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SYSTEMS-LEVEL QUALITY IMPROVEMENT

Usability Evaluation of Laboratory and Radiology Information Systems Integrated into a Hospital Information System

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Abstract This study was conducted to evaluate the usability of widely used laboratory and radiology information systems. Three usability experts independently evaluated the user interfaces of Laboratory and Radiology Information Systems using heuristic evaluation method. They applied Nielsen's heuristics to identify and classify usability problems and Nielsen's severity rating to judge their severity. Overall, 116 unique heuristic violations were identified as usability problems. In terms of severity, 67 % of problems were rated as major and catastrophic. Among 10 heuristics, "consistency and standards" was violated most frequently. Moreover, mean severity of problems concerning "error prevention" and "help and documentation" heuristics was higher than of the others. Despite widespread use of specific healthcare information systems, they suffer from usability problems. Improving the usability of systems by following existing design standards and principles from the early phased of system development life cycle is recommended. Especially, it is recommended that the designers design systems that inhibit the initiation of erroneous actions and provide sufficient guidance to users.

Keywords Developing countries · Evaluation study · Hospital information system · Laboratory information system · Radiology information system · User-computer interface · Usability evaluation

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Introduction

Providing high quality healthcare services can promote public health significantly. Institute of Medicine (IOM), citing multiple studies, asserted that information technology and information systems can play an important role in providing safe, timely, effective, and efficient healthcare services [1]. Such systems have the potential to promote patient safety through providing access to high quality information during clinical decision making processes [2].

Studies have shown that some of these systems could not achieve their predetermined goals or have not been well adopted [3]. For example, some systems may cause new kind of errors [4] or require more time from the providers to

accomplish their tasks with the use of these systems [5, 6]. Usability problems are enumerated among the main reasons for these deficiencies and it is highly recommended to continuously evaluate usability of the systems in order to be able to identify and tackle these problems [3, 7–10]. Poor usability can cause decreased efficiency and effectiveness leading to reduced confidence in the system and users' dissatisfaction [11, 12]. Systems with usability flaws may increase error potential and even lead to disaster [4, 13].

In the field of human computer interaction, usability refers to how well a user interface (UI) has been designed, so that it can be used by users efficiently, easily, and with satisfaction [9]. The International Organization for Standardization (ISO) defines usability as "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" [11]. Nowadays, usability evaluation has become very important in development of interactive healthcare information systems. The results of this evaluation in redesign phase could contribute to quality improvement and optimization of systems' UIs. Subtle improvement of UIs based on the results of usability evaluations can lead to higher user satisfaction [14], lower error rate, lower training and support costs, and higher efficiency and effectiveness [13].

So far, various methods have been applied to evaluate usability of interactive computerized systems. These methods are different based on their application, complexity, system development life cycle phase, evaluators expertise, and type of identified problems [13]. One of the most common usability evaluation methods is heuristic evaluation [13]. In this method few experts using a set of specified principles, namely heuristics, judge UI usability [15]. Heuristic evaluation have the following advantages; it is cheap, can be carried out by a low number of evaluators (3 to 5) without involvement of users, and identifies a relatively high number of usability problems in a limited time. Many studies have successfully applied heuristic evaluation for the usability evaluation of healthcare information systems. For example in two studies for the evaluation of a dental practice management systems [16] and a computer-based patient education program, heuristic evaluation identified high numbers of usability problems with high severity ratings [17].

Currently, hospital information system (HIS) is the most common and widespread information system in hospitals. HIS is an integrated system including multiple subsystems which support information requirements of different departments. Laboratory and radiology information systems (LIS and RIS) are two subsystems which are used widely in laboratory and radiology departments. Many users including technicians in laboratory and radiology departments use these subsystems to receive examination requests, schedule working routines and to communicate the results to healthcare providers. Timely access of physicians and other providers to the results of laboratory and radiology examinations is an important factor in efficient decision-making. Usability problems of LIS and RIS can jeopardize the effective and efficient interaction of the systems leading to miscommunication of the results and a delay in the process. Peute and Jaspers in their study on the usability of a laboratory order entry system identified 33 usability problems which leads to inefficiency [18].

Mashhad University of Medical Sciences (MUMS) with its 25 affiliated hospitals and healthcare centers, are the main providers of healthcare services in Khorasan Razavi (with six million population) and neighboring provinces. A customized HIS, called IHIS (Iranian Hospital Information System), with its subsystems including laboratory and radiology systems have been developed and utilized in hospitals operating by MUMS since 2002. Based on unpublished reports user interaction with these systems is somewhat difficult. To our knowledge, so far, no usability study has been done on the UI of IHIS and its subsystems. In a study the usability of a HIS in Iran was evaluated using IsoMetrics questionnaire based on ISO 9241 part 10. This study reported an average ergonomic quality for that HIS and recommended designers should consider more users' needs in designing and development of HISs [19]. Due to the important role of LIS and RIS subsystems in hospitals and the potential impact of their usability on laboratory and radiology results and finally on diagnostic and decision making activities of providers, in this study we evaluate the usability of the LIS and RIS, which are being utilized in MUMS hospitals.

Methods

Information systems

This study was conducted on the LIS and RIS embedded into a HIS used in 25 hospitals and healthcare centers affiliated to MUMS. Routinely about 1,000 daily active users interact with these two systems. Through the LIS and RIS, physicians' orders are sent to the laboratory and radiology departments. Technicians receive orders via these subsystems and enter the results to be communicated in response to the physicians' orders. The two subsystems are independent and run separately but they use identical UIs. An illustration of the LIS UI is shown in Fig. 1.

Study setting

Heuristic evaluation method focuses on the evaluation of UI design without involvement of users. Therefore, it can be done in laboratory setting. This study was performed at a computer laboratory in paramedical sciences faculty of MUMS. The usability evaluators, individually, evaluated the usability of the LIS and RIS against Nielsen's heuristics.

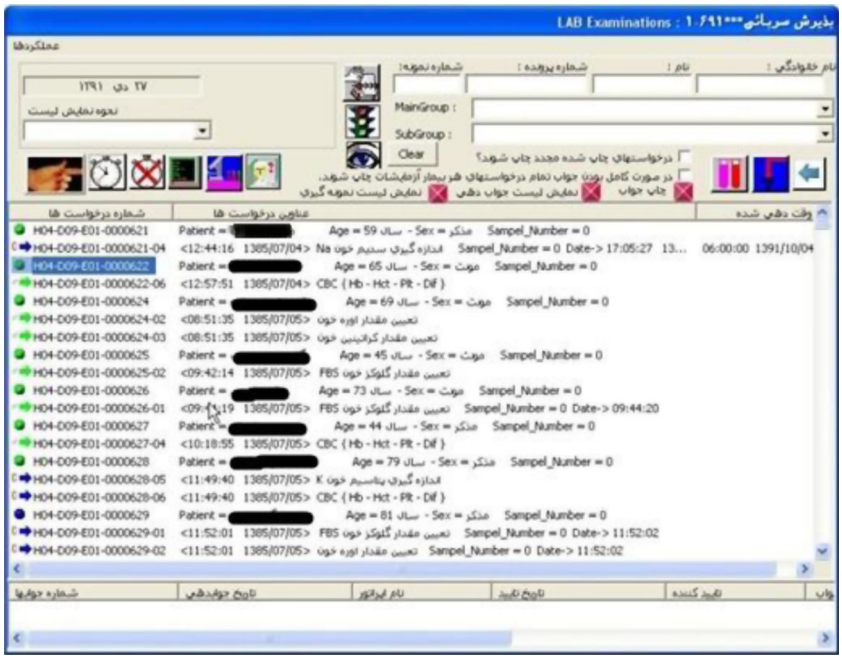

Fig. 1 An illustration of the LIS UI

Usability evaluators

We recruited three PhD students in medical informatics as usability evaluators. All of them passed theoretical and practical course of usability engineering and had experience with usability evaluation methods. The first evaluator, a doctor of pharmacy, had experience of working with various healthcare information systems for 10 years. The second, who has master's degree in medical records, had experience of using multiple HISs for 8 years. The third, having master's degree in computer sciences was familiar with different information systems.

Heuristic evaluation

Heuristic evaluation is one of and the most commonly used usability evaluation method [13]. In this method a few usability experts (3 to 5) investigate the usability of a UI against predefined usability principles, commonly called heuristics [13]. These heuristics indicate the characteristics of usable systems. Nielsen's heuristics are very common in this context (Table 1). In heuristic evaluation, each evaluator individually investigates the UI in two steps: navigation and analysis. In navigation step, the evaluator becomes familiar with the structure and scope of UI. Then in the analysis step, he/she focuses on design of UI and investigates whether it complies with heuristics. The results of this investigation are a set of design flaws which violated specified heuristics. The identified heuristics violations are considered as usability problems.

Data collection and analysis

This study was carried out in four phases: First, to get acquainted with the systems, each evaluator navigated the UI of the LIS and RIS and reviewed their structures. Second, three evaluators independently investigated the UI of the systems to identify any deviation of Nielsen's heuristics as usability problem. Third, in a consensus meeting composed of all three evaluators, identified usability problems in three lists were discussed and merged into a single list after removing duplications. Forth, each evaluator independently quantified the severity of identified problems based on the following factors [20]:

- Frequency: Is the problem common or rare?
- Impact: Is it difficult or easy for the end users to take over the problem?
- Persistence: Does it trouble the end users repeatedly or is it a one-time problem?

Nielsen's severity rating scale was used to rate the severity of each problem [21] (Table 2).

Finally the average severity of each problem was calculated. Decimal numbers were rounded to the nearest whole number to be able to categorize problems based on the standard severity scale presented in above list.

Results

The heuristic evaluation conducted by three evaluators on the LIS and RIS, which are used in MUMS hospitals, identified

Table 1 Nielsen's usability heuristics [21]

Usability heuristic	Description
1. Visibility of system status	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time
2. Match between system and the real world	The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order
3. User control and freedom	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo
4. Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions
5. Error prevention	Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action
6. Recognition rather than recall	Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate
7. Flexibility and efficiency of use	Accelerators— unseen by the novice user—may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions
8. Aesthetic and minimalist design	Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility
9. Help users recognize, diagnose, and recover from errors	Error messages should be expressed in plain language [no codes], precisely indicate the problem, and constructively suggest a solution
10. Help and documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large

158 usability problems. After removing duplicates, 116 unique problems remained. Our analysis was based on the unique problems. Table 3 presents the frequency of identified usability problems based on their severity and the violated heuristics.

The results show that "consistency and standards" with 21 (18 %) identified usability problems was the most frequently violated heuristic. Usability problems concerning other heuristics were less than 15 per heuristic. The heuristic "error prevention" with 6 (5 %) usability problems was the least frequently violated heuristic. The severity of more than 50 % of the problems concerning seven heuristics (heuristics: 3, 4, 5, 6, 7, 9 and 10) was major and catastrophic. Particularly, in two heuristics, "error prevention" and "help and documentation", more than half of the violations were scored as catastrophic.

The average severities of usability problems concerning three heuristics, "visibility of system status", "match between system and real world", and "aesthetic and minimalistic design" were minor while the average severities of problems related to other heuristics were major and catastrophe. 67 % (n=78) of the total number of identified usability problems (n=116) were rated as major and catastrophic (Fig. 2). Two examples of major and catastrophic problems are shown in Fig. 3.

Table 2 Nielsen's severity rating scale

Problem	Severity	Description
No problem	0	I don't agree that this is a usability problem at all
Cosmetic	1	Need not be fixed unless extra time is available on project
Minor	2	Fixing this should be given low priority
Major	3	Important to fix, so should be given high priority
Catastrophe	4	Imperative to fix this before product can be released

Discussion

Heuristic evaluation of the LIS and RIS subsystems, which are widely used in MUMS hospitals and healthcare centers, identified a high number of usability problems. More than half of these problems were major and catastrophic.

The results of our study carried out in a developing country showed that the heuristic with the largest number of violations is "consistency and standards". This result is inline with the results of studies from a developed country reporting a high number of violations concerning this heuristic [16, 17, 22, 23].

Table 3 Identified usability problems per violated heuristics and severity

Violated heuristic	Average severity*	Severity				Total	Example (Severity rating)
		Cosmetic	Minor	Major	Catastrophe		
1. Visibility of system status	2	0	8	6	0	14	The disabled icons are not clearly indicated. (2)
2. Match between system and the real world	2	0	6	2	1	9	The labels of buttons do not match their intended actions e.g., exit button. (3)
3. User control and freedom	3	2	2	6	3	13	There are not "undo" and "redo" functions. (4)
4. Consistency and standards	3	1	5	10	5	21	Buttons are not consistently labeled. (3)
5. Error prevention	4	0	0	2	4	6	The system does not prevent users to enter unrelated characters e.g., it allows entering numbers in patient name field. (4)
6. Recognition rather than recall	3	0	4	6	1	11	The optional and mandatory data entry fields are not clearly marked. (3)
7. Flexibility and efficiency of use	3	0	0	6	2	8	The system does not allow users to use keyboard shortcuts e.g., *Alt + f4* for exit. (3)
8. Aesthetic and minimalist design	2	0	7	5	0	12	Some buttons are not organized neatly and orderly on screen. (2)
9. Help users recognize, diagnose, and recover from errors	3	0	3	6	4	13	If an error occurs in data entry, the error message does not indicate related fields. (3)
10. Help and documentation	4	0	0	4	5	9	Where necessary, the system does not provide any help. (4)

*Average severities are rounded to the nearest whole number

This may be interpreted by the fact that despite recent advances in healthcare information systems, designers in both developed and developing countries pay low attention to the importance of consistent design and may not follow all UI design standards. This necessitates designers' awareness of UI design standards and their commitment to follow recommended standards in the development and improvement phases of information systems.

Another significant result unexpectedly demonstrated that the severities of 67 % of all violations are major and catastrophe and the average severity of all identified violations is major. Similarly, in two other studies from a developed country, which used the same severity rating [17, 24], the average severity of problems was major. The high number of usability problems with relatively high severity scores in the systems which are used in many hospitals and healthcare centers can be alarming. These potential severe problems may lead to poor usability of the LIS and RIS for its users and affect their interaction. In long term, these sort of problems can result in user dissatisfaction, or reluctance to use the system. Otherwise users look for convenient ways to work-around the problems [3].

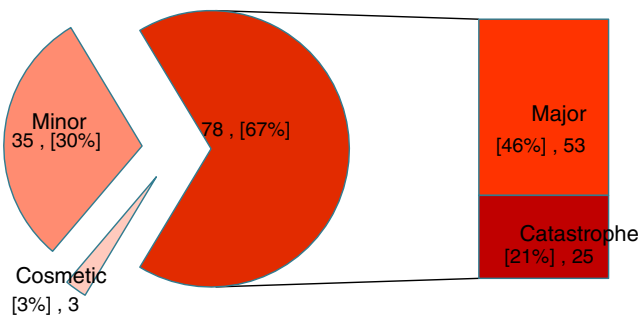

Fig. 2 Frequency of heuristic violations by severity rating

The lowest number of violations was related to "error prevention" and "help and documentation" heuristics. This may be due to the fact that "error prevention" and "help and documentations" functionalities are not provided in the system under evaluation. Therefore, evaluators did not evaluate existing UI components for these heuristics but they only reported a problem when a necessary component concerning one of these two heuristics was missing. The average severities of the problems concerning these two heuristics were catastrophe, which were higher than the averages concerning problems of other heuristics. Because of high severity rating, our evaluators recommend that such components are essential to be provided in the LIS and RIS. Similarly, in another study a small number of violations (4 items), which had been rated as catastrophic, was categorized in "help and documentation" heuristic [17]. Also, in a recent similar study, violations concerning "help and documentation" had been rated as major usability problems [24]. It seems that "help and documentation" components have not been sufficiently provided in some of the healthcare information systems, hence, usability experts emphasized on providing them.

Each identified usability problem in this study could negatively affect effectiveness of the systems, efficiency of processes, and satisfaction of its users. For example, in the case

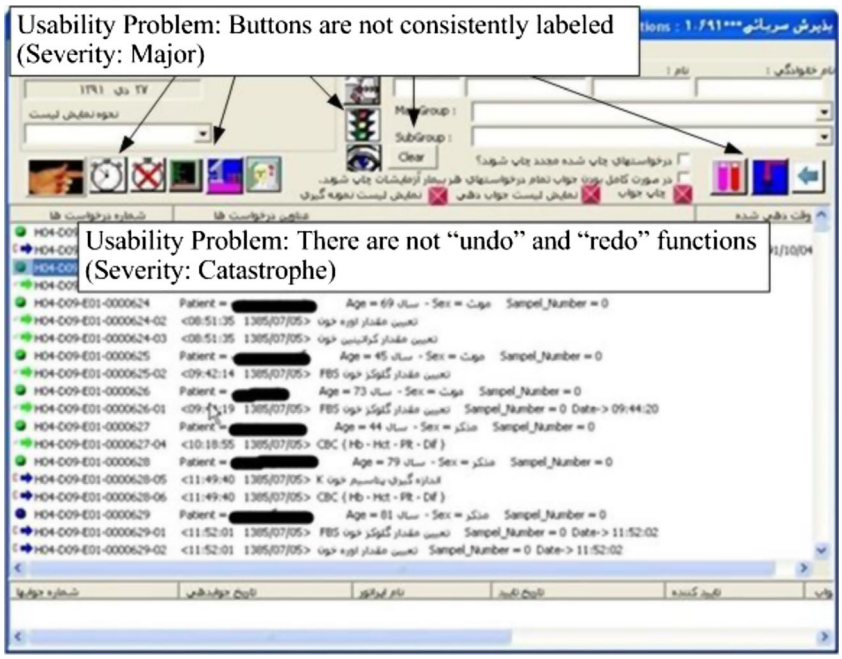

Fig. 3 Two examples of major and catastrophic problems

that the system does not provide any “help and documentation” about the function of a specific button, users may misinterpret its function or use it wrongly. This can lower the effectiveness of the systems or engage users in a useless effort to understand the intended action of that button. Using inconsistent labels and unfamiliar icons was one of the other common problems. Such problems in UI could impose cognitive burden on the users and cause user frustration and dissatisfaction.

The factors that prevent timely access of physicians to the results of laboratory tests and radiology could put patients at risk. A lot of usability problems identified in this study could cause delay in data entry and reporting of results. Inconsistent design, inflexibility of high-frequency commands, impossibility to undo or redo actions, poor distinction between mandatory and optional data entry fields, and many others are among these problems. The results of such evaluation studies are useful for designers, developers, and costumers. In addition to technological aspects, the designers and developers should take into account this sort of usability aspects in the design and development phases, in order to ensure their final products lead to effective information systems [25]. Moreover, having customers aware of these problems can result in a more precise selection of user friendly systems.

This study has two limitations. First, in this study heuristic evaluation method was used to evaluate the usability of LIS and RIS subsystems. Since, this method is used by usability evaluators without involvement of real users, some of the problems that are found in this study may not bother users in real working environment or real users may experience some problems that are not identified in this study. Hence, evaluating these subsystems by user-testing methods could validate our results. Second, this study was performed by participation of three evaluators. Employing more evaluators may increase the number of identified usability problems. However, a well-known study, estimating the optimum number of participants in heuristic evaluations, recommended that employing three to five evaluators would be cost-beneficial, with a high rate of identified usability problems [26].

Since, many problems were identified in the LIS and RIS, it supports the assumption that other subsystems in IHIS may have such problems. It is suggested that the usability of other IHIS subsystems to be evaluated using the method employed in this study. We recommend other similar organizations to evaluate the usability of their current information systems to be able to optimize their systems based on the findings. Moreover, during selecting and implementing new information systems, they should consider usability features as important factors for efficient systems. It is conceivable that optimization of systems after their implementation is more costly than during planning and design phases. Therefore, it is recommended that usability evaluation is started from the early phases of system development life cycle.

Conclusion

Nowadays, information systems are widely being developed and used in healthcare settings. This study supports the results of other studies indicating that, due to poor usability of some systems, users have problems when interacting with these systems. This can lead to users’ frustration and dissatisfaction.

Therefore, it is recommended that the UIs of such systems, which are used by a wide range of users, to be evaluated using different usability evaluation. Based on the results this study and other studies evaluated healthcare information systems disregarding existing design standards and consistency principles are the most common usability problems. Next to this, usability problems concerning lack of error prevention functionalities and unavailability of help and documentation components are the most serious ones. It is recommended that the designers design systems that inhibit the initiation of erroneous actions and provide sufficient guidance to users. Moreover, improving the usability of systems by following existing design standards and principles from the early phased of system development life cycle is recommended.

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Conflicts of interest The authors declare that they have no competing interests

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