. Functions should have one-to-one correspondence with user goals; the order of information presentation should match the order of user information processing.	Jaspers, Peute, Lauteslager, & Bakker (2008)
	6. Provide users with system navigation references.	Craig & Farrell (2010)
	7. Inherit the same information from previous fields to a new field.	Edwards et al. (2008)
	8. Use check boxes whenever possible.	Zopf-Herling (2011)
	9. Add a check box called other when appropriate, and allow free-text data entry when the check box is selected.	Indrani, Wyatt, & Li (2009)
Forgiveness and feedback	1. Provide feedback for user related to potential future actions and incomplete data set.	Belden et al. (2009); Graham et al. (2008)
	2. Integrate alarms into EMR interfaces when prescription errors are detected	Ventura et al. (2011)
	3. Make status information, and especially system state changes, more visible.	Rogers et al. (2013)

(continued)

TABLE 5: (continued)

Usability Issue	Guideline	Reference
Effective use of language	<ol style="list-style-type: none"> 1. Use clear names of functions and labels. 2. Integrate automated spell-checking technology and/or make an online medical dictionary accessible through the EMR interface (particularly if flexible data entry methods are supported). 3. Use familiar and unambiguous terminology and abbreviations. 4. Ensure users have all necessary options to select from. 	<p>Wajji et al. (2013); Indrani et al. (2009) Weber-Jahnke & Mason-Blakley (2012)</p>
Effective information presentation	<ol style="list-style-type: none"> 1. Templates can create visual barriers to critical information, and extra details should be eliminated. 2. Provide easy to read displays; ensure visibility of options. 3. Make meaningful use of colors. 4. Reduce number of dialog boxes and present only adjacent controls or controls that triggered the dialog. 5. Use icons in EMR interface design versus text labels. 6. Reduce the use of text templates. 7. Cluster related information on the same screen. 	<p>Belden et al. (2009) Graham et al. (2008) Caudill-Slosberg & Weeks (2005)</p> <p>Belden et al. (2009); Wajji et al. (2013) Belden et al. (2009) Belden et al. (2009)</p>
Customization/flexibility	<ol style="list-style-type: none"> 1. Allow for free and flexible formats in data entry, such as sketching and record annotation capability. 2. Integrate in EMRs flexible and fast data entry methods, such as voice recognition. 3. Provide capability to make entry and import documents in various formats. 4. Ensure system design matches real-world task or process design. 5. Provide access shortcuts for experts and notification and errors with different levels of details for novice and expert users. 6. Allow for user manipulation of underlying EMR database to change interface content. 7. Use multiple views for different HCWs based on their role, and add the feature of viewing notes from the perspectives of others. 	<p>Tasa, Ozcan, Yantac, & Unluer (2008); Rodriguez, Borges, Murillo, Ortiz, & Sands (2002) Caudill-Slosberg & Weeks (2005) Jaspers et al. (2008) Craig & Farrell (2010); Méndez & Ren (2012); Reuss, Naef, Keller, & Norrie (2007) Wu, Orr, Chignell, & Straus (2008)</p>
Safety issues	<ol style="list-style-type: none"> 1. Ensure accurate, up-to-date, clear, and relevant patient information. 2. Provide a limit on maximum dosage of medication, show out-of-range values and "stale" results, and provide feedback for EMR displays when data are out of range. 3. Reduce the number of fields for data entry, and provide the capability to override false alarms. 	<p>Rose et al. (2005) Pereira et al. (2012) Pereira et al. (2012) Chen & Akay (2011) Lowry et al. (2014) Caudill-Slosberg & Weeks (2005) Weber-Jahnke & Mason-Blakley (2012) Kumar & Aldrich (2010)</p>

Note. EMR = electronic medical record; EHR = electronic health record; C/P = copying and pasting; HCW = health care worker.

Weeks (2005) regarding coherent presentation of information and providing up-to-date and accurate information are related to the usability principle of effective information presentation, identified earlier. Kumar and Aldrich's (2010) recommendations regarding override of false alerts and reducing the number of fields for data entry in EMRs are related to Molich and Nielsen's usability principle of minimizing cognitive overload. Since user mental capacity is limited, many false alarms and data entry fields may compromise primary cognitive task performance, lead to mental fatigue, and ultimately result in medication errors.

Although the main purpose of EMR usability principles is to improve patient safety, there are some cases in which usability and safety trade-offs may occur. For example, one of the recommendations in Weber-Jahnke and Mason-Blakley's (2012) study related to enforcing limits on maximum dosage of medication entered by physicians. Such a recommendation may introduce a trade-off between efficient interaction and patient safety. The principle of efficient interaction focuses on minimizing the number of steps to perform a task; however, redundant checking of values by a pharmacy and rejecting out-of-range values may slow down the process of data entry by physicians. Edwards et al. (2008) also mentioned that the greatest trade-off in EHR design is providing a balance between efficient task performance and patient safety. They argued that several changes need to be made in EHR design in order to improve usability while maintaining patient safety.

In summary, several studies have been conducted on potential EMR safety issues by using structured hazard analysis techniques, including contemporary methodologies that take into account a broad range of risks as bases for control recommendations. Unfortunately, this area of research has yet to make use of deductive systems safety analysis techniques that would support inferences on sources of hazards in EMR use as a result of interface design features, including content and format.

DISCUSSION

Design Guidelines

The foregoing literature review leads to a set of EMR interface design guidelines for promoting usability. These guidelines are listed in Table

5 along with the specific references identified as bases for each guideline. In addition, the design guidelines are grouped according to the classes of usability problems previously identified at the outset of the review.

Interface Design Concept

The guidelines in Table 5 provide a basis for an enhanced EMR interface design concept. Although the enhanced design concept is applicable to different health care clinics, we present the concept in the context of a physiotherapy clinic in order to make clear design features and how those features support specific processes. Most current EMR interfaces include a collection of electronic forms (designed based on paper predecessors) that are linked to a main or system "home" page. A physician or other HCW simply sees digital versions of forms filled with data fields that are to be completed either through free-text entry or by choosing from options in a drop-down menu list. Unfortunately, as noted from the literature review, this general design concept has led to usability problems, including information overload, physician entry of unclear terminology (i.e., violations of effective use of language), errors in C/P incorrect information (violations of error prevention), complex interface navigation (violations of efficient interaction), and a lack of customization for various levels of users. In general, we propose that EMRs be designed for specific clinic or health care provider use; that is, each provider should be presented with a set of screens or information that is directly relevant to its specific operations. Customized icons and provider- or clinic-specific terminology should be also used in the interface. Such an approach would be aimed at addressing the lack of customizability of existing interfaces.

Clinical use of EMRs is largely focused on patient problem description and prescriptions. A clinician typically logs in to a system using one screen and then views a patient's records. In the enhanced EMR interface design, we recommend that the first information screen provide an overview of the system content using icons to represent various clinical functions. This design can address some of the usability problems identified in the literature, such as lack of effective

information presentation. In the event that a clinician is creating a new patient record, there is a need for data entry and visualization. It is typical in EMR design for this function to be supported through use of templates; however, templates have previously been found to cause errors and user frustration (Caudill-Slosberg & Weeks, 2005) and to violate some usability principles, such as effective information presentation as well as prevention of errors. One approach to minimizing template use in EMR design is to stage user interaction with the system, that is, to support data entry with one dialog and form visualization through another screen or window. For example, in physiotherapy clinics, therapists may enter and select data using a dialog and view a complete form or record on another screen versus entering data directly into fields of the form. The advantage of the staged interaction is reduced user attentional load and decreased potential for errors.

With respect to data entry dialogs, icons or check boxes can also be used to represent different parts of the body or physiological functions that may be affected. Use of check boxes reduces the number of free-text format sections that users have to fill out. This change will lead to reduction in data entry errors and improve efficient interaction between users and the system. A therapist can select icons/options to pinpoint problem areas and simultaneously generate record content. Once a patient has specified an area of pain, graphical controls (e.g., slider bars) can be used to collect data on the severity and frequency of pain occurrences. Again, data entry using such controls can serve to generate required form/record content.

Depending upon the icons/options or ratings selected by a therapist at each stage of patient problem description, a set of potential disease states should be presented for clinician selection. By using this approach, the interface content can be reduced and the clinician can narrow down the set of possible diagnoses. This feature addresses the potential for user information overload problems, as previously identified in the literature. Once a diagnosis is selected, the interface should support clinician identification of potentially causal factors (e.g., occupational and/or nonoccupational) in the disease state. For

example, a patient may identify severe low-back pain, and the EMR should support physiotherapist identification of posture, task repetition, force, and so on as potential work factors in the condition. We also recommend that this stage of the problem description be facilitated through icon selection in EMR dialogs in order to improve effective information presentation.

Finally, on the basis of the patient diagnosis and causal factor identification, prescriptions should be supported using separate dialogs with medication option selection and dosages. In the event that a special medication or dosage is needed, dialog design should include free-format text entry (Craig & Farrell, 2010) for the clinician. Although this approach can be error prone, the enhanced EMR interface design should include spell-checking and autocorrect functions to ensure accuracy of entries and prevent potential errors.

The main advantages of this new interface concept over current EMR designs include the following:

1. Reducing cognitive load: The amount of information presented to a user on each screen is minimized (e.g., fewer icons, options and data fields).
2. Increasing effective use of language: The risk of errors in patient diagnosis and interpretation due to free-format text entry is reduced. In most previous EMR designs, a clinician chooses a diagnosis from a list and whenever he or she cannot find a particular diagnosis, free-text entry occurs. This situation leads to errors in use of terminology and misinterpretation by other HCWs.
3. Improving efficiency of interaction: Screen navigation is facilitated based on user inputs. In current EMR designs, users are typically presented one general information page with links to access different forms/records for data entry. The new interface concept will increase the efficiency of this process by guiding users through related dialogs and screens based on inputs to the system.
4. Improving effectiveness of information presentation: The design supports a continuous process of icon and option selection versus form completion. Other studies have suggested this design approach for new EMR interfaces (e.g., Tasa et al. 2008) toward reducing user errors and promoting user readability.

5. Improving error prevention: The interface design supports explicit patient condition description and diagnosis. With previous EMR designs, the process of diagnosis occurs only in the clinician's mind, and a diagnosis is subsequently entered into the system. By following the new interface concept, the EMR could reduce clinician cognitive load and provide assistance in identifying the set of possible diagnoses and ultimately reduce the risk of an incorrect diagnosis.
6. Improving naturalness: The interface design will reduce the number of interruptions to clinician-patient interaction. Many physicians have commented that EMR use adversely affected interaction with patients (Singh et al., 2004), and they see themselves as secretaries when they have to enter information into several forms. The enhanced design will be helpful in terms of supporting physician notions of a diagnosis process and promoting interaction with patients by limiting form fills.

On the basis of the literature review, it is also important to observe a number of limitations of the existing body of research identifying EMR design problems, including the application of various methods of usability and safety analysis as well as the recommendations for design improvements. The majority of studies of EMR usability issues have employed descriptive or qualitative analysis methods, such as task analysis, functional analysis, user observation, user testing, interviews, behavior pattern analysis, heuristic evaluation, records review, and evaluation of reports before and after EMR implementation. Harrington, Kennerly, et al. (2011) made a similar observation in their review of literature on studies of EMR safety issues, specifically saying that descriptive or qualitative analysis methods had been used along with case studies and comparisons of designs. Related to this finding, the majority of studies identifying EMR usability issues make comparisons only between paper-based systems and EMRs. There are very few studies that include comparisons among multiple EMR designs in order to identify advantages of one alternative over another. Furthermore, to date, there are few studies presenting comparisons of different versions of an EMR interface in terms of the dimensions of usability (i.e., effectiveness, efficiency, satisfaction).

Another limitation of the present body of research is that among the studies making use of safety hazard analysis techniques to evaluate EMRs, no authors evaluated specific aspects of interface design. Authors of the studies reviewed here identified only general hazards related to the safety of EMRs, and system interfaces were identified only as an element that may lead to patient safety issues. Although these analyses are valuable in terms of providing general EMR safety guidelines and recommendations for the health care industry, they may not be useful in terms of controlling specific hazards related to EMR interface design.

Beyond this, all the hazard analyses presented in the previous studies employed inductive reasoning methods, including FMEA, TRA, STAMP, fishbone diagrams, and cause-and-effect analysis. That is, the methods allowed the authors to identify sources and mechanisms of hazard exposure and project potential negative outcomes. Although inductive safety analysis techniques appear to have been useful for identifying hazards associated with EMR use, there is a need to apply additional types of analyses, including deductive reasoning approaches, that is, hypothesizing negative patient events and deducing potential sources and mechanisms in EMR systems. Despite Weber-Jahnke and Mason-Blakley's (2012) contention that fault tree analysis (FTA) is not applicable to EMR use, the majority of failures in health care involving EMRs are attributable to specific events (e.g., HCW data entry) and occur in specific use scenarios. Fault trees can be created for specific EMR failure modes and contexts of use. It is also possible to develop a collection of fault trees (organized according to an event tree/scenario) for objective quantification of the frequency of potential hazards as well as identification of severity of outcomes for patients. The use of such methods may reveal additional causes of EMR failures and negative patient outcomes.

Based on these limitations, there are several directions of future research that should be pursued, including the following:

1. Use of quantitative usability evaluation methods in combination with qualitative methods in order to develop a more accurate understanding

- of EMR interface design problems. For example, task analysis and usability testing could be combined with risk assessment techniques in order to analyze whether changes in an EMR design might lead to improvements in user effectiveness and reductions in hazard exposure.
2. Comparison of different versions of existing EMRs from a usability perspective. Such analysis might reveal usability limitations that would otherwise be overseen when comparing an EMR design to use of paper-based records.
 3. Use of additional safety analysis techniques, including deductive reasoning methods, to identify certain EMR interface features (or manners of use) that could be root causes of user errors and potential negative patient outcomes. FTA is a deductive system safety analysis technique that could be used for this purpose. Requirements include description of an EMR use case along with identification of system elements that could fail or create hazards with the potential to lead to the negative patient outcome. The FTA could link a top event (e.g., "patient overdose") to basic events in EMR use or component failures. Related to these features, FTA can be both qualitative and quantitative in nature through the addition of system component failure probabilities or user error likelihoods to the analysis.

CONCLUSION

The first objective of this study was to identify usability problems related to EMR and EHR interface design. After reviewing related research articles, we found that EMR and EHR usability problems could be categorized as violations of naturalness, consistency, error prevention, minimization of cognitive load, efficient interaction, feedback, effective use of language, effective information presentation, and customization principles. The second objective of the study was to identify how EMRs had been evaluated using safety analysis techniques and what hazards had been revealed. It was found that inductive reasoning methods were used to analyze different aspects of EMR safety with none specifically focused on interface design. The final objective of the study was to formulate a set of EMR usability and general safety design guidelines along with a concept for an enhanced EMR design. The design guidelines extracted

from the literature were organized according to the usability problem areas or identified as addressing safety. The enhanced EMR design concept, focused on the diagnosis process and documentation, was for a system tailored to specific provider or clinic information needs with interface features aimed at reducing user information overload, navigation complexity, and errors in data entry and documentation.

The results of this study may be useful for companies developing EMRs for health care providers. The EMR usability problems identified here, based on the prior literature, may be insightful as to how interface design features are perceived and experienced by specialized users, such as doctors and nurses. By recognizing these issues, developers may be better able to make appropriate design changes toward more effective, efficient, and satisfying EMR use. In addition, the interface design concept presented in this work may provide some direction for addressing specific usability issues.

The limitations of this study include a focus of the review on finding usability problems related to EMR and EHR interface design as well as system safety issues. Focusing on other aspects of EMR design, such as safety enhancements compared to paper-based methods, might also be beneficial for revealing guidelines for enhanced interface design. Second, the proposed interface design concept focused on the diagnosis process and documentation. We did not make recommendations for any other functions as part of an EMR system. There are, however, many other functions supported by EMRs, including patient information recording, scheduling of appointments, reporting of test results, billing, and so on. Presentation of, and access to, these functions may also be prone to usability and safety issues and should be evaluated for design enhancements.

Finally, the proposed interface design is only in the conceptual phase. In future research, we recommend prototyping and usability testing to evaluate any new interface design and to compare usability outcomes with other current EMR systems.

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KEY POINTS

- Usability problems related to electronic medical records (EMRs) and electronic health records (EHRs) can be categorized as violations of naturalness, consistency, prevention of errors, minimizing cognitive load, efficient interaction, feedback, effective use of language, effective information presentation, and customization principles.
- The majority of studies of EMR and EHR usability issues have employed descriptive or qualitative analysis methods. Use of quantitative and qualitative usability evaluation methods (in combination) is recommended in order to develop a better understanding of EMR interface design problems.
- Inductive reasoning methods were used to identify different aspects of EMR safety with none specifically focused on interface design. Use of additional safety analysis techniques, including deductive reasoning methods, is recommended to identify helpful EMR interface features.
- A set of EMR usability and general safety design guidelines was formulated along with a concept for an enhanced EMR design. The guidelines and design concept focus on reduction of EMR usability problems in patient diagnosis and documentation processes.

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