Human Factors and Organizational Issues in Health Informatics: Innovations and Opportunities

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Summary

Objective: Human factors and ergonomics (HF/E) frameworks and methods are becoming embedded in the health informatics community. There is now broad recognition that health informatics tools must account for the diverse needs, characteristics, and abilities of end users, as well as their context of use. The objective of this review is to synthesize the current nature and scope of HF/E integration into the health informatics community.

Methods: Because the focus of this synthesis is on understanding the current integration of the HF/E and health informatics research communities, we manually reviewed all manuscripts published in primary HF/E and health informatics journals during 2020.

Results: HF/E-focused health informatics studies included in this synthesis focused heavily on EHR customizations, specifically clinical decision support customizations and customized data displays, and on mobile health innovations. While HF/E methods aimed to jointly improve end user safety, performance, and satisfaction, most HF/E-focused health informatics studies measured only end user satisfaction.

Conclusion: HF/E-focused health informatics researchers need to identify and communicate methodological standards specific to health informatics, to better synthesize findings across resource intensive HF/E-focused health informatics studies. Important gaps in the HF/E design and evaluation process should be addressed in future work, including support for technology development platforms and training programs so that health informatics designers are as diverse as end users.

Keywords

Human factors and ergonomics, human centered design, user computer interface, health informatics, health information technology

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1 Introduction

The goal of Human Factors and Ergonomics (HF/E) is to "improve people's lives by making technology work well for them", rather than making individuals adapt their behaviors to accommodate how designers have created technologies [1]. There is now broad recognition that health informatics tools must account for the diverse needs, characteristics, and abilities of end users, as well as their context of use. As described in this synthesis, HF/E frameworks and methods are becoming integrated into the health informatics research and practice community.

Health informatics researchers and practitioners continue to broaden their application of HF/E methods beyond the evaluation and critique of commercial electronic health records (EHRs). Because recent manuscripts have synthesized current knowledge related to the implications of poor EHR design [2,3], this manuscript focuses largely on the novel and exciting work being carried out in other application areas. The pervasiveness of mobile health technologies and the ability to customize EHR functions and displays significantly expands the opportunity to apply HF/E methods during the design of new health informatics technologies. We see evidence of the significant growth in research within these domains based on the numerous recent manuscripts published on these topics.

This manuscript is divided into three sections to help identify the scope of recent HF/E-focused health informatics research and allow us to define important HF/E gaps that the health informatics community needs to address. We describe where current health informatics publications fit into the HF/E design process, and the focus of HF/E-focused health informatics efforts with respect to types of technologies being developed and outcomes being measured. We then synthesize these findings and describe opportunities for future HF/E-focused health informatics research.

2 Methods

To understand the current nature and scope of integration of the HF/E and health informatics research communities, we manually reviewed all manuscripts published in several primary HF/E and health informatics journals and conference proceedings during 2020, including 2021 publications with available preprints. For the HF/E community, this review included the journals Human Factors, Ergonomics, Applied Ergonomics, and Ergonomics in Design, and the proceedings from the Human Factors and Ergonomics Association Annual Meeting and International Symposium on Human Factors and Ergonomics in Health Care. For the health informatics community, this review included the journals the Journal of the American Medical Informatics Association (JAMIA), JAMIA Open, Applied Clinical Informatics (ACI), ACI Open, International Journal of Medical Informatics (IJMI), the Journal of Biomedical Informatics (JBI), and the proceedings of the American Medical Informatics Association (AMIA) Annual Symposium. Each publication was coded according to: 1) the HF/E design cycle phase addressed (e.g., understand, create, evaluate), 2) the type of technology studied (e.g., EHR, CDS customization, mobile app, …etc.); and 3) the HF/E outcome measured (e.g., performance, safety, satisfaction).

3 Results

3.1 Diversity in Design Phase

While the design approaches used in the reviewed studies are diverse, they all fit into the simplified HF/E design cycle model shown in Figure 1 [1]. We therefore use this design cycle model to describe the diverse body of recent HF/E-focused health informatics research included in this synthesis. The studies included in this synthesis all addressed some subset of the *understanding* phase of the design cycle, some description of the *creation* phase, and/or various *evaluation* efforts they employed in their work. In doing so, HF/E-focused health informatics research seeks to understanding user needs (both clinician and patient), and/or the creation and evaluation of novel health informatics tools to address those needs.

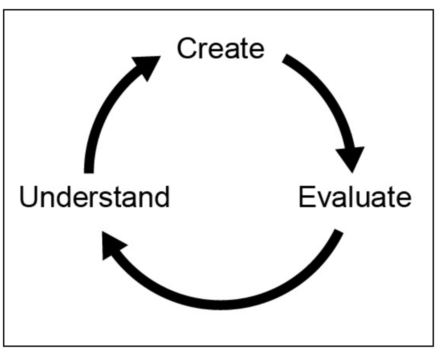

Fig. 1 HF/E Design Cycle [1].

Numerous HF/E design frameworks and models used by researchers and practitioners within the health informatics community align with the HF/E design cycle shown in Figure 1, including human-centered design (HCD), user-centered design (UCD), and the system development life cycle. HCD, defined by ISO, is both process- and outcome-focused, defined as an "approach to systems design and development that aims to make interactive systems more usable" [4]. HCD typically includes three general phases that are aligned with the HF/E design cycle: Inspiration (Understand), Ideation (Create), and Implementation (Create + Evaluate) [5]. UCD, while related to HCD, focuses more tightly on the needs of the specific end users of a design, and is more commonly used in health informatics research [4]. UCD consists of iterative design cycles that involve understanding of end user needs (Understand) and designing and iteratively refining prototypes with close involvement of end users (Create) before deploying final designs (Create + Evaluate). The Office of the National Coordinator of Health Information Technology (ONC) now requires a "user-centered design processes to be applied to EHR technology that includes certain capabilities" [6]. The exact UCD process is not prescribed by ONC, but resources exist from organizations such as NIST to provide guidance on UCD process with respect to EHRs [7]. Yet, one recent comprehensive study showed that vendors vary significantly in the quality of their UCD practices, ranging from well-developed UCD processes to fundamental misconceptions of the UCD process [8]. Several studies included in this synthesis addressed the value of following a user- or human-centered design approach broadly, either conducting UCD or HCD in their own work or noting the importance of these approaches in health informatics design [2, 7–17]. However, for the reasons above, readers of HF/E-focused health informatics manuscripts should be careful to interpret the authors' use of the (often confused) terms HCD and UCD, and not assume their design process is of high quality. Other manuscripts synthesize how user perspectives and needs can be integrated into various stages of a health informatics-focused versions of the systems development life cycle (SDLC), including project planning, analysis (Understand), design of the system (Create), implementation (Create + Evaluate), and system support/maintenance (Evaluate) [18, 19].

Shown in Table 1, the bulk of studies included in this synthesis focused on understanding user needs or on system evaluation efforts, but there was also a significant amount of work aimed at and creating technologies to meet user needs. These technology creation efforts may be driven by a recent shift in design capability to a broader community beyond EHR vendors, as the technology-focus portion of this synthesis describes the large volume of recent work focused on EHR customizations and mobile app development.

Table 1 HF/E design cycle phase addressed, and methods used in studies.

HF/E Design Cycle Phase	Understand	[9,17,20–51]
	Create	[9,11,15,30,41,46,50–70]
	Evaluate	[9,11,14,15,17,30,41,46–49,52–59,66–126]
Study Methods	Heuristic analysis	[16,23,41,62,69,70,121]
	Observation	[20,22,28,32,33,36,45,72,74,93,120,124]
	Focus groups	[7,9, 12,15,19,22,26,31,34,41,51,55,91,100,107,108,111, 118,122,127–133]
	Cognitive walkthroughs	[70,121]
	Interviews	[11,18,20,24–26,29,31–34,36,37,47,48,51,52,55,57,58, 70,74,78,79,82–84,88,93,99,112,114,117,119,120,122, 126,134]
	Structured usability testing	[7,16,18,66,67,69,120,132]
	User performance during simulated tasks	[54,69,93,105,113,118,123,125,135]
	Surveys	[14,30,31,35,48,52,55,57,64,66,73,76,83,87,88,91,93,99, 101,103,107–109,111,114,115,120]
	Questionnaires	[14,18,48,89,91,116–118,120,126]

The scope of analysis within which this HF/E design cycle occurs is diverse. For simplicity in communication, the HF/E community often partitions their scope of work into the three separate domains of cognitive, physical, and organizational ergonomics. Not surprisingly, HF/E-focused health informatics research often focuses on one of these three domains. Because health informatics technologies are often designed to support information-intensive work, many HF/E focused health informatics technologies aim to support clinician and/or patient cognition. Commonly used cognitive ergonomics-focused approaches such as cognitive task analysis, focus on supporting and improving a range of processes including clinician and patient comprehension, decision-making, distributed or team cognition, and errors [18, 136]. Some HF/E-focused health informatics research attempts to capture all three domains (cognitive, physical, organizational), focusing on the complex sociotechnical systems within which health informatics technologies are used. For example, SEIPS 2.0, a "sociotechnical work system → process outcomes" model based on the Systems Engineering Initiative for Patient Safety model (SEIPS), helps HF/E researchers and practitioners capture and evaluate the system elements impacting and being impacted by health informatics technologies [137, 138]. Another sociotechnical model developed by Sittig and Singh is "designed to address the socio-technical challenges involved in design, development, implementation, use, and evaluation of HIT within complex adaptive healthcare systems" [139].

Studies included in this synthesis used diverse methods to conduct the "understand → create → evaluate HF/E design" cycle phases, shown in Table 1. Many studies used or reviewed the use of one or more qualitative HF/E approaches, such as heuristic analysis, observations, focus groups, cognitive walkthroughs, and interviews. Others used or reviewed the use of one or more quantitative HF/E methods such as structured usability testing, user performance measurements during simulated tasks, surveys, and questionnaires. Many studies combined qualitative and quantitative methods, such as quantitative measurements during simulated tasks followed by debriefing interviews.

This large body of health informatics work using a diverse set of HF/E methods to carry out the "understand → create → evaluate" cycle is exciting. The volume of studies focused on understanding user needs, creating health informatics technologies to meet those needs, and evaluating technologies shows that HF/E frameworks as methods are becoming embedded in the activities of the health informatics community. The health informatics community would benefit from HF/E-focused health informatics researchers and practitioners focusing significant effort on consolidating methodological "understand → create → evaluate" best practices and ensuring that those best practices are accessible to the broad health informatics community. For example, evaluations of users' perceptions of system usability ranged widely. While methods and instruments measure different constructs, it would be helpful to come to agreement on best practices for qualitative and quantitative HF/E methods and making those recommendations accessible to the broad health informatics community. Doing so would help the HF/E-focused health informatics community better synthesize findings from these labor and resource-intensive studies.

3.2 Diversity in Technology Types

There are numerous ways we could categorize the technologies in the studies included in this synthesis, such as the mode of delivery (e.g., handheld, desktop, …etc.), interaction-type (e.g., voice, touch, gesture, etc.), or underlying algorithmic approach (e.g., practice guideline-based, AI, machine learning, etc.). In this synthesis, we focused on categorizing studies based on the expansion of health informatics design opportunities supported by the (relatively) recent ability to customize EHR interfaces, open APIs that allow developers to directly create new software tools leveraging EHR data, and increasingly accessible platforms for mobile app development.

Shown in Table 2, while some studies included in this synthesis were focused on physicians interacting with existing EHR computerized provider order entry (CPOE) interfaces, most studies in clinical settings focused on customizations to EHRs. Many technologies focused on the creation and evaluation of customized clinical decision support tools. The application of these customized clinical decision support tools varied widely in context, including diagnostic support [17, 132], antibiotic stewardship [36, 70], screening for and management of chronic conditions [53, 91, 119], identifying individuals at risk for varied clinical outcomes [50, 69, 87, 118].

Many studies focused on the creation and evaluation of customized data displays. These customized data displays also focused on a diverse set of application areas, including integrated dashboards [10, 61, 124], critical care displays [96], opioid management [123], plan of care tools [125], and patient-focused communication [11, 55, 98]. A smaller number of studies addressed non-EHR integrated information systems [9, 65, 68, 83, 112, 120], and EHR training design [46, 59, 135].

Many studies focused on creating and evaluating mobile apps, typically aimed at addressing the needs of patients and consumers. These mobile apps focused on a variety of chronic diseases such as diabetes and hypertension [63,122], cardiovascular health [30, 58, 121], cancer care [58, 127], mental health [13, 23, 25, 57, 110], seizure management [57], bladder monitoring [56], tuberculosis treatment [15], and parental education [40, 41]. A small number of studies focused on telehealth [10, 14, 140] and personal health records or patient portals [38, 109, 141].

While evaluations of EHR usability are still critical [2, 3], the ability of HF/E-focused health informatics researchers and practitioners to be designers of new technologies – rather than purely evaluators – is critical for health informatics technologies of the future to be useful to and useable by a variety of end users. HF/E-focused health informatics researchers and practitioners must therefore advocate for continued development of accessible design resources and platforms that allow them to be innovators.

Table 2 Technology types addressed in studies.

Technology types	CPOE interfaces	[105,113]
	Customized clinical decision support tools	[17,29,69,70,81,87,91,99,118,119,126,129,33,130,132,142,34,36,37,49,50,53,67]
	Customized data displays	[10,11,92,96,98,123–125,50–52,55,61,66,72,84]
	Mobile apps	[13,15,47,54,56–58,63,75,85,108,110,23,115–117,121,122,127,131,25–27,30,35,40,41]

3.3 Outcomes of Interest

HF/E methods aim to improve how individuals interact with complex systems. Qualitative and quantitative HF/E methods can help to understand and affect positive change on a range of human-system interactions, including supporting health information technology user cognition and understanding how health informatics technologies affect and are affected by complex sociotechnical systems within which they are embedded. These positive impacts of HF/E-focused health informatics research include improving the safety (reducing risk of injury or death), performance (increasing productivity, quality, and efficiency) and satisfaction (acceptance, comfort, and well-being) of health informatics technologies [1]. While HF/E-focused health informatics research ideally improves all three of these outcomes, the relative weighting of safety, performance, and satisfaction typically depends on the context of application, shown in Figure 2. The length of each leg on the triangle represents the relative importance of that outcome, with a longer leg meaning that outcome is typically weighted more heavily in that domain.

Part of the challenge in designing and evaluating health informatics technologies is the lack of clarity in which domain(s) a particular technology is deployed within. For example, EHRs and customized CDS and visual displays are typically deployed in high-risk workplaces. Yet, as we show below, the bulk of the evaluation measures from the HF/E-focused health informatics work included in this synthesis focused on measuring (often only) end user satisfaction. There are a multitude of likely reasons for this, including a known lack of system usability, an assumption about the interrelatedness of these measures (e.g., the impact of performance on satisfaction), and the relative ease of measuring perceived satisfaction. This tension becomes even greater as we consider how mobile health data might be integrated into the EHR – where the implementation of these technologies involves a consumer product and related technology deployed in a high-risk workplace.

While patient safety is often a motivator for the development of health informatics technologies, it is difficult to measure, and is therefore infrequently directly assessed – especially considering the HF/E concept of safety focuses on reducing risk of injury or death. Shown in Table 3, some studies in this synthesis instead focused on how EHR designs might negatively influence patient safety, including CPOE ordering accuracy [105], unexpected use of free text data entry [71], discrepancies in documentation during patient transfers [86], lack of patient identification during CPOE [113], and appropriate responses to alerts [134, 143]. Other studies use proxy measures that may be correlated with, or lead to, safety issues. For example, a recent analysis of an inpatient safety dashboard in the context of opioid management focused on measuring user performance (i.e., time on task, mouse clicks, mouse movement, cognitive load, and task inaccuracy) [123]. Another analysis of a patient safety dashboard measured system usage and perceived satisfaction [124]. A recent study focused on developing and evaluating a dashboard targeting acute kidney injury (AKI) to improve patient safety measured system usage and performance with respect to six quality indicators, but the quality measures were developed by end users – not validated safety measures [126]. The measures in these studies are important and likely related to safety outcomes, but the relative rarity of patient safety events and lack of empirically validated safety markers makes directly measuring the impact of health informatics design on safety quite difficult.

A larger set of studies focus on measuring aspects of performance (e.g., productivity, quality, and efficiency) via measures related to time to complete tasks, markers of task completion, and errors while completing those tasks. Many studies assessing performance measured how accurate or complete the user interaction with the system was, with those interactions varying from a layperson interpretating a visualization to a clinician documenting a patient encounter. Shown in Table 3, many studies focused on improving the efficiency of health informatics technolo-

Fig. 2 Relative weighting of HF/E outcomes by domain [1].

Table 3 Outcomes addressed in studies

Outcome measures	Safety	Potential impact of design on safety	[71,86,105,113,134,143]
		Proxy measures	[123,124,126]
	Performance	Accuracy and completeness	[9,16,17,52,57,93,96,98,102,117,118,125]
		Efficiency	[16,17,52,54,65,76,80,83,93,95,96,99,101,104,111,123,125]
	Satisfaction	Interviews and focus groups	[9,10,15,26,30,37,41,46,51,55,64,74,79,82,91,93,114,119,120,122,134]
		SUS	[9,16,46,54,57,72,117,120]
		TAM	[46,83,99]
		UTAUT	[54,82,116]
		Health-ITUES	[84,124]
		PSSUQ	[69]
		Computer system usability questionnaire	[125]
		TTF	[144,145]
		SUMI	[89]
		Object-action interface questionnaire	[126]
		NuHISS	[103]
		Self-developed questionnaires	[14,48,73,75,77,87,91,114,115]

gies, by measuring current inefficiencies due to issues such as dispersion of information across areas in the interface or interrupted workflows, and in some cases designing tools that improve (or at least maintain) user time to complete tasks of interest. The level of granularity of these time measures, however, ranged from milliseconds (e.g., eye movements when searching for information) to hours or days (e.g., time to complete results review).

Numerous studies assessed users' satisfaction with a given technology. Shown in Table 3, many studies used interviews and focus groups to glean users' perceptions. Others used a variety of questionnaire and survey instruments based on the System Usability Scale (SUS), Technology Acceptance Model, Unified Theory of Acceptance and Usage of Technology (UTAUT), Health-ITUES, Post-Study System Usability Questionnaire (PSSUQ), Computer System Usability Questionnaire, Task-Technology Fit (TTF), Software Usability Measurement Inventory (SUMI), Object-Action Interface (OAI), National Usability-focused HIS Scale (NuHISS), and self-developed questionnaires.

Health informatics researchers and practitioners clearly see the need for their work to jointly address the HF/E goals of improving safety, performance, and satisfaction. Recent research demonstrates the breadth of methods and measures being used by the HF/E-focused health informatics community to assess these three outcomes. Because injuries or safety events of a specific type are relatively infrequent or difficult to detect, safety is often measured via the prevalence of potentially unsafe actions or via proxy measure that may be correlated with safety. While performance and satisfaction are frequently assessed, there is relatively little cohesion around a standard set of methods or measures to use when evaluating health informatics technologies. By coming to agreement on methods to measure these outcomes, the health informatics community can better synthesize findings across studies.

4 Conclusion

The health informatics community is at an exciting time with respect to developing innovative technologies and interventions that truly improve system safety and performance and increase end user satisfaction. HF/E methods are becoming embedded in the culture of the health informatics community, with broad acknowledgement that the needs of end users should be accounted for the health informatics design. There is a significant gap, however, between the health informatics community acknowledging the importance of HF/E methods and the scattered nature in which these methods are being deployed. HF/E-focused health informatics would be well-served to coalesce around common design methods and outcome measures that can be easily communicated to the broader health informatics community. By not doing so, we are bypassing an opportunity to synthesize the important, time-consuming work being conducted across the health informatics community.

HF/E-focused health informatics researchers and practitioners can also be strong advocates for technology development platforms and design training programs that reduce barriers to entry for health informatics design innovators, supporting the democratization of health informatics design. HF/E-focused health informatics can also be strong advocates for building a community of health informatics designers that is as diverse as the end users of their designs.

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