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Information system design for a hospital emergency department: A usability analysis of software prototypes

Adem Karahoca [a,*], Erkan Bayraktar [a], Ekrem Tatoglu [b], Dilek Karahoca [a]

[a] Faculty of Engineering, Bahcesehir University, Besiktas, Istanbul 34349, Turkey
[b] Faculty of Economics and Administrative Sciences, Bahcesehir University, Besiktas, Istanbul 34349, Turkey

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ABSTRACT

Study objective: The purpose of this study is to evaluate the usability of emergency department (ED) software prototypes developed for Tablet personal computers (Tablet PCs) in order to keep electronic health records (EHRs) of patients errorless and accessible through mobile technologies. In order to serve this purpose, two alternative prototypes were developed for Tablet PCs: *Mobile Emergency Department Software* (MEDS) and *Mobile Emergency Department Software Iconic* (MEDSI) among which the user might choose the more appropriate one for ED operations based on a usability analysis involving the target users.

Methods: The study is based on a case study of 32 potential users of our prototypes at the ED of Kadikoy-AHG in Istanbul, Turkey. We examined usability of the prototypes for medical information systems by means of Nielsen's heuristic evaluation and cognitive walkthrough methods relying on 7-point scales, and scenario completion success rate and average scenario completion time, respectively.

Results: The implementation of MEDSI in our case study confirmed the view that the usability evaluation results of iconic GUIs were better than those of non-iconic GUIs in terms of Nielsen's heuristic evaluation, effectiveness and user satisfaction. For the whole sample, paired *t*-test scores indicated that there was a significant difference ($p < 0.01$) between mean values of Nielsen's usability scores toward MEDS and MEDSI indicating that MEDSI was evaluated more favorably than MEDS. As for effectiveness of the prototypes, significant differences ($p < 0.01$) were noted between MEDS and MEDSI in terms of both overall scenario completion success rate and average scenario completion time. Similarly, for the full sample of users independent sample *t*-test scores indicated that MEDSI was perceived significantly more favorable ($p < 0.01$) than MEDS in terms of overall user satisfaction.

Conclusion: The study provides two important contributions to the extant literature. First, it addresses a topic and methodology that serves potentially interesting to the biomedical informatics community. Drawing on good background information and appropriate context, it involves various aspects of usability testing. Another contribution of the study lies in its examination of two different prototypes during the design phase involving the target users.

1. Introduction

Usability simply means 'quality in use' and has been one of the widely accepted software quality factors which support a wide range of parameters to measure and observe both different and related software concepts, such as execution time, performance, user satisfaction and ease of learning [1]. It is a key dimension of the software quality assurance to develop bug-free software products. Usability is also defined as effectiveness, efficiency and satisfaction in the use of a product by specified users to achieve specified goals in a specified context of use [2]. In human–computer interaction and computer science, usability usually refers to the elegance and clarity in which the user interface of a computer program or a web site is designed.

The primary notion of usability is that an object designed by considering the users' psychology and physiology in mind may be more efficient to use (it takes less time to accomplish a particular task), easier to learn (operation can be learned by observing the object), and more pleasing for the user. This notion is very consequential in the emergency departments (EDs), which require a collaborative effort involving the contribution of several individual actors, who achieve their tasks working autonomously under pressure and sometimes with very limited resources, and serious time constraints where the efficiency, learnability and fulfillment of the system immediately come into prominence [3].

* Corresponding author. Address: Bahcesehir University, Faculty of Engineering, Software Engineering Department, Besiktas, Istanbul 34349, Turkey. Fax: +90 212 381 0550.
E-mail address: akarahoca@bahcesehir.edu.tr (A. Karahoca).

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The purpose of this study is to evaluate the usability of ED software prototypes developed for Tablet personal computers (Tablet PCs) in order to keep electronic health records (EHRs) of patients errorless and accessible through mobile technologies. The study mainly deals with two different prototypes: *Mobile Emergency Department Software* (MEDS) and *Mobile Emergency Department Software Iconic* (MEDSI), which were both designed in line with the user centered development process [4–6]. Health information systems (HISs) with secure connections to mobile devices are invaluable tools for efficient and effective provision of health services. HISs rely on accurate and reliable medical data collected from well defined medical processes to support high quality EHRs. In fact, utilization of mobile devices enables an online integration of EHRs into medical information systems, providing a good deal of convenience for the clinicians. They enable them to capture patient information and gain access to resources such as decision support systems in real-time at point-of-care with minimum errors [7–10]. However, despite their growing capabilities, mobile devices still have major limitations affecting their use in a 7×24 environment. Some of these limitations are related to their sturdiness, weight, battery capacity, connectivity, bandwidth, screen size, and data entry modality. Of the mobile devices, Tablet PCs are faster and easier to use for data entry, and have better handwriting recognition capability [11].

For efficient use of mobile devices to enhance the reliability of data, effective user interfaces have to be designed properly for medical systems in line with the human factors engineering (HFE) techniques. In doing this, a special emphasis should be placed on usability engineering in order to determine what and how users understand graphical user interfaces (GUIs) [12–14]. GUIs support hospital staff by providing more reliable data in order for the HIS to improve quality of EHRs [15–17]. Moreover, the user friendly GUIs have been generally proposed to overcome technophobia by using virtual keyboard based software for mobile devices [18]. They may also play an important role in convincing healthcare staff to use mobile devices instead of desktop computers [8,19] and handling the volume and complexity of clinical data by simplifying the integration of mobile devices to existing medical information systems.

2. Methods

2.1. Study design

This study essentially aims at examining the usability of the GUI prototypes developed for EDs of healthcare institutions. The primary data were collected through face to face interviews conducted with the potential users of prototypes at the ED of our sample institution during the summer of 2006. The executive board of the hospital under investigation initiated the information system development project at the ED and waived the requirement for informed consent.

2.2. Study setting

The study was conducted at Kadikoy-AHG of the privately-held Acibadem Healthcare Group (AHG) headquartered in Istanbul, Turkey. Acibadem Healthcare Group provides extensive healthcare services to general public with its nearly 5000 employees including 1000 physicians, 5 hospitals, 4 outpatient clinics, 1 central laboratory, 1 eye medical center and 1 medical center.

Since patient's records at the ED of Kadikoy-AHG were kept on paper forms and traced manually, the hospital intended to develop an information system for its ED integrated with the other hospital systems. This system would be used by physicians, nurses and clerical staff to be able to access the patient's medical history and test results quickly and also modify them easily when necessary.

The ED of Kadikoy-AHG had a total of 38 healthcare staff consisting of 6 physicians and 32 nurses within three-shifts, which constituted our sample for this study. As potential users of the system, the whole healthcare staff at the ED of Kadikoy-AHG participated in the study. As a hospital recruitment policy valid during the period of this study, the ED staff were used to be selected from among the experienced ones. The minimum required level of work experience at ED was 2 years. Since all of the survey participants filled printed ED forms manually, they were also quite familiar with ED procedures. In order to differentiate the users by their computer literacy, a test similar to the European computer driving license test (http://www.ecdl.org) was given to the participants. With this test, the knowledge level of the users on information technology concepts, computer usage and information communication, the use of word processing, spreadsheet, and presentation programs was identified. The nurses were then grouped into two categories as experts and novices in terms of computer literacy. It was found that 16 of the nurses were identified as novice users, where the rest of them were classified as expert users.

Same or similar types of tests were applied to both groups of users, nurses and physicians, separately. Since the low number of physicians as compared to nurses hindered us from implementing adequate statistical analyses, we only reported the test results related to nurses.

2.3. System description

2.3.1. Current system

Within the existing system at Kadikoy-AHG, the patient information was collected through conventional pen and paper, and kept manually on the printed ED forms. Later, these data on printed forms were entered to the hospital information system by an administrative assistant. When a patient arrived at ED, initially a nurse filled the ED form, and later a physician checked and reviewed it, and diagnosed the problem. The basic tasks performed by both nurses and physicians were listed in Table 1.

2.3.2. Proposed system

The proposed system could work on Tablet PCs via Wi-Fi network in line with the requirements of ED. There is a centralized database to store the patients' EHRs as well as to integrate ED with registration, laboratory and other medical departments through XML interfaces. MEDS has client-side software architecture and was developed as a Windows Application by using MS Visual Studio, while MEDSI has three-tier software architecture (client, web server and database layers) and was developed on ASP.NET platform. Web clients connect to the web server and send requests. The web server creates a session for the requests and captures pertinent data from the database server. Then, query results are sent back to the web clients through the web server.

Both physicians and nurses use Tablet PCs to record and review the patient information. Each Tablet PC can connect to the database to initiate physician and nurse sessions following the verification of username and password. The proposed system retrieves data related to a particular patient by using his/her protocol number which is exclusively assigned to each patient. Nurses use the system to register the patient if the patient's registration information may not be retrieved from the central database; key in personal and health information and closely follow up the physicians' orders and inspections, while the physicians utilize the system to view the patients' records and enter the patients' treatment data or update any patient data and also follow up the patients' conditions. After the patient's examination is completed,

Table 1
The tasks performed by the nurses and physicians.

Nurse tasks	Physician tasks
• Insert patient's identification information; • Define the patient triage scale (hardness of the pain); • List patient complaints; • Identify arrival reason(s) (e.g. traffic accident, injury, suicide and intoxication); • Ask patient's allergy to any medicine (e.g. penicillin); • Query any previous diseases and surgeries; • Ask addictions (e.g. smoking, alcohol and drugs); • Ask functional deficiencies (e.g. movement, hearing and talking, visual difficulties); • Query nutrition, mood, still used medicine and genetic family diseases; • Measure vital symptoms of patient (e.g. blood pressure, pulse, fever, respiration number and saturation parameters); • Define pain (e.g. scale, type, starting time, location, frequency, increasing and decreasing conditions); • Note nurse observations	• Control patient complaints (e.g. stomach ache, traumas, falling, fainting, vomiting, fever and chest ache) and add new complaints if necessary; • Fill the patient story; • Check the patient family information and add new information, if necessary; • Add observational notes; • Place pre-diagnosis; • Order inspection(s); • Fulfill pre-treatment procedures; • Check patient vital symptoms and nurse observations note; • Examine the inspections (e.g. laboratory results) • Determine the treatment plan and apply

the information about the patient is saved to the database, and then the session is terminated by logging out. Since making errors is inevitable in manual data entry, the proposed system suggests two interface designs using pop-up menus and checkboxes based on pen-input property of Tablet PCs, which will save time and also minimize typing errors.

2.3.3. Characteristics of the prototypes

Menu systems of non-iconic and iconic prototypes (MEDS and MEDSI, respectively) were designed from the printed ED forms based on the SOAP (Subjective, Objective, Assessment and Plan) methodology as suggested by Weed [20]. Both MEDS and MEDSI have the same functionality, although their interface designs are different. While MEDS has text-based GUI, MEDSI has iconic-based GUI in which icons were selected by a sample of healthcare staff at Kadikoy-AHG based on the tests that basically help to identify the most suitable and recognizable set of icons to represent the forms. A convenient sample included a total of 75 healthcare staff (consisting of 43 physicians and 32 nurses) from every department of the entire hospital (not only ED). Each member of the sample was requested to draw or define an icon to represent a particular form/medical term to be used in the GUI. Then, the icon with the highest level of popularity was selected to represent the medical term.

MEDS and MEDSI also employ different display design strategies. Table 2 provides a comparison of both prototypes in terms of design characteristics in line with the design principles as stated by Mullet and Sano [21] quoted in Shneiderman and Plaisant [22].

2.3.4. Task descriptions

Both prototypes are used by the nurses and physicians working solely for ED. As aforementioned, the analysis here focuses only on the task list of nurses, though it is also equally applicable to that of physicians.

For MEDS, the task list of nurses, S_{MEDS} = {T1, ..., T23}, is shown in Table 3. The first and fourth columns show task codes and task names, respectively. The fifth column labeled as 'task frequency' in Table 3 represents the frequency of each task performed by the nurses. Task frequency is calculated from a randomly selected 100 cases where the nurse fills the printed ED forms during a seven-month period. This information was used to determine the sequence of the forms for faster data entry while using MEDS. Hence the task sequence, S_{MEDS}, is rearranged on the basis of task frequency in the following manner: $S_{MEDS,1}$ = {T1, T2, T4, ..., T9, T14, T17, T18, T21, T23}. For instance, when a patient arrives at the ED, a nurse has to enter the patient's identification information to the system (T1) and then the MEDS allows her to proceed to the next task automatically according to the sequence in the list, $S_{MEDS,1}$. When a need arises for a task which does not exist in $S_{MEDS,1}$, the nurse should select this task from the menu system and fill out the relevant information accordingly. Fig. 1 depicts the menu system for MEDS for both nurses and physicians.

In MEDSI, the tasks were grouped into relevant categories including 'general information', 'health history', 'arrival information', 'treatment information' and 'observations'. Fig. 2 shows the menu system for MEDSI. For MEDSI, nurses at ED follow up the relevant forms in line with the following task sequence: S_{MEDSI} = {M11, ..., M15, M21, ..., M26, M31, ..., M38, M41, M42, M51, ..., M53}, as shown in the second and third columns of Table 3. S_{MEDSI} starts from task M11 for the new arrival patients. Then, the system passes automatically to the next task until completing the task M53.

2.4. Usability analysis

Drawing largely on the studies of the International Standards Organization, the final stage of the user centered development pro-

Table 2
Design characteristics of the MEDS and MEDSI.

Interface design characteristics	MEDS	MEDSI	Explanation
Organization of related tasks	LOW	HIGH	MEDS has a sequential task list as displayed in Fig. 1, but MEDSI has groups of tasks as shown in Fig. 2
Minimalist design	LOW	HIGH	MEDSI has well designed menu system with self-explained icons and GUIs
Drag and drop methodology	LOW	HIGH	Automatic data selection is used rather than typing in both prototypes, but in MEDSI additional components and methodologies are used
Soft and sharp colors	MEDIUM	HIGH	MEDSI utilizes softer tones and background colors in GUI than MEDS
Focus and flexibility	MEDIUM	HIGH	Having soft tones and highly usable components create relatively higher level of focus and flexibility for MEDSI than MEDS
Elegance and simplicity	LOW	HIGH	MEDSI is characterized by higher levels unity, refinement and fitness than MEDS

Table 3
Task sequence of nurses and physicians.

MEDS task code	MEDSI task code	MEDSI task group	Task name	Task frequency (%)
T1	M11	General information	Patient identity	100
T2	M32	Health history	Triage	100
T3	M15	General information	Translator	2
T4	M34	Health history	Arrival complaints	100
T5	M33	Health history	Judicial events	10
T6	M26	Arrival information	Allergy	100
T7	M21	Arrival information	Previous diseases	100
T8	M22	Arrival information	Previous surgeries	100
T9	M23	Arrival information	Addictions	100
T10	M36	Health history	Functional efficiency	65
T11	M25	Arrival information	Nutrition	3
T12	M14	General information	Religious belief	0
T13	M38	Health history	Mood	5
T14	M24	Arrival information	Still used medicine	100
T15	M12	General information	Family history	5
T16	M13	General information	Contact	12
T17	M35	Health history	Arrival vital symptoms	100
T18	M37	Health history	Pain	100
T19	M41	Treatment information	Required inspections	87
T20	M42	Treatment information	Requests and applications	57
T21	M51	Observations	Vital symptom observations	100
T22	M52	Observations	Observations of nurse	52
T23	M53	Observations	Discharged from hospital	100

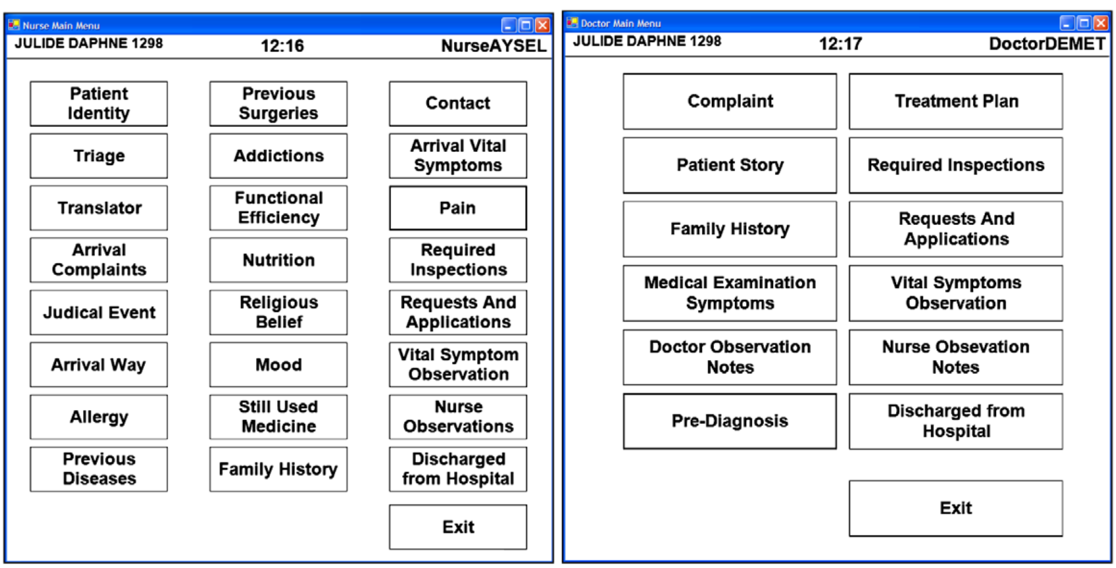

Fig. 1. The nurse and physician menu systems for MEDS.

cesses is the evaluation of the design prototypes which involve usability analyses of the software [6,23–25]. Usability involves a number of generic considerations cited in the extant literature [17,26]. Hom [27] identifies three types of usability evaluation methods, which include testing, inspection and inquiry. While usability testing approach requires representative users to work on typical tasks using the system or prototype, usability inspection approach calls for usability specialists or software developers, users and other professionals to examine and judge whether each element of a prototype pursues an established usability principle [28]. The usability inquiry approach, however, requires usability evaluators to collect information from the users about the prototype through surveys, field observations and interviews. In our experimental study, we inspected usability of our prototypes for medical information systems through a heuristic evaluation technique and cognitive science based usability tests, which are both explained in the forthcoming subsections [17,29,30].

2.4.1. Nielsen's heuristic evaluation

Although there is a consensus about the importance of the term usability, there are several approaches to measure usability [28]. Of these approaches, Nielsen's heuristic evaluation was adopted in the first stage of our usability evaluation. Heuristic evaluation is a usability engineering method to identify usability problems in the design stage of user interfaces [29,31–33]. Table 4 shows the Nielsen's ten factors for usability evaluation.

Nielsen's heuristic evaluation requires a small set of evaluators that examine and judge the interfaces relying on the principles of heuristic. The most critical point in this approach is to determine the number of evaluators to test the system. Obviously, the more evaluators are used to test the interface, the more problems will be detected, which will in fact increase the cost of evaluation. According to Nielsen, three to five experts in the relevant field are able to detect nearly 75% of the usability problems and maximize the cost/benefit ratio [29].

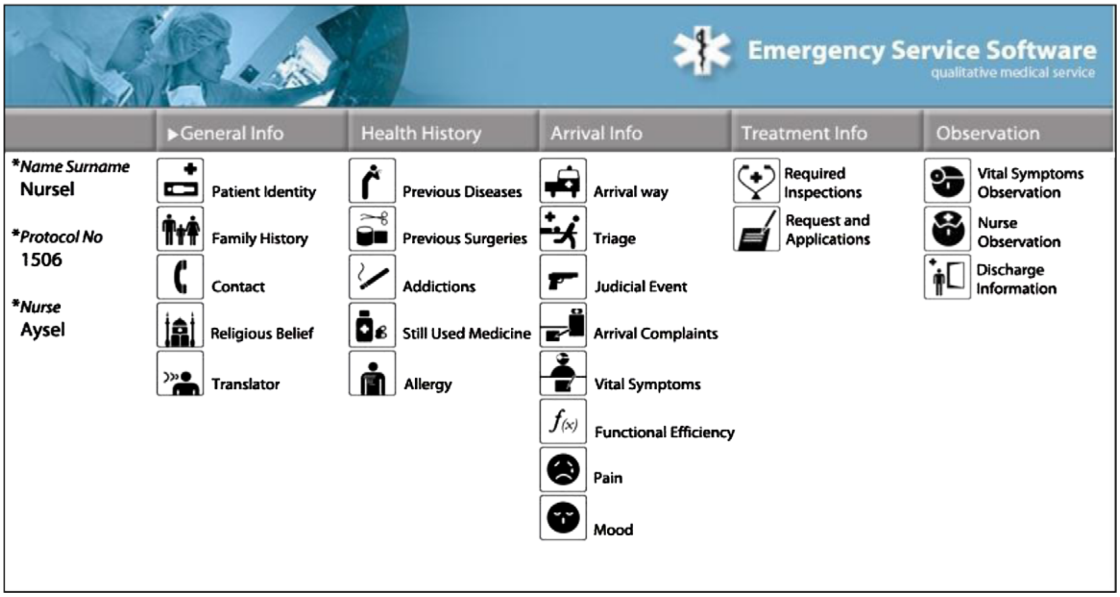

Fig. 2. Menu system for MEDSI.

Table 4
Heuristic evaluation technique: Nielsen's ten factor for usability evaluation.

Nielsen's ten factors
Visibility of system status
Match between the system and the real world
Consistency and standards
User control and freedom
Error prevention
Recognition rather than recall
Flexibility and efficiency of use
Esthetic and minimalist design
Help users to recognize, to diagnose and to recover from errors
Help and documentation

2.4.2. Cognitive walkthrough

The cognitive walkthrough (CW) method [34,35] is the second approach adopted in this study for usability inspection that focuses on evaluating a design for ease of learning by exploration. The CW method was developed to evaluate a particular design of a user interface by following the user's footsteps to use the system or perform a task. The major purpose of implementing CW methodology is to identify the simplest way to perform a task by creating an action sequence tree for the tasks and their sub-tasks [10,36]. However, to initiate a walkthrough, descriptions of the users along with one or more related tasks to be performed should be identified at the outset. In order to detect critical design flaws earlier in CW methodology and fix these anomalies of the prototype, the usability analysis should be completed at the very early stages of prototype development.

Drawing on the CW methodology to evaluate both prototypes, the following issues should be addressed: task description lists for the users; test scenario; and the evaluation tests for the usability of MEDS and MEDSI. In the evaluation of usability, the following tests were considered for the assessment of prototypes: *motivating potential of the jobs*, *effectiveness*, *learnability*, *and user satisfaction.* When using the CW method, 'successful completion' of a task involves meeting the following four criteria [37]: (1) achieving the right effect by the user; (2) ensuring the user's awareness of the availability of correct action; (3) enabling the user's association of the correct action with the desired effect; and (4) the extent of progress with regard to the fulfillment of the task if the correct action was taken.

2.4.2.1. Scenario setting. In order to evaluate both prototypes, the following scenario was developed based on the existing medical procedures and the most frequently encountered task lists ($S_{MEDS,1}$ and S_{MEDSI}) at Kadikoy-AHG.

> "Julide Akar was brought to the hospital ED as a victim of a car accident. She was taken to bed number 10 at the ED. According to her identification card, Mrs. Akar was born in Istanbul on 01.10.1954, and her cellular phone number is 555-4354567. She is currently suffering from dyspnoea and nose bleeding. She had an operation from her stomach because of gastric bleeding previously. She has emphysema in her lungs due to her addiction to alcohol and smoking. She has been smoking 20 cigarettes per day on average and also has been using 100 mg of aspirin 3 times a day to avoid arteriosclerosis. In her family, cancer has been seen. Her vital information was measured and they were: blood pressure 160 mmHg with a systolic value and 120 mmHg diastolic value, pulse 90, fever 39 °C, respiration rate 50 and oxygen saturation 90%, respectively. The patient has been complaining from extreme pain."

A software developer played the role of a patient above at the ED for each evaluation. The ED nurses and physicians were kindly requested to enter the patient data into the system within 15 min using each interface (MEDS or MEDSI) separately in an isolated room at ED. During the session, the project's targets and use of Tablet PCs were explained. The scenario was read and patient's information was documented, while the system usages were recorded by Cursor Recording Software and actions were saved to analyze each subject's behaviors later.

In two different sessions, the same scenario was used for testing both prototypes in order to reduce the variance which might stem from the use of different scenarios. Chronologically, MEDS was developed first and then MEDSI became ready for testing after 6 weeks on target users. Considering the fact that both prototypes have different display design strategies and there is a 6-week time lag between the two sessions, it was assumed that any familiarity of the user with the scenario after completing it for the first time using MEDS and repeating it a second time using MEDSI was negligible in order to remove any doubt concerning a potential learning curve effect that might bias the findings.

2.4.2.2. CW usability evaluation. The following aspects of usability tests for both prototypes were considered: motivating potential of the job, effectiveness of the prototypes, learnability and satisfaction of the end user.

2.4.2.3. Motivating potential of the job. In order to assure reliability of the evaluation tests, the motivating potential of the job based on our sample of 32 nurses were measured relying on Motivating Potential Scores (MPS) developed by Hackman and Oldham's job characteristics model [36]. Their model suggests that every job has five core characteristics that identify the motivating potential of a job. These five characteristics include skill variety, task identity, task significance, autonomy and feedback. Relying on MPS equation, the job's motivating potential was computed. A motivating job denoted by a high level of MPS score shows a clear evidence of all five job characteristics.

2.4.2.4. Effectiveness of the prototypes. Effectiveness of the system prototypes developed was measured based on scenario completion time and percentage of successfully completed tasks in the pre-test and post-test phases.

2.4.2.5. Learnability. Another aspect of usability is learnability, which can be described as how easily the prototype can be learned and how quickly the user can start to use the system [28]. In order to measure the learnability, the effectiveness tests which rely on scenario completion times for both prototypes in the pre-test and post-test phases was used in this study. Scenario completion tests were repeated within a 12-h period. Based on the learning curve theory, learning curve effects were also calculated [38].

2.4.2.6. User satisfaction survey. An overall user satisfaction survey was implemented to conclude our usability analysis. In fact, the users are expected to be satisfied with the use of software prototype [28]. To this end, a set of eight questions based on 7-point scales ranging from 1 (='not at all satisfied') to 7 (='very satisfied') were developed to measure the satisfaction level of users with MEDS and MEDSI separately, as shown in Table 5.

3. Results and discussion

3.1. Nielsen's heuristic evaluation

Before implementing Nielsen's heuristic evaluation technique, the menu systems for both MEDS and MEDSI were designed based on the feedback provided by nurses and physicians. Initially, only simple and absolutely necessary information about forms was provided to the users. Reactions and motivations of the users about the system were also considered carefully. The medical terminology used in prototypes were checked and proofread by both nurses and physicians. Later, all potential users who could easily test and evaluate the system were identified as the evaluators of the prototypes. Based on Nielsen's ten criteria, as shown earlier in Table 4, the potential users were asked to rate each criterion on a seven-point Likert scale ranging from 1 (='poor') to 7 (='excellent'). During this implementation phase of the prototypes, Nielsen's suggestions had a valuable contribution to enhance the usability of prototypes.

Table 6 provides a comparison of the mean values of usability based on the perceptual evaluation of Nielsen's 10 criteria toward MEDS and MEDSI. Since an internal reliability test showed a very strong Cronbach's alpha value of 0.88 for the multi-item scale (as shown in Table 4), indicating an excellent level of construct reliability [39], it was considered more feasible to compute mean values on the summated scale rather than computing mean value for each individual criterion. For the whole sample of survey participants, paired *t*-test scores indicated that there was a significant difference ($p < 0.001$) between mean values of usability scores toward MEDS and MEDSI indicating that MEDSI was evaluated more favorably than MEDS. In a similar vein, significant differences were also noted for each group of nurses identified earlier as novice and expert users in terms of their perceptions toward the usability of MEDS and MEDSI, confirming that iconic design prototypes were evaluated more favorably than non-iconic design prototypes.

We also examined whether there was any variation between both groups of users (novice and expert) toward MEDS and MEDSI in terms of the mean scores of usability. Independent sample *t*-tests indicated that there was no significant difference between novice and expert users ($t = 1.52$; $p > 0.05$) toward the usability of MEDS, suggesting that the usability perception of MEDS was not related to the extent of user's computer literacy. As for MEDSI, some significant difference, however, was found concerning the usability evaluation of both groups of users ($t = 2.42$; $p < 0.05$) in that expert users tended to evaluate the usability of MEDSI more favorably than novice users.

During the Nielsen's heuristic evaluation, the actions of the users were also saved in log files to further assess the efficiency of the implementation. In case of a wrong selection of a system function, the ability of the software to direct the user to the required screen was also tested. An attempt was further made to enable users to recognize objects, actions and options easily. Based on the test results, the forms and dialog boxes that might be considered somewhat rare and unnecessary were removed from the system for the sake of esthetic and minimal design. However, in order to enhance the visibility of forms, these forms were then split into smaller forms so as to reduce the number of data-entry boxes.

Table 6
Results of Nielsen's heuristic evaluation of MEDS and MEDSI based on computer literacy.

Level of computer literacy	MEDS	MEDSI	*t*-value
Novice ($N = 16$)	42.8	48.6	−12.20*
Expert ($N = 16$)	44.6	52.1	−21.21*
Total ($N = 32$)	43.7	50.4	−20.25*

Note: The mean values are summated scores based on subjective evaluation of Nielsen's 10 criteria toward MEDS and MEDSI on a 7-point scale ranging from 1 (='poor') to 7 (='excellent').
* $p < 0.001$.

Table 5
Items used to measure user satisfaction with MEDS and MEDSI.

1. The interface sizes are helpful for information entry
2. The interfaces help during the information entry
3. The program flow helped me
4. Information entry is practical
5. The order of the menu system is helpful to the information entry
6. Using the software system is faster than filling the printed ED form
7. The order of the menu system is similar to the printed ED form
8. Reading and following the form information is faster than reading from papers

Table 7
MPS scores with respect to computer literacy.

Level of computer literacy	Mean	Std. deviation	*t*-value
Novice ($N = 16$)	194.1	47.5	−3.03*
Expert ($N = 16$)	237.9	32.8	
Total ($N = 32$)	216.0	45.9	

* $p < 0.01$.

Finally, detailed description and suggestions were provided to the users in order to reduce flaws associated with the use of MEDS and MEDSI.

3.2. CW usability tests

3.2.1. Motivating potential of the job

Table 7 shows MPS scores of the sample with respect to the level of computer literacy. A significant difference was noted between novice and expert users ($t = -3.03$; $p < 0.01$) that the mean value of the MPS score of the expert users (237.88) was much higher than that of the novice users (194.13). This finding suggests that expert users have a more favorable perception of the motivating potential of their job than novice users, which might have a direct impact on the effective use of the prototypes developed for Tablet PCs.

3.2.2. Effectiveness of the prototypes

Tables 8 and 9 show the results of pre-test and post-test effectiveness, respectively, in terms of both scenario completion success rate and average scenario completion time from the perspective of novice versus expert users. For the whole sample of 32 nurses, the results of paired *t*-tests indicated that in the pre-test phase there was a significant difference ($p < 0.001$) between MEDS and MEDSI in terms of average scenario completion time, as shown in Table 8. In a similar vein, a significant difference ($p < 0.01$) was also noted between MEDS and MEDSI in terms of overall scenario completion success rate, which was measured based on the percentage of the nurses successfully completing the task within 15 min of their first trial. While the effectiveness of MEDSI was significantly higher ($p < 0.001$) than MEDS for both novice and expert users in terms of average scenario completion time, no significant differences were found between the effectiveness of MEDS and MEDSI in terms of scenario completion success rate for both groups of novice and expert users.

Table 9 indicates the results of post-test effectiveness in terms of scenario completion success rate and average scenario completion time from the perspective of novice versus expert users. For the whole sample of 32 nurses, the results of paired *t*-tests indicated that there was a significant difference ($p < 0.001$) between MEDS and MEDSI in terms of scenario completion time. This finding suggests that MEDSI performs better than MEDS based on scenario completion time. However, no significant difference was found ($p > 0.05$) between MEDS and MEDSI in terms of overall scenario completion success rate. For novice users, effectiveness of MEDSI was significantly higher than MEDS in terms of both overall scenario completion success rate ($p < 0.01$) and average scenario completion time ($p < 0.001$). As for expert users, MEDSI again was more effective than MEDS in terms of average scenario completion time ($p < 0.001$), although no significant difference ($p > 0.05$) was noted between the effectiveness of MEDS and MEDSI regarding the scenario completion success rate. Finally, when two groups of users were compared, the expert users significantly ($p < 0.01$) outperformed novice users in terms of the effectiveness of both MEDS and MEDSI.

3.2.3. Learnability

In Table 8, scenario completion times for MEDS and MEDSI were calculated as 376.3 and 317.4 s, respectively, while after the post-test these scores declined to 321.6 and 288.6 as denoted in Table 9, indicating a significant improvement over the pre-test scenario completion times. Based on the learning curve theory, these results represented 85.5% and 90.9% learning curve effects for MEDS and MEDSI, respectively [38]. The lower learning curve effect denotes a faster improvement in scenario completion time. Therefore, it might be concluded MEDS had faster learning curve effect as compared to MEDSI. This finding is not particularly surprising in that scenario completion times for MEDS were much greater than those for MEDSI. That is, when the users were first introduced to MEDSI, their adaptation to the system was much quicker so the effect of learning curve became lower when compared to MEDS.

3.2.4. User satisfaction survey

The results of user satisfaction survey for both prototypes are shown in Table 10. An internal reliability test showed strong Cronbach's alpha, with a value of 0.77 for the multi-item scale (as

Table 8
Results of pre-test effectiveness.

Level of computer literacy	Scenario completion success rate (%)			Average scenario completion time (s)		
	MEDS	MEDSI	*t*-value	MEDS	MEDSI	*t*-value
Novice ($N = 16$)	63.3	76.4	−2.22	402.2	346.3	3.95**
Expert ($N = 16$)	77.1	86.2	−2.36	350.4	288.5	6.69**
Total ($N = 32$)	70.2	81.2	−3.22*	376.3	317.4	7.18**

* $p < 0.01$.
** $p < 0.001$.

Table 9
Results of post-test effectiveness.

Level of computer literacy	Scenario completion success rate (%)			Average scenario completion time (s)		
	MEDS	MEDSI	*t*-value	MEDS	MEDSI	*t*-value
Novice ($N = 16$)	77.1	80.2	−2.92*	333.1	295.2	10.92**
Expert ($N = 16$)	89.1	88.8	0.38	310.0	281.9	12.13**
Total ($N = 32$)	83.1	84.5	−1.90	321.6	288.6	14.76**

* $p < 0.01$.
** $p < 0.001$.

Table 10
Results of user satisfaction survey for MEDS and MEDSI.

Level of computer literacy	MEDS	MEDSI	*t*-value
Novice ($N = 16$)	42.8	45.6	−12.20*
Expert ($N = 16$)	45.7	48.3	−21.21*
Total ($N = 32$)	44.3	46.9	−20.24*

Note: The mean values are based on summated score of subjective evaluation of satisfaction on a set of eight variables toward MEDS and MEDSI using a 7-point scale ranging from 1 (='not at all satisfied') to 7 (='very satisfied').
* $p < 0.001$.

shown in Table 5), exhibiting a satisfactory level of construct reliability [39]. For the full sample of users, MEDSI was perceived more favorably in terms of overall satisfaction ($p < 0.001$) than MEDS. An interesting finding, however, emerged with respect to the satisfaction scores of expert users in that they were significantly more satisfied ($p < 0.001$) with both prototypes as compared to novice users.

4. Conclusion

This study has made an attempt to test the usability of ED software prototypes developed for Tablet PCs in order to keep patient EHRs flawless and accessible through mobile technologies. The study serves two main contributions to the extant literature. One key contribution of this study is that it addresses a topic and methodology that serves potentially interesting to biomedical informatics community. Drawing on good background information and appropriate context, it involves various aspects of usability testing. Another key contribution of the study lies in its examination of two different prototypes during the design phase involving the target users.

The implementation of MEDSI confirmed the view that the usability evaluation results of iconic GUIs were better than those of non-iconic GUIs. As can be clearly noted from the study's findings, MEDSI had better usability than MEDS in terms of effectiveness, learnability and user satisfaction. The findings of this study also provided support to those of previous research [29,40].

This study provides a number of implications. First, it is evident that there is a clear need for simplified forms, with fewer elements and lower complexity. Thus, the use of icons becomes a key issue while avoiding complex icon designs to assure simplified interfaces. Using web-based applications, visual components can be improved by representing each process and its sub-processes with appropriate icons. Second, the usability of Tablet PCs has also been a major issue stemming largely from the use of small keys on virtual keyboards leading to mistyping. Thus, button sizes and flows received special emphasis on the development of both MEDS and MEDSI. The nurses and physicians found Tablet PCs relatively large and heavy in size, though they were also against inputting data through virtual keyboards. It is, however, possible to eliminate this barrier by using an appropriate language recognition tool for Turkish and also by increasing optional elements to be used in the forms. Adapting the system to Tablet PC environment, the usability of the system is significantly enhanced which will in turn reduce data input errors and increase data entry and query efficiency. Finally, through mobile ED software designed for Tablet PCs, this study suggests that moving ED processes to digital environment would significantly enhance service efficiency of the EDs within healthcare institutions in terms of mobility and flexibility along with data accuracy.

It should however be borne in mind that user based information systems evaluation is diverse and the requirements of these systems change over time. This study essentially focused on Tablet PCs, although there are several different mobile communication devices, which should be acknowledged as a limitation of this study. Similarly, software quality is not only limited to usability which focuses on visual and operational design of interfaces. According to HP's FURPS software quality model [41], functionality, reliability, and performance of the software should be considered for quality assurance in addition to usability.

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