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Human Factors in Patient Safety as an Innovation

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Abstract

The use of Human Factors and Ergonomics (HFE) tools, methods, concepts and theories has been advocated by many experts and organizations to improve patient safety. To facilitate and support the spread of HFE knowledge and skills in health care and patient safety, we propose to conceptualize HFE as innovations whose diffusion, dissemination, implementation and sustainability need to be understood and specified. Using Greenhalgh et al. (2004) model of innovation, we identified various factors that can either hinder or facilitate the spread of HFE innovations in healthcare organizations. Barriers include lack of systems thinking, complexity of HFE innovations and lack of understanding about the benefits of HFE innovations. Positive impact of HFE interventions on task performance and the presence of local champions can facilitate the adoption, implementation and sustainability of HFE innovations. This analysis concludes with a series of recommendations for HFE professionals, researchers and educators.

Keywords

human factors and ergonomics; patient safety; health care; innovation; adoption; dissemination; diffusion; implementation

1. Introduction

Patient safety is a major concern worldwide. In 2004 the World Health Organization launched the World Alliance for Patient Safety (<http://www.who.int/patientsafety/en/index.html>) that has initiated numerous programs and activities in areas such as infection control and safe surgery. A series of reports issued by the US Institute of Medicine (IOM) has clearly identified patient safety as a major problem in healthcare delivery (Institute of Medicine Committee on Quality of Health Care in America, 2001; Kohn, Corrigan, & Donaldson, 1999). IOM reports have addressed patient safety issues related to medication errors and adverse drug events (Institute of Medicine, 2006), duty hours and fatigue among medical residents (Ulmer, Wolman, & Johns, 2008), and working conditions of nurses (Institute of Medicine Committee on the Work Environment for Nurses and Patient Safety, 2004). There has been increasing effort at various levels of healthcare policy, accreditation, reimbursement, operations and associations to improve patient safety; the effects of these interventions and programs on patient safety is unclear however (Vincent, et al., 2008). Human factors and ergonomics (HFE) tools, methods, concepts and theories are often recommended as part of patient safety improvement efforts. For instance, the 2005 report by the US Institute of Medicine and the

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National Academy of Engineering lists HFE as a key systems engineering tool to design and improve healthcare systems, and produce improvements in quality of care and patient safety (Reid, Compton, Grossman, & Fanjiang, 2005). The question then arises as to how we can increase the uptake and use of HFE tools, methods, concepts and theories in order to speed up and improve patient safety efforts.

In this paper, we conceptualize HFE as an innovation that needs to be adopted and implemented in healthcare organizations. Using a conceptual model of innovation (Greenhalgh, et al., 2004), we identified various factors that can either inhibit or encourage HFE applications (i.e. innovations) in health care and patient safety. We conclude with a series of recommendations for HFE professionals, researchers and educators (see Table 2). The recommendations are organized by target group: (1) HFE professionals, (2) HFE researchers and (3) HFE educators. Each recommendation is provided a code (e.g., P1 for the first recommendation for HFE professionals, R2 for the second recommendation for HFE researchers, or E5 for the fifth recommendation for HFE educators); the recommendations are cited throughout section 2 of the paper using these codes.

2. HFE as an innovation in patient safety

The application of HFE in health care and patient safety is not new. In the late 1950's, Al Chapanis, one of the founders of the human factors discipline, and his colleagues at the Johns Hopkins University conducted a study of medication errors in hospitals (Chapanis & Safren, 1960; Safren & Chapanis, 1960a, 1960b). Using the critical incident technique method, they identified a total of 178 medication errors over a 7-month period that were classified in 7 categories (e.g., wrong patient, wrong dose of medication, omitted medication) (Safren & Chapanis, 1960a). Most (90%) causes of the medication errors fell in the following five categories: failure to follow required checking procedures, misreading or misunderstanding written communication, transcription errors, medicine tickets misfiled in ticket box, and computational errors (Safren & Chapanis, 1960a). Even though this research led to several recommendations for preventing medication errors, such as improving written communication (e.g., legibility of handwriting), medication procedures (e.g., double checking) and the working environment (e.g., design of the nurse station and of the medication preparation area) (Safren & Chapanis, 1960b), healthcare organizations have paid very little attention to this study's recommendations.

In 1996, a special section of the *Human Factors* journal on human factors in health care was published under the leadership of Bogner (1996). Several papers published in the special section address HFE issues related to patient safety, including the relationship between noise and pharmacists' accuracy in filling prescriptions (Flynn, et al., 1996) and team coordination in emergency care (Xiao, Hunter, Mackenzie, Jefferies, & Horst, 1996).

HFE is relevant for various functions within healthcare institutions to help solve many different kinds of problems, including patient safety (Carayon, 2005). For instance, HFE methods for analyzing the usability of technologies can be used by information technology staff in healthcare organizations that are involved in the design of computerized provider order entry, electronic medical record systems and other information technologies. HFE has been incorporated in the decision-making process used by a Canadian hospital for purchasing infusion pumps (Ginsburg, 2005). HFE has been applied to improve the design of healthcare technologies, such as PCA (patient controlled analgesia) pumps (Lin, Vicente, & Doyle, 2001) and infusion pumps (Zhang, Johnson, Patel, Paige, & Kubose, 2003), and the design of healthcare facilities (Reiling, et al., 2004). The incident reporting system for intensive care units created by Wu, Pronovost and colleagues (Wu, Pronovost, & Morlock, 2002) includes collection of data on various work system elements and HFE. Larsen and colleagues (2005)

applied HFE principles to the redesign of pharmacy-generated medication labels. These examples show the diversity of patient safety problems that can benefit from HFE. However, there is still a lot that needs to be learned about the applicability and application of HFE in healthcare organizations (Carayon, 2005).

Even though research on and applications of HFE for patient safety exist (Carayon, 2007), numerous HFE applications can be considered as innovations in the context of healthcare organizations. Those HFE applications can be categorized as (1) use of HFE tool or method (e.g., a healthcare organization performs a usability evaluation of a medical device or conducts a task analysis to identify sources of workload and error), (2) increase of general HFE knowledge provided to various staff of a healthcare organization (e.g., patient safety officers, risk managers and quality improvement staff of a healthcare organization are trained in HFE), and (3) recruitment of an HFE professional by a healthcare organization. Table 1 provides examples for each of these three types of HFE applications and innovations for patient safety. The HFE innovations for patient safety can also be categorized according to the three domains of HFE as defined by the International Ergonomics Association (2000): (1) physical ergonomics, such as physical ergonomic design of hospital facilities for enhancing hand hygiene practices, (2) cognitive ergonomics, such as assessment of workload, and (3) organizational ergonomics, such as teamwork (see Table 1 for additional examples).

To facilitate and support the application of HFE in healthcare organizations, we can consider HFE as an innovation whose diffusion, dissemination, implementation and sustainability need be understood and specified. Diffusion is the passive spread of innovations and changes, whereas dissemination involves active and planned efforts to convince target groups to adopt an innovation. The implementation of the innovation includes active and planned efforts to incorporate an innovation within an organization. An innovation is sustained if it is institutionalized and routinely used within an organization. In this paper, we use the conceptual model of innovation developed by Greenhalgh et al. (2004) to examine the potential challenges related to the use of HFE innovations in health care and patient safety. To our knowledge, Greenhalgh et al. (2004) conducted one of the most comprehensive reviews of research on innovations, which led to the development of a systemic model of innovation that is used in this paper. Other models of innovation exist, such as the well-known Diffusion of Innovation model (E. M. Rogers, 1962). However, these other models of innovation tend to focus on limited aspects of innovation. For instance, Rogers' (1962) Diffusion of Innovation model addresses the stages of innovation adoption. The review of the innovation literature by Wejnert (2002) discusses characteristics of innovations, characteristics of innovators and the environmental context, but ignores the process and dynamic issues related to innovation, such as adoption, assimilation, implementation and sustainability. In addition to its comprehensiveness, the literature review conducted by Greenhalgh and her colleagues targeted health care as a domain; therefore, their systemic model of innovation is relevant to our discussion of HFE innovations in patient safety.

Figure 1 provides a graphical representation of how we adapted the Greenhalgh et al. (2004) model of innovation to HFE applications. In order for the HFE application to be implemented in a healthcare organization, we need to examine the organizational characteristics (antecedents) that favor innovations, as well as the extent to which the organization is ready to adopt the innovation. Once the organization has decided to adopt the innovation, the implementation and sustainability of the HFE application occur. The impact of the HFE innovation on patient safety can then be evaluated and monitored. A number of people and organizations within (e.g., boundary spanners) and outside of the healthcare organization can influence the diffusion and dissemination of HFE in healthcare organizations. There is also a wider environment that can influence HFE applications in health care and patient safety. Each

component of the innovation model is discussed separately in the following section of the paper.

3. Analysis of HFE innovations

3.1 Characteristics of HFE as an innovation

Several authors have described key attributes of innovations that influence their adoption (Greenhalgh, et al., 2004; Wejnert, 2002). In this section, we discuss the following five attributes of HFE innovations: relative advantage, compatibility, complexity, task issues and nature of knowledge required.

3.1.1 Relative advantage of HFE innovation—HFE is more likely to be adopted by healthcare organizations if clear advantages in terms of effectiveness or cost-effectiveness can be demonstrated. So far, we lack this kind of systematic evidence (Henriksen, 2007). For instance, numerous healthcare organizations have begun to use HFE tools and methods, such as FMEA of high-risk processes (DeRosier, Stalhandske, Bagian, & Nudell, 2002; Wetterneck, et al., 2006) and usability evaluation of medical devices (Fairbanks & Caplan, 2004; Jaspers, 2009; Zhang, et al., 2003). Those applications of HFE tools and methods have been able to identify numerous system factors that contribute to medical errors and have consequently produced recommendations for improving work systems and processes. However, there is limited information on the ‘relative advantage’ of the application of HFE tools and methods [recommendations P10 and R1].

Much knowledge has been developed on HFE-related factors that can affect healthcare workers and organizations, such as poorly designed working conditions and low usability of healthcare technologies. However, there is a lack of evidence regarding the positive impact of HFE interventions on quality and safety of patient care [recommendation R1]. More research and knowledge need to be produced to understand the *fundamental* HFE issues involved in health care and patient safety (R. I. Cook, 2003), as well as methods for *integrating* HFE in the organizational fabric and structure of healthcare organizations (Carayon, 2005). With regard to fundamental research, Cook and his colleagues have argued for a deeper understanding of the complex work of healthcare providers (R. Cook, 2004; R. I. Cook, 2003; Nemeth, Cook, & Woods, 2004).

The question of how to evaluate and demonstrate the ‘relative advantage’ of HFE innovations needs to be addressed. An evidence base should be developed about the impact of HFE applications on patient safety [recommendation R1]. The costs associated with not applying HFE knowledge, i.e. the risks that remain unidentified if HFE is not used and applied, also need to be described and evaluated. These issues have important implications for HFE research in patient safety. HFE researchers need to make every effort to study healthcare system issues that have significant patient safety impact, not just issues that have intrinsic value for HFE research [recommendation R3]. They also need to understand the underlying relationships between work system factors and other HFE variables and patient safety outcomes (Carayon, Alvarado, & Hundt, 2007; Carayon, et al., 2006) [recommendation R4].

3.1.2 Compatibility of HFE innovation—Innovations that are compatible with the adopter’s values, norms and needs are more likely to be adopted (Greenhalgh, et al., 2004). A core principle of HFE is systems thinking: HFE professionals consider the network of interactions between individuals and various elements of their environment (or work system) (M. J. Smith & Carayon-Sainfort, 1989; Wilson, 2000). Shortell and Singer (2008) have identified four types of barriers to creating systems of safe care: strategic barriers (e.g., unclear responsibility for patient care and safety across organizations), cultural barriers (e.g., autonomy of physicians that may hinder effective teamwork), structural barriers (e.g., improvement at

the department or unit level versus improvement at the system level), and technical barriers (e.g., lack of evidence about what works). Each of these barriers can hinder the implementation and dissemination of HFE innovations in healthcare organizations [recommendation P1].

The potential conflict between the physician's professional model, including physician autonomy (Project of the ABIM Foundation, ACP–ASIM Foundation, & European Federation of Internal Medicine, 2002), and the systems approaches advocated by the discipline of HFE have been discussed by Smith and Bartell (2007). They propose that patient safety improvement activities can be implemented to support systems thinking while simultaneously preserving the professional role of physicians; an example is the implementation of multidisciplinary care teams that can create collaborative environments to supplement physician expertise in on-going patient care activities. Another example is the US ACGME's [Accreditation Council for Graduate Medical Education] identification of 'systems-based practice' as a core competency for medical residents: "Residents must demonstrate an awareness of and responsiveness to the larger context and system of health care, as well as the ability to call effectively on other resources in the system to provide optimal health care" [<http://www.acgme.org/outcome/e-learn/introduction/SBP.html>]. This example shows the increasing pressure on physicians to learn and adopt the systems thinking that is at the core of HFE. HFE professionals and researchers need to be aware of barriers to systems thinking in healthcare organizations and develop approaches for dealing with those barriers (Buckle, Clarkson, Coleman, Ward, & Anderson, 2006), as well as take advantage of existing patient safety efforts that incorporate systems thinking [recommendation P1].

Another approach to increase the compatibility of HFE innovations within health care is to consider the cultural characteristics of healthcare organizations (Carroll & Quijada, 2007) [recommendation R8]. Cultural characteristics of health care include scientific inquiry ("Health care practice is more effective when based on evidence" (Carroll & Quijada, 2007, p. 830)) and training ("We learn by repeated practice and feedback from experienced mentors" (Carroll & Quijada, 2007, p. 830)). Since 'scientific inquiry' is highly valued in health care, HFE innovations are more likely to be adopted and implemented if there is evidence about their effectiveness and impact on patient safety [recommendations R1 and E1].

3.1.3 Complexity of HFE innovation—Innovations that are simple to use are more likely to be adopted (Greenhalgh, et al., 2004). HFE innovations represent varying levels of complexity [recommendation P2]. For instance, with regard to usability, a relatively simple HFE innovation may be for the healthcare organization to require that vendors of medical equipment and devices evaluate the usability of their products. A more complex HFE innovation would be for the healthcare organization to have in-house usability knowledge, for instance, in the purchasing department that is in charge of procuring medical equipment and devices.

If an innovation is complex, it may be advisable, if possible, to divide it into small pieces and adopt pieces of the innovation incrementally [recommendation P3]. In the case of HFE innovations, an incremental approach would begin with the use of simple HFE tools and methods, which can demonstrate clear benefits, and then proceed with increased investment in HFE training of patient safety professionals, and finally with the hiring of an HFE professional or engineer.

On the practical side, HFE professionals need to devise creative ways of applying HFE in health care [recommendation P2]. For instance, we need to consider the workload and business of healthcare professionals [recommendation P4]; therefore, HFE methods that rely on active participation of healthcare professionals may be challenging to use because they require time investment (Bohr, Evanoff, & Wolf, 1997). If we are to involve end users in HFE design and

improvement activities, we need to create new approaches that do not add to the already high workload of healthcare professionals [recommendations R2 and R8].

3.1.4 Task performance of HFE innovation—According to Greenhalgh et al. (2004), an innovation is more likely to be adopted if it has a positive impact on task performance. Therefore, the implementation and diffusion of HFE is likely to succeed because many HFE interventions produce changes that are relevant to task performance. As specified in the IEA definition of ergonomics (International Ergonomics Association (IEA), 2000), the goal of HFE is to optimize human well-being and overall system performance. Therefore, the aim of many HFE innovations is to improve task performance. Such effort is more likely to be accepted by healthcare workers because they directly experience the benefits of such innovation [recommendation P4]. For instance, HFE innovations can help redesign healthcare work and processes by removing performance obstacles and facilitating performance (Carayon, Gurses, Hundt, Ayoub, & Alvarado, 2005). Staff in outpatient surgery centers have reported the following performance obstacles: conflict among nurses and between nurses and physicians, lack of staffing, noise and crowded environment (Carayon, et al., 2005). HFE principles can be used, for instance, to redesign the physical layout of outpatient surgery centers to reduce noise and its propagation, and to facilitate communication among the staff. This type of intervention can provide direct benefits to healthcare providers (i.e. improvements in task performance) and are, therefore, more likely to be accepted by them [recommendation P4].

3.1.5 Knowledge of HFE innovation—The knowledge required to design, implement and disseminate HFE innovations is very diverse. It relies on knowledge of basic scientific disciplines, such as physiology, sociology and psychology, as well as applied sciences, such as industrial engineering, business and management [recommendation E2]. This diversity in the HFE knowledge base may hinder the dissemination of HFE in health care (Greenhalgh, et al., 2004). One approach for dealing with this would be to use a phased approach where HFE is applied in very specific applications, for instance when a particular technology is being implemented or when a renovation is being planned [recommendation P3]. Once these HFE applications have demonstrated their effectiveness, HFE could be diffused and disseminated more broadly within the healthcare organization.

The dissemination of HFE could also rely on a network of HFE-trained healthcare providers spread throughout the organization and available to work on specific projects (Vicente, 2003) [recommendation E8]. This approach has been successfully used in the dissemination of office ergonomics knowledge within a public service organization (Haims & Carayon, 1998). It relies on intense involvement of HFE experts over a short period of time. In a ‘train-the-trainer’ model, the HFE experts then transfer their knowledge and expertise to a small group of selected employees. Over time, this group of employees gains HFE knowledge and experience, and the role of the HFE experts changes to a support role. The HFE-trained employees can represent the seeds for disseminating HFE knowledge and skills throughout the organization.

3.2 Organizational antecedents for HFE as an innovation

With regard to the assimilation of innovations, organizations can be characterized on the following dimensions: structure, absorptive capacity for new knowledge, and receptive context for change (Greenhalgh, et al., 2004). Many structural characteristics have been related to innovativeness (Rye & Kimberly, 2007; Wejnert, 2002). Organizations are more likely to assimilate innovations if they are large, mature, functionally differentiated and specialized, if resources are available for new projects, and if they have decentralized decision-making structures (Greenhalgh, et al., 2004). However, it is important to recognize that evidence

concerning the contribution of these structural characteristics to organizational innovativeness is weak.

It is possible that HFE may be more likely to be adopted by large healthcare organizations and systems as suggested by research on innovations (Greenhalgh, et al., 2004). Small healthcare organizations, such as small rural hospitals and small primary care practices, may find it more challenging to have access to HFE expertise [recommendations R5 and R8]. Healthcare organizations tend to be highly differentiated with many semi-autonomous departments and units [recommendation P6]. Such an organizational structure can facilitate the adoption and assimilation of HFE knowledge. For instance, in the redesign of a hospital intensive care unit, HFE knowledge can be used to improve the physical environment for both healthcare providers and patients. Such a local effort can succeed because the HFE effort is focused on a single unit that has some autonomy (and specific needs) regarding the physical redesign.

Healthcare organizations with a learning organization culture are more likely to adopt HFE innovations (Greenhalgh, et al., 2004). Understanding how HFE knowledge can be ‘absorbed’ by healthcare organizations deserves further attention. This can occur through direct participation in multidisciplinary research projects that involve HFE and healthcare disciplines (Carayon, 2006; Gopher, 2004) [recommendation R6] or through practical projects in which cycles of learning and feedback occur [recommendation R7].

Strong leadership, strategic vision and climate conducive to experimentation and risk are characteristics of organizations that are receptive to change (Greenhalgh, et al., 2004). HFE innovations are more likely to be adopted by healthcare organizations that have those characteristics [recommendation P5]. Implementation of HFE innovations can be particularly challenging, however, in healthcare organizations that tend to have strong professional boundaries and where professionals tend to function within mono-disciplinary communities (Ferlie, Fitzgerald, Wood, & Hawkins, 2005).

3.3 Organizational readiness for HFE as an innovation

An organization is ready for HFE innovations if there is tension for change and HFE is seen as a promising solution to current problems. There is pressure on healthcare organizations for improving quality and safety of care¹; this creates an environment more receptive to change. It is unclear whether healthcare leaders and top managers perceive HFE as having the potential to provide solutions for improving quality and safety of care. Therefore, information needs to be provided to healthcare leaders and top managers so that they understand the (potential) benefits of HFE; this information may be communicated in the form of case studies and actual examples of patient safety projects [recommendations P10 and P12]. HFE professionals and their scientific organizations have an important role to explain how HFE can help in improving patient safety [recommendation P12].

Organizational readiness for innovation is also influenced by the innovation-system fit, i.e. the fit between the HFE innovation and the organization’s values, norms, strategies, goals, and ways of working. This is discussed in a previous section (section 3.1.2) on how to improve the compatibility of HFE innovations with the cultural characteristics of healthcare organizations. Organizational readiness for innovation is also influenced by the assessment of implications (has the impact of the HFE effort been fully assessed and anticipated?), support and advocacy (is there support for HFE within the organization?), dedicated time and resources (have resources been allocated to the HFE effort?), and capacity to monitor and evaluate the innovation (is there a system in place for evaluating the actual and anticipated effects of the

¹For instance, in the US, in 2008, the Centers for Medicare & Medicaid Services (CMS) announced that reimbursement for “never events”, i.e. preventable medical errors that result in serious consequences for the patient, will be eliminated.

HFE effort?). All of this requires significant preparation and planning to ensure that the organization is ready for the HFE innovation [recommendation P5 and P7].

3.4 Adoption and assimilation of HFE innovation

Adoption of an innovation is typically accomplished by individuals, whereas innovations are assimilated by organizations. According to Rogers (1995), several aspects of adopters and the adoption process affect the innovation process: general psychological antecedents, meaning of the innovation for the adopter, adoption decision, concerns in preadoption stage, concerns during early use, and concerns in established users. The adoption process has been described by Rogers (1995) and Hall and Hord (1987). Rogers (1995) describes the adoption process as having five stages: awareness, persuasion, decision, implementation, and confirmation. A core element of the Concerns-Based Adoption Model of Hall and Hord (1987) is the change facilitators who have access to a resource system, and who are responsible for understanding the needs of the adopters [recommendation E9]. This model also highlights concerns occurring in various stages: preadoption stage (e.g., concerns for awareness and information), early use (e.g., concerns for information and training) and established use (e.g., concerns for feedback). HFE professionals involved in the implementation of HFE in healthcare organizations need to understand these different stages of innovation adoption and what is needed at each stage [recommendations P8 and E4]. For example, a healthcare organization wants to implement a systematic approach to usability evaluation of medical devices. At the preadoption stage, efforts will be needed to create awareness of the importance of usability: information about the importance of usability of medical devices for patient safety needs to be disseminated. At the early stage of adopting this HFE method, training on different usability methods may be necessary so that staff in the purchasing department can identify whether a medical device manufacturer has actually conducted some usability testing of the device considered for purchasing. Over time, the healthcare organization would evaluate the impact of usability evaluations of medical devices.

HFE is more likely to be adopted as an innovation if the adopters “are aware of the innovation; have sufficient information about what it does and how to use it; and are clear about how the innovation would affect them personally” (Greenhalgh, et al., 2004). There is increasing recognition by healthcare providers and organizations of the importance of HFE. However, healthcare leaders and top managers are somewhat unclear of the benefits that HFE efforts can offer to improve quality and safety of care (Carayon, 2005). The HFE community (HFE professionals, researchers, educators and professional organizations) needs to reach out to the ‘customers’ of the HFE knowledge, concepts and methods [recommendations P11 and P12]. Those outreach efforts are important to create and sustain awareness for HFE innovations.

Healthcare organizations, departments and teams that adopt HFE innovations are likely to go through a ‘messy’ process of assimilation, as opposed to a linear straightforward process (Greenhalgh, et al., 2004; Van de Ven, Polley, Garud, & Venkataraman, 1999). Healthcare organizations that initiate, develop and implement an HFE effort may experience setbacks and surprises. The ‘innovation journey’ as described by Van de Ven and colleagues (1999) is open and dynamic, and may take parallel, convergent and/or divergent paths. Therefore, people and organizations involved in the implementation of HFE in health care should expect setbacks and surprises. They should adapt to the evolving context and circumstances, and may need to revise the HFE tool, method or approach to fit the changing environment [recommendations P9 and E5]. These changes and events are part of a ‘normal’ innovation journey in which HFE knowledge, concepts and methods are assimilated by the entire healthcare organization. In the healthcare environment, this innovation journey is further complicated by the larger financial, legal and regulatory context.

3.5 Implementation and sustainability of HFE innovation

Once HFE has been identified as an innovation by a healthcare organization, the steps following the adoption include implementation and sustainability. Elements for system readiness discussed in a previous section (section 3.3) (e.g., support and advocacy, time and resources) are also relevant for implementation. Additional elements relevant for implementation include: an adaptive and flexible organizational structure, top management support and continued commitment, human resource issues, funding, intraorganizational communication, interorganizational networks, feedback, and adaptation/reinvention (Greenhalgh, et al., 2004).

Top management support and continued commitment to the HFE innovations is critical for the success of its implementation and sustainability. Commitment by top management has been identified as a critical factor in the change management literature in general (Kotter, 1996; M. J. Smith & Carayon, 1995; Weick & Quinn, 1999), and specifically in the literature on technological change in health care (Karsh, 2004). Involving top managers and other organizational leaders early in the innovation process will provide the necessary support and commitment for the implementation of HFE innovations [recommendations P5, P7 and E6].

The implementation and continued use of HFE innovations by healthcare professionals depend on their motivation, capacity, and competence. As recommended by the participatory ergonomics approach (Wilson & Haines, 1997), early involvement of individuals affected by the HFE innovations is critical for a successful implementation and for sustainability. If the HFE innovation changes the way work is done and tasks are performed, attention should be dedicated to training so that healthcare workers learn the new tasks and working methods.

The implementation and sustainability of HFE innovations can benefit from feedback on the impact of the innovation and the implementation process [recommendation P10]. Timely and accurate feedback can provide useful information for anticipating some of the potential difficulties and setbacks in the implementation process. It can also provide important information for the next innovation implementation, therefore creating a process of organizational learning (Hundt, 2007). Issues about the measurement of the impact of HFE innovations were raised in a previous section (section 3.1.1).

3.6 Diffusion and dissemination of HFE innovation

The spread of innovation can be conceptualized as a continuum between pure diffusion and active dissemination. Diffusion is characterized by unplanned, informal, decentralized processes, whereas dissemination involves planning and formal processes. Various elements help spread innovations: network structure, homophily (similarity in terms of socioeconomic, educational, professional and cultural backgrounds), opinion leaders, champions, boundary spanners and formal dissemination programs (Greenhalgh, et al., 2004).

Strong social networks can support and influence the adoption of HFE innovations. Network structures can be used to diffuse and disseminate patient safety innovations (Carayon, Kosseff, Borgsdorf, & Jacobsen, 2007). Such network structures can also contribute to the adoption of HFE innovations for improving patient safety [recommendation P6]. The presence of opinion leaders and champions in those networks can very much influence the adoption of HFE innovations. It is important to identify those opinion leaders and champions who will support the implementation of HFE innovations. This process can be facilitated by training opinion leaders and champions in HFE, and 'giving away' HFE to the end users (Carayon, Alvarado, & Hundt, 2003; Carayon, Alvarado, et al., 2007) [recommendation E8]. It is important to realize that opinion leaders can have either a positive or negative influence on the adoption of HFE

innovations (Ferlie, et al., 2005). Identifying those negative influences early on in the implementation process is important to anticipate potential difficulties and setbacks.

Using the homophily concept, HFE innovations are more likely to be adopted if healthcare professionals are trained in HFE and become the change agents for HFE innovations in their own healthcare organizations and associations. Several healthcare organizations have been recruiting physicians trained in HFE for leading their patient safety program. This can have major benefits for the diffusion of HFE innovations [recommendation E8].

Formal programs should be developed at the national and international levels to support the structured dissemination of HFE knowledge, tools and methods throughout the healthcare industry [recommendation P12]. Greenhalgh et al. (2004) list five characteristics of effective dissemination programs that can be applied to HFE innovations: (1) consideration for the needs and perspectives of potential adopters, (2) use of tailored strategies for different subgroups, (3) development of a communication message with ‘appropriate style, imagery and metaphors’ (page 603), (4) use of appropriate communication channels, and (5) evaluation and monitoring of objectives and milestones. The HFE community needs to clearly understand the HFE-related needs of healthcare organizations. Given the variety of patient safety problems in diverse healthcare settings, an effective strategy may be to focus on the most urgent needs and to identify the relevant stakeholders [recommendation R3]. In the dissemination efforts, it is important to clarify what needs to be communicated to the targeted audience, such as information about the scientific evidence of the HFE innovations, or knowledge on the feasibility of an HFE tool or method. Any dissemination program should be formally evaluated in relation to its objectives and intermediate milestones. National and international HFE organizations have a major role to play in establishing and implementing efforts for disseminating HFE in health care and patient safety [recommendation P12].

Individuals in boundary spanning positions can play a critical role in supporting the dissemination of HFE within and across healthcare organizations. For instance, local champions for HFE innovations in healthcare organizations may also be involved in formal dissemination programs at the national and/or international levels. Involving boundary spanners may produce benefits at both local and national/international levels [recommendation P12].

3.7 The wider environment

Many external factors influence the adoption of innovations (Rye & Kimberly, 2007; Wejnert, 2002), such as informal interorganizational structures, intentional spread strategies such as quality improvement collaboratives, uncertainty in the wider environment, and political directives (Greenhalgh, et al., 2004). Vicente (2003) conducted a longitudinal case study analysis of how a manufacturer of a PCA pump was influenced by external factors that led to increased attention by the manufacturer to patient safety and HFE. This case study demonstrates the larger environmental and sociotechnical factors that can influence the adoption of HFE by manufacturers of healthcare equipment.

In a previous section (section 3.6), we discussed the role of national and international HFE organizations in formal dissemination programs. Formal dissemination can take advantage of various policies and initiatives from legal and regulatory organizations [recommendations P11 and R9]. For instance, the US-based Joint Commission requires healthcare organizations to conduct risk assessments of high-risk processes; this has generated interest for many HFE tools and methods, such as FMEA. Visible efforts by the World Health Organization (WHO) in improving patient safety have also contributed to increased attention paid to HFE. The initiative by the WHO World Alliance for Patient Safety to develop an international classification for patient safety has clearly benefited from the involvement of HFE experts and researchers

(Runciman, et al., 2009; The World Alliance For Patient Safety Drafting Group, et al., 2009). For instance, the conceptual framework for the WHO international patient safety classification integrates the latest HFE research on error detection and recovery (Runciman, et al., 2009). HFE professionals and researchers need to get increasingly involved in healthcare policy development [recommendations P11 and R9].

Another mechanism to improve the dissemination of HFE innovations is to create collaboratives of healthcare organizations interested in assimilating and implementing HFE innovations. Effective collaboratives would be those with motivated teams and participants that have effective facilitation and technical support in HFE (Greenhalgh, et al., 2004). HFE and patient safety collaboratives could be created around major problems, such as management of workload, design of health information technology and medical devices, and error reporting. HFE professionals and researchers, therefore, need to know how to work in multidisciplinary teams [recommendation R6 and E3]. Healthcare organizations could share lessons learned about these patient safety topics; this will contribute to the dissemination of HFE knowledge that can help with specific patient safety issues [recommendation P13].

3.8 Linkages among components of the innovation model

We have described the different elements of the innovation model separately. However, it is important to understand the linkages among the elements of the model (Greenhalgh, et al., 2004). The adoption, assimilation, implementation and sustainability of HFE innovations in healthcare organizations is strongly linked to the larger environment as well as various formal and informal efforts aimed at spreading HFE innovations in the healthcare industry. External HFE experts can serve as change agents and knowledge purveyors that create the links between the different components of the innovation process. Formal dissemination programs by national and international organizations can facilitate the building of relationships between HFE experts and healthcare organizations and policy makers [recommendation P12].

Research shows that external change agents are more effective if the adopters of the innovation perceive them as credible; if they exhibit social skills and can develop strong interpersonal relationships with the end users of the innovation; if they build bridges between the developer of the innovation and the end users of the innovation by, for instance, relaying end user needs and concerns to the developer of a particular technology; and if they help and empower the end users develop their own evaluation of the innovation (Greenhalgh, et al., 2004). This research has a number of implications for HFE experts hired by healthcare organizations as change agents. First, the HFE experts should be perceived as credible. This requires that HFE experts have extensive experience in the healthcare domain, have a strong capacity for learning and listening, and are flexible [recommendations P9, E5 and E7]. Second, HFE experts should have strong interpersonal skills [recommendation E6]. This will facilitate communication between the HFE experts, on one hand, and the adopters and end users of the HFE innovation on the other hand. Third, the HFE experts should be knowledgeable about the HFE innovation itself, as well as the process for implementing the innovation [recommendations E2 and E4]. The training of HFE experts should allow for the development of skills and knowledge on how to be an effective change agent [recommendation E9].

4. Recommendations and conclusions

From the discussion about HFE innovations for patient safety, we can draw a series of recommendations for HFE professionals, researchers and educators (see table 2 for a list of recommendations). Each of the three HFE groups, i.e. professionals, researchers and educators, will need to address these recommendations in order to improve the spread of HFE innovations for patient safety. The three HFE groups will also need to work together to implement those recommendations. For instance, HFE professionals involved in patient safety work can help

HFE researchers to identify significant research issues. HFE educators need to understand the needs of HFE professionals and researchers in order to develop effective training and educational programs. The implementation of these recommendations requires individual as well as collective leadership on the part of the HFE community.

People involved in HFE practice, research and education in health care and patient safety can contribute to the spread of HFE, and may actually play important leadership roles in patient safety improvement efforts (Henriksen, 2007). Henriksen (2007) has proposed that HFE experts play an important role in transforming and redesigning healthcare systems for improving patient safety. Leape (2004) has called for HFE researchers and practitioners to take on the challenges of designing high-quality safe healthcare systems. This paper has proposed that HFE could be considered as an innovation; this has multiple implications for HFE professionals and researchers, and the training of HFE professionals and researchers.

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Figure 1.
HFE as Innovations in Healthcare Organizations (adapted from Greenhalgh et al. (2004))

Domains of Human Factors and Ergonomics (HFE) and their Relationships to HFE Innovations and Patient Safety

Table 1

Domains of HFE	Examples of HFE Innovations		
	Use of HFE Tools and Methods	Increase of HFE Knowledge	Recruitment of an HFE Professional
Physical ergonomics	<ul style="list-style-type: none">• Biomechanical analysis to analyze physical stressors that nurses are exposed to; link between worker safety and patient safety• Link analysis for the design of efficient layouts	<ul style="list-style-type: none">• Ergonomic design of workstations (e.g., nursing station in a hospital)• Environmental design (e.g., noise, lighting)	<ul style="list-style-type: none">• Renovation of a hospital unit• Building of a new healthcare facility
Cognitive ergonomics	<ul style="list-style-type: none">• Assessing workload• Usability evaluation of a medical	<ul style="list-style-type: none">• Usability• Training• Human error	<ul style="list-style-type: none">• Designing an event reporting system• Evaluating the usability of technologies
Organizational ergonomics	<ul style="list-style-type: none">• Evaluation of teamwork• Analysis of high-risk processes (e.g., FMEA)	<ul style="list-style-type: none">• Teamwork• Participatory ergonomics	<ul style="list-style-type: none">• Implementing crew resource management training in surgery teams• Designing work schedules for reduced fatigue and enhanced performance

Table 2

Recommendations for HFE Professionals, Researchers and Educators

Target Audience	Recommendations
HFE Professionals	<ul style="list-style-type: none"> • P1. Be aware of barriers to systems thinking; develop approaches for dealing with those barriers • P2. Know the complexity of HFE tools and methods; appropriately simplify HFE tools and methods • P3. Use an incremental approach to implementation of HFE innovations; from simple to complex; from low to high knowledge • P4. Use HFE knowledge to improve work and working conditions of healthcare professions • P5. Work on patient safety projects with healthcare organizations that have strong leadership, strategic vision and climate conducive to experimentation and risk • P6. Be aware of professional boundaries and social networks within healthcare organizations • P7. Conduct significant preparation work before applying HFE tool and method, including assessing potential impact of HFE innovation and evaluating support and resources • P8. Be aware of innovation adoption stages (i.e. awareness, information and training, and feedback); adapt HFE innovation to the adoption stage • P9. Be flexible • P10. Evaluate patient safety impact of HFE innovations • P11. Get involved in healthcare policy development • P12. Communicate with healthcare leaders and top managers about HFE and its (potential) benefits for patient safety; establish formal programs for disseminating HFE in health care and patient safety; work with 'boundary spanners' [<i>For national and international HFE associations</i>] • P13. Share best practices and lessons learned about patient safety improvement projects
HFE Researchers	<ul style="list-style-type: none"> • R1. Develop evidence of the impact of HFE innovations on patient safety: criteria, research designs, generalizability, role of context • R2. Develop and test simple, reliable and valid HFE tools and methods • R3. Conduct research on significant patient safety issues • R4. Develop models and theories about mechanisms between work system characteristics and other HFE variables and patient safety • R5. Disseminate research results to different types of healthcare organizations (e.g., small and large hospital) • R6. Work on multidisciplinary research projects • R7. Conduct action research with cycles of learning and feedback • R8. Develop HFE tools and methods adapted to different healthcare settings and to the complexity and cultural and structural characteristics of healthcare organizations • R9. Get involved in healthcare policy development
HFE Educators	<ul style="list-style-type: none"> • E1. Teach about healthcare culture (e.g., scientific inquiry) • E2. Teach diverse knowledge of HFE • E3. Teach about working in multidisciplinary teams • E4. Teach about innovation process and stages of adoption

Target Audience	Recommendations
	<ul style="list-style-type: none">• E5. Develop HFE students' ability to deal with uncertainty and ambiguity in innovation process• E6. Teach communication skills, in particular communication with top management and leadership• E7. Encourage HFE students to work on practical projects in health care• E8. Train healthcare professionals in HFE• E9. Teach HFE students how to be change agents