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Methodological Review

Navigation in the electronic health record: A review of the safety and usability literature

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ABSTRACT

Objective: Inefficient navigation in electronic health records has been shown to increase users' cognitive load, which may increase potential for errors, reduce efficiency, and increase fatigue. However, navigation has received insufficient recognition and attention in the electronic health record (EHR) literature as an independent construct and contributor to overall usability. Our aims in this literature review were to (1) assess the prevalence of navigation-related topics within the EHR usability and safety research literature, (2) categorize types of navigation actions within the EHR, (3) capture relationships between these navigation actions and usability principles, and (4) collect terms and concepts related to EHR navigation. Our goal was to improve access to navigation-related research in usability.

Materials and methods: We applied scoping literature review search methods with the assistance of a reference librarian to identify articles published since 1996 that reported evaluation of the usability or safety of an EHR user interface via user test, analytic methods, or inspection methods. The 4336 references collected from MEDLINE, EMBASE, Engineering Village, and expert referrals were de-duplicated and screened for relevance, and navigation-related concepts were abstracted from the 21 articles eligible for review using a standard abstraction form.

Results: Of the 21 eligible articles, 20 (95%) mentioned navigation in results and discussion of usability evaluations. Navigation between pages of the EHR was the more frequently documented type of navigation (86%) compared to navigation within a single page (14%). Navigation actions (e.g., scrolling through a medication list) were frequently linked to specific usability heuristic violations, among which flexibility and efficiency of use, recognition rather than recall, and error prevention were most common.

Discussion: Discussion of navigation was prevalent in results across all types of evaluation methods among the articles reviewed. Navigating between multiple screens was frequently identified as a usability barrier. The lack of standard terminology created some challenges to identifying and comparing articles.

Conclusion: We observed that usability researchers are frequently capturing navigation-related issues even in articles that did not explicitly state navigation as a focus. Capturing and synthesizing the literature on navigation is challenging because of the lack of uniform vocabulary. Navigation is a potential target for normative recommendations for improved interaction design for safer systems. Future research in this domain, including development of normative recommendations for usability design and evaluation, will be facilitated by development of a standard terminology for describing EHR navigation.

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Contents

1. Introduction

Use of electronic health records (EHRs) in the United States has increased since 2009 due to federal investment in the adoption and use of these systems [5]. Since the initial spike [6] in adoption, the clinician community has viewed EHRs as an improvement over paper systems but has expressed frustration with the level of usability of available systems [7]. Ellsworth and colleagues [8] described an increase in research of EHR usability coinciding with the national spike in adoption: the number of usability articles increased from 10 between 2001 and 2005 to 63 between 2011 and 2015. This increase in research publications suggests that the prevalence of EHRs in patient care has brought usability issues of these systems to the fore.

The human-computer interaction literature defines usability as the degree of effectiveness, efficiency, and satisfaction with which users of a system can realize their intended task [9]. The Institute of Medicine has recognized health information technology systems of poor usability as one of the major barriers to providing safe and efficient care for patients [3]. Research has highlighted a lack of adherence to user-centered design practices by commercial EHR vendors [10]. Government and industry have formally recognized this challenge by publishing criteria for EHR certification [11] and standard guidelines for the conduct of usability evaluations [12]. These efforts collectively suggest an increasingly shared view of the importance of research activity to identify desiderata for usable EHR systems.

Unfortunately, the EHR usability literature has suffered from poor reproducibility of evaluations due to variation in methodology and lack of standard reporting [8]. Publications tend to be descriptive or qualitative in nature [13]. We argue that another limitation of the EHR usability literature is that an important construct, *navigation*, has not received sufficient recognition or attention despite the established body of literature on navigation and errors in user-interface-based applications in the general human-computer interaction literature [14,15]. This study attempts to place navigation of an EHR in the general context of EHR usability. To that end, here we define EHR-based navigation as desktop-based interaction with user interface presentation and controls that allows users to locate and access needed information [16].

Navigation is a particularly important contributor to the usability of an EHR because information in an individual patient record tends to be scattered across multiple screens and sections [1], forcing the clinician-user to navigate repeatedly through the digital space to create an adequate mental model of the patient's condition. This experience of viewing information 'through' a graphical user interface is analogous to attempting to view the contents of an entire room through a keyhole in a door to that room; this analogy is known as the keyhole effect by the artificial intelligence field [4]. The clinician-user is limited to viewing one screen at a time, increasing the challenge of piecing information together. The Institute of Medicine has termed this phenomenon 'display fragmentation' [3]. Inefficient navigation in EHRs requires the clinician-user to store in working memory the information displayed on previous screens. When this cognitive load is too great, the clinician-user can forget the previously viewed information and could need to view the same screen a second time [17]. This navigation can reduce efficiency [17], increase cognitive load [18] by forcing the clinician to store information in working memory, and may lead to the possibility of medical errors [2,19].

EHR search functions (when available at all) can search only certain components of the record, forcing clinician-users to rely upon the system's navigation affordances to open attached PDFs, lab reports, images, and other non-searchable information [20]. Improved search functions for EHRs can reduce the need for user interface-driven navigation. Until that improvement is realized, usability engineering focused on user interface design can address immediate challenges to more efficient user interface-driven navigation.

We propose that a comprehensive construct of navigation for EHRs would capture navigation by the clinician-user between and within pages of the EHR user interface.

1. Between-page: Navigation action to display new information by moving to a new page in the electronic health record.
2. Within-page: Navigation action to display new information by moving within the current page in the electronic health record.

Despite this acknowledgment of the consequences of poor design for user interface navigation, it is unclear whether published EHR usability evaluations use a consistent terminology to describe navigation. Without a standard way to discuss the construct of navigation it is difficult to build on existing knowledge of the construct or to compare navigation from one system to the

next. This study will address this gap by determining how navigation is discussed in the current EHR usability literature. Our goal in the current study is to apply scoping review methodology to the existing EHR usability literature to (1) assess the prevalence of navigation-related topics within the EHR usability and safety research literature, (2) categorize types of navigation actions within the EHR, (3) capture relationships between these navigation actions and usability principles, and (4) collect terms and concepts related to EHR navigation. Our ultimate goal is to improve access to navigation-related research in usability.

2. Methods

We conducted a scoping review to identify usability evaluations of EHRs and abstracted concepts related to navigation from the eligible articles. We conducted this literature review following the Preferred Reporting Items for Scoping reviews and Meta-Analysis statement. Our review was limited to articles published between 1996 and 2016 as in [21] to evaluate the prevalence of discussion of navigability in EHRs over time as EHR adoption increased in the United States and attention to usability issues increased. However, the literature was not limited to publications from the United States.

3. Data sources

A search of electronic databases was conducted in February–March 2016 using MEDLINE, EMBASE, and Engineering Village. This database search was supplemented with expert opinion contributions.

3.1. Search terms

The literature search terms included keywords in two categories: (1) electronic health records and (2) usability and safety evaluations. A medical school library research specialist was consulted to refine the electronic database queries. A combination of keywords was used to assure a comprehensive document search (Tables A.1–A.3). The Medical Subject Heading (MeSH) search term *Computerized Medical Records Systems* was used instead of the MeSH search term *Electronic Health Records* as advised by the library research specialist because the *Electronic Health Records* search term was implemented in 2010. Additionally, a gold standard patient safety search string [22] was used in the MEDLINE and EMBASE searches. The model with the highest precision of this validated patient safety search strategy was used (Tables A.1 and A.2). The Engineering Village literature search followed the Engineering Village Searching Best Practices for the database's Expert Search function.

3.2. Inclusion and exclusion criteria

Articles had to include evaluation of the usability or safety of an EHR user interface via user test, analytical methods, or inspection methods [23]. As such, evaluations limited to subjective report of the user experience, such as user-completed questionnaires, were not included. Evaluations including but not limited to subjective reports were included. We defined evaluation as an analysis of the EHR that described the user interface design, organization, or features. Furthermore, we required the scope of the EHR under evaluation to be the EHR broadly (i.e., not a single page or module) to capture navigation within and across EHR pages. We defined EHRs as comprehensive medical information systems that contain data related to medical and treatment history for patients. This definition was chosen to be inclusive of international articles that do not follow, for example, the United States' Office of the National Coordinator of Health Information Technology definition of a certified electronic health record [11]. As such, we opened our search to include 'medical record systems, computerized' in MEDLINE and EMBASE and 'medical information systems' in Engineering Village. We defined user interface as the graphical user interface. Only English-language articles were included in this review.

Articles that failed to meet the inclusion criteria included topics such as fragmentation of care in the healthcare system, position papers describing the need to address usability in EHRs, evaluations of EHR usability methodologies, or articles limited to a description of the design or implementation of an EHR without a usability evaluation of the designed/implemented system.

3.3. Article selection and analysis

A total of 4334 references were retrieved from our initial search of electronic databases, specifically MEDLINE (n = 732), EMBASE (n = 2623), and Engineering Village (n = 979). A request for expert suggestions yielded an additional 2 articles. Results of the screening process are noted in the flow diagram in Fig. 1.

Duplicate articles were removed (n = 298) by EndNote detection followed by manual comparison by author for a total of 4036 unique references. Titles and abstracts from the final search strategy (N = 4036) were reviewed for potential relevance by one of the authors (LR), a graduate student in health informatics. Titular review excluded 3901 articles and initial abstract review excluded 85. Reasons for exclusion are listed in Fig. 1. Of note, 22 were excluded due to the scope of the EHR under evaluation being limited to the medication or other type of physician-order entry modules. Articles in question were retained for consensus abstract review. Abstracts of the 50 remaining articles were reviewed by two authors (LR, YS), and 31 articles were excluded (Table B.1).

Two articles [17,24] were added by expert opinion for a total of 21 articles. Expert opinion was provided by two internationally known experts in health information technology (health IT) safety and usability, and one expert in EHR interaction design and usability. In addition to Yalini Senathirajah, PhD (one of the authors of the current study), Elizabeth Borycki, PhD, and Andre Kushniruk, PhD provided suggestions. Dr. Senathirajah has conducted studies on EHR usability and interaction design for EHRs. Dr. Borycki is founding chair of the International Medical Informatics Association Working Group focusing on Health Informatics for Patient Safety, coined the term 'technology-induced error', and has authored many publications on health IT safety and design. Dr. Kushniruk is internationally known for conducting studies of health IT usability, safety and cognition in a variety of settings and systems.

The full text of each of the remaining 21 articles was then read by one health IT safety and usability expert (YS) and one health informatics graduate student (LR). These authors independently populated a matrix developed for descriptive article analysis (Table C.1).

4. Qualitative analysis

4.1. Identification of excerpts

Articles were reviewed in detail to identify navigation in an EHR. Excerpts were limited to the Results and Discussion section of articles and identified at the level of sentence fragment, sentence, or paragraph. Excerpts were selected by one author (LR) and reviewed by a second author (YS). Disagreements were identified and final decision for inclusion or exclusion was reached by consensus review to produce a codebook. Excerpts were then independently coded by the two authors (LR, YS). The authors again met to reach consensus on the line-by-line coding of excerpts,

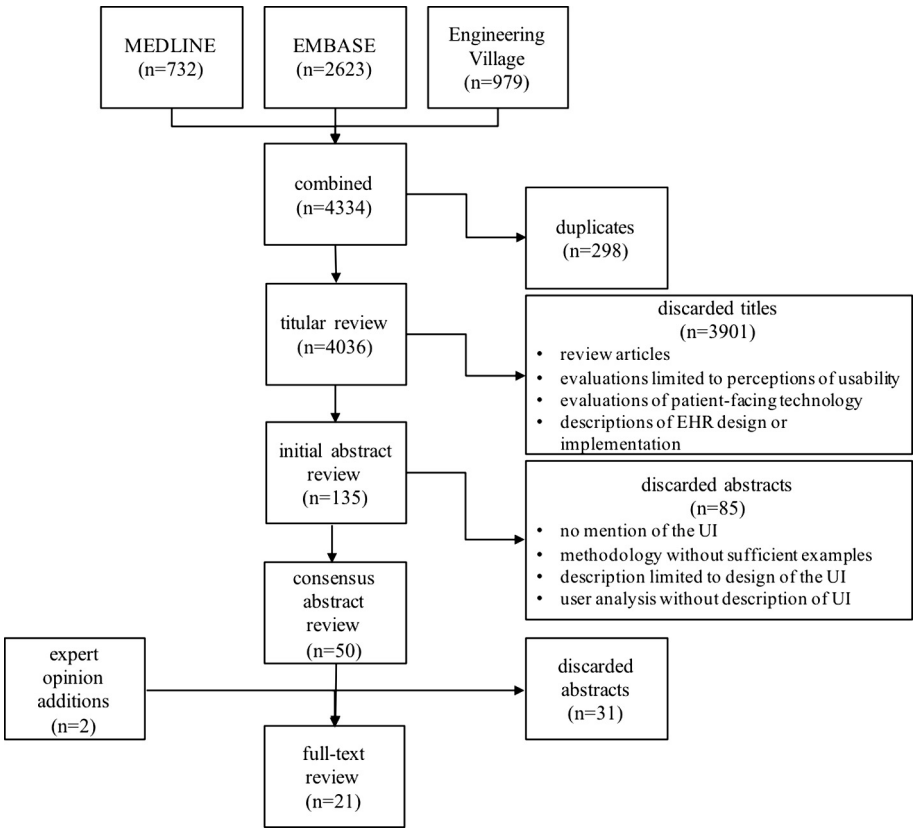

Fig. 1. Article selection methodology.

Table 1
Evaluation methodology characteristics.

Characteristic	Value	N	%
Methodology	Task analysis	12	57
	Heuristic evaluation	10	48
	Think aloud protocol	6	29
	Interview	6	29
	Survey	5	24
	Field observation	4	19
	Cognitive walkthrough	2	10
	KLM	2	10
	GOMS	1	5
	Semiotic inspection method	1	5
Evaluation setting	Laboratory	15	71
	Naturalistic	5	24
	Both	1	5

GOMS, goals, operators, methods, and selections; KLM, keystroke-level model.
Heuristic walkthrough was counted in both Heuristics and cognitive walkthrough.

Table 2
Frequency of mention of navigation action by article.

Article	Navigation action		
	Between pages	Within pages	Total
Ramsay 1997 [26]	2	0	2
Scandurra 2006 [27]	3	0	3
Edwards 2008 [28]	11	0	11
Fairbanks 2008 [29]	6	1	7
Thyvalikakath 2008 [30]	3	0	3
Shachak 2009 [31]	7	3	10
Zheng 2009 [32]	6	6	12
Corrao 2010 [33]	5	0	5
Saitwal 2010 [34]	16	2	18
Senathirajah 2010 [24]	10	1	11
Staggers 2010 [35]	1	0	1
Ahmed 2011 [36]	4	0	4
Kukec 2011 [37]	6	1	7
Pereira 2012 [38]	3	0	3
Hoyt 2013 [39]	0	0	0
March 2013 [40]	4	0	4
Rogers 2013 [41]	6	2	8
Tancredi 2013 [42]	6	2	8
Walji 2013 [43]	2	1	3
Neri 2015 [44]	15	0	15
Senathirajah 2016 [17]	5	0	5
Total	121	19	140

including the relationships between concepts. Literature excerpts were annotated using ATLAS.ti™ software (ATLAS.ti 7, Scientific Software Development GmbH, Berlin, Germany).

4.2. Identification of concepts

We structured our process to identify concepts related to navigation and usability by consensus coding for navigation actions and usability heuristics [25], respectively. Literature excerpts included both author statements and study participant comments.

5. Results

A total of 21 articles were analyzed. Articles were characterized by article and study characteristics and by evaluation methodology. Articles could be represented in multiple categories. For example, a 'Survey' methodology category exists despite the exclusion criteria of subjective reports of the user experience due to the inclusion of articles that described more than one methodology during usability evaluation.

5.1. Characteristics of included articles

Fifteen (71%) of the studies were conducted in the United States. More studies evaluated homegrown systems (48%) than

Table 3
Literature excerpts demonstrating relationship between navigation action and usability heuristic violation.

Excerpt	Navigation action	Usability heuristic	Safety concern [3]	Potential solution [45]
'...for example you're not taking a social history or family history at every single visit but it'll show up in every single note...which takes up a lot of room and makes the note way longer than it has to be. The problem is that if you don't include it, if you want to see it, you have to go clicking through note, note, note and it takes forever' [24]	Between-page	Flexibility and efficiency of use	Increased ordering time; New opportunities for errors (e.g., fragmented displays preventing a coherent view of patients' condition or problems, inflexible ordering formats generating wrong orders); Disruptions in cognitive and/or clinical workflow	Provide a configurable interface that allows for juxtaposition of relevant information together on screen; Design compatible workflows, such as integration of context sensitive hyperlinks to frequently pages frequently accessed in succession
The majority of participants said they want to have vital signs taken during triage pre-populated into their progress note or have a way to easily import the vital signs from triage. The participants said that it can be difficult to view the triage note once they are in the middle of writing their note [44]	Between-page	Recognition rather than recall	Increased note writing time; New opportunities for errors (e.g., fragmented displays preventing a coherent view of patients' condition with supporting data, inflexible documentation formats generating wrong information); Disruptions in cognitive and/or clinical workflow	Pre-populate templates (i.e., triage note) with data entered elsewhere (i.e., vital signs); Provide graphical summaries of important patient information to minimize screen space and maximize comprehensibility; Configurable interface that allows for juxtaposition of relevant information together on screen; Smart data entry in which answering a particular question would automatically add/remove additional data entry fields in the screen
Several of these issues related to instances in which the system required the users to reenter information. For example, when a set of new orders for a single patient is entered (which often occurs), the user had to enter much of the same information on each new order. However, on a case-by-case basis, the system could be configured to inherit information from previously completed forms. Utilizing this functionalist more would help alleviate the user's data entry workload and reduce opportunities for data entry errors [28]	Between-page	Error prevention	Introduction of workarounds (e.g., copy-and-paste); Increased ordering time; New opportunities for errors (e.g., incorrectly reentered information, copy-and-pasting extraneous, possibly outdated information); Disruptions in cognitive and/or clinical workflow	Pre-populate templates (i.e., orders) with data entered elsewhere (i.e., initial visit note); Smart data entry in which answering a particular question would automatically add/remove additional data entry fields in the screen
'A patient called to check something, so I opened his chart. When I returned to the visiting patient I forgot to close the new chart and continued writing in it instantly' [31]	Between-page	Error prevention	Increased relative risk of wrong patient errors	Prominent display of patient identifiers where important; Limit the number of patient records that can be open at once; Allow multiple patient records to be open at once but make subsequent records Read Only or clearly demarcated[46]
'I can't always find the instruction templates I want and it takes time to keep trying to find them. To write a discharge instruction you have to guess what the system calls it. For example if someone has a bat bite, I'd first try 'bat bite,' but no results, then I'd try 'rabies,' again no results, and finally 'animal bite' works. It is time consuming, so usually I just free text my instructions' [29]	Within-page	Flexibility and efficiency of use	Introduction of workarounds (e.g., select first relevant item); Increased relative risk of diagnosis and medication errors; Increased ordering time; New opportunities for errors (e.g., fragmented display of list preventing a view of already-selected items; Disruptions in cognitive and/or clinical workflow	Simplify lists; Use preattentive attributes [45] to highlight relevant options; Provide interactive tables to allow the user to sort and filter according to search needs; Provide flexibility regarding slight mis-spellings; Allow the user to begin to type desired item name and suggest options as the user types[45]
'...a lot of times it will skip right over that safety piece [falls risk], so unless you know you have to document on it, it'll skip, it'll miss it...I have to usually go back and find it, like scroll back all the way up' [41]	Within-page	Error prevention	Increased documentation time, Increased relative risk of rework due to data entry omission; Inflexible documentation templates generate wrong information; Disruptions in cognitive and/or clinical workflow; Introduction of workarounds (e.g., document in other area of chart)	Streamline data entry, such as by smart data entry in which answering a particular question would automatically add/remove additional data entry fields in the screen; Use minimalism to highlight important areas for documentation
By showing irrelevant and non-applicable menu options as clickable, the designers trick users into dead ends. For instance a menu option 'display available health declarations' is shown as clickable even when there aren't any health declarations to display. When the user selects the option, an error message is displayed stating that there are no declarations to display [42]	Between-page	Visibility of System Status	Increased EHR interaction time; Inability to access needed information may impede clinical workflow	Use informative hyperlink text and titles; Communicate to user whether data exists in destination page

commercial systems (33%), and four (19%) of the studies provided an inadequately detailed description of the system to determine whether it was a commercial product. Characteristics of the usability evaluations and their methodologies are summarized in Table 1.

5.2. Results of qualitative analysis

Navigation actions were mentioned in 20 of 21 articles reviewed (Table 2). The total number of mentions per article ranged from 1 to 19. Navigation between EHR pages was the most frequently mentioned type of navigation action (86%), followed by navigation within a single EHR page (14%). Navigation was mentioned in each usability evaluation methodology represented in the eligible article pool (e.g., task analysis, think aloud protocol) and evaluation settings (laboratory or naturalistic).

Navigation between pages was described as problematic when it required users to navigate between multiple pages to complete a task, such as the need to navigate 'across several windows', 'through two screens', or 'across a number of screen navigations' [36]. Other terms used describe the need to navigate through a 'long, multi-screen admissions documentation entry process' [28], through a 'number of different data screens' [40], 'away' from the current screen [30,38], 'between screens' [17], 'to the next tab' [43], by 'opening and closing charts' [31], 'from one screen to the other' [30], using 'sequential feature combinations' and switching between 'two features back and forth' [32], by 'additional navigation steps' [36], from 'screen to screen' [28], through 'dialogue flow' (50), by 'clicking through note, note, note' [24], and through '17 pages of stuff' [41]. Navigation within pages was described as scrolling, 'scroll-down' [31], and 'scrollback' [41], and browsing within 'extremely large' lists [37].

Relationships between navigation actions and usability heuristics were identified in each article. Identification of relationships enabled the authors to categorize the associations between a navigation action with its potential impact on usability (Table 3). For example, scrolling (within-page navigation) could impact the degree to which the EHR affords Recognition rather than recall (usability). Unique mentions of these relationships were identified per article through consensus coding by two of the authors (LR, YS).

A total of 109 relationships between a navigation action and a usability heuristic violation were identified (Fig. 2). An excerpt describing a single navigation action could appear in multiple usability heuristic violation categories. For example, a participant in one article observed that 'after selecting a consult timer, you must scroll down to click 'Save' and I would like it to go back to the 'Main' screen instead of back to the consult timer screen' [29]. This observation describes inefficient navigation between pages in a fashion that violates both 'User control and freedom' and 'Flexibility and efficiency'. Therefore, navigation actions were captured in a one-to-many relationship when appropriate.

Overall, the usability heuristic violations most frequently associated with any navigation were Flexibility and efficiency of use (31 unique instances), followed by Recognition rather than recall (16 unique instances) and Error prevention (16 unique instances).

The usability heuristic violations most frequently associated with between-page navigation were Flexibility and efficiency of use (26 unique instances), followed by Recognition rather than recall (13 unique instances) and Error prevention (11 unique instances). Investigators and participants identified consequences of excessive between-page navigation, such as data entry errors (Table 3), including entering data into the incorrect patient chart (43).

The usability heuristic violations most frequently associated with within-page navigation were Flexibility and efficiency of use (5 unique instances) and Error prevention (5 unique instances). Scrolling was problematic when it impaired the clinician-user's ability to locate information or data entry prompts (Table 3) and when it resulted in the clinician-user's selection of an incorrect item or patient from a list [31].

Investigators and participants identified ways to improve between- and within-page navigation. One common suggestion from investigators and participants was to bring relevant information together on one page by 'pre-populating' [44] or

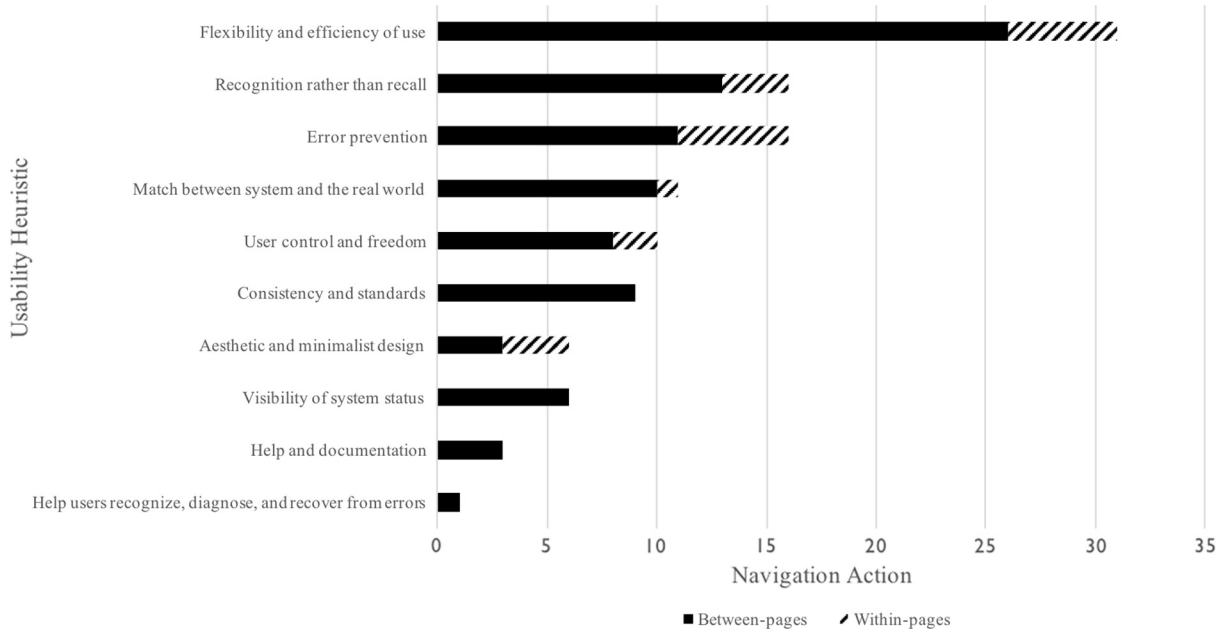

Fig. 2. Frequency of literature excerpts linking navigation actions to violations of usability heuristics.

designing pages to 'inherit' [28] information from other pages to reduce errors related to data reentry. Participants expressed the desire to minimize within- and between-page navigation by use of 'hyperlink shortcuts or 'take me to' buttons' (44), dashboards, such as 'a single screen summarizing key clinical data' and 'a multi-panel view [...] allowing concomitant views' (57), and by integrating 'relevant information and data using less windows and screens (46) in order to have information available during other tasks (41). In other words, to 'do [things] side by side' (54). Likewise, participants expressed the desire to minimize the inefficiencies of between-page navigation by 'speed[ing] up the dialogue flow' (50).

6. Discussion

We completed four aims in this study. First, we addressed the prevalence of navigation-related topics within the EHR usability and safety research literature. 95% of the articles in this study reported on navigation actions in their EHR usability evaluation. The set of manuscripts was small (21 articles met final eligibility criteria after removal of other usability articles because of lack of detail). In the context of this limitation, our finding suggests that usability researchers are already capturing navigation-related issues, albeit not as a primary aim of usability evaluation. Furthermore, navigation was mentioned regardless of usability evaluation methodology despite the diverse range of methodologies among eligible articles. These findings collectively suggest that navigation is a cross-cutting construct relevant to usability evaluations. By explicitly identifying and categorizing navigation actions in future usability evaluations, research can enable the comparison of EHRs in terms of end-user workflow to complete similar tasks. To identify the frequency of scrolling or screen-switching to document an allergy, for example, is to begin to compare EHR systems in a concrete and repeatable way. This is the type of reproducibility in EHR usability research called for by Ellsworth and colleagues' 2016 systematic review of EHR usability articles [8]. By considering navigation within a task-oriented framework, EHR usability researchers can more clearly identify the application of their findings to clinical tasks.

Second, we categorized types of navigation actions within the EHR and third, captured relationships between these navigation actions and usability principles. Based on narrative review of the general Web navigation literature, we identified a need for the construct of EHR navigation to include within-page user actions in addition to between-page user actions. The scoping literature review demonstrated that navigation between and within pages in the EHR was prevalent in the literature and that both levels of navigation were linked to usability heuristic violations, some with implications for patient safety. Although between-page navigation was more prevalent, both between- and within-page navigation were linked to Error prevention.

Multiple articles identified usability challenges related to navigating between and within pages in the EHR (Table 3). Some recommendations to address these challenges were identified in the literature, and we have linked usability challenges, safety effects, and potential solutions, including mechanisms for smart data entry and grouping together relevant information on a single page. As demonstrated in published articles [47,48], an additional design method to reduce navigation is the use of in-line, or non-interruptive, clinical decision support in lieu of additional dialogue boxes during a clinician-user's workflow. The in-line method presents users with information located on a screen normally invisible to them at the time. This type of non-interruptive alert can be safely incorporated into a clinician-user's workflow to help combat alert fatigue [47] and decrease unnecessary laboratory ordering [48]. The common strategy to improve EHR navigation suggested by this literature review was to reduce the number of actions required by users to display needed information. This strategy was often proposed by users in the desire to juxtapose clinically relevant information together on-screen to facilitate cognition. Such juxtaposition of clinical information elements in the digital space of the EHR is a predictable form of intelligent use of space as described in the literature on work practices and cognitive science [49]. Juxtaposition of information via flexible systems would address the problems inherent in the keyhole effect and resulting display fragmentation, which are sources of potential error, as described by the Institute of Medicine [3]. Display fragmentation presents particular dangers in EHRs because of the high cognitive demands of clinical reasoning, often in stressed conditions. Thus there is great need for information systems that do not place unnecessary load on working memory, freeing the clinician-user's cognitive resources for higher reasoning. Therefore, improving EHR navigation may result in multiple benefits to users, such as cognitive support for complex clinical reasoning, in addition to greater efficiency and advantages for patient safety.

Our fourth aim in completing this literature review was to collect terms and concepts related to EHR navigation. The variety of terminology (e.g., navigation action verbs, user interface components) used to describe concepts related to navigation created some challenges to identifying and comparing articles. This result highlighted a barrier to clearer description of EHR-based navigation. The collection of specific instances of navigation problems may also serve as a starting point for explanation of the problems to interaction designers in our search for design solutions. To help make those design solutions comprehensive, EHR navigation research can consider navigation within a task-oriented framework so that the application of research findings to specific design problems in clinical workflow is more readily apparent.

Limitations of this study include the use of a single reviewer in the first phase of the article selection process, increasing the possibility of potential missed articles, and the small number (n = 21) of articles determined to be eligible for review. However, this small yield was somewhat expected based on the recent scoping review by Ellsworth and colleagues [8] that demonstrated low reproducibility and a large amount of qualitative findings in EHR evaluation research. This fact, in addition to our strict inclusion criteria (for example, the requirement for evaluations to use analytic or user test methods), reduced the corpus of eligible literature for consideration. Notably, our decision to include only evaluations of entire EHRs meant excluding articles on computerized provider-order entry (CPOE) modules when the evaluation was limited to the single module, which meant excluding a robust portion of the EHR-related usability literature. This limitation was accepted as a compromise to ensure we would capture substantial between-screen navigation, such as that which frequently occurs with a clinician-user's need to access multiple modules for a single EHR-based clinical task. It is likely that inclusion of articles limited to CPOE modules would have increased the prevalence of mentions of within-page navigation actions because scrolling has been linked to electronic prescribing errors, whether scrolling through large EHR pages [50] or individual drop-down lists [51].

This scoping review is by definition limited to identifying the construct of EHR-based navigation among a broad combination of study methodologies. We were limited to identifying mentions of this construct in the published literature, with the aim of providing the foundation for future research to pose more

narrow research questions, such as identifying the impact of the frequency or consecutive repetition of navigation action types on usability.

Another limitation of this review was our decision to omit the Cumulative Index to Nursing and Allied Health Literature (CINAHL) database from the search strategy. Given that MEDLINE & EMBASE provide key coverage of important nursing and allied health journals it is unlikely that CINAHL would have provided additional, critical articles for the present topic, electronic health record usability, which is not unique to the nursing and allied health fields. However, we acknowledge this potential weakness of our search strategy. Lastly, the published articles describing the usability evaluations were the authors' only source of knowledge of the actual EHR user interfaces and navigation mechanisms. Further research is needed to expand this description of navigation to include more detail in the form of sub-categories.

7. Conclusion

Improving our understanding of navigation and what constitutes ideal pathways in clinical tasks that require use of the EHR is one aspect of the larger goal to improve EHR usability engineering. We observed that navigation was frequently mentioned in EHR usability evaluations but was seldom the primary aim. This observation suggests that navigation is a potential target for normative recommendations for EHR usability design and evaluation. To this end, future research should address the lack of standard terminology for describing EHR navigation. Ultimately, the ability to describe navigability across systems may be of national interest in improving interaction design for safety. Because of the critical nature of EHR components such as CPOE to patient safety, future research should determine whether specific EHR components need their own normative recommendations for navigation.

Conflict of interest

None declared.

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Appendix A

See Tables A.1–A.3.

Table A.1
Electronic literature search terms for EMBASE[a].

1	Medical records systems, computerized/	
2	Limit 1 to yr = "1996-current"	
3	((Interaction or interface) adj2 design).tw.	
4	Usability.tw.	
5	(Exp safety/OR Err$. ti,ab.) AND (patient$.ti,ab.) AND (Exp Health Care Organization/ OR Exp Health Care/ OR Medic$.ti,ab. OR Exp Health Care System/ OR Hospital$.ti,ab.)	
6	3 or 4 or 5	
7	1 and 2 and 6	2623

[a] EMBASE (OVID) 1974 to 2016 Week 06.

Table A.2
Electronic literature search terms for MEDLINE[a].

1	Medical records systems, computerized/	
2	Limit 1 to yr = "1996-Current"	
3	((Interaction or interface) adj2 design).tw.	
4	Usability.tw.	
5	*Medical errors/	
6	3 or 4 or 5	
7	1 and 2 and 6	732

[a] MEDLINE (OVID) In-process & Other Non-Indexed Citations and Ovid MEDLINE (R) 1946 to Present.

Table A.3
Electronic literature search terms for ENGINEERING VILLAGE.

1	(Medical information systems) WN CV	
2	(User interfaces) WN CV	
3	(User centred design) WN CV	
4	(Human computer interaction) WN CV	
5	(Safety)	
6	(Safety-critical software) WN CV	
7	(English) WN LA	
8	2 or 3 or 4 or 5 or 6	
9	1 and 7 and 8	979

Appendix B

See Table B.1.

Table B.1
Articles excluded from abstract review.

Reason for exclusion	N	Detailed explanation
Methodology paper	11	Description of methods with no robust case evaluation
Lack of UI description or analysis	5	Evaluations with no written or visual depiction of the UI or elements of the UI
Single EHR module	5	Articles that described usability evaluations of a single feature of EHR (e.g. Allergy module)
Abstract only	4	Articles with no full-text version available
Subject was user performance, not UI	2	Articles that compared the performance of two groups of EHR users
Not EHR	1	Evaluations of other clinical information systems
Single UI feature	1	Evaluations of a single feature of the UI (e.g. search function)
Limited to user perceptions	1	Evaluations of user perceptions without written or visual depiction of the UI or elements of the UI
Mobile version of EHR	1	Articles that described usability evaluations of mobile device versions of EHRs
Total	31	

UI: user interface; EHR: electronic health record.

Appendix C

See Table C.1.

Table C.1
Classification scheme used to organize full-text review of eligible articles.

Author	Year	Title	Country	Study Design	Setting	Participants (N)	Background of Participants	EHR type	Survey	Think aloud protocol	Interview	Heuristic Evaluation	Cognitive Walkthrough	Task analysis	KLM	GOMS	Field observation	Semiotic Inspection Method	Methods (N)
Ahmed A, Chandra S, Herasevich V, Gajic O and Pickering BW	2011	The effect of two different electronic health record user interfaces on intensive care provider task load, errors of cognition, and performance	United States	Both	Laboratory	20	Clinical	Homegrown	1			1		1					3
Corrao NJ, Robinson AG, Swiernik MA and Naeim A	2010	Importance of testing for usability when selecting and implementing an electronic health or medical record system	United States	Both	Laboratory	4	Clinical	Commercial	1	1		1							3
Edwards PJ, Moloney KP, Jacko JA and Sainfort F	2008	Evaluating usability of a commercial electronic health record: A case study	United States	Inspection methods only	Laboratory	6–8	Clinical	Commercial				1	1						2
Fairbanks RJ, Guarrera TK, Karn KS, Caplan SH, Shah MN and Wears RL	2008	Interface design characteristics of a popular emergency department information system	United States	Inspection methods only	Naturalistic (ED)	3	Clinical	Unknown			1	1					1		3
Hoyt R, Adler K, Ziesemer B and Palombo G	2013	Evaluating the usability of a free electronic health record for training	United States	Test methods only	Laboratory	Unknown	Non-clinical	Commercial	1					1					2
Kukec M, Ljubic S and Glavinic V	2011	Need for usability and wish for mobility: Case study of client end applications for primary healthcare providers in Croatia	Croatia	Inspection methods only	Laboratory	8	Non-clinical	Homegrown				1							1
March CA, Steiger D, Scholl G, Mohan V, Hersh WR and Gold JA	2013	Use of simulation to assess electronic health record safety in the intensive care unit: A pilot study	United States	Test methods only	Naturalistic (Medical ICU)	38	Clinical	Commercial						1					1
Neri PM, Redden L, Poole S, Pozner CN, Horsky J, Raja AS, Poon E, Schiff G and Landman A	2015	Emergency medicine resident physicians' perceptions of electronic documentation and workflow: A mixed methods study	United States	Test methods only	Laboratory (medical simulation center)	8	Clinical	Homegrown			1			1					2
Pereira R, Duarte J, Salazar M, Santos M, Neves J, Abelha A and Machado J	2012	Usability evaluation of electronic health record	Portugal	Inspection methods only	Laboratory	6	Non-clinical	Unknown				1	1						2
Ramsay J, Popp HJ, Thull B, Rau G	1997	The evaluation of an information system for intensive care	Germany	Test methods only	Laboratory	30	Clinical	Homegrown		1	1			1	1				4
Rogers ML, Sockolow PS, Bowles KH, Hand KE and George J	2013	Use of a human factors approach to uncover informatics needs of nurses in documentation of care	United States	Test methods only	Laboratory	12	Clinical	Unknown		1		1							2
Saitwal H, Feng X, Walji M, Patel V and Zhang J	2010	Assessing performance of an electronic health record (ehr) using cognitive task analysis	United States	Inspection methods only	Laboratory	2	Non-clinical	Homegrown						1	1	1			3

(*continued on next page*)

Table C.1 (*continued*)

Author	Year	Title	Country	Study Design	Setting	Participants (N)	Background of Participants	EHR type	Survey	Think aloud protocol	Interview	Heuristic Evaluation	Cognitive Walkthrough	Task analysis	KLM	GOMS	Field observation	Semiotic Inspection Method	Methods (N)
Scandurra I, Hagglund M, Mostrom D and Koch S	2006	Heuristic evaluation extended by user analysis: A fast and efficient method to identify potential usability problems in health information systems	Sweden	Inspection methods only	Laboratory	6	Clinical	Homegrown				1							1
Senathirajah Y, Kaufman D, Bakken S	2010	Cognitive Analysis of a Highly Configurable Web 2.0 EHR Interface.	United States	Test methods only	Laboratory	13	Clinical	Homegrown	1	1									2
Senathirajah Y, Kaufman D, Bakken S	2016	User-composable Electronic Health Record Improves E ciency of Clinician Data Viewing for Patient Case Appraisal: A Mixed-Methods Study	United States	Both	Laboratory	11	Clinical	Homegrown		1				1					2
Shachak A, Hadas-Dayagi M, Ziv A and Reis S	2009	Primary care physicians' use of an electronic medical record system: A cognitive task analysis	Israel	Test methods only	Naturalistic (PCP's offices)	25	Clinical	Commercial			1			1			1		3
Staggers N, Jennings BM and Lasome CE	2010	A usability assessment of AHLTA in ambulatory clinics at a military medical center	United States	Test methods only	Naturalistic (ambulatory)	17	Clinical	Homegrown		1	1	1		1			1		5
Tancredi W and Torgersson O	2013	An example of an application of the semiotic inspection method in the domain of computerized patient record system	Sweden	Inspection methods only	Laboratory	Unknown	Unknown	Unknown										1	1
Thyvalikakath TP, Monaco V, Thambuganipalle HB, Schleyer T	2008	A usability evaluation of four commercial dental computer-based patient record systems	United States	Both	Laboratory	20	Clinical	Commercial				1		1					2
Walji MF, Kalenderian E, Tran D, Kookal KK, Nguyen V, Tokede O, White JM, Vaderhobli R, Ramoni R, Stark PC, Kimmes NS, Schoonheim-Klein ME and Patel VL	2013	Detection and characterization of usability problems in structured data entry interfaces in dentistry	United States	Both	Both	68	Clinical	Commercial	1		1			1			1		4
Zheng K, Padman R, Johnson MP and Diamond HS	2009	An interface-driven analysis of user interactions with an electronic health records system	United States	Test methods only	Naturalistic (resident clinic)	30	Clinical	Homegrown						1					1

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Glossary

Display fragmentation: phenomenon resulting from the separation of potentially related patient data across multiple sections of an electronic health record [1–3]

Keyhole effect: a phenomenon defined by artificial intelligence to describe the restriction of a user's view of the total relevant information to a portion of the relevant information [4]

Navigability: the degree to which the presentation and controls of the EHR graphical user interface afford these actions

Navigation: interaction with user interface presentation and controls that allows users to locate and access needed information