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Human Factors and Health Information Technology: Current Challenges and Future Directions

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Summary

Objectives: Recent federal mandates and incentives have spurred the rapid growth, development and adoption of health information technology (HIT). While providing significant benefits for better data integration, organization, and availability, recent reports have raised questions regarding their potential to cause medication errors, decreased clinician performance, and lowered efficiency. The goal of this survey article is to (a) examine the theoretical and foundational models of human factors and ergonomics (HFE) that are being advocated for achieving patient safety and quality, and their use in the evaluation of healthcare systems; (b) and the potential for macroergonomic HFE approaches within the context of current research in biomedical informatics.

Methods: We reviewed literature (2007-2013) on the use of HFE approaches in healthcare settings, from databases such as Pubmed, CINAHL, and Cochran.

Results: Based on the review, we discuss the systems-oriented models, their use in the evaluation of HIT, and examples of their use in the evaluation of EHR systems, clinical workflow processes, and medication errors. We also discuss the opportunities for better integrating HFE methods within biomedical informatics research and its potential advantages.

Conclusions: The use of HFE methods is still in its infancy - better integration of HFE within the design lifecycle, and quality improvement efforts can further the ability of informatics researchers to address the key concerns regarding the complexity in clinical settings and develop HIT solutions that are designed within the social fabric of the considered setting.

Keywords

Systems-oriented approach, macroergonomics, socio-technical frameworks, patient safety, human factors

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Introduction and Background

The cognitive demands of the clinical work environment constrain the attentional resources of clinicians, and affect their ability to make safe and efficient patient care decisions. In high-velocity clinical environments, the cognitive demands are acute, and decisions are often made with partial information. While health information technology (HIT) is viewed as a major contributor to mitigating some of these challenges, there has been a significant debate on its potential impact and use [1]. Recent reports have suggested that HIT implementations do not guarantee improvements in the quality of patient care [2] or patient safety [3]. The purported advantages of cost savings have also not been realized [4]. The causal detrimental effects have been attributed to a number of factors including usability challenges of interfaces [5] and medical devices [6, 7], clinical workflow and processes [8], and lack of tools for cognitive decision support [9, 10]. The consensus opinion among researchers regarding the lack of success of HIT has been the lack of human factors and ergonomics (HFE; also referred to as *Human Factors Engineering*) considerations in the design and implementation of HIT [11]. The inadequacies of the use of HFE in the design of HIT has been highlighted in a recent Institute of Medicine (IOM) report that called for effective integration of HFE approaches in the design, evaluation, and implementation of HIT in clinical settings [1]. Previous reports from the IOM and the National Academy of Engineering (NAE) [11] have also identified HFE approaches as one of the key factors in developing and delivering better healthcare systems.

HFE is a scientific discipline that provides insights into design (or redesign) of healthcare systems and processes impacting patient safety and quality of care [12]. The focus of HFE is on improving human performance [13-15] by accounting for their cognitive and physical limitations. The importance of HFE approaches are reflected by their inclusion as one of the eleven topics of relevance for patient safety in the WHO (World Health Organization) patient safety curriculum [16].

Recent initiatives, such as the ones launched by the Office of the National Coordinator for HIT in the United States, have put significant focus on the role of HIT (especially EHRs) in clinical settings. Additionally, in the US the monetization of incentives for the use of EHRs has also increased the impetus for their use [17]. However, positive effects notwithstanding, the use of HIT in clinical settings can lead to unanticipated consequences such as errors and adverse events [3, 18].

The role of the larger organizational context and the contextual aspects for the development and integration of HIT in clinical settings have been proposed in several recent reports [1, 19]. These reports and other recently reported research argue that the utilization of HIT systems requires a close relationship between the HIT systems and the expertise and skills of healthcare professionals (19). Macroergonomics is a sub-domain of HFE that realizes the role of the socio-technical context in developing patient safety and quality initiatives [20]. In this survey paper, we review the recent literature in HFE, with a specific focus on the macroergonomic approaches to (a) examine the theoretical and foundational models of HFE that are being advocated for achieving patient safety and quality, and their use in the evaluation of healthcare systems; (b) and the potential for macroergonomic HFE approaches within the context of current research in biomedical informatics.

Method

We searched for literature on HFE in healthcare settings that were available in Pubmed, CINAHL, Cochran, and other related databases. We narrowed our search focus to recently published research (2007-2013), and focused on both theoretical and empirical research in macroergonomic aspects of HFE.

Models of HFE in Healthcare

HFE utilizes a holistic approach towards design/re-design and evaluation of systems, while accounting for people, tools/technologies they use, their physical environment, and the organizational considerations, for the purpose of achieving the goal of "joint optimization of the social and technical elements of a system" [21]. In other words, HFE approaches are based on the assumption of "designing in" safety measures – i.e., the efforts of HFE researchers and designers are on developing interventions that account for all the potential possibilities for errors (or process inefficiencies). Other mitigations and interventions (such as education and training) are considered only when the design solutions are inadequate. In other words, HFE adopts a design-oriented scientific approach towards patient safety that relies on systematic design interventions to mitigate potential safety hazards in the healthcare system (e.g., [22, 23]).

In addition to evaluating human behavior, abilities, and limitations for the design of tools, HFE researchers have successfully designed and streamlined technologies and systems that are used by clinicians, hospital administrators, and patients. For this, researchers have drawn on decades of research from multiple domains including safety in nuclear power plants and aviation (see for example, [20]). While the earliest reported studies of HFE in healthcare, which focused on medication errors in hospitals [24, 25], are several decades old, they have not received significant research attention until recently.

In the remainder of this section, we describe some of the key human factors models that have been discussed in the literature, and their applications for patient safety and quality initiatives. First, we discuss models from aviation that have been adapted for healthcare practice. The foundational underpinnings of these models and their shortcomings are also described. Second, macroergonomic models that account for the complex interactions in a healthcare environment are described.

Aviation-based Models

The predominance of aviation models for developing patient safety improvements is well acknowledged (e.g., [26, 27]). Researchers have drawn analogies from aviation to healthcare and made a strong argument for the translation to the clinical domain of insights from several decades of HFE studies. Even though we have learned a great deal from the aviation domain, the relative success and the extent of the translation of HFE ideas from aviation to healthcare is still open to debate, as evidenced by the recent point-counterpoint article in the British Medical Journal that addresses whether we have "gone too far in translating ideas from aviation to patient safety" [28, 29].

The models of HFE in aviation were based on using the systemic approach for identifying the deficiencies that contribute to failures or sub-optimal performance. Successful applications have included cockpit designs [30], structured communication protocols [31], and effective incident reporting [32]. Crew Resource Management (CRM) training evolved as a systematic approach based on the insights drawn from decades of research on aviation practice and safety principles. CRM training has been applied extensively in healthcare with varying amounts of success, primarily to improving communication and teamwork [33, 34] and improving processes (e.g., [35]). Others have discussed marginal benefits from the CRM training approach [36, 37]. For example, McColloch et al. [37] used a systematic review of literature to evaluate the effects of teamwork training (based on aviation models) and found weak evidence for the success of these training models. Similarly, Catchpole et al. [36] found that the significant number of latent errors and failures diminished improved compliance to procedures through teamwork training.

While a conclusive judgment regarding the success of CRM training in healthcare cannot be made, given its still nascent stage of application in the healthcare domain, several interesting factors should be discussed. First, as Catchpole [26] discusses, the focus of CRM approaches is on behavioral safety, a methodology that does not address the complex technological, organizational, and task-related issues that arise in healthcare settings ; hence, CRM-based training approaches may be ineffective in healthcare settings. Second, in contrast to highly engineered systems (such as transportation, nuclear power, and aviation) that are technologically mediated, healthcare requires significant human input. For example, in aviation, the human interactions are with an engineered system (i.e., an aircraft), while in healthcare clinicians interact with patients with significantly varied conditions and illnesses, which rapidly change over time. Such inherent differences in the nature of system response between an engineered system and a natural system [38] add an additional layer of complexity that makes aviation-style training approaches less successful. This aspect is further discussed in a later section on socio-technical design in healthcare.

Macroergonomic Models for Improving Patient Safety and Quality

Human factors frameworks for evaluating patient safety and care quality have been predicated on macroergonomic approaches. Macroergonomics approaches consider an entire system (e.g., an intensive care unit (ICU) or a primary care practice), interactions between the various components of that system, and its relationships with other systems [39]. The key elements of macroergonomics for patient safety include the following [39]: (a) systems-oriented approach, (b) joint optimization of human performance and well-being, (c) consideration of the organizational and socio-technical context, and (d) interactions between the various elements of the system. While similar to other systems-oriented approaches, such as resilience engineering and cognitive systems engineer-

ing [39], macroergonomics utilizes a more holistic perspective in accounting for system performance (e.g., clinicians in a healthcare system), well-being and safety of personnel and patients (e.g., job stressors, workload), and outcomes (e.g., patient safety).

For example, the *work system* in an ICU would include the clinicians (physicians, nurses, physician assistants, support staff, pharmacists), the technology that they use (e.g., EHR, monitors), and their interactions. There are several external considerations – *interaction with other units*, such as transfer from other units such as the emergency department, *organizational practices*, such as on-service time and time of rounds, and *regulatory aspects* such as federal reporting needs. While considering the design or incorporation of new tools in an ICU, a macroergonomic approach would consider all of these aspects. Below, we provide a short description of the various macroergonomic models that have been used for improving patient safety and quality in healthcare systems.

SEIPS Model

The SEIPS (Systems Engineering Initiative for Patient Safety) model explains patient safety and healthcare quality as a function of work systems and processes [40, 41]. The model is based on the *structure-process-outcome* model developed by Donabedian [42], and consists of three interacting components: the work system, its effects on care processes, and outcomes. The SEIPS model draws on three core human factors principles: systems-orientation, person-centeredness, and design-driven improvements [39, 43]. Systems-orientation is derived from the holistic approach towards studying a healthcare system as a whole; person-centeredness is derived from considering individuals (or teams) as the central aspect of healthcare work with the assumption that tools, technologies and support systems must be designed and developed with an understanding of the users' strengths and limitations; and design-driven improvements focus on improving healthcare work through the development of tools and work activities that can optimize human as well as team performance (See Figure 1).

The work system consists of people (e.g., physicians, nurses and other support staff), tasks (range of tasks that a person has to perform), tools and technologies (electronic tools and devices that have to be used for completing the tasks), the physical environment, in which these tasks are performed (e.g., interruptions, physical layout), and the organizational factors that affect the work activities (e.g., management, rules). In addition, the work system is also affected by external factors such as intitutional policies and externally imposed guidelines (e.g., regulatory rules). The above-described elements of the work system are interacting, and not standalone. For example, a physician's task of entering patient orders is affected by (a) the physician characteristics (role, cognitive characteristics such as expertise and experience, and psychosocial aspects such as motivation), (b) the nature of the tools used for order entry (e.g., using CPOE vs. writing notes and calling the order in), and (c) the organizational practices and norms. The model assumes that the work system elements interact and affect the care and workflow processes, which in turn, affect healthcare outcomes such as safety and, more generally, healthcare quality [20].

The model also incorporates two feedback loops: between the work system and care processes, and between the work system and outcomes. The feedback loops provide metrics for possible redesign – changes in outcomes or care processes can be traced to work system deficiencies. For example, an increase in medication errors can be traced to the clinicians administering the drugs, their task activities, the tools they use to perform these tasks, and the protocols they have to follow in performing these tasks (see example in [44]). In the SEIPS model, the re-design efforts must consider these various work system components and their interactions.

Holden et al. [43] proposed an extension of the SEIPS model, SEIPS 2.0, which introduced contemporary HFE concepts to characterize complex healthcare environments. Three concepts are introduced that help to better explain the SEIPS model: *configuration*, referring to the dynamic interactions (direct and indirect) between the various components of the work system that

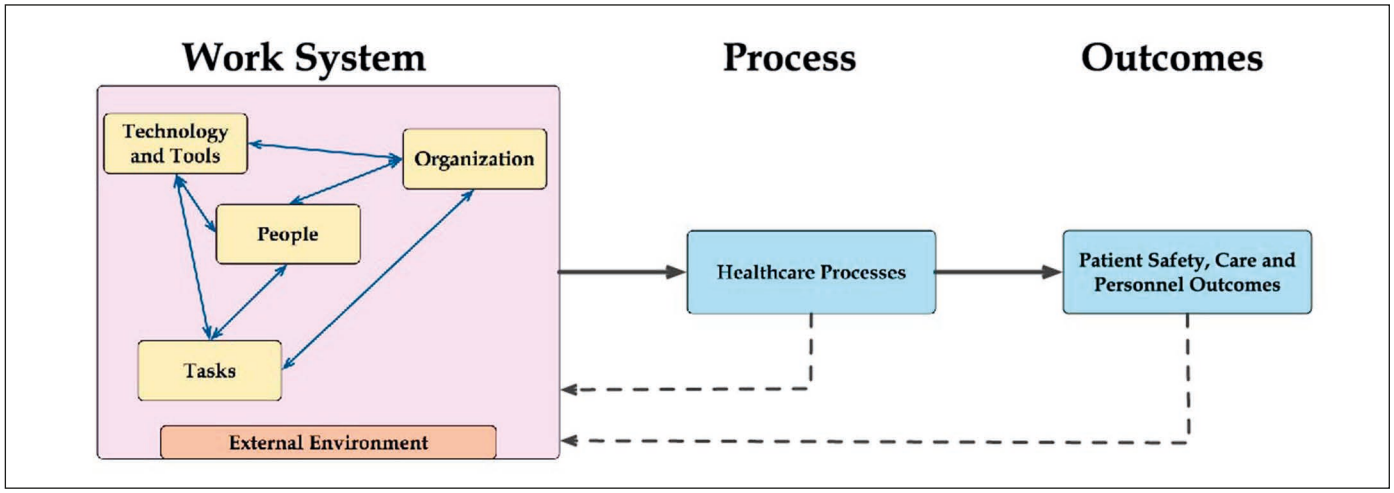

Fig. 1 SEIPS model, adapted from [39].

affect the processes and outcomes; *engagement*, referring to the individuals (clinicians, patients) and healthcare teams that perform various activities; and *adaptation*, referring to the dynamic feedback loops that create intended and unintended outcomes. A key takeaway from this extended model is the need for a multi-level approach that accounts for the interaction between the various levels of the healthcare system such as from organization to tasks.

The SEIPS model has been applied to the study of several quality and safety problems including medication safety [45], emergency room readmissions [46], and management of nursing workload [47, 48]. For example, Wetterneck et al. [45] used the SEIPS framework to categorize the factors contributing to the incidence of duplicate medication orders using a CPOE system. The contributing factors included technological (database design, algorithms, data display on the CPOE), team related (duplications during handoff communication at shift changes) and organizational/work environment (roles, team structure). In other words, the authors characterized the issues within the context of the components of the work system (individuals, teams, organization and their interactions) helping in the identification of a set of socio-technical factors for medication order duplication. Such an approach provided a holistic set of factors that contribute towards the duplication of medical errors. Similarly, Gurses and Carayon (2007) used a multisite, cross-sectional, survey-based study to characterize the nature of performance obstacles faced by ICU nurses and categorized them into various work system components such as perceived workload, job stress, and quality and safety issues [47].

While the empirical research using such macroergonomic models are few and far in between, there has been a recent push towards the use of such models. There is also better awareness among the patient safety and quality research community regarding the possibilities afforded by the model.

Healthcare Professional Performance Model

Karsh et al. [13] proposed a complementary HFE paradigm for patient safety that was predicated on the performance of the healthcare professional (HCP). The model consisted of three interacting components: performance inputs, transformational processes, performance outputs, and feedback loops between these three components. The performance inputs represent the work system components - physician and patient, tasks, tools, organizational and external factors [40]. The transformational processes represent how the inputs affect HCP's physical, cognitive and social/behavioral performance. For example, the expertise and skills of physicians influence their abilities to identify and filter irrelevant patient case related information. The outputs represent the successful completion of tasks (e.g., giving patient the required medication or entering orders). The three components of the model have inherent feedback loops between them that act as input into other processes. The feedback loop also serves as a learning mechanism, acting as a guide for future actions on similar processes or events. The HCP performance model relies on the core HFE principles of improving healthcare technology, practices and processes through the design of tools and interventions that support HCP performance [49-51].

This model has been applied to characterize the use of technology in clinical settings [52], clinician performance using HIT, and error reporting [53]. For example, Holden and Karsh [52] utilized the HCP performance model to conceptualize a theoretical multi-level model that describes HIT usage behavior.

Other Models

There are other important human factors models that have been developed and used. Beuscart-Zephir et al. [54] developed a work system optimization model that consisted of four stages: evaluation and analysis of the work system and the requirements of the stakeholders in the system; collaborative design of healthcare technology; iterative formative and summative evaluations and redesign; and evaluation of the new system and its impact on patient safety [54]. This model was used in a qualitative evaluation of the medication ordering, dispensing and administration process using a system lifecycle-based HF approach [55]. Observations, usability evaluation, and simulated tasks were used to develop patterns of work organization and processes. Usability problems, physician-nurse communication challenges, and the nature of collaboration were identified as key issues. These were translated into system requirements for the redesign phase. The ensuing system was further optimized using iterative evaluation with stakeholders.

One of the earliest systems approach models was proposed by Vincent et al. [56]. They identified a set of factors that must be considered for evaluating patient safety incidents and errors including poor communication, workload, organizational changes, tasks and work environment. They developed a framework for evaluating patient safety incidents based on Reason's model of organizational accidents [57]. The framework accounted for patients, clinical staff, teams, organizational practices, and the distinctive regulatory and economic practices in medicine. While being a precursor to the previously described models, the model by Vincent et al. [56] took a systems-based approach towards studying errors in clinical settings.

Implications of Macroergonomic Models for Biomedical Informatics

A critical review by Waterson on the use of the systems approach for studying patient safety found that much of the literature focused on the studies of errors and perspectives for risk/error reporting [58]. He also reported that the focus of much of the research was at the level of individuals (patients, clinicians) with limited attention paid to the "interaction between the system levels" [58], leading to the conjecture that the term "systems approach" was possibly used "rhetorically" or even incorrectly. Russ et al. raised similar concerns regarding the general understanding of the science of human factors – they argued that there might be misconceptions regarding human factors principles and methods within the healthcare community [59]. Irrespective of the specific concerns that have been raised, the lack of integration of human factors in healthcare can impede patient safety and quality improvement efforts.

The use of a holistic, systemic evaluation framework provides several advantag-

es for patient safety and quality initiatives. First, these studies utilized a multi-method approach, providing insights regarding the work system processes from multiple perspectives. For example, Wetterneck et al. used clinician surveys, heuristic evaluation and task analyses for identifying the source, nature and progression of duplication of orders [45]. Second, a holistic approach regarding multiple aspects of a system is often considered. In other words, individual, team, organizational and other contextual environmental factors are considered for each clinical environment. As a result, the issues in a work system are captured from multiple perspectives providing the ability to effectively discern potential issues that hamper the quality and safety of patient care.

However, several interesting aspects on the empirical research on HFE can be drawn: first, the focus on medication errors and error reporting provides only a partial representation of patient safety and quality issues. For example, issues related to performance and efficiency also are important considerations that have received lesser attention. Second, as described in the next section, there is a significant amount of work that has utilized HFE approaches without explicitly mentioning the systems-oriented aspects. Nevertheless, a better integration of systems-oriented, holistic perspectives can provide further clarity and direction to informatics research, which are discussed in further detail in the section on informatics implications.

Evaluation of HIT Systems Using HFE

A vast majority of the published studies do not use the previously discussed macroergonomic models for design or evaluation. Instead, they rely on developing a comprehensive understanding of a healthcare or patient safety problem that needs to be contextually addressed. We provide a review of the research literature that addresses the use of HFE in the design or evaluation of HIT.

HIT systems are intended to assist clinicians in streamlining their activities by acting as cognitive aids in distributed collaborative environments. Such external tools are expected to aid memory and cognition [60], reduce cognitive demands and offloading of tasks [61, 62], and support decision-making [63]. Given the significant challenges faced by clinicians in using HIT systems, it is reasonable to assume that their design or their incorporation into the clinical environment has been less than ideal.

Recent work by Ash et al. [64] and Campbell et al. [65] identified several unintended consequences of EHR use including increased communication problems, decreased performance while using the system, "copy and paste" problems, and loss of situation awareness. Others have shown the significant transformations in the work activities introduced (e.g., [66]), including workaround strategies and adaptations [67-69]. These workarounds were also observed in decision-making and reasoning strategies. For example, Kushniruk et al. found that the reasoning strategies of physicians were driven by the on-screen information organization [70]. Similar patterns of changes were observed in a study by Patel et al. [63], who found a transformation in knowledge organization resulted in changes in reasoning strategy when clinicians moved from paper to electronic records – from a data-driven to a hypothesis driven reasoning strategy. This change in strategy persisted even when the physicians went back to using the paper-based records after using electronic records for about one year. While workarounds and adaptive strategies have been a part of healthcare work (see [71]), the inherent risks to patient safety can be introduced [10].

Studies on the use of CPOE systems included their effect on medication dosage, errors, and adverse drug events. Recent research has shown that CPOE use has increased task completion time [72], order entry duration [73] and potential for increased rates of mortality [74]. Other studies have reported on decreased medication errors while using CPOE systems (e.g., (75-77]), increased performance and efficiency of physicians [78], decreased pharmacy orders [79], and reduced patient length of stay [80].

Koppel et al. [3] identified several detrimental effects of CPOE use that increased the potential for errors. Twenty-two situations were identified and categorized into fragmentation of information and user interface issues, including the potential for selecting wrong patient and medication, delays in medication orders, potential delays and inflexibility of ordering screens.

In a case study of medication dosage error using a CPOE system, Horsky et al. [81] used a combination of usage logs, interviews and usability inspection methods to identify the source and evolution of the error. The error was attributed to a combination of usability issues, including lack of appropriate feedback (and work processes), a mismatch between human thinking about volume and dosage, and what the system allowed, and sub-optimal provisions in the system to mitigate the potential for error. A combination of interface design layout changes, functionality modifications, the use of alerts, as well as an adequate training program for the residents were incorporated to mitigate the possibility of future errors.

Carayon et al. [20] reviewed a set of studies that used HFE approaches for designing (or improving) patient safety practice. The studies covered a range of HIT tools including radiotherapy and telemetry system. Chan et al. utilized HFE methods to evaluate and re-design a radiotherapy delivery system [82, 83]. Field observations and heuristic usability evaluations were used to identify workflow and usability issues. The redesigned radiotherapy system was evaluated by using simulated scenarios. Results showed that the use of the redesigned system led to fewer errors and greater efficiency in the workflow.

Kobayashi et al. [84] redesigned an emergency department (ED) telemetry system using HFE systems analysis methods including field observation, information discussions, function diagnostic, and surveys. Core issues related to physical, cognitive and coordination challenges were mitigated in an iterative redesign process. A pre-post evaluation showed significant improvement in arrhythmia detection and demonstrated improved physician satisfaction.

While HFE methods have been extensively used in research on HIT, their applications have essentially been local – i.e., addressing specific healthcare problems within a context – and have often not been directly connected with healthcare outcomes. As the research moves forward,

the adoption of macroergonomic models can lead to more comprehensive design and evaluation procedures.

Challenges of using HFE Approaches in Healthcare: Implications for Informatics Research

In the previous sections, we outlined some of the theoretical models that have been developed and used in applied healthcare settings for evaluating HIT systems. We also reviewed recent literature on the use of HFE approaches for improving healthcare systems and practice.

While much of current biomedical informatics efforts on HIT development and improvement have acknowledged the importance of considering HFE in the design and evaluation process, its adoption and use is often incomplete. In a recent commentary, Gurses et al. [21] argued HFE approaches need to be better integrated for patient safety improvement efforts. Their recommendations include better mechanisms for healthcare workers to understand HFE, create external forces that require better integration of HFE into the design process through better investment and better HFE training initiatives in graduate programs. While implementing most of these initiatives would require long-term investment and planning, preliminary efforts towards considering HFE approaches should start through their use in research and quality improvement (QI) efforts. In the rest of this section, we highlight three important considerations for informatics researchers.

Addressing Complexity

One of the major factors that influence activities and tasks in clinical settings is the inherent complexity of the clinical environment [85]. Prior research on healthcare complexity has argued for a systems-oriented, holistic approach to studying and understanding healthcare systems [86-88]. However, most of the prior work studying healthcare complexity has been inherently descriptive, providing limited analysis or evaluation examples, and limited insights for researchers and practitioners [89]. HFE approaches, with their foundational principles grounded in a systems-oriented approach, are a natural fit for studying complex environments [13]. In other words, HFE approaches provide a natural mechanism for addressing one of the most-discussed challenges (i.e., complexity of the healthcare domain) in informatics.

Such an approach provides an effective mechanism for simplifying (i.e., decomposing), identifying specific target problems [90] and addressing those problems. For example, while considering the challenges of care transitions within a hospital, several relevant aspects need to be considered – participants involved in care transitions (physicians, nurses), the venue, tools and technologies being used, the distribution of information, and the organizational considerations (e.g., protocols to be followed) and guidelines.

Several researchers have utilized such an approach to decompose and identify specific target problems within the healthcare system including usability, handoff of patient information and teamwork. Smaller scale models have also been developed for specific aspects of healthcare work. For studying usability issues with EHR, Zhang and Walji [5] developed a framework for EHR usability, called TURF (Task, User, Representation and Function). TURF provides a framework for "describing, explaining and predicting" differences in usability across EHR systems, but is limited to laboratory-based evaluation studies.

Macroergonomic approaches provide a holistic but contextual mechanism for evaluating problems in complex settings. Utilizing such an approach would require functionally identifying key healthcare problems such as errors, and then using multi-pronged methods for studying the work system from multiple perspectives (e.g., the tasks that cause potential errors, how teams potentially mitigate these effects, the role of technology). Identifying how these varied aspects of the work system contribute to a specific healthcare problem under consideration can provide initial perspective of studying complex clinical settings.

Socio-technical Approach

The modern healthcare domain consists of a system of interactions between people, artifacts and their environment. In other words, the activities of clinicians are highly contextualized within their organizational environment using a plethora of electronic (e.g., EHR, monitors) and non-electronic (e.g., paper charts) tools. Understanding the nature of work activities, their influences, and their impact requires a socio-technical approach [19, 91] – one that accounts for the complex interactions between human behavior and actions, and the tools and technologies in the environment [92]. Though the specific aspects of HIT design and implementation can be considered as "engineered complexity" [38], the complex interactions between clinicians, their needs, and their use of HIT add to the complexity of the healthcare system. Understanding these interactions and their direct and latent impacts is at the heart of the socio-technical approach to studying systems.

One of the primary theories for addressing and evaluating human interactions – with each other, peers and technology – in distributed collaborative environments is distributed cognition (DCog) [60, 93-95]. The DCog framework provides an effective mechanism to characterize the socio-technical interactions including distributed work activities, interactions between human agents, technology, and their environment. The use of this framework in studying healthcare settings has been advocated by a number of researchers (e.g., [96-98]) using a systems-oriented perspective (96, 99, 100]. For example, Cohen et al. [99] characterized the distribution of cognitive activities and processes among groups and individuals in a psychiatric emergency department and identified the vulnerabilities and latent flaws that can potentially cause errors with the ED system. Traditionally, observational methods were used to develop distributed cognitive perspectives of clinical environments. However, technological advances and innovations, made possible by radio frequency identification sensors and the development of associated algorithms, afford new techniques for capturing data in clinical settings [101-103].

Methodological Considerations

One of the important aspects of HFE approaches is the focus on intensive, multiple and convergent methodologies for capturing activities, tasks and variances within and across clinical settings. Researchers (e.g., [49]) have argued for the use of additional methods that capture the healthcare practitioners' performance and efficiency. For example, Holden [49] cited a number of examples of methods that can potentially be used, including the use of simulations [104], work systems analysis [105] and work domain analysis [106]. In the recent past, much has been written about HFE methods and their importance for informatics – including usability, retrospective analysis of errors, workflow and processes and task analysis (e.g., [54, 107]). We propose two approaches that can potentially be useful in better integrating HFE approaches to clinical practice: the use of temporal methods and the integration of HFE approach into QI efforts.

One of the important characteristics of healthcare work is its temporality (e.g., [108]). Care activities, workflow and related tasks evolve over time and capturing these using a temporal framework can provide interesting insights. Several research studies have utilized such temporal approaches to characterize work activities and their impact on patient safety outcomes. For example, studies on patient handoffs have used the temporal analysis of data to identify breakdowns that affect safety (e.g., [109, 110]), and the degree of shared understanding among the members of the patient care team [111]. These insights were used in the design of patient handoff tools in critical care environments that were aligned with the work practices and requirements of critical care work activities.

Others have used similar trace-based approaches to identify the information seeking activities of clinicians in the context of HIT use [112, 113], and deviations from trauma protocols [114]. For example, Vankipuram et al. [114] found distinct patterns of deviation from protocol between experts and novices – with experts often deviating from protocols in innovative ways to dynamically respond to the complexity of the patient case. The results provided significant insights for the contextual design of protocols that accounted for the psychosocial aspects of human behavior in complex settings. A more comprehensive description of some of these approaches can be found in Patel et al. [115].

Another important aspect is the better integration of the HFE approach into the QI projects in hospital settings. While most hospital QI efforts rely on lean methods [116], there is significant scope for incorporating HFE methods [117]. For example, QI projects are often focused on a specific unit or department's immediate needs – reducing infections or improving handoffs. HFE methods can be used in such situations to capture the requirements that are more comprehensive, such as understanding stakeholder needs and work practices, and identifying potential sources of error and cognitive load.

Conclusions

The early success of HIT adoption and use has been tempered by the increasing number of reports on its unintended consequences, potential for errors and impeding effective performance. Questions regarding the causal underpinnings of these effects have led to several reports from the IOM and the NAE, which have highlighted several key criteria for the failure of HIT, as well as recommendations for improvement. Chief among their recommendations is the use of HFE methods for the design and evaluation of HIT. Based on a survey of recent literature on HFE, we found that while the models of HFE are evolving, their application in healthcare settings is still in its infancy. While there is clearly a realization of the importance of HFE in clinical settings, the logistics – both scientific and practical – of their use requires further thought and planning. Biomedical informatics researchers have utilized HFE methods locally, i.e., studying specific problems, but a more comprehensive perspective using the systems-oriented approach would be required for more effective HIT implementation and use.

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