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Commentary

To err is not entirely human: Complex technology and user cognition

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Errors, misunderstandings, and inaccuracies, large and small, are routine occurrences in our everyday activities. We can live with imperfection most of the time, but we require healthcare to be 100% error-free and medical devices to run flawlessly. When our high expectations are not met, society feels violated. Given the complexity of medicine, we should not be surprised that mistakes occur. However, we can ask health care technology designers to play an active role in mitigating the effects of user error in medicine. Clinical medicine is a uniquely complex field for which computing technology needs to be developed according to novel and often unprecedented design principles.

Health information technology (HIT) has undoubtedly reduced the risk of serious injury for patients during hospital stays. However, its true potential for preventing medical errors remains only partially realized and, paradoxically, as has been demonstrated in a recent *JAMA* article [1], some systems may even give rise to hazards of their own. In our view, errors are the product of cognitive activity in human adaptation to complex physical, social, and cultural environments. How well the design of HIT complements its intended setting and purpose is critically important for safe and effective performance.

There are few professional fields that pose as great a challenge to the use of computers as clinical medicine. Many safety-critical domains have been relying heavily on automation and computing for decades. Comparisons of healthcare and aviation often point out how information technology successfully transformed an entire industry and increased passenger safety [2]. The decision-making processes of a clinician, however, are perhaps more akin to those of a firefighter brigade commander than to the pilot of an airliner. In these domains, decisions are sometimes made with little or unreliable evidence, and changing circumstances dictate quick adjustments in the planning of actions.

The recent *JAMA* report [1] suggesting that clinical ordering systems (CPOE) may in fact contribute to medical errors is a sobering reminder of the often inadequate fit of current computing technology to clinical work. Cautionary statements about a new kind of medical error that may ensue from working with information systems [3] and anecdotal evidence of the tremendous challenges to the implementation of clinical computing technology [4] have appeared periodically in the research literature. Importantly, the *JAMA* study makes the characterization of technology-related medical errors its central thesis. The authors are conveying their belief that it is the flawed design and poor integration with clinical work rather than the technology itself that is at the root of its suboptimal performance. They point out that attention needs to be given to the errors CPOE systems can cause in addition to the errors they help to prevent and that many identified problems with CPOE implementations could in fact be easily corrected. Thus a lack of attention to the principles of human–computer interaction (HCI) in clinical software design is becoming a critical safety hazard.

Cognitive science and HCI research address many of the concerns that make the integration of computing and clinical practice an arduous task. Designers need to understand in detail the idiosyncrasies of the environment in which clinicians work. In a typical hospital setting, task flow may be context-dependent, users may follow non-linear completion strategies due to interruptions, uncertainties permeate many decisions, and the highly

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collaborative nature of assessment and treatment is critically dependent on clear and speedy communication. Clinical information technology engineers design systems to support tasks for which there is little analogy or precedent outside medicine. There is currently a need for theoretical frameworks and system design principles grounded in cognitive theory and developed specifically for healthcare environments. Clinical systems built according to such guidelines would allow expedient, faster, and less error-prone user interaction.

In our research, we consider errors in human or machine performance to be inevitable. They cannot be totally eliminated but can be useful phenomena for crafting recovery techniques. It is essential to understand what cognitive processes are active in diagnostic reasoning, decision-making or interaction with patients, colleagues, and technology to manage errors that occur during routine clinical work. Achieving flawless performance with error-free systems is a laudatory but unrealistic goal. We believe that the most suitable approach to error management is to develop adaptive systems that anticipate errors, respond to them, or allow intervention before an adverse event results.

Several areas of healthcare-related research have been informed by or have directly adapted theories and methods from cognitive science [5]. System and device usability inspection, for example, has provided numerous insights into the decision-making processes of users, and allows analysis of errors within the context in which they occur. Studies of electronic infusion pumps [6,7] or order-entry systems [8] have described how specific configurations of controls, display characteristics, and types of feedback may engender errors or promote unsafe work practices.

Human cognition in complex domains is to a great extent context-dependent. Direct observation of activities in the environment where devices are used and situation-specific analysis of errors are invaluable sources of reference for system development. In hindsight, users or incident reviewers can identify only overt failures and their perceived causes. However, layers of technical complexity hide the significance of subtle errors that may be of little consequence by themselves but that interact and accumulate to become more momentous. For example, we have developed a comprehensive analysis method of HIT-related medical errors [9] that combines cognitive usability evaluation of the system with the analysis of use logs and structured interviews of the key players to provide a detailed description of how the error developed. A cognitive taxonomy of medical errors [10] has also been proposed to categorize systematically medical errors along cognitive dimensions.

Human cognitive activity in computer-supported clinical workplaces is also the subject of research from a more general perspective than usability studies of particular devices. For example, the effects of electronic medical record (EMR) systems on the way in which clinicians obtain, organize, and reason with knowledge has been the subject of a study [11]. Because many electronic records and ordering systems integrate active decision-support functions that are triggered either by user actions or changes in stored data, the understanding of medical decision-making and reasoning processes is a prerequisite for assuring that such systems present the right information, in the most appropriate form, at exactly the time when it is needed. These cognitive processes and structures also need to be considered in selecting terminology and category labels used in menus, on buttons, for control widgets, and in informational or warning messages. Failure to address these issues can lead to interactions that are unnecessarily prolonged or unsuccessful in that they can force users to explore nonintuitive menu structures and pathways to find a command that corresponds with their intended goal or to guess the meaning of a button label.

Perhaps the most important impetus for doing cognitive research in medicine is developing the foundation for theories of medical errors and interventions of error reductions. There is a growing recognition that many errors are neither solely attributable to lapses in human performance nor to flawed technology, but develop as a product of their interaction [12]. From our own research perspective, this interaction takes place within a distributed cognitive system composed of active agents (humans, computers) and artifacts (notes, texts, other technology, etc.) Cognition is considered to be a process of coordinating, mediating, and redistributing knowledge representations that are internal (i.e., in the mind) and external (e.g., visual displays, written instructions, etc). Environmental, social, cultural, organizational, and regulatory factors contribute to the complexity of these systems that stretch over human beings and the technology they work with.

Computing technology and artifacts are integral parts of this cognitive process and should be designed to correspond to human characteristics of reasoning, attention, and memory constraints (human-centered design). The introduction of a new technology affects the performance of the entire system: it induces a change in user behavior as they are completing new tasks and follow different procedures [13]. An optimal fit of technology to the environment and to the needs of users is therefore of paramount importance for design and successful implementation of HIT.

Users should not be required to adapt to poorly designed technology. Human-centered design of HIT can increase efficiency, usability, ease of learning, user adoption, retention, and satisfaction, and decrease the rate of medical errors. Recent special issues of the *Journal of Biomedical Informatics* have collected a set of original research and method papers that specifically address these issues [36(1–2), Feb 2003, 38(1), Feb 2005].

Some of the recurring problems reported by Koppel and colleagues are relatively easy to resolve—for example, by using larger fonts and less text-saturated displays, by using only those drug dosages, strengths, counts, bag sizes, and packaging that are in fact available at the hospital pharmacy, or by having fewer "nagging" reminders. Other troubling aspects of clinical computing that Koppel and colleagues describe require more extensive reengineering. Our experience and discussions with the clinical systems industry would suggest that the cognitive design issues we have summarized here are seldom considered in the development and implementation of commercial systems.

The utter lack of standards among CPOE systems precludes blanket statements and generalizations about these systems' effectiveness or utility as a technology solution. Ultimately, the *JAMA* article is describing one system and one implementation at one point in time. Excessively hopeful expectations may have also contributed to the recent dismay over that system's less than perfect performance record. Order entry is still an emerging technology undergoing rapid development. It is also a dynamic process that includes both human beings and technology and that mediates collaborative efforts. Most of the newly observed class of errors can be characterized, understood, and reduced with sufficient attention to the cognitive complexities of human–computer interaction.

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