

# Evolution of Human Factors Research and Studies of Health Information Technologies: The Role of Patient Safety

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## Summary

**Objectives:** The objective of this survey paper is to present and explain the impact of recent regulations and patient safety initiatives (EU, US and Canada) on Human Factors (HF)/Usability studies and research focusing on Health Information Technology (HIT).

**Methods:** The authors have selected the most prominent of these recent regulations and initiatives, which rely on validated HF and usability methods and concepts and aim at enhancing the specific process of identification and prevention of technology-induced errors throughout the lifecycle of HIT.

**Results:** The analysis highlights several points of consensus: 1) safety initiatives or regulations applicable to Medical Devices (MD) tend to extend to HIT, 2) Usability is considered a fundamental dimension of HIT safety, 3) HF/Usability methods and the overall Human Centred Design (HCD) approach are considered efficient solutions to ensure the design of safe and usable HIT. However, it appears that MD manufacturers, and a fortiori HIT designers and developers are still far from being able to routinely apply HCD to their products

**Discussion and conclusion:** On the research side, we need to analyze manufacturers' difficulties with the application of the HCD process and imposed standards. For each given category of HIT, we need to identify the fundamental usability dimensions and design principles likely to impact patient safety independently of workplace settings or organizations. These should be described in terms of usability flaws, corresponding usage problems experienced by users and related outcomes. This approach requires good quality and well structured reporting of Human Factors/ Usability research studies on HIT.

## Keywords

Human engineering, usability, patient safety, regulation, medical informatics applications

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## 1 Introduction

Human Factors (HF) is an important area of health informatics research. Over the past several years, research studies have reported that poorly designed and implemented Health Information Technology (HIT) may negatively influence the process of patient care, clinician workflows and health professional work activities as well as introduce technology-induced errors. Increasingly, we have seen governments' and international bodies' attempt to address these issues through investment in further analysis and regulation of systems.

The objective of this survey paper is to present and illustrate the impact of recent regulations and patient safety initiatives on HF studies and research in the area of HIT systems. Awareness of the role of HF issues in the success or failure of HIT applications has been growing steadily over the past two decades. In parallel, we have observed the progressive emergence and organization of the corresponding research field, i.e. Human Factors (or Ergonomics) as applied to Health Informatics, the organization of experts in the domain, and the development of knowledge in the form of guidelines and recommendations for the design and implementation of usable and safe HIT products. HF expertise is applied through Human Factors Engineering at all stages of HIT projects, including the [1, 2]:

- Design and development of products
- Implementation of products in the clinical setting and all related activities, including

parameterization and organizational design of the work system in which products are to be implemented

The present survey paper limits its scope to the first category of tasks, i.e. the **design** (or **re-design**) and **development** of **HIT applications** and the corresponding **Human Factors activities** usually referred to as “**usability**”.

Since the publication of the IOM report “To Err is Human” [3], prevention of medical errors has been a strategic activity for healthcare organizations and institutions at the national and international level. Health information systems and applications have been considered promising tools to enhance safety of healthcare systems and processes; therefore, a wide range of incentives throughout the developed [4, 5] and developing countries [6] have emerged. This high expectation underlines the need for increased attention to observations and evidence that some HIT products may not only fail to prevent known medical errors but may also contribute to the emergence of new types of errors [7, 8]. Growing concern over medical errors related to the introduction of HIT into clinical settings has arisen and these errors, which are sometimes called “use errors” or “technology-induced errors”, have generated a number of initiatives and, more importantly, new regulations applicable to HIT, e.g. the revised European Medical Device Directive [9]. In the past two years, enforcement of these initiatives and regulations have resulted in a notable demand for usability studies of

HIT and for extended HF research to better prevent use errors / technology-induced errors in healthcare [10-12]. Based on the experience and expertise of the authors, this survey paper summarizes this recent evolution and identifies emerging and persistent research challenges.

## 2 Background

### 2.1 Human Factors / Ergonomics and Usability

According to the International Ergonomics Association, [13] Human Factors or Ergonomics<sup>1</sup> is “the scientific discipline concerned with the understanding of interactions among humans and other elements of a (work) system, and the profession that applies theory, principles, data and methods to design in order to optimize human well being and overall (work) system performance”. Safety is a critical component of system performance.

There are several domains of specialization in Human Factors or Ergonomics, namely Physical Ergonomics, Cognitive Ergonomics and Organizational Ergonomics (or macroergonomics). Various aspects of HIT design and implementation are concerned by these dimensions of HF. Cognitive ergonomics is by far the most important domain of HF for HIT design. It addresses essential aspects of individual and collective healthcare tasks such as decision making, human-computer interaction, mental workload, human reliability and work stress, which are of critical importance for interaction with HIT tools.

HF work and research rely heavily on qualitative methods, which have been progressively structured, organized and standardized into an overall approach referred to as Human-Centered Design - HCD (or User-Centered Design - UCD) [14]. This particular process to system design is iterative in nature and includes several key steps, as illustrated in figure 1:

- analysis and understanding of the context of use, which includes the observation and analysis of the work system in which the product is to be implemented, along with a review of existing literature reporting incidents or use errors with similar products
- specification of users' requirements, including the identification of key usability features for the system under design
- design solutions
- iterative evaluation of the usability of design solutions

The process goes on until evaluation demonstrates that the system under development satisfies all specified requirements. In this HCD approach, observation and analysis of existing work systems and their technology is an essential part of HF work. For decades, HF professionals or ergonomists have been observing people at work interacting with all sorts of tools and artifacts. In doing so, ergonomists have progressively identified essential characteristics of these tools that make them more or less easy to use and easy to learn how to use. This is how the concept of “usability” comes into play. Usability is “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” [14]. Usability goes way beyond the features of the

Graphical User Interface (GUI) (e.g. legibility of the texts, layout and prompting of information and tools), and deals more generally with the fit between systems' behavior and users' needs. Considering HIT applications, one of the most important usability features which violations may engender important usage problems and negative outcomes is the compatibility of the system with clinicians' activities, essentially those with a cognitive nature [15, 16].

In summary, the contribution of HF/Usability expertise to HIT is twofold:

- the identification of key usability features of various categories of HIT applications or functions that should be considered mandatory design principles to obtain usable and safe systems
- the methodological knowledge to properly implement and eventually adapt the HCD process to HIT systems

### 2.2 HIT Usability and Patient Safety Concerns

HIT systems are designed and implemented in clinical settings to improve the quality of healthcare work and to improve patient, clinical and organizational outcomes, especially where patient safety is concerned [12, 17]. Indeed HIT has the potential to reduce medical errors [3] and has proven to do so

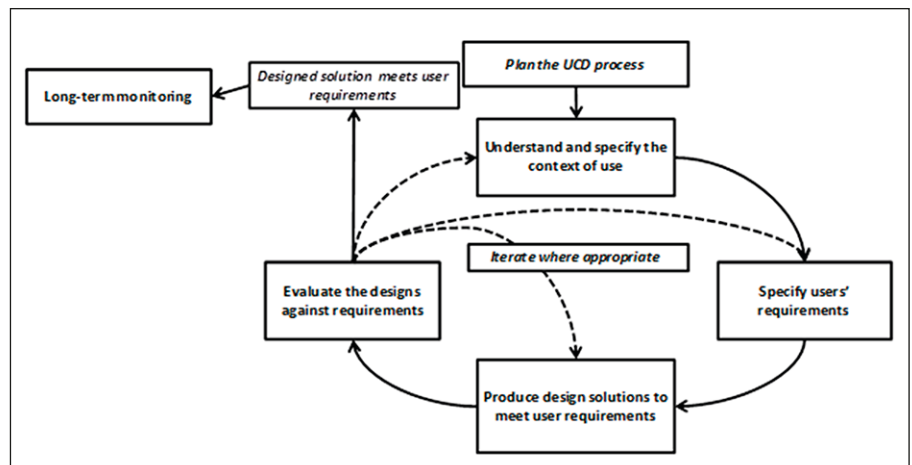


Fig. 1 the Human-Centered Design (HCD) process adapted from the ISO 9241-210:2010

<sup>1</sup> Human Factors and Ergonomics are synonyms and may be used interchangeably.

in some studies [18]. Unfortunately, in spite of continuous progress in HF knowledge, too many HIT systems (including recently developed ones) still suffer from severe usability flaws that make them prone to use errors and potentially dangerous in terms of patient safety. Growing awareness about the potential negative impact of poor usability of the products delivered to healthcare professionals has acted as a powerful leverage to support Human-Centered approaches to the design of HIT applications and systems. The ultimate objective of most initiatives in this domain is to prevent medical errors due to systems' usability flaws, usually referred to as "use errors" [19-21] or "technology-induced errors" [7, 11].

It is acknowledge that software in the healthcare industry can be either safe or unsafe [22]. More importantly, researchers have identified that some software features, functions and workflows either improve or detract HIT's safety and quality [11, 12, 23-26]. As HIT has the ability to improve the quality and safety of healthcare while at the same time introducing new opportunities for patient harm, injury, disability and death [7, 27, 28], there is a need to understand features and functions of HIT that lead to improved safety and eliminate those that lead to technology-induced errors [23].

### 2.2.1 Use Errors / Technology-induced Errors

Technology-induced errors are those errors that "arise from: (a) the design and development of a technology, (b) the implementation and customization of a technology, and (c) the interactions that emerge during the operation of a new technology and the new work processes that arise from a technology's use" [23]. Technology-induced errors differ from unintended consequences. Unintended consequences form a broad range of "unexpected results" resulting from a technology's use. They may be classified as either 'desirable' or 'undesirable' [29]. Technology-induced errors are among the many unintended consequences that result from technology's use [23]. Attention to HF throughout the software development lifecycle can prevent many technology-induced errors.

Over the past several years, we have seen a significant rise in the number of reports of such technology-induced errors in both research and popular literature [8, 11, 27, 30]. There are several reasons for this:

- an increase in the number and diversity of HIT systems that are being implemented, as some governments are incentivizing health care organizations and physicians to implement electronic records in countries such as the Canada and the United States [4, 31],
- an increased awareness among healthcare professionals and organizations about the real need to be concerned about these types of errors [11, 32],
- a recognition by governments and vendors that healthcare should expect vendors to provide high quality HIT that supports healthcare work [33, 34], and
- an increased media attention to reports, where HIT systems have led to death or disability [27, 28].

The number of reports of technology-induced errors is growing while at the same time national, provincial and state governments are struggling to find ways of identifying, preventing and addressing them [35, 36] through industry regulation [33, 37, 38].

### 2.2.2 Examples of Technology-induced Errors that Could be Prevented

According to the literature, some HIT features and functions have contributed to harm, disability and death. Researchers have noted the importance of documenting examples of technology-induced errors. A review of Australian and U.S. incident reports outlined a number of technology-induced errors [27, 28]. Table 1 provides some examples of technology-induced errors identified from incident reporting databases.

Methods developed by usability and clinical simulation researchers show considerable

promise in the identification of technology-induced errors. Researchers have identified specific features and functions of software as well as their emergent workflows as leading to error. Often, the rigid, linear, structured work processes reflected in HIT user interfaces do not adequately address health care professionals' actual work processes, which typically are nonlinear and flexible. Exposure to such systems can affect healthcare providers' information gathering and reasoning strategies [39]. In addition, HIT systems and end users interact in working environments that are very complex. Within these environments, tasks carried out by healthcare professionals are often context-dependent, unpredictable, interrupted, and rely on clear and timely communication between different stakeholders [40]. Introduction of poorly designed HIT into these complex health care environments can cause disruptions in communication among clinicians and may lead to workarounds [41-45]. These misfits between HIT designs and workflow processes create new opportunities for new sources of error.

Most of the time, technology-induced errors are identified after a system has been put into use [30] or after life threatening errors have occurred [27, 46]. Such work is important; however, in the future we need to shift from documenting and addressing errors after they have occurred, to preventing their occurrence or mitigating their effects on patient safety at the design stage [10, 11]. It is worthy to note that HF researchers and usability engineers indeed have the capability to identify the interface design features, functions and emergent workflows that may have error-inducing properties before the system is actually implemented. For example, the evaluation of a prescribing system at the prototype stage [11] noted data entry, display visibility, locating, speed, database content and defaults as error prone features. If not fixed, these usability problems would lead physicians to make errors when using this system.

**Table 1** Examples of technology-induced errors from incident reporting databases

A small font size was used to communicate information. This led to poor display usability. As a result the strength of a medication was not adequately displayed. An overdose of epinephrine occurred and this led to a myocardial infarction in a patient.

The system did not provide medication doses in milligrams. This led to a patient receiving three times the maximum dose of Tylenol-oxycodone (within a 24 hour period).

### 2.2.3 Methods Used to Identify and Prevent Technology-induced Errors

Internationally, researchers are attempting to develop methods that can be used to identify technology-induced errors. These methods are integrated within the HCD process and can be applied before a system is implemented, following its implementation, during technology optimization or maintenance, or after an error has occurred [11, 36, 47] (see Table 2).

Usability testing and clinical simulations have demonstrated their value in relating interface design [10, 35, 48], the clinical workflows emerging from using a technology and technology-induced errors [24, 49]. These methods are also very efficient in supporting HIT procurement, and they allow organizations to identify and purchase safe HIT that fit their organizational needs [50]. Ethnographic approaches have been used to identify technology-induced errors after a system has been implemented [43, 51]. Case study approaches and mixed methods have been used to understand the confluence of factors that contribute to technology-induced errors in order to prevent their future occurrence [8, 15].

Few published studies have fully explored the application of root cause analysis to develop an enhanced understanding of new and emerging technology-induced errors in

healthcare [8, 15, 36, 52]. To date, studies have documented the relationship between systems design, knowledge organization, reasoning and decision making [39]. Future research on HF methods and models should be more emphasized. Here researchers need to explore the link between HIT design features, quality of decision-making and errors [39, 53].

## 3 Initiatives to Prevent Use Errors and their Impact in Terms of HF Research

A number of recent national and international initiatives rely on validated HF and usability methods and concepts to enhance the specific process of identifying and preventing technology-induced errors throughout the lifecycle of HIT [54]. Most of these initiatives address one (or a combination) of the following objectives:

- Require the integration of a standardized (safety-oriented) HCD process during the design and development of HIT products, and try to control and normalize the HCD process.
  - Example: European revised Medical Device Directive (MDD) [9] and

enforcement of harmonized standards IEC 62366:2007, IEC 60601-1-6:2004, 2007 & 2010 [19-21]

- Identify and eventually standardize, for each type of HIT tool or group of functions, safety-critical usability features or design principles that should be complied with.
  - Examples: Handbook of requirements for health data display published by the Australian standards organization [55]
  - Microsoft and NHS Common User Interface initiative which proposes a portfolio of standards and guidance relating to the design of user interfaces for HIT products with the objective of reducing use errors [56]
- Enhanced oversight of HIT by supporting the monitoring and reporting of incidents and errors induced by the technology.
  - Example: efforts of IOM to encourage reports of users experience [57] and the resulting recent initiative by the ONC for a “Health IT Patient Safety Action and Surveillance Plan” [58]
- Integrate HF / usability methods, concepts and guidelines within procedures aiming at certifying the quality of a HIT product.
  - Example: integration of a minimum usability assessment into the EHR certification criteria in the US [59] and recommendation by NIST for a HCD process for EHR technology [38]
- Development of a safety-oriented culture in organizations that develop, implement and monitor HIT, where reporting and solving safety issues involving health information systems is the focus.
  - Example: Canada’s Health Informatics Association is developing a eHealth Safety program that focuses on education and awareness among those involved in the HIT and health care industry, development of standards and guidelines, and monitoring and reporting [60].

In the following section we briefly describe initiatives in Europe, Canada and the US regarding HIT usability and highlight their impact on HF research in HIT.

**Table 2** Possible set of methods that can be used to prevent technology induced errors

Stage of Development and Implementation	Methodology
During HIT Design phase	<ul style="list-style-type: none"> <li>▪ ethnography (observations, interviews)</li> <li>▪ (cognitive) task and workflow analysis and modeling</li> <li>▪ heuristic evaluation with a focus on safety</li> </ul>
During HIT Development	<ul style="list-style-type: none"> <li>▪ heuristic evaluation with a focus on safety</li> <li>▪ cognitive walk through to assess safety issues</li> <li>▪ usability testing</li> <li>▪ clinical simulation</li> <li>▪ clinical plus computer based simulations</li> </ul>
After HIT Implementation	<ul style="list-style-type: none"> <li>▪ ethnography (interviews, focus groups and observations)</li> <li>▪ rapid assessment of clinical system interventions</li> <li>▪ usability testing</li> </ul>
During HIT Optimization or Maintenance	<ul style="list-style-type: none"> <li>▪ heuristic evaluation with a focus on safety</li> <li>▪ case study approach</li> <li>▪ mixed methods</li> </ul>
After an Error has Occurred	<ul style="list-style-type: none"> <li>▪ case study approach</li> </ul>



### 3.1 Example of the Revised European Medical Device Directive

The revised Directive 2007/47/EC [9] was published in 2007 and put into use and enforced in March 2010. The revision includes two major changes of relevance to HF for HIT.

#### 3.1.1 Usability as an Essential Requirement for CE Marking

Usability is now explicitly mentioned as an essential requirement for CE marking to secure patient safety (along with the safety of the system's users). According to the revised Directive "it is necessary to expressly set out the need to consider **ergonomic** design in the essential requirements. In addition the level of training and knowledge of the user, such as in the case of a lay user, should be further emphasized within the essential requirements. The manufacturer should place particular emphasis on the consequences of **misuse** of the product and its **adverse effects** on the human body." This means that the design of a Medical Device (MD) must integrate a usability engineering process as part of the existing Risk Management process; this implies a clear focus on the risk of use errors and their prevention. To achieve this goal the manufacturer is supposed to adopt a HCD approach, and to document it. The resulting "usability file" has to be checked for conformity by certification bodies delivering CE marking. Mandated standards IEC 62366:2007, IEC 60601-1-6:2007 & 2010 [19-21] describe how to apply the HCD to MD and provide instructions for documentation. As they are harmonized with the revised MDD, compliance with these standards is considered compliance with the MDD.

#### 3.1.2 Software Considered as Medical Devices

A number of safety-critical software are now considered medical devices, including stand alone software contributing to diagnosis or treatment (e.g., Computer Clinical Decision Support Systems). According to the revised MDD, a MD is "any instrument, apparatus, appliance, **software**, material

or other article, whether **used alone** or in combination, including software intended by its manufacturer to be **used specifically** for **diagnostic** and/or **therapeutic purposes** and necessary for its proper application". Such types of software are considered MD [61] and therefore need CE marking to be allowed to be marketed and put into use. This opens interesting opportunities of reimbursement from National Health Insurance (in France), in case a vendor decides to go through the required additional steps such as clinical trials that demonstrate the safety and potential benefit of the new MD-software. This process will allow the vendor to get its technology registered on the list of products and services qualifying for reimbursement.

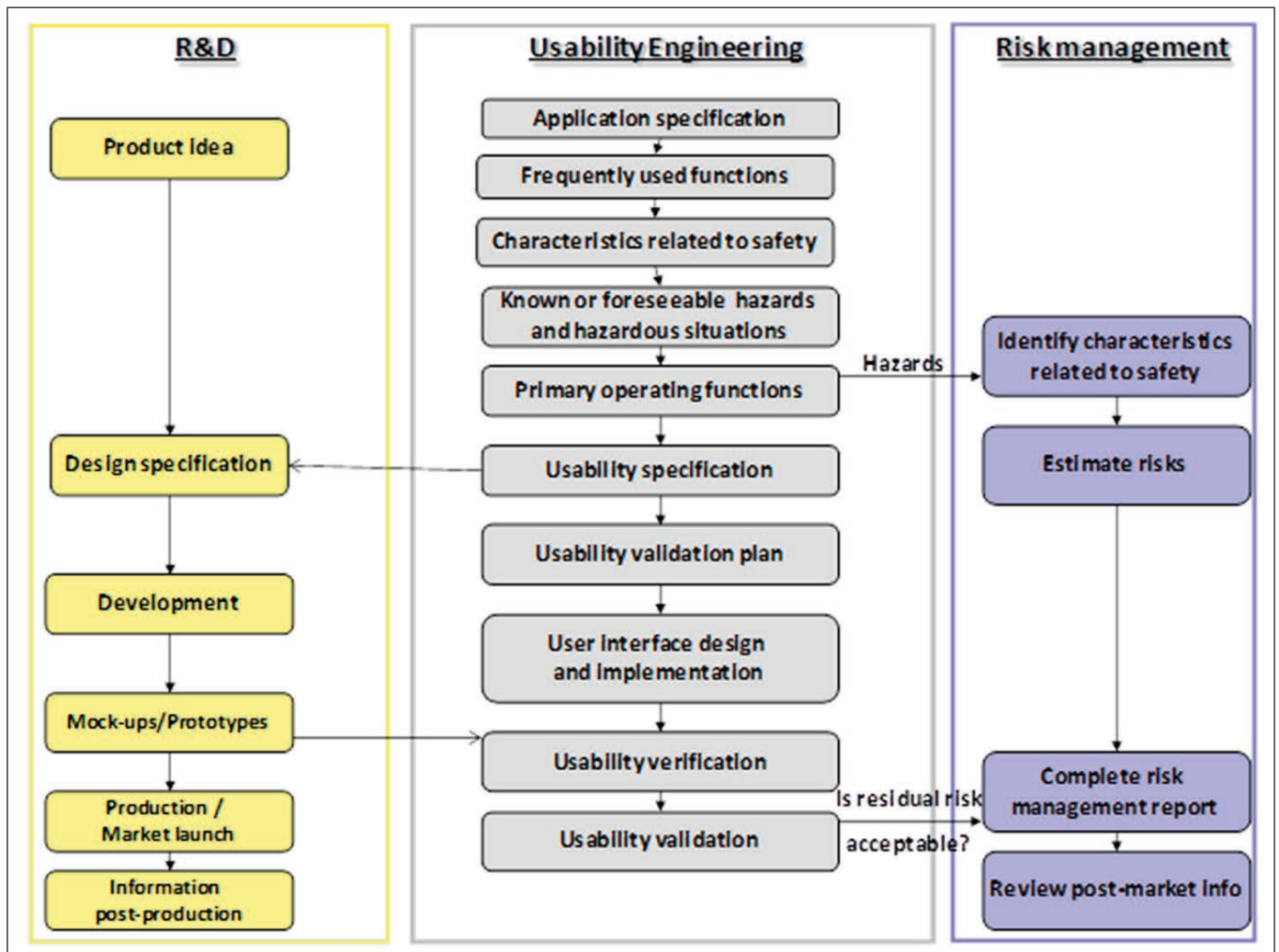
#### 3.1.3 Impact for HIT HF Studies

Enforcement of the revised MDD has provoked a significantly increased demand for consultancy regarding the documentation of the usability file (and to perform usability validation and evaluation) by a number of manufacturers, including HIT vendors. Within each project led by the French authors of this chapter, there was an opportunity to investigate manufacturers' difficulties with the new critical requirements and harmonized standards [62]. Manufacturers (a generic term to refer to stakeholders and people in charge of building and documenting the CE marking file for the MD) have a poor understanding of the concept of usability. They are often unable to identify incident reports or users' negative feedback on their MD as a "use error" caused by "usability flaws" of the Human-Machine Interface (HMI). Misunderstanding the true nature and etiology of use errors, they also miss the *raison d'être* of the MDD essential requirement, i.e. to prevent use errors through improvement of the product itself but also its HMI. Additionally, the workload of usability engineering tasks is often underestimated and manufacturers have difficulties budgeting these tasks. One consequence of this situation is that health authorities, certification bodies and manufacturers themselves acknowledge the necessity to systematically involve HF/usability experts in the usability engineering process and documentation of the usability file.

Moreover, the standards supposed to guide the safety oriented HCD and the documentation of the usability file [19-21] are poorly written, ill-structured and require sound HF/usability expertise as well as knowledge of risk management to be properly understood and applied. Although both standards refer to HCD, it is challenging to properly assign each step of the IEC standards to its proper HCD phase as described in the ISO 9241-210; this is clear when comparing figure 2 with figure 1.

The HCD phase labeled "understand and specify the context of use" includes the first five steps of the IEC 62366:2007 standard, namely "application specification", "frequently used functions", "characteristics related to safety", "known and foreseeable hazards and hazardous situations" and "primary operating functions". The HCD phase "specify users' requirements" in ISO 9241-210 corresponds to the IEC 62366:2007 standard step "usability specification", while the HCD phase "produce design solutions to meet users requirements" is referred to in IEC 62366 as "user interface design and implementation". Finally the ISO 9241-210 last phase of HCD "evaluate the design against requirements" is distributed across the IEC 62366 three steps of "usability validation plan", "usability verification" and "usability validation".

The most difficult (and confusing) part of the usability engineering process as described in the IEC 62366 standard is without doubt the one corresponding to the analysis of the context of use. The description and analysis of the context of use cannot be simply summarized by the documentation of "application specification" and "frequently used functions". The identification of the "characteristics related to safety (of use)" therefore relies on HF experts' understanding of the context of use, including collaborative aspects of the tasks, and of the true nature of users' interaction with the system. The standard also requires documenting "known or foreseeable hazards and hazardous situations". This task requires access to reports of past incidents or errors with similar MDs. Moreover manufacturers are supposed to publish an objective information about the trade-offs between safety, benefit and harm of their MD. But they consider knowledge



**Fig. 2** List of usability engineering tasks and their relations to the R&D and Risk management processes according to the IEC 62366:2007. The usability file is supposed to document how each task has been carried out (method) and what are the corresponding results.

about the design of their MD, especially drawbacks and glitches, as confidential. Not sharing software problems is an industry implicit norm to keep competitors at bay; this is true in many countries [63].

### 3.2 Example of the Health Canada Directive: Software Regulated as a Medical Device

In Canada two organizations are involved in the regulation and certification of healthcare software: Canada Health Infoway and Health Canada. Canada Health Infoway is involved in projects related to electronic health records

and works with the provinces and territories in Canada to facilitate the adoption and use of HIT [31]. Canada Health Infoway provides federal level certification services where health information systems privacy, security, interoperability and management are concerned (not safety) [64]. Health Canada's Therapeutic Products Directorate is responsible for regulating the "advertising, manufacture and sale of medical devices in Canada" through the "Food and Drugs Act" and "Medical Devices Regulations". In 2011, Health Canada began to regulate software (e.g. electronic medical records) as medical devices. The approach is based on elements from the EU (i.e. risk-based classification

system and quality system requirement) and the US FDA (i.e. post-market and pre-market licensing) regulatory systems [37].

According to Health Canada, "software is regulated as a medical device" when it "provides the only means and opportunity to capture or acquire data from a medical device for aiding directly in the diagnosis or treatment of a patient" or "replaces a diagnostic or treatment decision made by a physician" [37]. Health Canada has four classes of medical devices (i.e. I to IV). Class I devices are the lowest in risk whereas class IV devices are the highest. Class I devices can be used to view images and other data in real time "for the purpose of aiding in

treatment and diagnosis of a patient”. Class II devices include “medical device software that is an adjunct to another medical device and is involved in data manipulation, data analysis, data editing, image generation, determination of measurements, identifications of a region of interest in an image, or identification (by an alarm or alert) of results from a monitor that are outside of an established range”. Class II devices could include electronic medical records [37].

To sell or import a Class I device, manufacturers, importers and distributors need to employ a licensed importer (or distributor) or they require an Establishment License. In Establishment Licensing, manufacturers are responsible to ensure devices sold in Canada comply with medical device regulations [37]. To sell or import a Class II device in Canada, a manufacturer must also obtain a License. This involves submitting an application, paying a fee and providing a copy of a valid ISO 13485:2003 quality system certificate. Manufacturers also need to apply for an amendment if the device has been changed. The License is renewed annually [37]. To date, several electronic medical record manufacturers have applied for and successfully obtained a Class II license [65]. ISO 13485:2003 focuses on promoting regulatory requirements, controls in the workplace and risk management, and has a few references to usability [66]. Health Canada is also responsible for other regulatory aspects of medical devices, including mandatory problem reports, recalls, handling of complaints, investigative testing involving human trials and special access [37]. The amount of information about how an organization demonstrates the usability of a medical device is limited.

### 3.3 Examples of US Initiatives for HIT Usability

In the US, several federal agencies and professional organizations have initiated programs targeted at HF and usability of HIT. The Agency for Healthcare Research and Quality (AHRQ) has provided support to HIT research and dissemination, including in the areas of HF and usability of EHR [63], HF of clinical decision support [67, 68], usability and workflow integration of

HIT, in particular in ambulatory care [69], and HF in the design of consumer health IT [70]. Research sponsored by AHRQ has described practices used by HIT vendors for EHR usability [63]. Whereas HIT vendors recognize the importance of HF and usability and report to be committed to producing usable EHR products, they use very limited and weak practices for usability and HCD. They seem to lack the personnel resources and expertise in usability engineering. In addition, as indicated earlier, vendors tend to view usability as a competitive factor and are, therefore, reluctant to share best practices and data on EHR-related problems.

The Office of the National Coordinator for Health Information Technology (ONC) has supported the work conducted by the Institute of Medicine (IOM) on health IT and patient safety [33]. As a follow-up to the IOM report on health IT and patient safety, the ONC has recently issued the *Health IT Patient Safety Action and Surveillance Plan* for public comment [58]. This plan is focused on patient safety issues of HIT, but gives major attention to HF issues, such as design of HIT interfaces and workflow integration. This plan clearly outlines the critical role of usability in the design of safe HIT products: “The safety of EHR developer products and services can be improved by encouraging the development and adoption of recognized industry standards for usability and quality management processes can further ensure.” (page 17).

NIST is another federal agency that has significantly invested efforts and resources in HIT usability by creating a number of guidance documents on EHR usability. For instance, Schumacher and Lowry [38] describe methods and processes for enhancing the usability of EHR technology. In this report, the recommended HCD process includes an iterative flow of the following activities:

- Understand user needs, workflows and work environments
- Engage users early and often
- Set user performance objectives
- Design the user interface from known human behavior principles and familiar user interface models
- Conduct usability tests to measure how well the interface meets user needs

- Adapt the design and iteratively test with users until performance objectives are met. NIST has also issued guidance documents regarding unique HF and usability challenges for specific patient populations, such as children [71].

The two major professional associations related to HIT, the Healthcare Information and Management Systems Society (HIMSS) and the American Medical Informatics Association (AMIA), have also contributed to increasing the awareness of HF and usability of HIT. For instance, in 2012, the HIMSS EHR Usability Task Force issued usability guidelines to be used by small- and medium-sized practices when selecting an EHR [72]. Recently, AMIA created a task force on EHR usability and published preliminary results and recommendations [73].

## 4 Persistent Challenges

The analysis of recent safety initiatives and regulations regarding HIT usability highlights several points of interest:

- The frontier between HIT and Medical Devices is blurred; as a consequence, safety initiatives or regulations applicable to MD, including those specific to HF/Usability, tend to extend to HIT
- Usability is considered a fundamental dimension of HIT safety
- HF/Usability methods and the overall HCD methodology are considered efficient solutions to ensure the design and development of safe and usable HIT

However, it appears that MD manufacturers, and a fortiori HIT designers and developers are still far from being able to routinely apply the HCD to their products. Difficulties are of various nature and some of them pose interesting research challenges.

### 4.1 Manufacturer’s Difficulties with the Application of the HCD

The standards supposed to guide manufacturers in this process, e.g. IEC 62366:2007 and 60601-1-6:2004, 2007 & 2010 [19-21] are not usable by non HF experts, and some



parts remain unclear even for ergonomists. Additionally, the usability maturity level of manufacturers and companies is often poor [74] and not all companies have access to HF expertise to handle the HCD management of their products. This situation impedes the proper planning, budgeting and running of HCD tasks.

On the research side, we need to analyze and better understand manufacturers' difficulties with the application of the HCD process and compliance with imposed standards [62;75]. This analysis is necessary to understand actual barriers, beyond manufacturers' mere reluctance towards new regulations. We also need to analyze systematically the format and content of standards to identify confusing and unclear sections. The combination of both analyses would help draft efficient guidance documents, documentation templates, illustrative case studies etc. It would also help identifying clearly when and how HF expertise is needed.

On the practical/organizational side, we need to make the HF expertise and guidance more visible and accessible to manufacturers and to support all forms of education and training of stakeholders in HF for HIT and MD. Combination/integration of usability studies with preclinical studies and eventually certification procedures also offers interesting perspectives. In a previous paper [1], we advocated the need for Clinical Centers for HF/Usability of Health (Information) Technologies, this still holds true in a context where manufacturers seek support to comply with new regulations and safety expectations. In this context, the French government initiative to create and support several (eight) Clinical Investigation Centers for Innovative Technologies – CIC-IT [76] is promising and starts to show interesting results, including for HF support to HIT industry and medical devices manufacturers. For instance the CIC-IT network has initiated and will coordinate the upcoming European project ITECH which aims at optimizing research & innovation and transfer products and services in HIT. This project includes a section devoted to HF issues and the role of HF in the innovation to market process. This project will provide an opportunity to better identify manufacturers' and HIT vendors' difficulties with the necessary application of the HCD and try to find

methods and tools to overcome the problems at a European and international level.

## 4.2 Difficulties with the Analysis and Description of the “Context of Use”

Most of the papers addressing the application of HCD to HIT and MD focus on the last phase, i.e. “Evaluate the design against requirements”. Those papers report usability evaluation studies of products at various stages of their development and implementation. As highlighted in table 1, we dispose for these studies of reliable and quasi harmonized methods. The benefits of these methods in preventing use errors is also established [10, 48].

We have less papers and reports on the first phase of the HCD, i.e. the understanding of the context of use [77]. This phase indeed, which is critical in terms of usability, safety and utility of the product under design and development is often underestimated and poses fundamental research challenges.

The understanding of the “context of use” relies mostly on ethnographic methods (see table 1) and requires HF expertise to be properly carried out. On site observation and interviews of the users help HF experts understand users' tasks, activities, workflows, mental processes, communication and cooperation procedures etc. and to identify foreseeable usability-related risks. This work provides the basis for usability specifications. However, given the richness and multidimensional characteristics of such data, the description and modeling of the context of use remains difficult to document. This difficulty and the numerous formats of description make hazardous the comparison of descriptions and analyses of the contexts of use for similar products.

In terms of research we need to improve our capacity to identify, for a given category of HIT system or product (e.g. medication CDSS, BCMA, medication CPOE, Laboratory Information System - LIS, etc.) the fundamental dimensions of the “context of use” (tasks, cognitive processes etc.) that would hold whatever the workplace and the organization, and that are important in terms of patient safety and use errors. Descriptions or formalizations of these analyses should be re-usable for other projects targeting

the same type of tool. To carry out safety oriented analyses of the context of use it is also necessary to complement the ethnography methods with a review of reported / published HF/usability related incidents or accidents with similar applications or devices. Such specific information is not readily available. However recent research work on databases of patient safety incidents [27,28] demonstrated that:

- The databases investigated do host reports of computer or HIT related incidents, but in very small proportion (0,1 % to 0,2%); this percentage is expected to grow in the future
- A thorough secondary analysis of the reported incidents is necessary to properly identify use errors. Usability expertise is then required to link the description of these use errors to precise usability flaws of the system.

On the research side, systematic usability analysis of MD / HIT related patient safety incidents needs to be extended and refined in order to seek evidence linking usability principles - usability flaws - usage problems - negative outcomes (medical errors, patient harm). Efforts to support and organize incident reporting of HIT [78] and all forms of users' experience with HIT [57] will progressively provide interesting material for HF experts to work on.

## 4.3 Challenges Related to the Reporting of Usability Studies

Ultimately, the most important contribution to HF / Usability knowledge related to HIT comes from scientific reports of usability studies. It is therefore important that the research community may search and access good quality and well structured scientific reports of usability studies of HIT. Unfortunately, previous systematic review work on such reports has highlighted a number of problems [79].

First, system application domains (e.g. the type of system evaluated, the clinical context of use and the types of system users), system functions and features, case study objectives, stages of system development, research meth-



ods applied, and study outcomes vary greatly across reports. An even more important problem is that these studies have been inconsistent and have not been comprehensive in their reporting. Second, the studies reviewed were incompletely described and lacked details on system functionalities, context of use, user groups, and the system development stage, HF methods applied, usability principles followed to give a few examples. Due to these large variations in HIT application domains, HIT features, and other study aspects and details reported on, the HIT design and usability studies were difficult to compare on their outcomes. The wide variety in the kinds of interactive healthcare applications, their contexts of use as well as the various kinds of methods applied and outcome measures defined limited the generalisability of findings, complicated the appraisal of outcomes, meta-analysis and harmonization of the available evidence. Generally, it can be concluded that the reporting of HIT design and evaluation studies is in vital need of improvement.

When the goal is to build an evidence base of sound HIT design and usability principles, reporting on these kinds of academic studies should be of a certain degree of quality: complete, homogeneous and unambiguous. The wealth of evidence in research on HIT design and usability evaluation remains under-utilized if we do not undertake efforts to standardize the reporting of these studies. There is thus a need for a framework to guide the scientific reporting of HF and usability studies of interactive healthcare technologies for ensuring high quality reporting of these studies. When scientific reports on these types of studies become consistent and complete, future HIT development projects might benefit from lessons learned concerning the methods to apply to prevent user errors, enhance user efficacy, efficiency and to reveal HIT features that may or may not contribute to safe use of a technology.

The first ideas for development of such a framework were gathered during a meeting of the IMIA WG- Human Factors Engineering for Health Informatics at the MEDINFO conference 2010. The IMIA WG acknowledged that without a framework providing guidance of the reporting of HIT design and usability evaluation studies, the building of a proper evidence base of usability and

design principles of HIT that lead to safe and efficient use in practice would remain hampered. In a collaborative effort of the IMIA WG - Human Factors Engineering for Health Informatics and the EFMI WG - Human and Organizational Factors of Medical Informatics, the Dutch and French authors of this paper therefore set out to develop a framework of good practice of reporting on HIT design, development and usability studies. The framework will provide a set of principles to follow for comprehensive and unambiguous reporting of HIT design and usability evaluation studies with the objective to reduce variation and improve on the publication reporting quality of these studies. The principles are inspired by the literature on HIT design and usability studies, standards on human-centered design activities of computer-based interactive systems and existing experience of the IMIA and EFMI WGs members. The first version of the framework has been developed in an iterative process and pilot-testing phase involving experts from the HF and usability domains for HIT of the IMIA and EFMI WGs [80]. The next step is reaching international consensus on the framework by an international Delphi-study among the HF and usability experts in the health informatics community.

#### 4.4 Toward Usability Design Principles for HIT Applications

We also need to make progress in the identification of essential HF / Usability features or principles that are either desirable for a given type of software or on the contrary need to be definitely banned from the design. For instance, interesting research work is going on to identify key usability principles for medication related CDSS, based on expert consensus [81-84] or fundamental cognitive research [85].

### 5 Conclusion

In line with recent position papers advocating for more and better HF / usability research for HIT [73], the present survey paper has highlighted the impact of regu-

lation and patient safety initiatives in this domain, and shown that similar approaches have been adopted by the EU and North America (Canada and US). HF and usability research and studies have demonstrated their importance and their impact on the quality of care and patient safety. Indeed they appear today as a key to getting all expected benefits and promises from innovative HIT. Usable IT systems do improve patient care. Unusable and poorly designed systems are, at best, not used and therefore useless, or at worst they may generate poor performance and technology-induced errors. Throughout the world there is a need for regulatory bodies to promote Human Centered Design of Medical Devices and HIT. Research teams working in this domain must continue to explore all dimensions of system-user interactions and support the evolution of regulations, e.g. by improving the quality of harmonized standards. HF research and academic teams also have a role in disseminating this knowledge amongst students, researchers, stakeholders, companies, and healthcare professionals to improve the quality and the usability of future HIT applications.

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