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A Systematic Review on the Designs of Clinical Technology

Findings and Recommendations for Future Research

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Human factors (HF) studies are increasingly important as technology infuses into clinical settings. No nursing research reviews exist in this area. The authors conducted a systematic review on designs of clinical technology, 34 articles with 50 studies met inclusion criteria. Findings were classified into 3 categories on the basis of HF research goals. The majority of studies evaluated effectiveness of clinical design; efficiency was fewest. Current research ranges across many interface types examined with no apparent pattern or obvious rationale. Future research should expand types, settings, and participants; integrate displays; and expand outcome variables. **Key words:** *human-computer interaction*, *human factors engineering*, *medical device*, *medical error*, *patient safety*, *usability*, *user interfaces*

HAVING usable technology is an imperative for contemporary nurses. Less optimal technology designs affect error generation and productivity, create extreme frustration, and even result in system deinstallation. The design and development of usable technology can better be ensured by using human factors (HF) concepts. HF principles, research methods, and techniques are widely available outside healthcare to enhance nurse-technology interaction effectiveness, efficiency, and user satisfaction. Yet, these critical elements only trickled into healthcare in the early 1990s despite having completely penetrated other industries such as aviation.

The Institute of Medicine (IOM) ushered HF concepts into the healthcare consciousness by linking HF to error prevention.[1] Research in HF, usability, and human-computer interaction, all related concepts, expanded greatly over the past 10 to 15 years. However, no review exists for examining available HF-related research or its diffusion into the nursing arena. Thus, the purposes of this article were to (1) systematically review the literature for HF-related research in healthcare, (2) evaluate the impact to nursing areas of interest, and (3) recommend future research directions.

BACKGROUND

HF is a broad term for a set of related concepts about human interactions with tools in associated environments. Figure 1 depicts these concepts and their relationships.[2] All HF-related concepts consider human needs, abilities, and limitations, including cognitive aspects, and assert an axiom of user-centered

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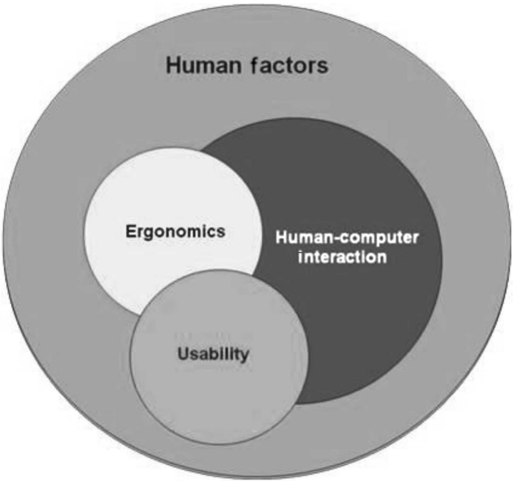

Figure 1. The relationship of human factors concepts. Adapted from Staggers.[2]

design.[3,4] HF encompasses the design, use, and evaluation of tools in a broad sense to a wide variety of tools—for instance, the design and use of an airplane cockpit, the design of a hammer to fit the female human hand, or incorporating known concepts about human memory and attention to improve work systems for successful sponge counts in an operating room. Ergonomics emphasizes physical attributes and designs of tools such as the size of lettering on intravenous (IV) pump so that labels are viewable from across the patient's bed, the design of a computer mouse, or the layout of equipment in an intensive care unit (ICU) to promote optimal workflow. Human-computer interaction focuses on computers and applications for humans while its closely related concept, usability, stresses the design, interaction, and evaluation of both devices and computer applications by examining specific tasks and interaction outcomes within particular contexts. Examples include the design of an electronic medication administration record for multidisciplinary use, and its subsequent redesign for specific tasks unique to an emergency department setting. Human-computer interaction can also include the design of software to support a group of users working on a shared document or social sanctions from inappropriate blogs among a group of clinicians discussing cardiomyopathy research.

The unique methods available from the HF domain allow researchers to elicit critical thought processes (eg, cognitive task analysis), work methods (eg, naturalistic observation), and/or tasks that are crucially important for the design of tools, devices, and information systems. Research methods such as ethnographic and qualitative techniques are also useful in defining key user requirements for tools and evaluating existing tools for effectiveness.

Most important, the commonly held goals of HF are to improve the effectiveness, efficiency, and satisfaction of humans interacting with tools (Fig 2).[5] Effectiveness includes the usefulness of a tool to complete work (tasks) and the safety of the tool. Examples of efficiency include productivity such as the time to complete specific tasks, the number of clicks to perform tasks, the costs of the tools, and/or the amount of training time needed for users to learn a software application. Satisfaction can include the perception of any aspect of the tool and typically includes perceptions about workload or the effectiveness of the specific design.

In this article, we focus on the design and evaluation of user interfaces for clinical technology. Optimal technology design is vital to healthcare because the work and associated tools can be life-critical. For example, in a tragic event, faulty software design for controls in a radiation machine caused a patient to scream in pain during treatment and later die because of a radiation overdose.[6] Zhang et al[7] and Graham et al[8] both outline serious usability problems with IV pumps, including

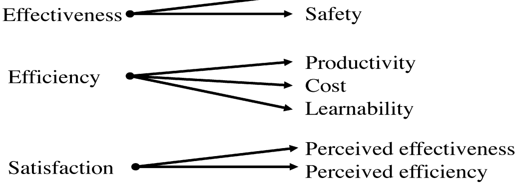

Figure 2. Human factors research goals. Adapted from Staggers.[2]

issues that are likely to cause medical errors. Given the considerable impact of HF in healthcare, we examined available research about the design of clinical technology organized by using the goals of HF: design effectiveness, efficiency and satisfaction.

METHODS

Formal methods were used to perform a systematic review and ensure a thorough search and retrieval process. Procedures included article relevance assessments, data extraction, and data analysis.[9] Poor quality studies were not eliminated, as it is common in many systematic reviews, because our goal was to describe the available HF research in healthcare. The years 1980–2009 were included. Substantial technology changes for devices and information systems since 1980 would make earlier references not pertinent. Criteria for inclusion were as follows: peer review publications in English; stated research findings; any study design or method from any country; analyses of medical devices, tools, user interfaces, clinical information systems, and electronic health records (EHRs) in healthcare environments; and any user including health providers or patients. Excluded articles were studies about ergonomics (eg, cumulative trauma disorders, and occupational medicine); in conference proceedings; about medical transcription devices; about descriptions of HF-related concepts without research findings; about usability analyses in nonhealthcare settings, about designs solely for patients; and about descriptions of work activities or error analyses.

Extensive literature searches were conducted by using the research databases Cumulative Index of Nursing and Allied Health Literature (CINAHL), Ovid MEDLINE, PsycINFO, INSPEC, and the Evidence-Based Medicine (EBM) Reviews: Health Technology Assessment Database (CLHTA) from 1980 to 2009. Key search terms were as follows: (human-computer interaction or HCI) and (human factors or usability) and (health$ or healthcare or medical) and (nurs$). Reference lists of publications were checked for any additional references. Authors independently reviewed citations for relevancy and applied the relevancy criteria; any questionably relevant articles were discussed until consensus was reached. The authors focused on technology targeted to clinicians only.

RESULTS

The search criteria yielded 11 916 articles; delimiting articles to those with health$ or healthcare or medical terms resulted in 2234 articles; again delimiting this search to articles with a nursing emphasis resulted in 215 articles. The abstracts from this set of 215 articles were reviewed; 34 articles met the relevance criteria. These articles are summarized in Table 1 with all usability findings. Authors of 18/34 articles examined 17 different application or screen design interfaces and authors of 6/34 studies evaluated 5 different graphical interfaces, 5/34 different remote/telemedicine systems, and 5/34 different medical device user interfaces.

Authors included multiple outcome variables; these details are found in Table 2, divided into 50 separate studies. Studies were then classified into 3 categories based upon goals for HF research: effectiveness (24/50), efficiency (10/50), and satisfaction (16/50). The study design and aims, sample, setting, methods, and findings were extracted from each relevant article.

Evaluations in effectiveness

Authors of 24 studies evaluated effectiveness aspects of user interfaces. Effectiveness is the usefulness and safety of an interface in completing a task (See Fig 2). Authors of 7 studies illustrate the variability of types of software being tested, for example, the usefulness of software that automatically created a family pedigree diagram from family history data, a mobile medical emergency services medical record for paramedics, a laboratory

Table 1. Types of user interfaces by major findings across combined effectiveness, efficiency and satisfaction categories

Source (First author)	UI type	Major findings
Graphical displays (6)		
Effken[10]	Graphical interfaces	Novel display type positively affected amount of drug usage and target range, but not time to treatment.
Staggers[11]	Graphical versus text interfaces	Response time faster, fewer errors, and higher satisfaction with graphical interface for orders management.
Effken[12]	Graphical interfaces	Display type positively affected successful treatment, amount of drug usage, and vitals target range; visualizers (cognitive style) kept vital signs in target range.
van der Meijden[13]	Graphical interfaces	Usability assessment due to underutilization and low satisfaction; issues in information and quality, training, and project communication most important
Liu[14]	Graphical interfaces	Fewer user errors with graphical interfaces.
Lamy[15]	Graphical interfaces	More correct responses with graphical interfaces.
Medical Device Interfaces (5)		
Lin[16]	PCA pump	Complex programming sequences increase user cognitive workload.
Lin[17]	PCA pump	Redesign of PCA modes decreased errors and improved task completion time.
Zhang[7]	1-Channel IV pump	One hundred ninety-two heuristic violations in 1 pump; serious violations can lead to error.
Graham[8]	3-Channel IV pump	Two hundred thirty-one heuristic violations; severe violations in consistency, flexibility, and undo.
Despont-Gros[18]	Digital pen technology	Unexpected cognitive burden placed on users; high acceptance.
Mobile/remote devices (5)		
Lindberg[19]	Telemedicine system	Sound and visual quality of telemedicine interfered with care processes
Lin[20]	Wireless PDA with physiological monitoring	High rating on performance in mobility, ease of use, and monitoring.
Hun Yoo[21]	Mobile diabetes management system	Cognitive workload greater with increasing system operations; task time and error rate negatively affected by workload.
Tang[22]	Digital emergency medical telemedicine system	21/48 usability problems rated as catastrophic due to poor visibility and inadequate data synchronization.
Wu[23]	Hand-held electronic medical record	Good usability included intuitive features, accessibility to information, to be considered usable needs to be fast and time saving; information completeness, ordering details, billing functionality, and integration were other concerns.

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Table 1. Types of user interfaces by major findings across combined effectiveness, efficiency and satisfaction categories (*Continued*)

Source (First author)	UI type	Major findings
Application/screen designs (18)		
Staggers[24]	Levels of screen density	Found information faster, more accurately, and high satisfaction on high density.
Mills[25]	Levels of screen density	Cognitive characteristics predicted users' time and accuracy.
Terazzi[26]	Clinical laboratory software	User perceived lack of control of software.
Fuchs[27]	Clinical decision support	Converted from simple man-machine interface with complex data entry to graphics; processing time 1minute per case; software easy to use, comprehensive, and useful in cancer risk evaluation/early cancer detection.
Alberdi[28]	Trend monitoring system	Clinicians would observe patient first, then use trending as adjunct only.
Horsky[29]	Order entry system	Considerable cognitive demands on users and patient safety errors
Patterson[30]	Clinical decision support	6/19 barriers (#1 = workload reduced effectiveness of clinical reminders).
Johnson[31]	Family pedigree software	Less time on redesigned interface
Hortman[32]	Nurse practitioner outcomes database	Mean satisfaction scores 3–8 (of 9). Discovered unclear elements, for example, date field and how to enter vital signs.
Chaikoolvatana[33]	Diabetes management tool	Useful, easy to use, and understandable; easy to move from one topic to another and designs, colors, figures, and diagrams were appropriate; quality of audio and completion time a user concern.
Allen[34]	Paper based screen shots	100 heuristic violations; 41% related to consistency.
Peute[35]	Laboratory order entry system	25 usability problems—flexibility, navigation, visibility, and word meanings.
Staggers[36]	Electronic medication administration record	High user satisfaction but only 90% of medication tasks completed correctly.
Wallace[37]	3 patient care guideline interfaces	More successful searches, greater accuracy with homegrown interface than proprietary ones.
Edwards[38]	Commercial electronic health record	134 potential usability issues; 10% rated as severe.
Martins[39]	3 interfaces displaying longitudinal clinical data	Higher complexity queries answered faster with computerized interfaces versus paper charts.
Narasimhadevara[40]	Interface for transplant nurses	Absence of the ability to edit certain documents led to poor usability ratings in control. Overall high scores for helpfulness, learnability, and efficiency.
Fonda[41]	Internet based diabetes management program	Neutral to favorable usability scores. Higher ratings for visual appeal, content versus ease of use, performance, and support features.

Abbreviations: IV, intravenous; PCA, patient-controlled analgesia; UI, user interface.

Table 2. Evidence table of clinical technology design (User Interface) studies

Source	Study design, aims	Sample setting	Methods	Findings
Effectiveness				
Lindberg[19]	Evaluated home telemedicine device for usability.	Four RNs; 4 rural project sites, 38 elderly or people with disability, Kansas.	Three case studies of patients. Most usability issues detected during informal interviews between telemedicine nurses, VP of nursing.	Adequate sound quality is important, but technically difficult to achieve. Nurses found computerized data collection process awkward, time-consuming, and manner of answering questions cumbersome (related to a software design problem). Core of problem is a mismatch between telemedicine, standard nursing procedures, and protocols.
Effken et al[10]	Study 1: Compared 3 display types—TSD, IBD, and EPD on time to initiate treatment, detect critical events. Study 2: Displays changed, same variables. Study 3: Studied novice, expert nurses.	Study 1: 19 psychology undergraduates. Study 2: 13 psychology undergraduates Study 3: 6 expert, 6 novice critical care nurses.	Study 1: 6 trials (3 scenarios × 2 trials) for common ICU clinical problems. Study 2: Same methods except participants allowed to practice with display. Study 3: Same displays, methods.	Study 1: Display type not significant on time to initiate treatment; TSD and IBD had greater number of drugs than those of EPD; percentage in target range greater for EPD. Study 2: EPD $<$ IBD $<$ TSD for time to initiate treatment and number of drugs used. Study 3: Experts outperformed novices in time in target range when using TSD and IBD. Experts neither did initiate treatment later nor did they use fewer drugs than did novices.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Lin et al[16]	Study 1: Determined design flaws for PCA. Study 2: Compared old/new PCA perceived mental workload.	Study 1: 9 nurses, recovery room, large medical center. Study 2: 12 nursing students laboratory setting, Canada.	Study 1: Interviews, observations PCA pumps. Study 2: Used common programming tasks workload measured by NASA-TLX.	Study 1: Complex programming sequences in old PCA; no way to remind users how many parameters to program into PCA, sequence, steps completed, and remaining. Study 2: Participants exposed to old interface first benefit most; vice versa had less benefit. No differences in mental workload.
Terazzi et al[26]	Evaluated homegrown clinical laboratory procedures software against known commercial software.	Forty-four users in cardiology, in-house laboratory, third-party laboratory (14); hospital and rehabilitation institute, Italy.	Interviews	User interviews confirmed perceived lack of control influenced by unexpected program faults (eg, software stops unexpectedly) occurring after initial implementation.
Fuchs et al[27]	Evaluated a computerized clinical decision support system (CaDet) used to detect cancer on validity, reliability, and usability.	Study 1: 250 case histories of patients with cancer. Study 2: 60 outpatients. Study 3: 5 general practitioners, 60 patients, Israel.	Study 1: Determined relative risk of patients having cancer and need for provider action. Study 2: Compared CaDet with actual clinical information.	Study 1: 82% of tumor cases would have been called to the physician's attention before the cancer was diagnosed. Study 2: CaDet alerted 3 cancer cases by high scores, 6 others had no cancer but nonmalignant pathology justified diagnostic procedures. No alert in 51 patients and no cancer found.
Alberdi et al[28]	Evaluated computerized trend monitoring system (MARY) on the use for clinical decision making.	Fifteen physicians, 19 nurses interviewed; 15 physicians, 10 nurses in simulated trends; NICU, United Kingdom.	Eight observation sessions for 1–2 hours. Think aloud sessions during 14 simulated trend graphs reviews.	<50% would use MARY as primary source. Would observe baby first; use computerized monitors next. Junior doctors relied on information from direct patient contact, Senior doctors relied on data provided by monitors.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Effken and Doyle[12]	Compared cognitive style (visual or verbal) and 3 interface designs. TSD, IBD, EPD on time to initiate treatment, number of drugs used, and time in target range.	Eighteen undergraduate nursing students, Arizona Health Sciences Center, Tuscan, Arizona.	Computer simulations of hemodynamics using 3 scenarios (hypertension, heart failure, and fluid overload) in 18 trials. Visual, verbal scales from Richardson's Verbalizer-Visualizer Questionnaire.	Clinical problems treated most successfully with EPD (80%). Patients in target range more often with EPD > IBD, TSD. Visualizers kept patient within target range 54% of the time; verbalizers 44%. Visualizers (79%) corrected more problems than did verbalizers (60%). Students quicker to initiate treatments, used fewer drugs with EPD > IBD, TSD. Visualizers scores related to how often to the percentage of time system kept in target range by using EPD.
Horsky et al[29]	Study 1: Characterized interaction complexity. Study 2: Identified sources of error, performance with an order entry system.	Study 1: 2 researchers. Study 2: 7 physicians, laboratory setting.	Development version of a commercial system. Study 1: Modified cognitive walk-through using 7 orders. Study 2: 6 clinical scenarios, wrote orders, talked aloud, were videotaped × 1 hour.	Study 1: Considerable demands on user cognitive resources (details given). Users must remember system-specific knowledge at strategic points. Study 2: Errors per user = 1–5. 5-omitted orders; 2-wrong allergy data; 1-wrong order set, others; patient safety implications. Heavy cognitive demands, especially on users lacking a conceptual model of system.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
van der Meijden et al[13]	Compared workstations (graphical, electronic record for stroke patients) on work coordination.	Twelve physicians, acute care hospital, The Netherlands.	Audiotaped, transcribed in-depth interviews. Short questionnaires about use. Stroke UI evaluated via chart reviews, usage logs interviews coded and analyzed by using Nud*IST.	Usage pattern of the GUI varied by type of clinical area. Four points emerged after analyzing interview data: system information and quality, use, training and support, and communication. Three themes were rated as very important to users of the stroke UI including: system information quality, use, and project communication. Only stroke interface had all required functionality. Number of available workstations too limited. Consulting physicians refused to use stroke interface.
Zhang et al[7]	Evaluated two 1-channel volumetric infusion pumps against 14 heuristics to determine patient safety issues.	Four graduate students (IT, psychology), 2 different 1-channel volumetric infusion pumps, Houston, Texas.	Used 14 heuristic evaluation factors (combined Nielsen and Shneiderman factors and tailored to medical devices)	One hundred ninety-two heuristic violations (against recommended methods) across 89 usability problems in pump 1; 121 violations for 52 usability problems in pump 2. Pump 1 had more serious problems likely to lead to medical errors. Volumetric infusions pumps were not identified by authors.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Graham et al[8]	Evaluated 3 channel IV infusion pump interface against 14 heuristics.	Three cognitive science experts; 1 senior ICU RN; One 3-channel IV pump, United States.	Used 14 heuristic evaluation factors (from Nielsen, Shneiderman and tailored to medical devices).	Two hundred thirty-one heuristic violations (deviations from recommended design methods); most violations in consistency and language. Fewest violations occurred under "Help and Documentation" when help was needed. Severe violations requiring immediate attention were across factors including *consistent* meaning of words, *flexibility* in creating shortcuts, and *undo*, which allows a user to reverse actions to recover from errors.
Liu and Osvalder[14]	Compared numerical and graphical ventilator displays on meaning of deviations from normal.	Six expert ICU nurses, university hospital. Usability testing: 20 nursing students, Sweden.	Six task randomized scenarios; 4 pilot tests prior to usability study.	Nurses had difficulty understanding traditional numerical diagrams; ventilator modes modified on the basis of interviews. Graphical interface induced fewer errors about the meaning of deviations.
Patterson et al[30]	Determined potential barriers to the use of computerized reminders.	Two pilot study; 6 study sites; 59 interviews of physicians, nurses, pharmacists, and others. Twenty-nine observations of attendings, 1 nurse, 4 case Managers, Virginia.	Two observers did field observations while providers used 10 HIV clinical reminders; Semi-structured interviews and handwritten notes.	Six of 19 barriers reduced effectiveness of HIV reminders at more than one site due to workload, time to document why reminder did not apply, inapplicability to situation, training, quality of patient-provider interaction, and use of paper forms.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Johnson et al[31]	Developed and evaluated a new interface for family history. Study 1: Design requirements. Study 2: User needs. Study 3: Compared new UI to 3 other pedigree drawing programs on functionality, usability. Study 4: Heuristic evaluation of new UI. Study 5: Usability test of new versus old on time.	Study 1: Healthcare providers in Texas. Study 2: 481 members from Genetic Counselors Society. Study 3: 2 unspecified experienced users. Study 4: 8 unspecified participants. Study 5: 16 unspecified participants.	Study 1: Task analyses, heuristic evaluation of old UI, open-ended questions. Study 2: Survey for functional needs. Study 3: Entered 10 families' data into the original family pedigree program. Study 4: 12 common tasks with new interface. Heuristic evaluation by researcher. Study 5: 12 tasks.	Study 1: Current problems—visibility, consistency, use of natural language, informative feedback, minimizing memory load, reversible actions, error messages, and flexibility. Study 2: Most used function = drawing a pedigree freehand. 30% used computers to collect family history. Study 3: Editing time for direct manipulation (2.6 minutes), form fill-in (10.5 minutes). Study 4: Major problems on new UI for how to begin, continue data entry, and label information on pedigree. Redesigned. Study 5: 13–14 minutes less time on redesigned version.
Hun Yoo and Chul Yoon[21]	Evaluated a mobile diabetic management system on difficulty of use and task completion times.	Forty participants, virtual laboratory.	Two tasks in the same order. Developed CDI relation between information, interface, and task procedure experience. Simulator tracked mouse movements and task times.	Comparisons of CDI, user performance tests closely related; number of interfaces, available operations affect the cognitive operations, difficulty experienced by users mean time for tasks 1 and 2 was 134.2 seconds and 67.2 seconds, respectively; and error rate was lower for task 2.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Tang et al[22]	Study 1: Compared 2 early prototypes for emergency medical system on usability heuristics. Study 2: Conducted a field study of fourth prototype.	Study 1: 3 usability experts. Study 2: 2 paramedics Houston, Texas.	Study 1: First, second of 4 prototypes compared on 14 usability heuristics; severity rating 0 to 4 (none to catastrophic problem). Study 2: Videotaping of 2 ambulance runs.	Study 1: First, second prototype—Usability problems 45/26; heuristic violations 93/47, and average severity rating 2.84/2.80. Most due to consistency, visibility, match to the real world violations. Study 2: 48 usability problems of which 21 described as major or catastrophic requiring immediate attention, such as not providing visible feedback when a user created a new patient record during an emergency run and also, lack of data synchronization among different system components; 6/21 problems had negative effect on paramedic performance during emergencies.
Allen et al[34]	Evaluated paper-based screen shots from a Web site by using a condensed set of heuristics.	Four usability experts, 18 screen shots, laboratory setting, eastern United States.	Five heuristics.	One hundred violations; 41% consistency; 41% minor; 22% low priority; 22% major usability problem; and 6% usability catastrophes Designers able to fix 70% of all issues. Validated the use of just 5 (vs 14) heuristics.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Despont-Gros et al[18]	Evaluated a digital pen and paper technology on fit with work processes.	Thirty-three ER nurses, University hospital ER, Geneva, Switzerland.	Pretrial observation to understand triage process; ethnographically informed observations over 7 days; acceptance survey (developed by the authors; 5 axes: recorded users).	A total of 1183 triage forms; 22 surveys ER: interruptive patterns, complex lifecycle of triage form, intricate user interactions on form, and speed of decisions. Pen: improvement; acceptance "high" but unexpected cognitive burden (looks like a pen but does not behave like one; having to remember to validate data not typical for paper form; pen cap is a power switch).
Peute and Jaspers[35]	Determined critical problems with laboratory order entry system and analyzed critical data entry problems.	Two analysts usability testing: 7 users (3 neurologists; 4 neurologists in training), laboratory setting, The Netherlands.	Cognitive walk-through: 6 tasks and 29 actions. Coded goal problems (wrong task), action problems (does not know correct action); Severity rated. Usability testing: Think aloud; 4 scenarios to order laboratory tests.	Cognitive walk-through identified 25 potential usability problems (eg, inflexibility of system, inability to navigate, visibility, and incomprehensible button labels). Usability testing confirmed cognitive walk-through; 8 more problems; errors of omission; and inefficient order behavior.
Staggers et al[36]	Study 1: Determine functions for medication activities. Study 2: Determine accuracy for a novel eMAR design.	Study 1: 12 military nurses, 2 medical centers, and 1 primary care clinic, eastern and western United States. Study 2: 20 navy clinical nurses, military medical center, western United States.	Study 1: Videotaped interviews with talk aloud and semi-structured questions. Study 2: 9 "typical" medication process tasks.	Study 1: Created process flow diagrams and prototype eMAR. Study 2: 90% of all medication tasks completed correctly (low), errors in finding most current medications, and medication routes with patient safety implications.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Wallace et al[37]	Compared 3 patient care guideline interfaces (2 proprietary and 1 homegrown) on search success.	Thirty RNs, health science center, United States.	Eighteen clinical scenarios.	Higher percentage successful attempts for homegrown interface, fewer wrong items. Unsuccessful searches (18%) and incomplete searches (12%). Wrong items indicate need to refine document format, content, and indexing.
Edwards et al[38]	Determined usability issues for a commercial electronic health record (with order entry, medication administration, clinical documentation	Four usability theory or practice experts, 3–4 nursing, respiratory care experts, pediatric hospital, southeast United States.	Experts used heuristic walk-through: (1) task-focused analysis, (2) compared to Nielsen's heuristics.	One hundred-thirty four potential usability issues for admission, orders functions (44% and 28%); navigation, layout (15). 10% anticipated to be severe and most minor.
Lamy et al[15]	Compared text and graphical interfaces by question type (explicit, implicit) on errors	Eleven general practitioners, France.	Graphical had gray anatomical, functional pictograms and textual drug monograph excerpts. Searched for answers to questions.	Correct responses higher with graphical (16 vs 27). Most errors-contraindications or drug interactions GUI (5), TI (18).
Wu et al[23]	Evaluated a prototype hand-held device having an electronic medical record for usability issues, functionality.	Five family physicians, 4 internists from different settings, Toronto, Ontario.	Three clinical scenarios. Think aloud sessions, audio and video recorded.	52/54 required tasks completed. Five major themes developed during usability sessions by using mobile EMRs including design and system characteristics, device dimensions including difficulty entering information on small devices, ability to review record, and completeness of information, ability to order tests, add comments to orders and confirmation of orders, and integration of preferred functionality such as decision support and billing systems.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Efficiency				
Staggers and Mills[24]	Compared 3 levels of laboratory information density displays on speed, accuracy.	One hundred-ten clinical nurses (ICU; medical surgical; maternal-child) in a medical center, eastern United States.	Character-based laboratory data; 40 tasks in 5 interaction blocks.	Information found twice as fast on high versus low density screens overall and after practice. No difference in accuracy; error rate was 4%.
Mills and Staggers[25]	Correlated spatial memory, spatial visualization, and perceptual abilities on nurses' time, errors, for 3 levels of laboratory information.	One hundred ten clinical nurses (ICU; medical surgical; maternal-child), medical center, eastern United States	Character-based laboratory data; 40 tasks in 5 blocks.	Nurse cognitive characteristics predicted 35.9% of speed, 21.5% accuracy; younger nurses with higher spatial memory faster on high and low density screens; and nurses with higher spatial visualization faster on moderate density.
Lin et al[16]	Study 1: Determine design flaws for a new PCA. Study 2: Compared old and new PCA on time, and error rates.	Study 1: 9 nurses, recovery room, large medical center. Study 2: 12 nursing students in a laboratory setting, Canada.	Study 1: Interviews, observations PCA pumps. Study 2: Used common programming tasks (PCA, continuous, PCA + continuous) repeated × 2 for each UI, workload measured by NASA-TLX.	Study 1: Complex programming sequences in old PCA; no way to remind users how many parameters to program into PCA, sequence, steps completed, and remaining. Study 2: Mean programming time 15% faster with new interface. Participants exposed to old interface first benefit most; vice versa had less benefit. Ten errors on new PCA and 20 on old one.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Staggers and Kobus[11]	Compared graphical, text-based interfaces on time, and error rates.	Ninety-three nurses, military medical center, eastern United States.	Ten blocks of tasks.	2× faster response time with graphical Errors 6× greater with text.
Lin et al[17]	Compared 2 PCA interface designs on time, and errors.	Twelve recovery room nurses, Toronto General Hospital, Ontario.	Performed 6 tasks on each.	Task completion faster new > old. More errors old (29) > new (13) for PCA mode selection, new UI (8) > old (4) for bolus mechanisms.
Liu and Osvalder[14]	Compared numerical and graphical ventilator displays on deviation detection time, and error rates.	Six expert ICU nurses, university hospital; usability testing: 20 nursing students, Sweden.	Six task randomized scenarios; 4 pilot tests prior to usability study.	No differences for deviation detection time and error rate in assessing overall picture.
Wallace et al[37]	Compared 3 interfaces for patient care guidelines (2 proprietary and 1 homegrown) on time.	Thirty RNs, health science center, United States	Eighteen clinical scenarios.	Successful items correctly identified among 3 interfaces ranged from 3.0 to 3.4 minutes. Unsuccessful attempts to identify items among 3 interfaces ranged from 4.7 to 5.4 minutes. Unsuccessful or incomplete search attempts were attributed to document format and organization of interfaces.
Martins et al.[39]	Compared 3 displays (KNAVE II, ESS, and paper) on efficiency, accuracy of finding answers in time-oriented clinical data typical for oncology protocols.	Study 1: 8 MD/PhD students, residents, and fellows. Study 2: 5 physicians, United States and Israel.	Study 1: 10 clinical queries of increasing complexity. Study 2: 6 queries of increasing difficulty.	Study 1: No difference in time overall. KNAVE II faster for hard and hardest queries. Easy queries faster in ESS and paper. Higher accuracy with KNAVE. Study 2: All completed <30 minute with KNAVE and ESS; ran out of time with paper. More accuracy using KNAVE II versus ESS (110/120 correct vs 69/120).

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Lamy et al[15]	Compared text (drug monograph) and graphical (pictograms) interfaces by question type (explicit and implicit) on response time.	Eleven general practitioners, France.	Searched for answers to questions.	Responses 2× faster with graphical than with text; explicit question types time less on graphical (15%) versus text (70%).
Narasimhadevara et al[40]	Usability testing of new transplant interface for nurses on learning time.	Stage 1: 3 transplant nurses. Stage 2: Previous 3 nurses, 1 head nurse, 1 patient care assistant, and 8 nurses. Stage 3: 10 transplant nurses, Montreal, Quebec.	Stages 1 and 2: Used short and iterative development cycles. Observations, extensive note taking. Stage 3: Satisfaction measured by SUMI.	Global median scores for SUMI including efficiency, affect, helpfulness, control, and learnability was >60. Greater than 50 is considered to be an indicator or good quality software in usability metrics.
Satisfaction				
Staggers and Mills[24]	Compared 3 levels of laboratory information density displays on user satisfaction.	One hundred ten clinical nurses (ICU; medical surgical; maternal-child), medical center, eastern United States.	Character-based laboratory data; 40 tasks in 5 interaction blocks.	User satisfaction greatest for high density screen overall and after practiced with all screens.
Mills and Staggers[25]	Correlation of spatial memory, spatial visualization, perceptual abilities on nurses' speed, and accuracy on 3 levels of laboratory information.	One hundred ten clinical nurses (ICU; medical surgical; maternal child), medical center, eastern United States.	Character-based laboratory data; 40 tasks in 5 interaction blocks on user satisfaction.	No relationship between cognitive variables and user satisfaction with any display types.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Fuchs et al[27]	Evaluated a clinical decision support system (CaDet) to detect cancer on ease of use.	Study 3: 5 general practitioners, 60 patients Tel Aviv, Israel.	Study 3: Patients completed a friendliness questionnaire. Physicians completed questionnaire on design, ease of use, contribution to cancer detection, and acceptability.	Study 3: All patients found CaDet easy to use. All physicians found CaDet easy to use, thought it acceptable and that it would make a contribution in cancer detection.
Staggers and Kobus[11]	Compared graphical- and text-based interfaces on user satisfaction.	Ninety-three nurses, military medical center, eastern US	Ten blocks of task trials. Used QUIS.	Satisfaction greater for graphical interface than for text.
Lin et al[17]	Compared 2 PCA designs on interface preference, and mental workload.	Twelve recovery room nurses, Toronto General Hospital, Ontario.	Performed 6 tasks on each. Perceived mental workload by NASA-TLX.	Nine preferred new interface, 1 preferred old, and 2 no preference. Workload reduction for new > old for continuous, PCA + continuous modes tasks.
van der Meijden et al[13]	Compared workstations (graphical, electronic record for patients who has had stroke) on satisfaction.	Twelve physicians, hospital setting, The Netherlands	Short questionnaire about user satisfaction.	Communication about future goals and intended benefits between management and end users was not optimal. Had there been a better dialogue between management, end users, and developers/implementers, then expectations, plans, fears, and wishes could have been exchanged; clinical workstations could have been exploited much better. Some systems such as the stroke electronic patient record had greater impact on users' work and users preferred paper formats to electronic.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Lin et al[20]	Wireless PDA-based physiological monitoring system evaluated on TV, usability perceptions compared to older commercial pulse oximetry.	Study 1: TV: 20 health volunteers (11 men, 1 women). Study 2: Usability: 50 medical personnel (30 nurses and 20 doctors) emergency department, Taiwan	Study 1: TV: Compared pulse oximetry of wireless device to commercial oximetry. Study 2: Usability: used device × 1 month, answered usability questions. Survey evaluated overall system (1–5 Likert scale; 5 = completely satisfied), 3 areas: mobility (size and weight), usability (easy operation; easy monitoring), and performance during patient transport. (1–10 Likert scale; 10 = completely satisfied).	Study 1: TV of new device: Error in pulse oximetry; <±2%; error in heart rate <±2 beats per minute. No error in real-time data transmission. Study 2: Medical staff—high rating on performance 4.64/5.00. New outperformed older models in mobility (weight 8.8 vs 4.7; size 8.9 vs 4.9), usability (easy operation 8.6 vs 5.1) and easy monitoring 8.7 vs 5.1).
Liu and Osvalder[14]	Compare numerical and graphical displays on preferences.	Six expert ICU nurses, university hospital; Usability testing: 20 nursing students, Sweden.	Six task randomized scenarios; 4 pilot tests prior to usability study.	Nurses preferred alarms with fewer hierarchical levels.
Hortman and Thompson[32]	Evaluated an outcomes database on user satisfaction.	Four nursing faculty and 1 student; Laboratory setting, Midwest, United States	Questionnaire for User Interface Satisfaction	Mean scores 3–8 (9-point scale) Specific comments: unclear date fields, unclear methods to enter vital signs, tab stops not in a logical order; and limited space to type “reason for visit.”

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Johnson et al[31]	Developed and evaluated a new interface for family history. Study 5: Usability test of newly revised versus original on user satisfaction.	Study 5: 16 unspecified participants; randomized to original and redesigned interface	Study 5: Did 12 tasks, completed Computer System Usability Questionnaire.	Study 5: User satisfaction improved.
Chaikoolvatana and Haddawy[33]	Evaluated a provider multimedia diabetes management program on usability.	Twelve (2 nursing, 3 pharmacy, and 7 volunteer students), Laboratory setting, Thailand.	Interacted with the diabetes program, completed a 20-item survey developed by the authors about program.	Found computer literacy issues. Students "generally thought the program was easy to use" but it took too long to complete.
Staggers et al[36]	Study 2: Determine user satisfaction for a novel eMAR design.	Study 2: 20 Navy clinical nurses military medical center, western United States.	Study 2: Used 9 "typical" medication process tasks. QUIS.	Study 2: High QUIS scores; 7.2–7.9 (on a 9-point scale).
Wallaceet al[37]	Compared 3 interfaces for patient care guidelines (2 proprietary and 1 homegrown) on user perceptions.	Thirty RNs, health science center, United States.	Eighteen clinical scenarios 5-point Likert survey (5 = very positive) of user perceptions.	Average ratings for information seeking sessions higher with successful search outcomes versus unsuccessful; finding related to unsuccessful session taking longer, finding wrong information, and information not making sense to user. Easy to find information rated between 1.5- and 2.0 of the 5.0 for most positive responses.

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Table 2. Evidence table of clinical technology design (User Interface) studies (*Continued*)

Source	Study design, aims	Sample setting	Methods	Findings
Fonda et al[41]	Explored participants expectations, interpretations, functionality of internet-based Comprehensive Diabetes Management Program (CDMP)	Five nurses (3 diabetes nurse educators, 1 home health nurse, 1 urban hospital nurse; 1 physician from an urban hospital, Boston, Massachusetts	Observations (mouse movements, paths tasks, verbalizations, recording errors; Usability Score survey on visual appeal, content, ease of use, performance, support features; interview data on user impressions	Usability Scores neutral to favorable (range 3.20–4.04); higher for visual appeal, content vs ease of use, performance, support features. Participants wanted ability to customize application. Participants' mental model did not match functionality. Participants did not quickly grasp all terminology
Martins et al[39]	Compared 3 interfaces (KNAVE II, ESS, and paper) on efficiency, accuracy of finding answers in data, and user satisfaction	Study 1: 8 MD/PhD students, residents, and fellows Study 2: 5 physicians, United States and Israel.	Study 1: 10 clinical queries of increasing complexity, user satisfaction measured by Standardized Usability Score questionnaire. Study 2: 6 queries of increasing difficulty.	Study 1: KNAVE II had higher usability scores. Study 2: Higher usability scores with ESS.
Narasimhadevara et al[40]	Usability testing of new interface on perceived ease of use, and user satisfaction.	Stage 3: 10 nurses, transplant ward, Montreal, Quebec.	Stage 3: Satisfaction measured by SUMI.	SUMI average 62; range 57–63 (good) on all except control subscale; low control scores due to not giving RNs control to change medications. Learnability measured through SUMI was greater than 60.

Abbreviations: CDI, combined difficulty index; eMAR, electronic medical administration record; EPD, etiological potentials display; ER, emergency room; ESS, electronic spreadsheet; HIV, human immunodeficiency virus; GUI, graphical user interface; IBD, integrated balloon display; ICU, intensive care unit; IT, information technology; KNAVE II, knowledge-based navigation of abstractions for visualization and explanation; PCA, patient- controlled analgesia; RN, registered nurse; PDA, personal digital assistant; QIUS, Questionnaire for User Interaction Satisfaction; SUMI, Software Usability Measurement Inventory; TI, text interface; TSD, traditional strip-chart display; TV, technical verification; UI, user interface; VP, vice president.

procedures system, and a nurse practitioners outcomes database with graphics.[22,26,31,32] Researchers have found that users were more successful in searching for information on homegrown interfaces compared with that on proprietary ones, users prefer systems that reduce cognitive effort, and that complex queries could be answered more successfully with graphical interfaces versus paper.[29,31,37,39,] In device/system reviews using heuristics, researchers also found severe usability problems caused by limited information visibility and faulty data synchronization, possibly leading to medical errors. Also, limited system flexibility and poor navigation systems caused users to get lost in the application and confusion about what labels mean led to potential for patient harm.[22,34] To avoid some of these circumstances early in the design process, researchers recommend including users in development lifecycle to identify users needs and expectations of design requirements.[28,33]

Authors of 4 studies examined the effectiveness of graphical interface designs on clinician decision making for patients who has had a stroke, ventilator-dependent patients, and patients requiring hemodynamic monitoring and the safety of using a novel electronic medication administration record. Graphical designs improved initiating treatments, determining needed medications, and detecting patients' deviations from normal physiological parameters; visual cognitive learning styles (versus verbal) resulted in better ability for clinicians to keep vital signs within a target range with advanced physiological monitoring interfaces.[10,12,14] However, nurses' medication accuracy was low for medication tasks that required them to scroll beyond the current field of view in a new graphical medication record, despite substantial training with the interface.[35]

The authors of 2 studies evaluated the usability of IV pumps and judged their compliance with recognized design guidelines called heuristics. Authors found heuristic violations or noncompliance with recommended design guidelines for 2 different 1-channel volumetric IV pumps from 2 different vendors,[7] and one 3-channel pump commonly used in the ICU setting.[8] The vendors and model numbers were not provided. The heuristic for consistency was violated most frequently. Inconsistencies do not allow users to determine the clear meaning of interface elements such as labels. For example, 1 pump button labeled "off" for 1 infusion channel could be confused with the pump "stop" button. Authors found catastrophic usability errors in IV pumps. In 1 study, a pump adjustment was hidden on the rear of pump handle; this location may cause an inadvertent setting change when a user is just moving the pump. More important, the location makes the button hard to locate to readjust the pump back to normal.[7]

Two studies included evaluation of patient-controlled analgesia (PCA) pumps. In these studies, complex programming sequences and multiple user modes increased mental workload of nurses; a redesign of the PCA interfaces improved cognitive loads and potential errors in programming the devices.[16,17] Another set of authors caution that devices can be very confusing when they look like a familiar object (a pen) but behave differently (the cap on the pen was a power button).[18] These kinds of designs can result in increased cognitive burden, training, and/or redesign.

Authors of remote/mobile device studies examined telemedicine in home health environments,[19] electronic diabetes management programs,[21,33,41] and a hand-held electronic medical record for physicians.[23] Sound and visual quality during patient assessments interfered with effective assessments. A mismatch between manual nursing assessment practices and an early telemedicine device design caused delays and difficulties in completing care assessments.

Two different clinical decision support systems were evaluated, a cancer detection system and clinical reminders for patients with human immunodeficiency virus (HIV).[27,30] Researchers assessed the ability of a system to accurately diagnose and inform clinicians. In the HIV reminder study, researchers uncovered barriers that reduced effectiveness of the reminders: workload, time required to document information about the reminder, and duplication paper form systems, among others.

One set of authors evaluated a commercial EHR in a clinical setting.[38] Researchers identified 134 usability issues; 13 (10%) were potentially severe. For example, long, multilevel screens were confusing to use during admission documentation procedures, while clinicians simultaneously obtained a medical history from patients; subsequently, clinical documents in the EHR had to be reconfigured by the vendor before use.

Evaluations of efficiency

Efficiency aspects (Fig 2) examine productivity (time), costs, efficiency errors, and learnability (defined as the capability of a software product in enabling a user to learn how to use it). Accuracy is also important here because inaccuracy in keystrokes takes more time, impacting user costs and productivity. Five of the 10 efficiency studies were evaluations of graphical interfaces (5/10). For example, researchers found that a 3-fold increase in information density on screens allowed users to be twice as fast while not impacting accuracy. Users do not have to page between screens to find data.[24] Graphical user interface design compared with text or paper systems also allowed clinician users to be twice as fast and more accurate in keystrokes.[11,15,25,39,]

New user interfaces enhanced users' performance. Researchers demonstrated that improved designs for PCA pumps allowed users to avoid complex programming sequences, thereby reducing the time and errors.[16,17] Design can impact search times for clinical information. One study compared search times for patient care guidelines among different displays and found that users spent nearly twice the search time with one display due to poor document format and organization in the interface.[37]

Evaluations of satisfaction

User satisfaction is measured by perceived effectiveness or perceived efficiency of the user interface. Satisfaction was measured in 16/50 studies; new interfaces involving user input for graphical displays and redesigned interfaces of all kinds had higher satisfaction ratings. User satisfaction was measured in studies that evaluated new types of software for clinical processes such as medication administration, order entry, or documenting on transplant patients (Table 1). Usability problems that negatively affect user satisfaction with interfaces included system inflexibility, poor navigation, poor information quality, lack of control of the system, and limited visibility of system status.[13,40] Researchers found that users want interfaces that are intuitive, formats that allow visible data input, for example, for birthdates (eg, MM, DD, YYYY) and include consolidated information with high-level information presented first.

Clinicians want technology that is easier to operate and easy to understand, such as alarms with fewer hierarchical levels.[14,20] To obtain favorable user satisfaction results, technologically savvy clinicians also want an option to customize the interface for their own use, for example, some clinicians want to dial in their target ranges on specific measurement levels for their patients.[41]

DISCUSSION

This systematic review outlines the existing research for the design of clinical technology across its outcomes of effectiveness, efficiency, and satisfaction. The majority of current studies evaluated effectiveness aspects of clinical technology interfaces. Studies about interface efficiency were fewest in number. Of course, a blend of these goals would be optimal to ensure efficient and effective clinical technology design.

Current research on technology design

Current research ranges across a myriad of technology interface types. The types of interfaces examined to date neither have apparent pattern nor have they been assessed with any obvious rationale such as their frequency of use in clinical settings.

Although usability studies have not yet penetrated healthcare widely, researchers have discovered elements of design worth attention. For example, dense screens are faster for nurses' information detection and still as accurate as less dense screens. Thus, designers will want to include dense screens in systems so that clinicians avoid unnecessary movement between screens to search for information. The caveat is that dense screens need to include pertinent information, which means that designers will need to understand how clinicians make decisions and with what information. More careful attention should be paid to attention-grabbing methods for data located outside nurses' field of view as it can easily be missed even when nurses are trained on an application.

Graphical designs facilitate both efficiency and effectiveness measures. These designs improve time to treatment, detecting physiological parameter deviations, and time to complete a wide variety of tasks (eg, orders, laboratory procedures, searching for clinical data). A graphical design is especially important for tasks requiring navigation across applications or screens in a system and can improve performance as much as twofold.[11]

Researchers overall found improvements in redesigns of older interfaces and with iterative designs created in combination with user testing. Initially, readers might ascribe this finding to a publication bias; however, its prevalence across so many studies can also confirm the validity of the usability axioms of user-centered design and the value of usability testing.

Device evaluations and the sole assessment of an active EHR uncovered serious usability issues such as safe programming of PCA, IV pumps, and designs that interfered with critical processes such as documenting an admission history. Serious usability issues can be alarming, for instance, nurses were able to program a pump to give an inadvertent overdose without an alarm or warning. The Food and Drug Administration (FDA) currently requires usability testing for devices; however, the seriousness of the findings in the handful of studies here suggests that the FDA expand usability testing, that facilities assess the usability of devices as part of their purchasing processes, and that a department such as quality improvement evaluate devices for their safety in their institutions, especially older ones.

Future research directions

Recommendations for future research are made in these areas: (*a*) expand the types, settings, and participants for usability testing, (*b*) develop integrated displays, and (*c*) expand outcome variables in usability studies.

Expand the types of evaluations, settings, and participants

Types of evaluations

The types of evaluated devices are limited to date. The interfaces for a handful of devices were formally evaluated, including 2 IV and 2 PCA pumps. A systematic method for evaluation is needed such as assessing devices based upon their prevalence and use in clinical settings. Obviously, many more devices exist in the clinical setting than were examined to date. Just in an ICU setting alone, numerous physiological monitors and devices (invasive and noninvasive) have an array of alarms with distinctive tones, blinking lights of different colors and shapes, all demanding attention.

Common tools such as IV pumps and the one evaluated EHR had serious usability violations. To ensure safe practice, usability evaluations of clinical technology tools need to be greatly expanded to alleviate potential hazards. Even more important, usability studies are critically needed to examine the cognitive burden, errors, and workflow issues that may exist *across* devices in clinical settings. How nurses learn, remember, and use the myriad of devices is worthy of more investigation. How to design technology to work symbiotically across tools is needed. A national database is needed for known device assessments particularly for older models with known safety issues.

The IOM[42] encourages the adoption of health information technology as one solution to medical errors. Yet, only one set of authors evaluated an active EHR. HIMSS Analytics reported that just over 1900 US Hospitals are at stage 3 of EMR adoption which includes integration of clinical documentation (flow sheets), clinical decision support error checking, and radiology archiving systems.[43] With the impetus to increase EHR implementations, increased health information technology funding in 2009, and the increasing infiltration of EHRs into diverse sites, usability assessments of commercial EHRs are needed to better understand the impacts of these products. Although some vendors incorporate prototyping and usability testing into their development cycles, this practice is not yet widespread. EHR components should be rigorously and iteratively tested using HF principles by vendors, representative end users, and HF experts to ensure adequate design *before* installation.

The majority of tested technologies are those in clinical practice. The findings from these studies are striking, illustrating sources of potential error. Technology used in educational and administrative functions is underrepresented. Expanding usability testing into these arenas would be welcomed. HF evaluations of curricular software, especially commercially available products, are needed. Usability evaluations would provide important details about successes and failures for others as they plan to implement new models of learning. Optimal interfaces for nurse executives and administrators are another area for promising research.

Evaluation settings

The majority of current research settings are laboratories or simulated clinical settings. In the future, studies in naturalistic settings are highly encouraged. These kinds of settings would allow researchers to examine the role of interruptions, competing demands, and other typical work issues within the context of their particular technology design. Naturalistic settings would provide researchers with new knowledge and understanding about how technologies are actually used in clinical practice versus artificial settings. Two areas of investigation would help researchers understand how clinical technology affects nursing workflow, patient care and the efficiency of nursing services. The first is understanding the work-arounds that nurses create from using clinical technology, and the second is understanding competing demands in naturalistic settings. Clinical technology could then be designed more appropriately to match nurses' work design and thought process.

Participants

Interdisciplinary teams participated in 2 device studies; interface assessments included 11 interdisciplinary teams. The IV pump studies and 2 graphical interfaces studies used psychology studies participants. Actual clinical users should be included in the future across types of nurses including nurse anesthetists, seemingly absent from usability studies to date.

More studies are needed to emulate the kinds of teamwork that occurs with clinical technology in sites. For instance, nurses and pharmacists are underrepresented in evaluations of the impact of computerized provider order entry despite the fact that they are both integral to the orders management process and safe execution of orders.[44]

Develop integrated displays

Computerized support is needed to help nurses integrate information across devices and EHR applications. These integrated data summaries would display pertinent patient data, such as at the change of shift. Currently, nurses must integrate data and information from devices and EHRs themselves, typically by remembering data.[45] Nurses gather data from various sources, organize the information, and apply knowledge to recognize untoward trends or symptoms. Clinicians currently complain that the "big picture" of the patient is difficult to obtain with the sea of data in contemporary EHRs. A recent report from the Academies Press[46] recognized the urgent need for better cognitive support from EHRs, including help integrating data.

Expand outcome variables in usability studies

The most commonly examined outcome variables were user satisfaction, heuristic violations, time, and errors. User satisfaction was an outcome variable in 16 studies. Yet, user satisfaction provides only a partial insight into technology design. A better assessment would allow investigators to understand *why* a design improves satisfaction. And, nearly all researchers claim high user satisfaction, although this finding may be due to a publication bias. Other variables such as performance measures (time, accuracy) and aspects of decision making (correct treatment, detecting adverse events, and patient safety errors) may be more telling aspects of usability evaluations. An expanded list of variables is available elsewhere.[2] Thoughtfully chosen outcome variables should be mainstays of future usability research. EHRs in particular should be evaluated from a multimodal perspective to assess both efficiency and effectiveness aspects.

Finally, the gap between research and practice needs to be bridged. Interface evaluation and products from research proved useful and productive. Yet, research products often remain fixed in the research arena. In the future, bridging this gap should be part of the researcher's agenda.

Limitations

This review included literature available in refereed journals. Other relevant studies may be available in dissertations, reports, and unpublished venues. In the future, other authors may wish to examine studies from conference proceedings and in other languages besides English. Synthesizing results across this myriad of studies, variables, devices, methods, and participants was particularly challenging. Additional insights are possible in this body of work.

CONCLUSION

Usability analyses are critically needed in clinical care settings to evaluate the myriad of equipment, monitors, and software used by healthcare providers to care for patients. These kinds of analyses provide necessary information about the cognitive workload, workflow changes, and errors occurring from poor technology design. More examinations that include unstudied nursing specialties and settings are needed to provide rich, detailed accounts of experiences with clinical technology. More interdisciplinary work is needed to ensure that clinical systems are designed for maximum benefit of all stakeholders, to increase understanding of information needs and requirements across settings, and to understand shared user performance with devices. Research needs to be conducted in actual practice settings and rural and community settings to outline excellent and less optimal technology designs. Expanding this area of research would enable a better fit between nurses and technology to reduce errors and increase nurses' productivity.

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