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Computer-based drug ordering: evaluation of interaction with a decision-support system

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Abstract

Provider order entry systems (POE) often incorporate active decision-support component for drug dosing. The efficacy of automated alerts that suggest dose amounts to the clinician in real time depends in part on how well they are timed to fit into the decision process and on their representational structure. We have conducted a cognitive evaluation of an interaction with a POE system that offered active decision support for heparin dosing with the goal of characterizing its effectiveness and opportunities for error. Two researchers completed a cognitive walkthrough of an ordering task based on a clinical scenario. In addition, seven clinicians were asked to enter a set of orders in an experiment using the same scenario. The analysis revealed that users without a solid conceptual knowledge of the ordering system followed patterns of inefficient interactive behavior resulting in delays and some errors. Physicians often did not take full advantage of automatic dose computation provided by a decision support component and used it largely as reference. The calculated dose was not perceptually salient in the generated alert and required users to engage in meaning interpretation of the displayed information. Better visual presentation of the alert message would likely result in faster and less cognitively demanding interaction.

Keywords:

Order entry systems; decision support; cognitive evaluation; drug ordering; medical errors; cognitive engineering.

Introduction

The administration of therapeutic drugs is a complex and multifaceted task. The process often requires the synthesis of general and context-specific medical knowledge, the gathering and interpretation of past medication history and relevant patient data, skill in dose calculation, and effective communication of orders to clinical staff. Typically in clinical practice, this task may be repeated several times a day by a clinician.

This process requires uninterrupted focus of attention and careful, detailed work that can be cognitively taxing. Errors of judgment or simple computational mistakes [1, 2] are frequently the result of momentarily insufficient information processing capacity [3]. The potential of drug injury by inappropriate medication is great and patients frequently suffer serious consequences [4].

One of the primary purposes of order entry applications is to address the dangers of errors in medication ordering. Computer technology has proven to be highly effective in completing repetitive and calculation-intensive tasks. A sizable proportion of drug prescription process is rote calculation of the dose, frequency and possible weight-based adjustments. Order entry technology allows clinicians to off-load this computation onto the system which also performs consistency checks in real time (e.g., the placement of decimal points and correct units of measure). This allows clinical users to direct more of their limited cognitive resources on higher-level functions such as treatment planning, medical reasoning and appropriate drug selection.

Many advanced ordering systems offer decision support facilities to determine optimal dosing by automatically calculating adjustments based on patient weight or renal function stored in the medical record [5, 6], and check for interactions with other concurrently prescribed drugs, known allergies and diseases [7]. Some may also prompt the user to enter required corollary (consequent) orders [8]. Applications that allow direct entry of medication orders are among the most difficult clinical computing applications to develop, yet they have been demonstrated to dramatically reduce serious medication errors [4]. The complexity of design is partially determined by the number and combination of conditions that an algorithm needs to consider before it triggers alerts or reminders. The form and timing of these alerts is, however, also a significant challenge to interface designers. Relevant information needs to be presented to the clinician in the closest possible proximity to the point when a decision is being made [9], in a representational form that allows quick and unambiguous interpretation of the message.

In this paper, we present a cognitive analysis of interaction with a dynamic decision support tool for the dosing of heparin administration integrated to an order entry system. Our goal is to characterize ordering effectiveness, changes to ordering behavior and opportunities for error attributable to the interaction process. The approach we employed is informed by Norman's theory of action [10], particularly in using the cognitive walkthrough [11] to characterize the behavior of a skilled user. The principal methodology for the analysis is the distributed resources model of human-computer interaction [12]. This analytical framework was previously used by the authors to characterize the unnecessary cognitive complexity of a POE interface and to explain patterns of errors in a simulated order entry scenario [13].

The design of a user interface for ordering systems of such significant complexity needs to incorporate features developed with regard to the principles of human-computer interaction and cognitive engineering to achieve a high level of effectiveness and usability. Decision support systems that present patient-specific recommendations in a form that can save clinicians time have been shown to be extremely effective, sustainable tools for changing clinician behavior [14].

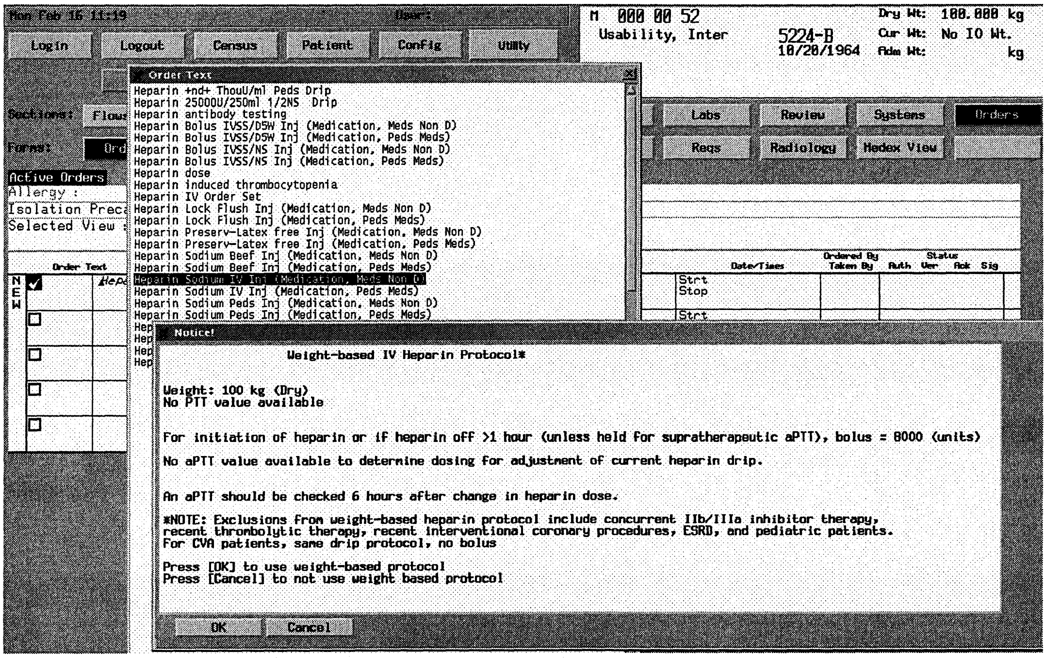

Figure 1 - Heparin dosing alert screen with weight-based calculation

Clinical information systems as complex as POE embody a wide range of representational types, including narrative text, structured fields, tables, charts or trend lines. The representational structure of displayed information determines the level of cognitive complexity any given task will require [15]. External representations may provide information that can be directly perceived and used without being interpreted [16]. For example, the color, shape or spatial placement of an alert window may indicate the level of urgency or denote the context of the information as general advice or patient-specific recommendation. Using the most appropriate form of display will affect the speed and accuracy of mental processing during task completion. Research has suggested that decision-making tools are the most effective when delivered in real time at the point of care (e.g., integrated with order entry and triggered by the activation of a drug order) and seamlessly embedded into workflow [17, 18].

Our analysis will help to characterize the complexity of interaction with decision support features during clinical ordering. Specific recommendations to POE developers may be articulated based on our findings and observations of clinician interactive behavior. Improvements in speed and usability will facilitate the implementation of this technology in hospitals.

Methods

Tasks such as drug ordering or assessing patient's status can be described as having a relatively invariant abstract structure. This structure consists of a sequence of component sub-tasks that are invariant regardless of the medium in which it is embodied. For example, if a clinician needs to calculate a drug dose based on patient's weight, she needs to obtain the weight, the dosing and adjustment formula, and apply calculation. These abstract task then may be carried out according to what information resources are available: recall the formula from memory or look it up in a book or on the computer, and then apply mental arithmetic, paper calculation or use a pocket calculator to compute the specific dose. A decision support system integrated in POE will complete this same task at the appropriate time within the workflow using its own information sources: patient weight from medical record and a stored calculation algorithm, and input from the user (e.g., the name of the drug and route of administration). The availability and configuration of these resources may either facilitate quick and accurate task completion if optimally implemented, or impede the overall performance and slow down the user [19].

Our analysis consists of a two-pronged approach. First, two investigators completed a cognitive walkthrough of an ordering task according to a clinical scenario. We then contrasted our findings with data generated by clinicians completing an identical experimental ordering task based on the same scenario. A modified version of the cognitive walkthrough determined the abstract structure of the task and characterized the resources required to complete each component sub-task.

The combination of these two methods, the cognitive walkthrough analysis and empirical data collection, is intended to a) evaluate the extent to which the need for necessary information resources is supported by the POE system, b) characterize the effectiveness of the decision support reminder in reducing the cognitive effort of users, and c) identify possible sources of error. The focus is on in-depth qualitative analysis of performance, thus necessitating fewer subjects than a typical system evaluation.

Table 1: Results of a cognitive walkthrough: task components and available resources

Task	Abstract Task	Required Resources	POE Support	Notes
1	Infer the need for heparin administration to patient	General medical expertise, patient assessment, treatment plan	*none*	
2	Recall general heparin dosing procedure	Specific knowledge of institutional guidelines, medical expertise	*none*	Alert with this information is triggered later in the process
3	Plan specific ordering procedure	Conceptual knowledge of a specific POE system, user skill	*none*	User needs to recall where to find the needed orders in the system
4	Gather needed data	Patient weight, medications, diagnosis, allergies, medical history	Integrated EMR	All values are not always visible or accessible when needed
5	Calculate bolus dose	Weight-based formula (80 U/kg bolus, 18 U/kg/hr drip)	Decision support dose calculator	No rule explanation, dose suggestion "buried" in the text
6	Generate a bolus order	Built-in order template	Order available	DS not triggered for reorders
7	Calculate drip rate	Weight-based formula (80 U/kg bolus, 18 U/kg/hr drip)	Decision support dose calculator	No rule explanation, dose suggestion "buried" in the text
8	Generate a drip order	Built-in order template	Order available	DS not triggered for reorders
9	Generate PTT check order	Built-in order template	Order available	Reminder only in the initial alert
10	Review orders and values	Completed orders	List of orders	Quick visual review not possible

Development version (without live patient data) of a commercially available POE system was used for both the walkthrough analysis and for subject experiment. The scenario required the clinician to initiate heparin therapy and is presented below:

You just admitted an obese (100 kg) patient with obvious DVT rule out pulmonary embolus. Because she may go for pulmonary angiography, you decide to anticoagulate with heparin. Write the orders for heparin administration.

The task required subjects to 1) develop a problem representation of the clinical scenario, 2) recall the general components of a heparin ordering procedure, 3) calculate a weight-based dose and 4) enter appropriate orders.

Cognitive walkthrough

This analysis is designed to simulate expert user performance. Two researchers completed the walkthrough with the assistance of a physician who was an expert POE user. The clinical task required entering orders for a total of three orders: a heparin bolus followed by a drip, both with a weight-based dosing, and a corollary order to check PTT (partial thromboplastin time) values six hours after the drip initiation. The system suggested the bolus dose to be 80 U/kg and the drip 18 U/kg per hour. The total computed dose was automatically shown to the user when the order was selected from a pick list. The presence and accessibility of information resources was recorded at every system state (i.e., screen transition).

Experimental order entry by clinicians

Seven internal medicine physicians with a year or more of daily order entry experience and a range of 2-5 years of clinical experience were given a written clinical scenario and instructed to enter appropriate medical orders while verbalizing their thoughts (a think-aloud protocol). Computer screen video signal was captured and recorded so that mouse movements, actions and screen transitions could be later analyzed. Subjects' comments were transcribed and coded for a cognitive task analysis. Each session lasted about 15 minutes.

Results and discussion

Cognitive walkthrough

The cognitive walkthrough identified ten abstract component sub-tasks and the resources needed for their completion (results in Table 1). User interaction was generally well supported by available resources. The integration of the electronic medical record was essential for the automatic computation of the weight-based dosing suggestion. The decision support alert was triggered at a time clinicians would most need access to it.

The institutional guideline for heparin administration, however was embedded in the same alert (Figure 1) containing the calculated dose, triggered later in the process when the planning stage of the order is generally completed. The user might need this information earlier in the decision process (Task 2 in Table 1) and available on demand, perhaps through an interface control (e.g., an infobutton). Without the knowledge that a specific guideline is available in the system, the user may initiate search of ancillary sources (e.g., a printed guideline), unnecessarily prolonging the process.

The graphical representation of the dosing suggestion window was poorly conceptualized. The primary information – the patient-specific calculated dose, is embedded in text containing general information about heparin prescription guidelines. It is not evident without further interpretation that the needed calculation has been performed and the result is available for consideration. A different representational form that would enable the quick perceptual judgment that dose calculation for this patient has been performed could reduce this extra cognitive effort. For

Table 2: Experimental order entry by seven clinicians: cognitive activities and errors

Finding – Activity	Description	Subjects
Cognitive effort		
Calculation, estimate	Heuristic estimate or calculation of dose performed independently of DS calculator	1,2,3,4,5,6
Alert interpretation	Thorough reading of alert to infer its function as a patient-specific dose calculator	1,2,3,4,5,6
Dose formula evaluation	Engaged in estimating the basis of dose calculation used by the system algorithm	1,3,4
Errors		
Alert interpretation	Misidentified as a general guideline or a reminder for corollary PTT order	2,5
Entry format	Entire dose entered in a slot for rate, or bolus order mistaken for a drip	1,2,5
Deviation from suggested dose		
Decision support not used	Entered dose was different from guideline dose	2,5
Decision support used	Change of dose after considering suggestion in the alert	7

example, presenting only the calculated dose in a window with clear description on what basis was the result derived (e.g., the "80/18" formula) would have been a better choice and a more salient representation. There is a reminder to add the corollary PTT check order. However, it is presented out of the logical workflow as an addition to the calculated dose alert and not at the end (Task 10), when the user reviews order completeness.

Experimental order entry by clinicians

All seven subjects entered appropriate sets of orders, although Subject 6 opted not to order a bolus dose. One subject adjusted the recommended bolus dose of 8000 Units to 5000 Units while others followed the recommendation. There was more variation in the drip rate dosing: two subjects ordered 1500 U/hr rate, and one ordered a 1700 U/hr rate. All others entered the recommended 1800 U/hr drip rate. Five subjects used the automated dose calculation feature to inform their decision, and two (Subjects 2 and 5) did not recognize the alert as providing dose calculation facility. Results and description of actions taken by the subjects are presented in Table 2.

Six subjects computed, estimated or used a heuristic to get the dose amount at some point before the system-calculated dose presentation. They generally used the result generated by the computer as a reference point for their own estimate. Consequently, they did not derive all the speed and accuracy benefit and did not reduce their cognitive effort the feature was in part designed to do. Five subjects correctly identified the reminder as primarily an automated dose calculator. One subject (S7) lowered the system-calculated drip dose without engaging in any calculations, apparently altering the dose based on prior experience.

Two subjects did not use the decision support feature because they misidentified the alert as a general guideline reminder and did not notice the dose calculations embedded in text. The following coded excerpt from a verbal protocol (Subject 2) illustrates the way she failed to apprehend the affordances of this feature because of its lack of perceptual salience.

GOAL: Select heparin bolus from a pick list

ACTION: Click on "Heparin Bolus IVSS/D5W Inj"
SYSTEM RESPONSE: "Weight based Heparin Protocol" alert, suggested dose 8000 Units
INFERENCE: Evaluate dose, decide on using protocol
"and the computer is telling me, no PTT ... ah, ah, I'm assuming that the PTT is normal because ... this patient hasn't been on anything ... and I'm gonna use the weight-based protocol. "
SUBGOAL: Use Weight based Heparin Protocol
ACTION: Click OK on the alert window
SYSTEM RESPONSE: Order detail window displayed
SUBGOAL: Complete a heparin bolus order
I'm gonna bolus with 5000
ACTION: Type "5000" at the dose prompt, click OK

The interface did not effectively structure the interaction and the clinician proceeded to enter her own dose.

Three subjects expressed their need for better understanding of the dose computation by the system. They guessed that the algorithm was based on the "80/18" dosing formula (described above) since the computation was an easy multiplication by 100. In most real situations, however, users would not be able to "validate" the system's reasoning without resorting to calculation that is more complicated. It was evident that subjects wanted to be sure that the system based its recommendation on the same assumptions they would have made. The inclusion of the basis for automated computation with the alert is a feature that is likely to foster users' trust in the appropriateness of dosing suggestions.

All subjects correctly entered the corollary PTT check order, although only four reviewed orders for completeness. The subjects could not check all the entered values, however, as the graphical presentation of finalized orders did not allow a simple visual inspection of all entered data.

Three subjects mistakenly entered a rate value (e.g., 18 U/kg) into a slot in the order screen for the complete dose (e.g., 1800 U/hr - the rate multiplied by weight). This error generated a further alert from the system as it detected an out-of-range entry in one of the fields, prolonging the interaction. Theoretically, this could have resulted in an erroneous dose order if the ranges allowed in both fields overlapped. This apparent confusion was likely caused by the fact that the entry fields were adjacent and that the meaning of rate and dose could have been easily misinterpreted.

Conclusion

Drug medication errors are known to have high prevalence and significant associated cost. The decision support facility of provider order entry systems afford improved patient safety. However, like other complex medical information technology, they present formidable challenges in terms of usability and learnability of system features. The alert provided by the order entry was not optimally used by most subjects and not used at all by two of the clinicians. The affordances were not effectively conveyed and thus could not be exploited to the fullest. The results should be available in a form supporting quick perceptual judgments and in a manner that reduces cognitive effort.

The methodology we have adapted for this research may be useful for identifying areas where improved design may have a direct impact on performance and thereby minimize errors. The complexity of an interface may result in suboptimal use of features designed to increase accuracy and speed of order entry. Provider order entry systems are inherently complex. However, the use of effective external representations can focus users' attention on dimensions of the interface that warrant immediate attention. Cognitive analyses can be used to discriminate between more or less effective representations and suggest design solutions to more productively structure clinicians' interaction with information technologies.

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