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User-Centered Design Improves the Usability of Drug-Drug Interaction Alerts: A Validation Study in the Real Scenario

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Abstract

Decision support systems can alert physicians to the existence of drug interactions. The Hospital Italiano de Buenos Aires, Argentina, has an in-house electronic health record with computerized physician order entry and clinical decision support. It includes a drug-drug interaction alert system, initially developed under traditional engineering techniques. As we detected a high alert override rate, we rebuilt the knowledge database and redesigned the alert interface with User-Centered Design techniques. A laboratory crossover study using clinical vignettes showed that new alerts were more usable than traditional ones.This paper aimed to validate these results through a controlled and randomized experimental study with two branches (old vs. new design) in a real setting. We analyzed, quantitatively, every fired alert between April 2015 and September 2016. Finally, we performed user surveys and qualitative interviews to inquire about their satisfaction and perceptions.In real scenarios, user-centered design alerts were more usable, being more effective and satisfactory, but less efficient than traditional alerts. "Safe omission", as a new concept, emerged from our stratified analyses and interviews.

Keywords:

Drug Interactions; Expert Systems; Software Design

Introduction

In 1999 the Institute of Medicine released the report "To err is human", stating that a quarter of total medical errors were related to medication [1]. Even though most errors are harmless, some of them can cause variable damage, including death. Fifty percent of these errors take place during drug prescription [2]. A common mistake is to neglect drug-drug interactions (DDI) [3]. Clinicians awareness of DDI can prevent related adverse drug events, but at least half of the time they are not recognized [4]. Clinical decision support is "the use of information and communication technologies to bring relevant knowledge to bear on the healthcare and well-being of a patient" [5]. For example, if physicians enter medication orders electronically, these systems can show drug safety alerts, including overdoses, duplicate orders and drug-drug interactions. Therefore, clinical decision support systems seem to be an appropriate solution, as they have shown improvements in both quality of care and resource optimization [6–8]. Although, several studies showed their low performance and high override rate [9–12]. From our perspective, these systems have at least five potential drawbacks: Excessive alerts (mostly with low clinical significance) due to imprecise knowledge databases, leading to alert fatigue [13]; Low quality interfaces, lacking ofworkflow integration and intuitive design [14]; Lack of context information in the system hinders complex rules [15,16]; Absence of alert monitoring prevents improvement processes [17]; and Implementation variability, even for the same vendor, secondary to standards deficit [18].

In the mid-2000s, the Hospital Italiano de Buenos Aires, Argentina, implemented an in-house electronic health record system with computerized physician order entry (CPOE). Shortly after, we launched a clinical decision support system for drug-drug interaction alerts, developed with traditional software engineering. Clinical pharmacology experts created a local knowledge database in Spanish. We monitored periodically the CDSS performance and found a high alert override rate. Thus, we first focused on improving the knowledge database quality [19]. Our analysis included the systematic evaluation of each DDI according to clinical relevance, to eliminate combinations with a low probability of harm (false positives), as suggested in a recent consensus [20]. We also adapted the Lexicomp® alert severity tiers according to potential reaction seriousness [21], following recommendations from Paterno et al. [13]. Only the two highest risk ratings (D and X) were considered clinically relevant and triggered intrusive alerts. As alert acceptance remained persistently low, the chief medical information officer ordered the DDI alert system withdrawal, to look for other potential issues. Previous research by Seidling et al. found that the alert display quality most strongly predicted DDI alert acceptance [22]. Therefore, we endeavored to improve the alert design through User-Centered Design (UCD) techniques, as they have demonstrated to increase adoption and usage efficiency of health information technology tools [23]. According to Patel and Kannampallil, human-computer interaction is a fundamental aspect to consider when developing computer systems [24]. UCD is a process framework that makes a system usable and understandable by accounting for end-users' needs, wants and constraints, through the whole product cycle. Following perspectives from Norman, UCD starts by understanding and specifying the context and requirement analysis, and then designing and iteratively testing solutions [25]. This systematic process is regulated by ISO 9241-210 "Human-centered design for interactive systems" [26]. For Kushniruk et al. participatory design goes beyond UCD and cooperative design approaches to include end users as active participants in the design and decision making [27]. We started the analysis with an heuristic evaluation [28] of the standard alert, noting several issues regarding minimalism, consistency, feedback, visibility and documentation. Then, we reformed the DDI alerts by using a participatory design approach. As described in a state-of-the-art reference handbook for the

subject, participatory design can be defined as "a process of investigating, understanding, reflecting upon, establishing, developing and supporting mutual learning between multiple participants in collective 'reflection-in-action'; the participants typically undertake the two principal roles of users and designers where the designers strive to learn the realities of the users' situation while the users strive to articulate their desired aims and learn appropriate technological means to obtain them" [29]. A team of three health informatics specialists and two usability experts worked with final users following the ISO 9241-210. This phase took place at the HIBA from September 2013 to April 2014, and was undertaken in three stages (inquiry, participatory design, and usability testing), as described in a previous publication [30]. The whole process was iterative; each stage included prototyping cycles for domain saturation to reach the best possible model. The participants were physicians that worked in outpatient and inpatient settings. Fictitious patient scenarios (clinical vignettes) were developed based on real clinical cases [31], taking the most frequent and significant examples of DDI from our clinical data repository [11]. The last UCD prototype was developed as a new software version [30]. Afterwards, we performed a laboratory crossover study to test its usability, using new clinical vignettes. We found that new alerts were more usable than traditional ones, regarding efficiency, effectiveness, and user satisfaction [32]. A deep insight of this study was published recently in the Journal of Biomedical Informatics [33].

This paper aims to validate the lab results in a real scenario, through a controlled and randomized experimental study, measuring the same variables as preceding studies (efficiency, effectiveness and user satisfaction).

Methods

Setting

The Hospital Italiano de Buenos Aires (HIBA) is a non-profit healthcare academic center founded in 1853, with more than 2,700 physicians, 2,700 other health team members (including 1,200 nurses), and 1,800 administrative and support employees. The HIBA network includes two hospitals in Buenos Aires city and its suburban area, 750 beds (200 for intensive care), 41 operating rooms, 800 home care beds, 25 outpatient clinics and 150 associated private practices. It has a Health Maintenance Organization (Plan de Salud) that covers more than 150,000 people and provides health services to another 1,500,000 people who are covered by affiliated insurers. Between 2013 and 2014, the HIBA admitted more than 45,000 inpatients, conducted 45,000 surgical procedures (50% ambulatory) and 3,000,000 outpatient visits. The HIBA is a teaching hospital, with more than 30 medical residency-training programs, 34 fellowship programs and 400 residents and fellows in training.

Since 1998, the HIBA has run an in-house developed health information system, which includes clinical and administrative data [10]. Its Electronic Health Record system called Italica, is an integrated, modular, problem oriented and patient centered system that works in different clinical settings (outpatient, inpatient, emergency and home care). Italica allows computerized physician order entry for medications and medical tests, and storage and retrieval of test results, including archived images. It was the first hospital in Argentina and the second in Latin America to be certified by the HIMSS as level 6+ in the Electronic Medical Record Adoption Model. In recent years, our Health Informatics Department at the HIBA prioritized UCD in the design and development culture to enhance the usability of healthcare software. We conducted lectures, launched a pilot project, and assembled a usability team for service and dissemination [34].

Methodological Design

The HIBA Institutional Review Board approved the research protocol. The study was performed in a tertiary academic center, with users from different settings (outpatient, critical, and non-critical inpatient). For our experimental study, we randomly assigned physicians (system users) to two branches. We compared two different DDI alert interfaces: the standard one (developed under traditional techniques) and the participatory design model, generated under UCD techniques. Drug-drug interaction alerts were reinstated to the prescription system in April 2015. The clinical decision support system used the same DDI knowledge database and inference engine from previous stages of the study. The alert system ran every time a new prescription was placed and searched the knowledge database for potential interactions between each substance already on the list and the new drug. When an interaction was detected, the system opened a DDI alert modal (a dialog box or pop-up window that was displayed on top of the current page). Depending on the assigned branch, the physician would see the standard or the UCD version of the alert. The standard DDI alert interface can be seen in Figure 1.

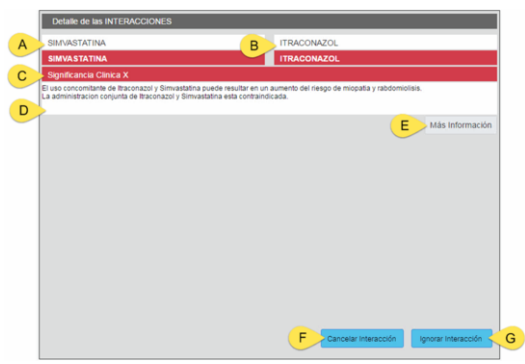

Figure 1– Standard DDI Alert Interface (letters correspond to descriptions): the two drugs (A and B), the clinical significance (C), a brief explanation (D), a "learn more" button (E), and the action buttons to cancel the prescription (F) or ignore the alert (G).

Compared to the standard version, the new interface version had a different communication message, changing the displayed elements, warning colors and proposed actions (as shown in Figure 2). New output actions were specifically created for the novel DDI alerts.

Study Population

Physicians fulfilling the exclusion and inclusion criteria were selected for each clinical setting (outpatient, non-critical, and critical inpatient). All had worked with CPOE but had not been recently exposed to the original DDI alert, because it had been withdrawn more than 3 years earlier. Inclusion criteria were as follows: working as a physician of any specialty in the hospital for more than a year by March 2015. Physicians with previous participation in alert design or test stages were excluded. Users were randomized using their hospital ID to one of the two branches: the original interface and the participatory design version. None of them were aware of this allocation.

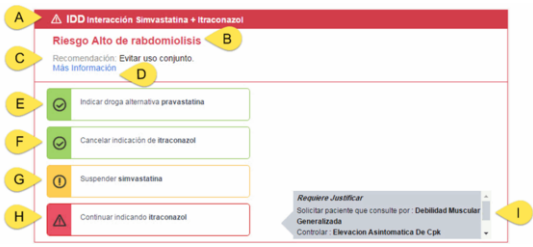

Figure 2– New Software Version Interface (letters correspond to descriptions) displaying the drugs involved and their risk (A), the drug interaction risk and severity (B); the main recommendation (C); a "learn more" link (D); the action buttons to "prescribe an alternative drug" (E), "cancel drug 2 prescription" (F), "cancel drug 1 prescription" (G) and the "keep both drugs" option to ignore the alert (H), which required justification and monitoring (I).

Measurements

We retrieved data from every fired alert from May 1st 2015 to September 30th 2016. We analyzed the metadata from each of them, including: the date and time, number of clicks on the "learn more" link and on the action buttons ("accept", "cancel" and others), and the text for override justification. We also retrieved participants' demographical information. All data was treated confidentially, and accessed only by authorized researchers. As in the previous lab study, efficiency, effectiveness and user satisfaction were selected as usability metrics to compare the performance of the new UCD alert against the standard version. Efficiency was measured as the time required to resolution. We defined that the alert was solved when the user finished the tasks and closed the modal window. As we could not witness participants' reactions as in the lab study, we measured effectiveness according to the actions taken within the alert: it was "accepted" if the user decided not to prescribe the causative medication (or chose other alternative option), and was "canceled" if he kept the prescription. One way of identifying confounding is to examine the primary association of interest at different levels of a potential confounding factor. Therefore, we performed stratified analyses for both types of interfaces depending on different criteria: Interaction risk rating (severity); Setting: outpatient, critical, or non-critical inpatient; User seniority; Pair of drugs (combinations). Regarding user satisfaction, a brief survey translated and adapted from Zheng et al. [35] was conducted. It was similar to a Likert scale, in which the respondent indicated the degree of agreement with the satisfaction statements on a 4-point scale: totally disagree, disagree, agree, and totally agree. We automatically sent the questionnaires through Surveymonkey® [36] to every user exposed to an alert. The message started with a short explanation on the subject, and showed a sample image of the alert that has been previously displayed. The system sent a reminder email after 48 hours. We closed the poll after 25 responses from each branch, considering domain saturation. We also collected user perceptions through direct qualitative interviews to a sample of exposed physicians. They were invited by email and we scheduled a meeting with those who accepted.

Statistical Analysis

Descriptive statistics were presented for all variables in the comparative study. Interval variables were parameterized by mean, median and quartiles. For categorical variables, the observed frequency (total number of observations within the category) and relative frequency percentages were used. Statistical analyses for all tests were performed using the R software environment from R Project for Statistical Computing [37]. Statistical significance was considered when the probability was lower than 0.05.

Results

We analyzed the metadata of every triggered DDI alert from May 1st 2015 to September 30th 2016, within the hospital CPOE. There were 310 DDI alerts shown to different physicians: 168 (54%) were traditional alerts and 142 (46%) were UCD alerts. See Table 1 for demographical information. From 4141 drug interactions included in the knowledge database, the highest severity risk rating D and X represented 10% (440 combinations). In this study, there were just 94 pairs of drugs (2%) involved in the alerts during the yearly analysis.

Table 1– Demographics of Participants from both Branches. Year values are expressed as median (Q1 –Q3).

	Traditional Alert	UCD Alert	p
N	168 (54%)	142 (46%)	
Age (years)	32 (28-34)	31 (29-34)	0.92
Gender	F=57 %	F=56 %	
Seniority (years)	3 (2-4)	3 (1-4)	0.68

Time measured for efficiency was taken from the moment the window popped up to its closing. Table 2 shows that UCD alerts required less time for completion than traditional ones.

Table 2– Alert Resolution Efficiency, with time in seconds expressed as median (Q1 –Q3).

Variable	Traditional Alert	UCD Alert	p
Time (seconds)	17 (9-25.5)	10 (5-20.5)	0.009

Effectiveness was measured by the amount of accepted and canceled alerts. The global analysis is shown in Table 3.

Table 3– Alert Resolution Effectiveness, as absolute and relative (%) frequency of accepted and canceled alerts.

Result	Traditional Alert	UCD Alert	p
Accepted	84	42	
Canceled	84 (50%)	100 (70%)	<0.001

The stratified analysis regarding the risk rating of the interaction is shown in Table 4. Regarding setting (outpatient, critical, and non-critical inpatient), seniority, and specific drug combinations stratified analyses, there were no significant differences between both branches.

Table 4– Alert Resolution Effectiveness, as the quantity of accepted and canceled alerts stratified by risk rating.

Risk	Result	Traditional Alert	UCD Alert	p
D	Accepted	48	1	<0.01
	Canceled	61	79	
X	Accepted	38	18	0.21
	Canceled	23	21	

In Figure 3 we present the results of one of the questions from the satisfaction survey.

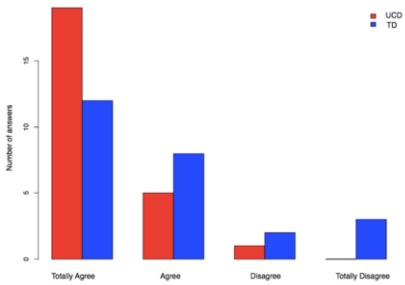

Figure 3– Satisfaction Survey Results regarding Alert Utility: "DDI alerts are useful for patient care" (p = 0.03). The bars represent the amount of answers for each degree of agreement. Red is for UCD and blue for traditional interface.

We performed 12 interviews, 5 were traditional and 7 UCD interface users. We analyzed their perceptions on the triggered DDI alerts. Utility perception differed regarding seniority, with better appraisal from junior physicians.

Discussion

This paper shows the fourth phase of a long-standing research project at the HIBA. The first phase implied the knowledge database redesign [19]. The second phase included two cycles of participatory design sessions, in which interface prototypes and evaluations focused on qualitative aspects [30]. Participants agreed that they wanted short, clear, and quick alerts [14,15]. A laboratory crossover study using clinical vignettes was the third phase. It showed quantitatively that our UCD method was a reliable way of designing and developing better DDI alerts. The results regarding effectiveness, efficiency, and user satisfaction were similar to those in Russ et al. [23]. Regarding efficiency, the new interface required less time to complete the task but the same amount of clicks and justification words as in the old one, probably due to quick and enhanced interaction with the alert. The UCD interface showed statistically significant improvements in effectiveness and user satisfaction. The interviews showed that nearly 60% of the users preferred the UCD interface.

Such promising results required a real scenario validation study. Regarding the alert override, our results were similar to previous publications that reported cancellation rates between 49% and 96%[9]. The global effectiveness was higher for the standard version, opposing our previous lab study results, in which the UCD interface performed better. We then performed a stratified analysis and detected that there were no significant differences in effectiveness regarding X risk rating ("avoid combination"). The D risk rating ("modify regimen") had a slight trend for the standard version. The qualitative approach of surveys and interviews gave an insight on these results. The surveys were answered a long time after the alert exposure (weeks), thus they might reflect user attitudes towards the software instead of their opinions on the task itself. The new UCD alert scored better in the satisfaction survey than the traditional alert. From the interviews analyses, we discovered that senior staff relied more on their clinical experience, while junior physicians appreciated the benefits of the decision support. Both agreed about the utility of the new UCD alert, as it can prevent unintended errors especially in the context of urgencies, work overload, and time constraints. Resident physicians also used the CDSS as a learning opportunity. We also realized that alerts usually fail to change the physician intention to prescribe. Thus, providers keep ordering the drugs despite potential interactions. Although, they monitored the drug effect and adverse events as they have been warned in advance. We named this medical awareness as "safe omission". This might be underlying the high alert override rate found in many previous CDSS studies.

The research was done in a single academic center using in-house developed software and thus might not represent other institutions.

Conclusion

In real scenarios, user-centered design alerts were more usable, being more effective and satisfactory, but less efficient than traditional alerts. "Safe omission", as a new concept, emerged from our stratified analyses and interviews.

It is necessary to continue the analysis of human-alert interaction, especially regarding the "safe omission" phenomenon. Further research in this field is recommended.

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