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Technology induced error and usability: The relationship between usability problems and prescription errors when using a handheld application

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Summary This paper describes an innovative approach to the evaluation of a handheld prescription writing application. Participants (10 physicians) were asked to perform a series of tasks involving entering prescriptions into the application from a medication list. The study procedure involved the collection of data consisting of transcripts of the subjects who were asked to ''think aloud'' while interacting with the prescription writing program to enter medications. All user interactions with the device were video and audio recorded. Analysis of the protocols was conducted in two phases: (1) usability problems were identified from coding of the transcripts and video data, (2) actual errors in entering prescription data were also identified. The results indicated that there were a variety of usability problems, with most related to interface design issues. In examining the relationship between usability problems and errors, it was found that certain types of usability problems were closely associated with the occurrence of specific types of errors in prescription of medications. Implications for identifying and predicting technology-induced error are discussed in the context of improving the safety of health care information systems.

1. Introduction

According to the Institute of Medicine's report on patient safety ''To Err is Human'', medical error is a

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significant cause of death and disability [1]. According to the American Hospital Association, estimates suggest approximately 44,000 Americans die as a direct result of medical error every year [2]. Statistics indicate medical error is now the eighth leading cause of death in the United States, surpassing AIDS and some forms of cancer [3]. This problem is not unique to the United States. More recent research from other countries (e.g. Canada, Australia and New Zealand) has produced similar results [4—6].

Medical errors may have a number of causes, ranging from the cognitive limitations of humans, to temporary slips in knowledge and problems with health care workflow. Information technology has the potential to dramatically decrease medical errors by streamlining workflow and providing such features as automated alerts and reminding. Consequently, the study of medical errors has become an increasingly important topic in health informatics. The complex nature of this problem has lead to the development and testing of a number of information systems that could be used to prevent medical error, among them the development and implementation of physician order entry systems and a variety of software for supporting the process of medication ordering in a number of settings (i.e. hospital and community) [1]. Over the past several years there have been a number of studies that have documented the effectiveness of such systems in hospital settings. Some of these systems have lead to significant reductions in adverse events including unnecessary laboratory testing, adverse events involving drug—drug interactions, transcription errors. They hold considerable promise for improving safety in health care [7—10].

However, despite these potential benefits, use of new information technology in healthcare also has the unintended potential of increasing medical errors if not designed properly [11]. For example, more recent studies of health care information system use have suggested poorly designed systems and applications can introduce *new* classes of errors. It has been suggested that systems and applications historically considered a source of error reduction may lead to other latent types of errors when such systems are introduced and in some cases contribute to more errors overall [12]. The type of errors that will be the focus of this paper can be termed *technology induced errors*.

1.1. Usability and it relationship to error

There are a number of approaches that can be used to study error. This includes laboratory based studies where conditions can be controlled and in some cases simulations conducted of situations where errors might occur (e.g. simulations of operating rooms) [13]. Other approaches include audits of medical records and naturalistic study of errors as they occur in real settings. Critical incident analysis has been used to study errors once they have occurred. Here, events involving error are reviewed and individuals are asked to recall the events surrounding an error to identify its cause. This approach may also involves a review of documentation.

A recent trend in health informatics evaluation has been the application of methods from usability engineering to improving system design [14]. Usability engineering involves the systematic analysis of a system's usability (i.e. how effective, efficient and enjoyable a system is from the perspective of end users of the system) in context of use. Usability inspection is one method for analyzing a system, where an analyst systematically steps through a system or interface, applying principles of good design to assess where problems might occur with end users [15]. A second approach to usability engineering is known as usability testing, where the actual interaction of subjects with a system under study are analyzed to identify usability problems. The systematic application of usability testing to predict technology induced error in health information systems holds considerable promise to help improve the safety of systems introduced to health care. However, the relationship between usability engineering practices for identifying potential usability problems and the occurrence of actual medical errors that may result from sub-optimal designs remains to be more fully explored [12].

In our work we have employed a usability testing approach to studying the relationship between usability and error. This has typically involved video recording the actual process of use of a healthcare information system under study, followed by subsequent detailed analysis of the resulting video record. In addition, subjects are typically asked to ''think aloud'' or verbalize their thoughts while using the system. The approach borrows heavily from both cognitive science and the emerging field of usability engineering.

1.2. Usability and handheld applications in healthcare

Over the past few years, handheld computing devices have become increasingly used in health care settings for a range of applications, such as providing clinicians with access to reference materials, guidelines, on-line information resources and databases. Such devices also have a potential role of dramatically streamlining procedural aspects of health care, such as interacting with patient records and writing prescriptions. However, issues related to enhancing the design of these applications, and ensuring their use does not increase the potential for medical error need to be addressed. In particular, usability issues involving handheld computing provides an excellent test bed for studying technology induced errors in health care.

1.3. Study objectives

In this paper we examine the relationship between identified usability problems and actual errors in entering prescribed medications in the context of an experimental evaluation of a handheld prescribing tool. Therefore, the purpose of the study will be to explore the relationship between system usability and medical error. More specifically, we ask the research question ''Can system usability be used to identify and predict aspects of system design that could lead to medical error?''

In this study we describe an experimental evaluation of a handheld prescription writing tool with the objective of: (1) identifying usability problems, (2) identifying actual errors in writing prescriptions using the tool and (3) examining the relationship between usability problems and errors. We describe our method which allows us to tease apart usability problems related to user interface design issues from problems related to the content of information provided by such systems. We then examine the relationship between identified usability problems and actual errors that occur. It will be argued that approaches to evaluation that can be used to assess usability problems not only have an important impact on making systems easier to use, but can also be used for identifying aspects of system design and content that may potentially lead to medical error.

2. Materials and methods

A handheld prescription writing software application was used. The software is a commercially available product that contains a database of 8000 medications and supplies. The program allows users to maintain a database of patients and enter prescriptions in it at any time, including the point of care. Once completed, medications can be printed and given to the patient for fulfillment. The handheld device used in this study is a VisorPro, manufactured by Handspring Inc., running Palm OS version 3.5.2H3. The VisorPro utilized a *Presenter-to-Go* compact flash card (Margi, Inc.) to connect to an LCD projector for projecting the interface of the PDA (as the subject interacted with it) onto a nearby projection screen. As described below, subjects were asked to interact with the prescription writing software on the PDA in order to carry out specific medication entry tasks. In order to obtain video recordings of all the users' interactions with the PDA (and the software under study) a video camera was trained on the projection screen to record all interactions. Fig. 1 illustrates the experimental set-up employed, and more generally the components of our portable handheld usability laboratory.

2.1. Subjects

Ten participants were recruited to take part in the study. All of the participants were Internal Medicine physicians working in an outpatient ambulatory clinic. To be eligible to participate, all of the physicians had to have used palm-based handheld devices for at least a year. The participants ranged in age from 26 to 76 with a mean age of 33. All of the participants reported that they used a computer several times a day and owned a palm-based handheld device. They reported using their handheld device at least once a day and doing so for drug reference (10/10), medical knowledge reference (7/10) and patient tracking (2/10).

2.2. Procedure

Each participant initially received standardized training on the use of the handheld prescription writing application. The training consisted of an overview of the application and guided performance of prescription writing and refills. The study protocol contained two sections: a medication list and a clinical vignette. The medication list consisted of four medications: Lipitor, Synthroid, Premarin, and Amoxicillin. These medications were chosen from a list of the most commonly prescribed medications in the United States. Participants were asked to print the first two medications from the medication list and visually inspect the content of the resulting prescriptions.

Participants were then asked to read a short clinical scenario and then enter relevant prescriptions into the handheld application. The clinical cases described either a young woman with gastritis or a middle-aged man with sinusitis. Both scenarios included a description of an initial visit, followed by a repeat visit. Each 'visit' included writing appropriate prescriptions and refills so as to simulate actual patient care encounters. Participants were required to write refills as part of the scenario.

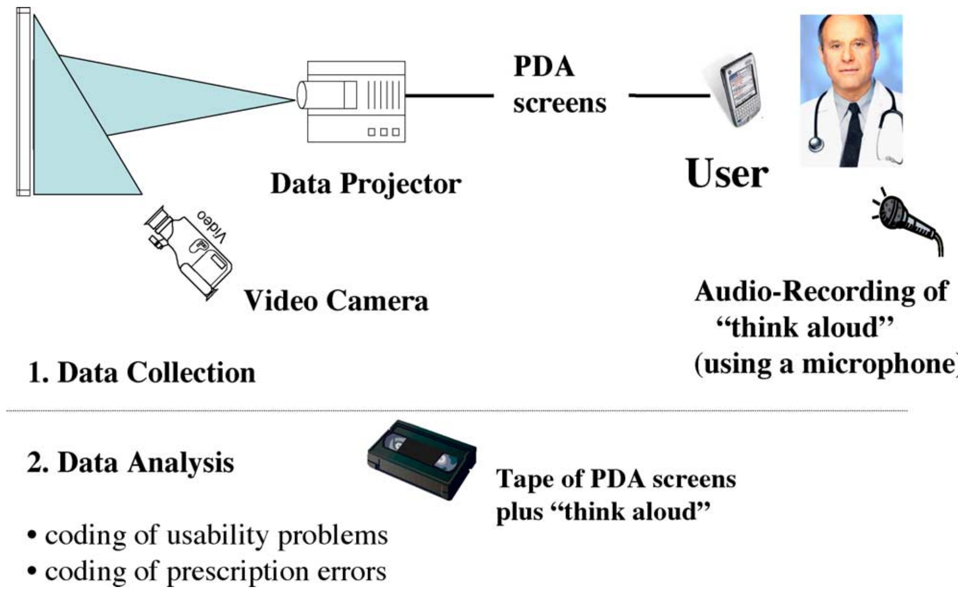

Fig. 1 Portable handheld usability laboratory.

Participants were encouraged to ''think aloud'' and verbalize their thoughts about the software and hardware as they carried out each task. Subjects' verbalizations were audio recorded for subsequent protocol analysis [16]. In addition all of the screens of the handheld device were video recorded (by outputting the screens of the device to a LCD projector using the *Presenter-to-Go* flash card and then video recording the projection of the screens). The audio track of the video recording of the screens contained the corresponding subject verbalizations as they worked through the tasks (modifying the method described in [14] for the analysis of human—computer interaction).

2.3. Analysis

The audio recordings of the participants as they interacted with the device and software were first transcribed verbatim. Analysis of the video and audio data was then conducted in two phases.

2.3.1. Phase 1: coding of usability problems

The video tape of each subjects' interaction was reviewed by two investigators having expertise in usability analysis (the tapes were coded together and any discrepancies in coding resolved through discussion). This part of the analysis consisted of annotating the transcripts of the subjects' ''thinking aloud'' with codes indicating problems encountered in using the system. The coding scheme was based on one described by Kushniruk et al. [17] and included categories for identifying the following usability problems from the analysis of video-based data: (1) interface problems—this includes categories for identifying problems with: *data entry, display visibility, navigation, locating information, following procedures, printing, speed,* and *attention*, (2) content problems—this includes categories for problems with: *database* (e.g. the content of the medication database does not include a desired medication) and *default* (e.g. a problem occurring due to an incorrect default dosage or medication).

2.3.2. Phase 2: coding of prescription errors

The video tape of each subjects' interaction was also reviewed by two medical experts (independently of the coding of usability problems) to identify errors made in the entering of the prescriptions (i.e. where discrepancies occurred between what the physician was asked to enter and the actual prescription entered using the handheld device). A coding scheme was developed to identify prescribing errors: (1) type of medication prescribed, (2) medication dose, (3) frequency of medication administration, (4) route of administration and (5) period of medication administration.To characterize the cognitive nature of error in entering the prescriptions, the following coding scheme was developed (as inspired by, but modified from the work of Norman [18]): (1) *slips*—an error (e.g. incorrect medication entry) which at some point the user notices and corrects (typically unintentional events such as typos), (2) *mistakes*—an error (e.g. incorrect medication entry) which is not corrected by the subject.

2.4. Comparison of usability problems to errors

In the final phase of the analysis the investigators examined the relationship between usability problems and errors in medication entry. For each medical error identified, the record of coded usability problems was examined to determine if the usability problem had been associated with any actual data entry errors.

3. Results

Each hour of video data took approximately 2 h for the coding of usability problems and about two additional hours for the coding of errors. The coding of both usability problems and errors was reviewed by a second experimenter. There was nearly complete agreement on the coding of problems and errors, with minor disagreement being resolved during subsequent discussion and review of video and audio data.

The following is an example of an excerpt from the coded transcript of a physician "thinking aloud" while entering medications (see below). The number in the example corresponds to the actual time on the VCR counter. The annotations and video codes for both usability problems and errors are given in boldface:

- 02:26 Subject: "Amoxillin, 250 capsule, po, two times a day, is that one of our options q8 darn, q8 hours times 7 days."
- 0:2:28 **SUBJECT ENTERS** 250 mg tid × 7 days (30 dispensed)
- 002:30 Subject: " Oh wait, I wanted to dispense 30 come back. Let me think about that, 7, 8, 24. He just got 6 extra tablets!"
- **USABILITY PROBLEM #1 — DISPLAY VISIBILITY —** not clear that a drop down menu should be used in order to enter "q8h"
- **ERROR #1 MISTAKE** — " tid" entered instead of "q8h"
- **USABILITY PROBLEM #2—DEFAULT INAPPROPRIATE**
- **ERROR #2 SLIP**—30 dispensed instead of 21

In the example above the subject was asked to enter a prescription for Amoxicillin 250 mg po q8h × 7 days (21 dispensed). However, the subject entered ''tid'' instead of ''q8h'' for frequency of medication dosing and also dispensed too much medication (30 dispensed). The subject did not catch the first the error in frequency as so it was coded as a ''Mistake''. However, he corrected the second error in dosage and so it was coded as a ''Slip'' as described Section 2.3. In terms of usability problems the same segment of video had been independently coded as indicating there was usability problem coded as ''display visibility'' as it was not clear to users that they should use a drop-down menu to see the whole screen. In addition, the number of dispensed medications did not automatically change to be appropriate for the number of days (i.e. this was a ''Default'' problem—where an inappropriate default appears that the subject does not notice until the medication is incorrectly prescribed).

The frequency of coded usability problems for all 10 subjects (subjects S1—S10) in Table 1. On the left-hand side of the table, the different categories of coded usability problems are listed. As can be seen the total number of usability problems related to the INTERFACE was 61 while problems related to the CONTENT accounted for 12 coded problems. Of the specific codes for the INTERFACE, the most frequent problem was related to *display visibility* (19 total occurrences across all subjects—see Table 1), where problems were identified involving the subject not being able to see required information on the screen (and additionally, with the subject failing to search or scroll to it). Content problems were typically related to the program's medication database being incomplete (e.g. the medication database did not contain generic drug names) and inappropriate default values automatically appearing (e.g. for dosages, number and frequency of dispensed drugs) on the screen for specific medications. On the bottom row of Table 1 the total number of problems coded for each of the 10 subjects is given. As can be seen all the subjects encountered usability problems. As can also be seen in the far right-hand column of Table 1, in total 41% of the occurrences of usability problems related to the INTERFACE were associated with error, while 16.7% of problems related to CONTENT were associated with error. Overall, 37% of identified usability problems were associated with errors in entering medications (see the bottom right-hand cell of the table).

In Table 2, the frequency of recorded medication entry errors is broken down in terms of slips and mistakes (as defined above) and presented in relation to each category of usability problem. For example, there were a total of 19 display visibility problems coded from the transcripts. From Table 2, we can see that these problems were associated with 4 coded slips and 12 coded mistakes (involving the wrong medication information being recorded undetected by the subject). On the far right-hand column, for this category of usability problem, the percentage of its occurrences that are

Table 1 Usability problems and their relationship to medication entry errors.

	Subjects										Total usability problems by category	Total errors	% Usability problem associated with error
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10			
Problem													
Interface													
Data entry		1	3		1	1				3	9	7	77.8
Display visibility	1	3	1	2	2		1	1	5	3	19	16	84.2
Navigation				1	1			1	1		4		0.0
Locating	1					2			3		6	1	16.7
Procedure	1		1	2	1	1	1	1	2	1	11		0.0
Printing		2	1		1	2			1	1	8	1	12.5
Speed								1	1	1	3		0.0
Attention								1			1		0.0
Total	3	6	6	5	6	6	2	5	13	9	61	25	41.0
Content													
Database	4	1	1							2	8		0.0
Default	1								1	1	3	2	66.7
Training manual									1		1		0.0
Total	5	1	1	0	0	0	0	0	2	3	12	2	16.7
Grand total	8	7	7	5	6	6	2	5	15	12	73	27	37

associated with error is 84.2% ($16/19 \times 100$). Other categories of usability problems highly associated with error in entering medications included data entry problems (the first category of usability problems listed in Table 2), such as ergonomic problems arising from difficulties entering values correctly using the handheld's stylus. In must be noted that subjects were able to identify and correct 50% of errors associated with a usability problem (i.e. slips). However, the remaining errors associated with a us-

Table 2 Errors broken down into slips and mistakes.

	Total usability problems by category	Slips	Mistakes	Total errors	% Usability problem associated with error	Probability of an error occurring	Odds of an error occurring
Problem							
Interface							
Data entry	9	7		7	77.8	0.8	4:1
Display visibility	19	4	12	16	84.2	0.8	4:1
Navigation	4				0.0	0	0
Locating	6	1		1	16.7	0.2	1:4
Procedure	11				0.0	0	0
Printing	8	1		1	12.5	0.1	1:9
Speed	3				0.0	0	0
Attention	1				0.0	0	0
Total	61	13	12	25	41.0	0.4	2:3
Content							
Database	8				0.0	0	0
Default	3	1	1	2	66.7	0.7	3:7
Training manual	1				0.0	0	0
Total	12	1	1	2	16.7	0.2	1:4
Grand total	73	14	13	27	37	0.4	2:3

ability problem were not caught by subjects (i.e. mistakes).

Some types of usability problems increased the probability of subjects committing an error (i.e. slip or mistake). For example, in looking at the column entitled *probability of an error occurring*, we can see that data entry; display visibility and default usability problems have high probability of occurring in association with a medical error (greater than 60%). Usability problems with a medium to low probability of occurring in association with a medical error (less than 59%) include locating and printing. Usability problems associated with navigation, system speed, attention, database content, lack of a training manual did not occur in conjunction with a medical error. In the last column of Table 2 we calculated the odds of an error occurring in association with identification of a usability problem.

4. Discussion

In this paper, we have employed a usability engineering approach to the evaluation of a handheld prescription-writing program. By collecting and analyzing both video and audio data on users' interactions with the program we have been able to characterize a variety of usability problems associated with use of the prescription writer. By coding for categories of user problems, the approach taken was able to identify the most frequent usability problems, which consisted of difficulties related to the user interface, including problems resulting from the limited amount of information that could be displayed on such devices and problems in data entry. An objective of the study, as described in Section 1 was to move the next level in being able to relate identified usability problems with actual medical errors made in using an application such as a handheld prescription writer. It was found that particular usability problems were associated with the occurrence of error in entering medication. For example, the problem of inappropriate default values automatically populating the screen of the system under study was found to be closely related to errors in entering wrong dosages of medications. Furthermore, it was also found that certain types of errors were associated with mistakes (not detected by users) while others were associated with ''slips'' often consisting of unintentional errors.

In 50% of the cases where an error occurred, the subjects were able to identify and correct the error before the medication was ordered. However, in the remaining 50% of cases the subjects believed they had entered the medication order correctly (as evidenced by the transcripts of the video and audio data of think aloud processes). Therefore, they were not aware of medication error transpiring. In addition to this, although this study used a limited number of subjects, the occurrence of medical errors was found to be fairly frequent. This has sobering implications when one considers the widespread use of physician order entry systems and the increasing trend toward using palm-based applications in real world settings.

In recent years usability engineering has become increasingly recognized as being important in guiding the design, evaluation and implementation of information systems [19]. In this paper we have demonstrated that different types of usability problems may be associated with specific types of errors. The ability of methods from usability engineering to be able to predict medical errors holds considerable potential for assessing health care information systems regarding safety and ensuring that such systems do not inadvertently introduce medical errors.

The study described in this paper is part of a larger research program where methodological approaches to the analysis of usability of systems are being explored for prediction of types of problems related to specific interface design features [20]. In our current work we are extending evaluation of handheld devices from the laboratory to naturalistic health care settings in order to determine how generalizable the results are and to assess how well laboratory-based analyses, (such at that described in this paper) can be used to predict errors in real settings. In addition, we are conducting parallel studies involving a range of information systems and platforms, including Web-based electronic medical records (EMRs) and hospital-wide medication order entry systems.

The intersection between the emerging field of usability engineering and the study of error in medicine is a new and exciting area that holds considerable promise not only for improving the design and implementation of a range of systems but also for ensuring the safety of the new information systems we introduce in health care. The usability testing of the new applications we develop will be essential in order to identify technology-induced errors *before* they occur in real settings and situations. Although the literature has shown that information systems may decrease error in medicine, the idiosyncratic and varied nature of design of health information applications argues for the usability testing of *each* of these systems and devices to predict aspects of design that may be related to error prior to their widespread dissemination.

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