Cognitive Analysis of Decision Support for Antibiotic Ordering in a Neonatal Intensive Care Unit

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Summary

Background: Clinical decision support systems (CDSS) are a method used to support prescribing accuracy when deployed within a computerized provider order entry system (CPOE). Divergence from using CDSS is exemplified by high alert override rates. Excessive cognitive load imposed by the CDSS may help to explain such high rates. Objectives: The aim of this study was to describe the cognitive impact of a CPOE-integrated CDSS by categorizing system use problems according to the type of mental processing required to resolve them.

Methods: A qualitative, descriptive design was used employing two methods; a cognitive walk-through and a think-aloud protocol. Data analysis was guided by Norman's Theory of Action and a theory of cognitive distances which is an extension to Norman's theory.

Results: The most frequently occurring source of excess cognitive effort was poor information timing. Information presented by the CDSS was often presented after clinicians required the information for decision making. Additional sources of effort included use of language that was not clear to the user, vague icons, and lack of cues to guide users through tasks.

Conclusions: Lack of coordination between clinician's task-related thought processes and those presented by a CDSS results in excessive cognitive work required to use the system. This can lead to alert overrides and user errors. Close attention to user's cognitive processes as they carry out clinical tasks prior to CDSS development may provide key information for system design that supports clinical tasks and reduces cognitive effort.

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1. Background

Clinical decision support systems (CDSS) integrated into a computerized provider order entry (CPOE) system is one method of supporting accurate medication prescribing, particularly for complex prescribing tasks [1]. These systems frequently consist of alerts that provide clinicians with patient assessments and guide them toward an appropriate course of action [1]. Although there are reports of improvements in prescribing resulting from these systems, there are also reports of divergence from accepting recommendations. Furthermore, errors associated with the use of CDSSs have been well-documented [2–5].

Several studies report alert override rates ranging from 75–96% [6–8]. One reason proposed for these is poor integration with user workflow [4, 6]. A well-designed CDSS should support the ability of the user to efficiently complete tasks while avoiding unnecessary disruptions in workflow [9, 10]. Workflow is thought to occur on multiple levels. An individual's cognitive or thought-related processes as they carry out tasks provides insights into workflow at the level of the individual [11]. Understanding a user's mental model of a particular task can provide important information about how a CDSS may be structured so that tasks can be appropriately supported. Divergence between the user's mental model and the task model presented by the CDSS can result in increased cognitive effort required to complete tasks, potentially leading to alert overrides and errors [4, 12]. Cognitive effort refers to the amount of cognitive work required to complete a task. A closely related concept, cognitive load, refers to 'working memory' in which a finite amount of information can be processed at a given time; information that is more complex leads to increased cognitive effort and is said to have an increased cognitive load [13]. Studies that examine the cognitive processes of users employing existing systems may be used to evaluate functions that facilitate or hinder task completion by highlighting the cognitive processes required to use the system in a particular domain [14]. Research that clarifies clinician responses to CDSS in the context of specific clinical scenarios and related tasks may provide information to improve our understanding of the meaning of override rates in particular situations and identify areas for future system improvement [15].

2. Objectives

The purpose of this study was to characterize the cognitive impact of a CPOE-integrated CDSS by categorizing system use problems according to the type of mental processing required to resolve them. Clinicians practicing in a NICU at an academic medical center were recorded as they interacted with a CPOE system and related CDSS for antibiotic prescribing. These recordings were analyzed using a theoretical model describing cognitive distance that defines the type of mental processing required to use a particular interface. Areas for future improvements in CDSS functions that could better support clinical tasks were identified.

3. Methods

3.1. Theoretical model

We employed Hutchin's extension to Norman's Theory of Action describing cognitive distances to develop the analytical framework [12, 16]. Norman's theory proposes a cyclical model starting with a goal, followed by generation of a plan of action, carrying out of the action, response by the system, and interpretation and evaluation of the response by the user, which in turn leads to generation of new goals [16].

The concept of a "gulf" is used to illustrate the gap between the goals of a user and the physical actions or affordances provided by a system to facilitate task completion [14]. The degree of mental processing involved in formulating an intention to act and determining how to use a system to meet a goal is referred to as the *gulf of execution*. The mental processing required to evaluate the systems response to actions is referred to as the *gulf of evaluation* [16].

Cognitive distance is a concept used to describe the degree and type of mental transformation required to bridge the gulfs of execution and evaluation [12, 16]. Three types of cognitive distance correspond to both the gulf of execution and the gulf of evaluation: semantic distance, articulatory distance and issue distance (▶Fig. 1) [12, 16]. On the gulf of execution side, issue distance sits between goal and intention, semantic distance sits between intention and action, and articulatory distance sits between action and execution. On the gulf of evaluation side, issue distance sits between evaluation and a new goal, semantic distance sits between evaluation and interpretation, and articulatory distance sits between perception and interpretation [12, 16].

Semantic distance is the relationship between what the user wants to communicate and the meaning of the corresponding expression in the interface language. When clear and concise concepts are represented directly in the interface, semantic distance is decreased [12]. When complex, ambiguous or vague icons or words are used to represent a concept, semantic distance is increased. For example, a field that requires specific information to be entered such as a drug name should use words that are familiar to the intended user so that it is easier for the user to identify this field as the correct place to enter the drug name. Articulatory distance concerns the relationship between the meanings of the expression and their physical form. Physical form can be a sequence of keystrokes or mouse movements and clicks [12]. For example, once a user identifies that a drug name can be entered in a specific field they need to be able to determine if they must type out the name or choose it from a dropdown list [12]. For the gulf of evaluation, articulatory distance refers to the effort involved in understanding the form of changes in the interface that occur in response to an action [12]. For example, when an order is entered, the user must be able to clearly see that the order is complete, has been added to the patient's list and will be visible to the appropriate people such as nurses and pharmacists. Issue distance represents the cognitive effort required when a shift in goal is necessary. Cognitive effort is required to understand that the original goal cannot be achieved or that a shift in goal is needed to achieve task completion [16]. For example, a goal shift impacting the gulf of evaluation may occur when the user evaluates the results of actions like entering a drug order and new information is revealed, such as a laboratory result requiring the user to consider the new information. If the appearance of this laboratory result is not expected or needed at this point in the process, then the CDSS process is out of sync with the user's approach to the process. The presentation of this information at this point requires to user to follow a different course than was originally intended [16].

3.2 Study Design

A descriptive, observational design was used that employed two methods, a cognitive walkthrough and a think-aloud protocol. These approaches apply techniques that break down the sequence of steps involved in specific tasks as they are carried out by system users. In this way, we were able to characterize types of problems users may encounter when interacting with the system [17].

3.3 Setting

The study was conducted with clinicians in a Neonatal Intensive Care Unit (NICU) at a quaternary care center. The CPOE system (Eclipsys 4.5 Atlanta, Ga.) and its related CDSS have been in place in the NICU since 2002. CDSS rules within the CPOE are developed by the hospital alerts committee in conjunction with clinicians and relevant content experts such as pharmacists. Prior to implementing the CPOE system, a team of clinical pharmacists, pediatricians, nurses and information systems professionals in the medical center developed rules for pediatric and neonatal dosing for approximately 200 commonly used medications. The system provides default dosing, route and frequency suggestions based on the rules developed. Clinicians may accept or change default dosing suggestions. Alerts must be acknowledged but can be followed by either a change or cancellation of the order or by proceeding with the order as is. Order sets have been developed by NICU clinicians to address typical scenarios in which multiple orders are entered. We employed a development version of the CPOE system to test participants as they carried out a set of the tasks. No actual patient data were used.

Existing CDSS alerts within the CPOE system were used to evaluate cognitive effort required to complete the prescribing tasks (▶Table 1).

3.4 Participants

Clinicians who had completed at least one training rotation or who were in practice as a care provider in the NICU were eligible for inclusion in the think-aloud protocol.

Eight clinicians, including three pediatric residents, three neonatal nurse practitioners (NNP), one pediatric hospitalist, and one physician assistant (PA) were recruited for the think-aloud protocol. Of the three NNP's, one had 23 years' experience in the NICU, the other two had 2 and 4 years' experience respectively. Two of the pediatric residents were in their first year of residency and one was in the second. The hospitalist had three years in the NICU and the PA, 1.5 years. The CPOE system had been in use in the NICU since 2002.

3.5 Procedures

The first method used was a cognitive walkthrough. This is an expert-based evaluation method that simulates a user's cognitive processes as they interact with an interface to carry out tasks [18]. This was followed by a think-aloud protocol in which individuals with domain knowledge were asked to perform specific tasks using the system and to verbalize or "think-aloud" as they carried out the tasks [19]. These verbalizations provided a description of the user's cognitive problem-solving activities occurring during the task simulation [20].

Two scenarios were used that were developed based on information gained from focus groups with NICU clinicians for a study related to antibiotic prescribing practices (described elsewhere) [21]. A neonatal nurse practitioner with twenty years of NICU experience was recruited as a pilot subject to confirm that the scenarios were typical examples of premature infants with early and late-onset sepsis. Based on the pilot review, the scenarios were simplified and shortened accordingly.

Scenario A involved an infant with late-onset sepsis who required treatment with vancomycin and gentamicin. This infant had an elevated serum creatinine of 1.7, which reflects a dramatic decrease in kidney function. Because these antibiotics are primarily eliminated by the kidney, a creatinine level this high would trigger a specific alert that warns the prescriber that standard antibiotic dosing regimens should not be used for this infant. The first task in this scenario was to enter an order for vancomycin. The second was to enter an order for gentamicin. Scenario B involved an infant with early onset-sepsis. In this scenario, the infant required admission orders including gentamicin and ampicillin. The task was to enter the admission orders using the NICU general admission order set.

The cognitive walkthrough was completed by the first author (BS) under the guidance of a cognitive psychologist with expertise in the conduct of this method of system evaluation (DK). The goal was to identify potential usability problems that would guide the development of the coding framework to be used to analyze the participant recordings in the think-aloud protocol.

After informed consent was obtained, the study participants were asked to carry out the same tasks completed in the cognitive walkthrough. Recordings were captured via Morae™ video-analytic software (TechSmith Okemos, MI.). Recordings from the pilot participant, one NNP and one resident were examined to clarify the original definitions for the coding framework developed based on the cognitive walkthrough. These were used to reflect both the clinical and system experience of the participants. The pilot participant was new to the CPOE system, the NNP had over twenty years' experience practicing in the NICU and had six years' experience using the CPOE system and the resident had only one year of clinical experience and one year of system experience.

3.6 Data Analysis

For the cognitive walkthrough, scenario-based goal-action sequences were identified and potential problems that may be encountered by users were described. The goals, associated sub-goals, possible cognitive or perceptive activities required to reach goals, physical actions required to reach goals and any associated problems that may occur based on these sequences were identified. Nielsen's ten usability heuristics were used as the basis for identifying potential usability problems in the cognitive walkthrough. These usability factors include:

1. recognition rather than recall,
2. flexibility and efficiency of use,

3. aesthetic and minimalist design,
4. help users recognize, diagnose and recover from errors,
5. help and documentation,
6. visibility of system status,
7. match between system and the real world,
8. user control and freedom,
9. consistency and standards, and
10. error prevention.

These heuristics provide general recommendations for designing user interfaces that keep cognitive effort at a minimum [22].

The coding framework was then developed based on Norman's Theory of Action plus cognitive distances that categorized potential usability problems identified in the cognitive walkthrough An iterative process was used to clarify and refine the original items and assign them to three categories of cognitive distance.

The final coding framework was reached by consensus. The categories identified were then used to code the recordings of all subjects in the think-aloud protocol. Individual subject recordings were coded by the first author using the identified framework. A validation process followed in which a second researcher (LC) coded the recordings using the same framework. During the validation process both researchers viewed the recordings together to come to agreement regarding discrepancies regarding categories of cognitive distance.

4. Results

4.1 Cognitive walkthrough results

Task 1 in scenario A was to enter an order for vancomycin. Task 2 was to enter an order for gentamicin. For the vancomycin order, ten sub-goals were identified, while seven were identified for the gentamicin order. The vancomycin order triggered three alerts, the aminoglycoside check, laboratory history and renal impairment dosing alerts. The gentamicin order triggered two alerts, the laboratory history and the renal impairment dosing alert. Both orders triggered the pediatric dosing support previously described. For scenario B, the cognitive walkthrough revealed two possible paths users might take when entering orders using the order sets. Each of these paths was coded for potential usability problems. For path 1, sixteen sub-goals were identified to complete the task. Two alerts were triggered plus the pediatric dosing support. For path 2, fifteen sub-goals were identified and two alerts were generated. ▶ Table 2 illustrates the number of sub-goals required for completion of each task in the two scenarios. The grouping of problems according to Nielsen's principles included unclear icons, lack of clear screen direction leading to unclear task processes, multiple buttons on a screen that may cause task confusion, excessively long or error-prone drop-down lists, poor layout of items on a screen, information erroneous to the task, blank or unused fields, and words or phrases that were unclear. ▶ Table 3 describes the usability problems identified in the cognitive walkthrough and the cognitive distance categories to which they were assigned. ▶ Figure 2 provides an excerpt from the cognitive walkthrough. ▶ Table 4 describes the final coding framework that was developed as described above.

4.2 Think-aloud protocol results

The video recordings obtained from the participants in the think-aloud protocol were then reviewed and analyzed for occurrence of events that might indicate potential usability problems by two reviewers. Through a consensus-building iterative process, a total of 134 events were identified across all participants.

The most commonly occurring problems were related to issue distance (problems that trigger a recognition that a goal shift is necessary (▶ Fig. 3, n = 54). This was followed by those relating to ar-

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ticulatory distance (problems with recognition of physical actions required to carry out tasks, ▶Fig. 4, n = 48) and semantic distance (problems understanding language or icons used on the screens, ▶Fig. 5).

The frequency of problems identified for each participant for both scenarios ranged from 6 to 33 events. The NNP with the highest number of events (n = 33) was also the NNP with the most experience in the NICU (23 years). The PA, the hospitalist and one of the residents had the next highest event rates. The frequency of problems related to each category of cognitive distance for each subject is shown in ▶Table 7.

For all eight subjects, the most frequently occurring problem related to issue distance was information timing. This was characterized by laboratory alerts that were out of sync with the point in time when the users' required the information. For example, the alert displaying serum creatinine levels appeared after users had found the information at an earlier point in the order-entry process using resources outside of the CPOE system (▶Fig. 3). One participant who had already noted the elevated serum creatinine noted the alert and stated "creatinine, I already know it's high". The user identified the steps they would take to deal with this problem before entering the order. When the alert appeared, it interrupted the task process and was ultimately overridden by the user.

A second problem in the category of issue distance was information mistrust. It was common for subjects to verbalize that they were not sure they could trust the information in the screens. This occurred most often when users were evaluating system calculated drug dosages. Typically, participants verbalized that it was not clear from the screens how the system calculated dosages were determined. Therefore, users looked up information in their trusted sources. Participants commonly would consult a reference such as Neofax® and calculate the dose using a pocket calculator, then use the system-provided dose as a comparison.

Repetitive information was also a common trigger of issue distance problems. When two drugs were ordered in the same session, they triggered the same alerts. The second time an alert was presented, it was overridden. The interruption to the ordering process caused by the alerts appearance caused a need for a goal shift. In other words, the user's attention was diverted from one task, completing the drug order to another, the need to resolve the alert. As one subject stated, "It gets you in the habit of clicking and just ignoring."

Lack of salient cues in the interface to guide users through their tasks was the most commonly occurring problem in the category of articulatory distance. Multiple buttons on a screen that did not clearly guide the user through the next step in a task was a frequent cause of this problem. For example, when a user triggered more than one alert while entering an order, the alerts appeared on one screen in a list. The subjects would view one but miss the second and third alerts, causing an error window to appear warning them they must go back and view the remaining alerts (▶Fig. 4).

An additional cause of increased articulatory distance was confusing display of information such as drug calculation information that appeared on the opposite side of the screen from the dose entry field (▶Fig. 5). Lack of clarity regarding whether to type a drug frequency into a text box or use a drop-down list was an example of a lack of cues to indicate how to perform an action. Words or icons that interfered with the participant's ability to form an intention to act were the most frequently occurring problem related to semantic distance. For example, a renal impairment dosing alert appeared at the end of the order-entry process for both gentamicin and vancomycin. The alert is meant to advise the user that the patient may require an adjustment to the drug frequency based on their creatinine level. The language on the screen was confusing and users were often not sure what the alert was telling them. As a result, it was unclear how to proceed. They typically overrode the alert without changing the order (▶Fig. 6).

It was noted that a problem related to one category of cognitive distance often triggered problems related to the other categories. For example, when a screen with multiple alerts appeared for an order set, this caused a problem with issue distance, forcing users to revise their task process. Confusing wording on the same screen caused a problem related to semantic distance which then caused the user to be unable to determine what action to take next, thus creating a problem related to articulatory distance. This sequence of events caused an incorrect button selection which deleted orders creating a need to repeat tasks that had already been completed (▶Fig. 7). This illustrates how these types of usability problems can lead to increased task complexity, which can result in errors that can potentially impact patient care.

5. Discussion

The goal of this project was to characterize the cognitive impact of a CDSS using a framework describing cognitive distances that defines the type of mental processing required to use the features of a particular interface [16]. The theory of cognitive distances is an extension to Norman's theory of action. This addition allows a more specific characterization of the ways in which a particular system can impact cognitive load. Although the extension to Norman's theory was described by Hutchins many years ago [12], the use of the extension has not been reported in previous studies of healthcare systems evaluations. The cognitive distance concept provides a way to more precisely characterize the gulf between user's intentions and the affordances of the system. This represents an innovative use of the model.

The cognitive walkthrough revealed potential problems that might occur due to screen design such as layout, use of buttons, drop-down lists and data entry fields, while the think-aloud protocol revealed problems related to the sequence of information presented in the CPOE system. According to Hutchins et al., a mismatch between the goals of the user and the physical actions afforded by the system, increases cognitive distance [12]. Impact on cognitive load is directly related to impact on cognitive distance (i.e., increased cognitive distance results in increased effort required to process information), therefore these demonstrated increases in cognitive distance indicate an increased impact on cognitive load imposed by the system.

We found that frequent goal shifts introduced by the use of pop-up alert screens may impose a potentially heavy cognitive burden by increasing issue distance [16]. In a recent study of a widget-based electronic health record system it was reported that users' mental processes were supported by allowing them to assemble relevant information into one screen as they saw fit [23]. Integrating information such as laboratory results and vital signs into drug order entry screens or providing split screen views that allow clinicians to view information from different modules simultaneously are examples of other possible approaches that can address this problem.

Issue distance was also increased by a lack of trust in system provided information. This occurred when clinicians were reviewing system-calculated drug dosages. In our case, system-calculated drug dosages were calculated based on widely used drug references. Suggested doses were based on the most common indication for the drug. Clinicians using the system were not aware of this. Visibility of the source used to provide dosing suggestions may help improve clinicians' trust of the information. In addition, CPOE screens contained a field that described the dose calculation information. However, clinicians often did not see or pay attention to this information. This may have been because the information was in an unexpected place on the screens (dose entry field on the left and calculation information on the right) or because the language contained in the field was not consistent with the user's language (▶ Fig. 4). Re-arranging the screen and using language consistent with the user's language may better support the user's task process and reduce this source of cognitive distance. In a study by Killelea et al., it was reported that pediatric dosing suggestions were frequently changed from system defaults [24]. They suggested that dosing systems should capture the indication for the drug order in order to provide context-specific suggestions. In this way, the need for clinicians to validate or change the suggested dose may be reduced, thus reducing the mental effort required to use the system.

Repetitive alerts were also a source of increased cognitive effort. Systems that recognize a continuous CPOE session where multiple orders are entered may help to address this problem. When an alert has been viewed, it should not be repeated in the same session. However, certain information should remain visible to the user throughout the ordering session such as laboratory results, calculations of creatinine clearance, patient weight and allergy information. When this type of information is delivered via a pop-up alert screen, it is interruptive to the user's thought process resulting in increased cognitive effort. In our study, this led to overrides and alert fatigue, particularly upon the second viewing of the same alert.

The problem of unclear screen directions resulting in increased articulatory distance is an example of a discrepancy between the goals of the user and the affordances provided by the system. Cognitive theory posits that human beings develop mental representations or models of tasks [14]. When a user's mental model of a task is mismatched with the representation of the task in the system, a transformation must take place resulting in increased cognitive effort needed to complete the task [14].

Reducing cognitive effort by reducing articulatory distance can be supported by incorporating cues in the interface to guide a user through tasks. Hiding buttons that are inappropriate or highlighting the correct button to guide the user to the next applicable step in the process are examples of ways in which cognitive effort can be reduced through the use of affordances in the interface. The incorporation of appropriate affordances, or visible controls in the user interface has been recommended as a method to support improved system usability in electronic health record systems [25].

Confusing language used in alert screens created an increase in semantic distance. When users had difficulty understanding information, it was misinterpreted or the alert was overridden. Nielsen's ten usability heuristics recommend that there must be a match between the system and the real world. Words, phrases and concepts on the screens must be familiar to the user [22]. In addition, information must be presented succinctly in order to be effective in actual clinical situations [26]. When clinicians are required to scroll through multiple screens, they are more likely to override or cancel the alert. ▶ Table 6 provides suggestions for design that may be able to address some of the usability problems encountered in this study.

Finally, we noted that multiple usability problems can interact to compound the complexity by creating a situation where cognitive distance is increased in several ways. The combination of these different issues results in a widening of the gap between the goals of the user and affordances provided by the system to facilitate accurate task completion. This gap can result in users ignoring or misinterpreting important information or in serious system-use errors that can potentially impact patient care. Van der Sijs et al., used Reason's model of accident causation to explain how alert overrides can result in errors [4]. They noted that error-producing conditions that exist in the environment can negatively effect individual performance. The design of a CDSS that creates a mismatch between a user's thought flow and the information flow in the system resulting in excessive cognitive effort ultimately may create such an environmental error producing condition. Research should investigate the ways in which users conceptualize a problem prior to system design to gain an understanding of how to best provide information to support clinical processes and prevent these kinds of errors.

6. Conclusions

This study evaluated the impact of clinical alerts on cognitive load by assessing changes in cognitive distance. Increases in cognitive distance illustrate a mismatch between users task-related thought processes and those imposed by the system. Providing clear direction through the use of salient cues in the interface may reduce semantic and articulatory distance. Reducing redundancy of alerts and providing updated, clinically relevant information synthesized into one easily accessible screen may reduce issue distance and promote improved coordination between user workflow and system workflow.

Understanding how decision support tools impact cognitive load provides us with a method for improving our understanding of how these tools are used in specific patient care situations. Combining this with other evaluation methods may be helpful in providing a more complete understanding of the effect of decision support on clinical care.

7. Clinical Relevance

The results of this study will help to provide the foundation for technology characteristics that may be necessary for a CDSS that can improve clinician's ability to successfully complete medication ordering tasks in a NICU. The methods used served to identify typical pathways used by clinicians when ordering antibiotics. This can then be translated into design ideas that can be used by system developers to support this important clinical task.

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8. Limitations

This study took place in an academic medical center located in a major metropolitan area. Results may not be the same in other locations or in non-academic medical centers where processes followed to enter orders are not the same. We also used a commercial CPOE product that is part of a clinical information system. Results may be different in other systems. Additionally, this study was focused on clinical practice in the NICU; results may not be generalizable to other patient populations or clinical practice in other types of patient care settings.

This study was a laboratory-based study, therefore we were not able to evaluate problems that may occur as a result of interruptions which may be frequent in the NICU setting. Research that evaluates system usability in real world situations is needed to further our understanding of how these systems may facilitate or hinder accurate task completion in actual patient care settings.

Conflict of Interest
The authors declare they have no conflicts of interest in this research.

Protection of Human and Animal Subjects
The study was performed in compliance with the World Medical Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects, and was reviewed by the University Institutional Review Board.

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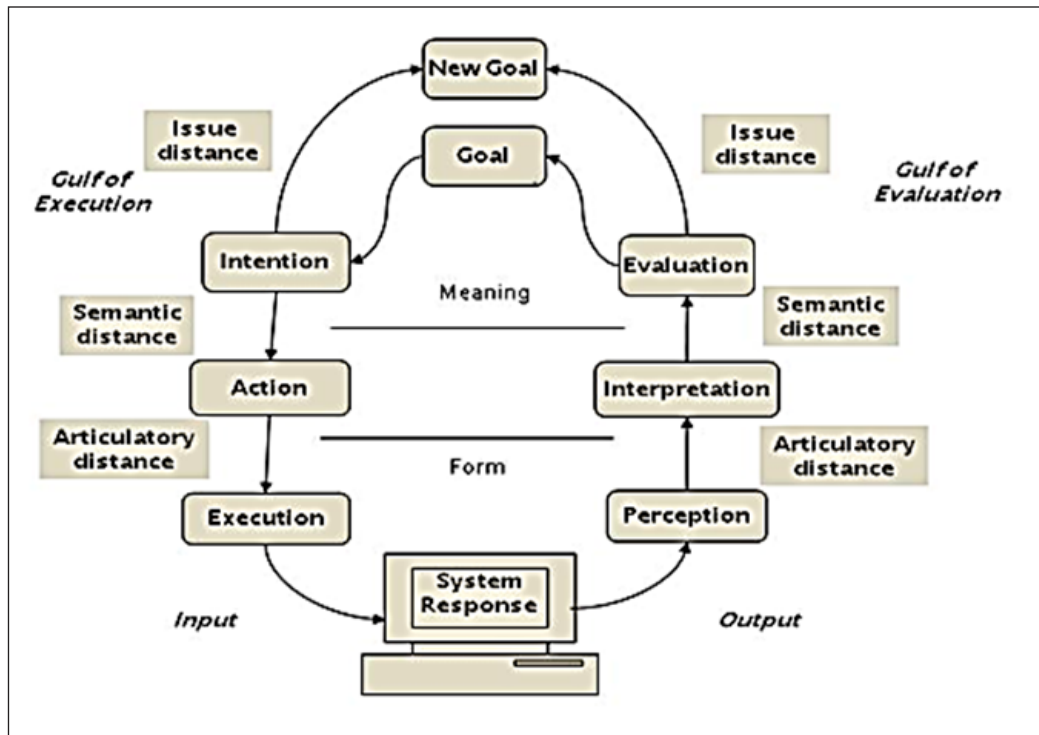
Fig. 1 Normans' model of action with categories of cognitive distance (Adapted from: "The AVANTI Project: Prototyping and evaluation with a Cognitive Walkthrough based on the Norman's model of action." By: Rizzo A, Marchigiani E, and Andreadis A. Symposium on Designing Interactive Systems; 1997; Amsterdam, The Netherlands.)

Fig. 2 Cognitive walkthrough example: renal impairment dosing alert

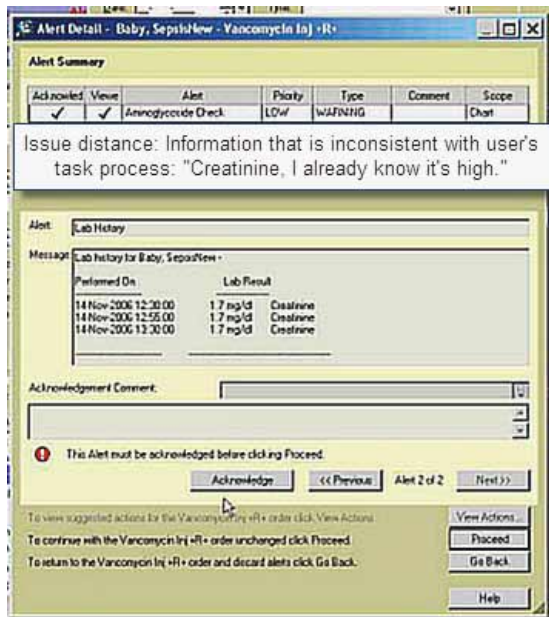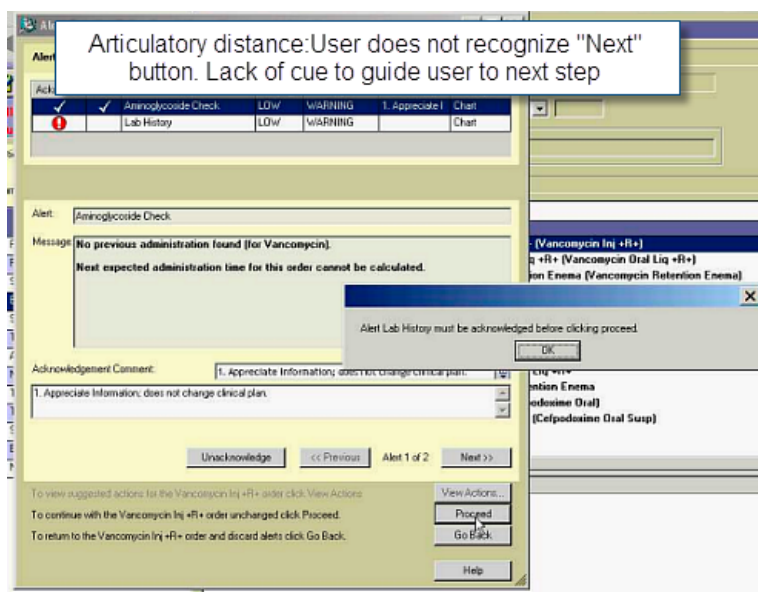**Fig. 3** Screen shot illustrating issue distance

Fig. 4
Screen shot illustrating
articulatory distance
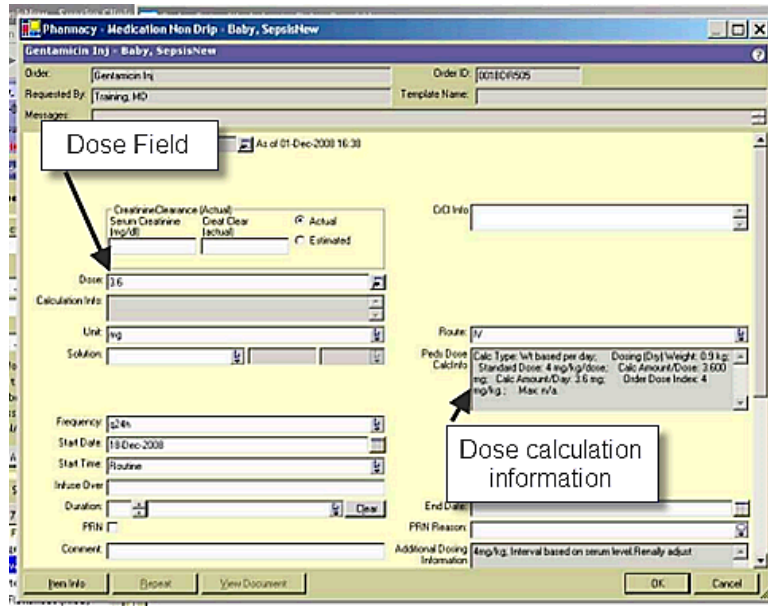
Fig. 5
Articulatory distance:
screen layout

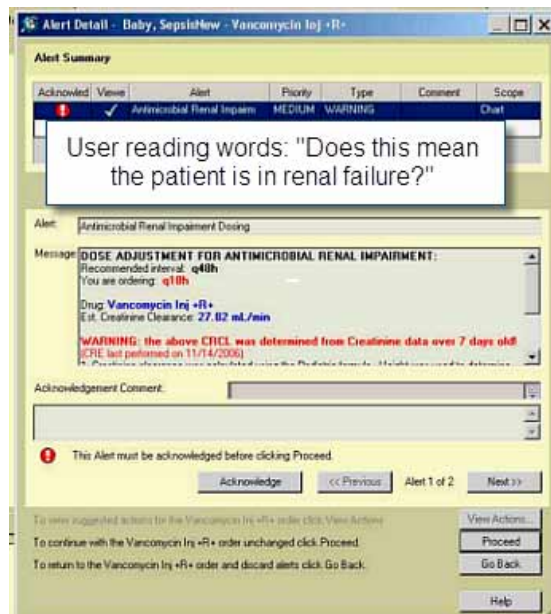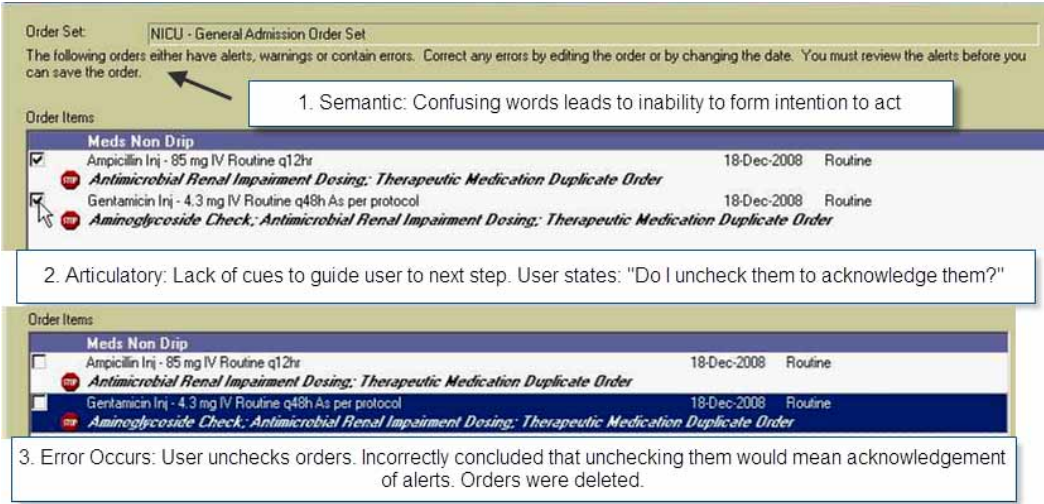**Fig. 6** Screen shot illustrating semantic distance

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Fig. 7 Multiple problems leading to error

Alert Name	Description
Aminoglycoside check	Provides time of last dose of any aminoglycoside
Laboratory history	Provides lab results for creatinine and drug levels
Renal impairment	Recommends dose based on renal function
Duplicate drug	Warns of repeat order
Pediatric dosing	Default dose/frequency based on gestational age/wt.

Table 1

Antibiotic alerts used in CPOE system

Table 2 Cognitive walkthrough results

Scenario	Task/Path	Sub-goals	Alerts	Dosing Suggestion
		n	n	yes/no
A: Individual Orders	1	10	3	yes
	2	7	2	yes
B: Order Set	1/i	16	2	yes
	1/ii	15	2	no

Table 3 Usability problems identified in the cognitive walkthrough

Problem Encountered	Description	Cognitive Distance Category
Icon Selection	Difficult to determine what an icon means or what kind of information would be revealed if the icon were clicked.	Semantic
Unclear task process/lack of screen direction	It is not clear how to use the screens to complete the steps involved in a task. The screens do not provide any cues to guide the user through the task	Articulatory, Issue
Multiple buttons	Multiple buttons are present on a screen but it is not clear what the result may be from choosing one button over another or which button should be clicked first.	Articulatory
Drop-down list	Drop-down list may be excessively long or items in a list may be too close together making it easy to make an incorrect choice by mistake.	Articulatory
Screen layout	Layout of information on a screen may make finding specific items or fields difficult.	Articulatory
Erroneous information	Information that is not needed for the task	Semantic
Blank or unused fields	Fields on the screen that contain no information and are not required for the task	Articulatory
Information clarity	Information that does not clearly convey meaning to the user	Semantic

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Table 4 Coding framework for think-aloud protocol

Cognitive Distance Category	Associated Usability Problems
Semantic distance = words/icons that reflect user's world „WHAT DOES IT MEAN?"	1. Word(s), phrase(s) or icon(s) that interfere with a user's ability to form an intention to act (e.g., confusing language used, words/phrases in drop down list are confusing 2. Word(s), phrase(s), or icon(s) that interfere with a user's ability to evaluate the results of their action (e.g., error message that does not provide user with concrete information about what the user just did) 3. Information not required for task (e.g., irrelevant or excess information)
Articulatory distance = ability to know what the physical action needs to be AND to actually carry out the physical action „HOW DO I DO IT?"	1. Lack of salient cue to guide user to the NEXT step (e.g., unclear which button to select, ambiguous or vague icons, blank fields font too small to read, user unaware that a drop down list exists, screen layout does not match users mental model) 2. Lack of salient cues that prevents a user from knowing that a function exists (e.g., term 'search' in search field should read 'type drug name here to search', not evident that a drop-down list exists, blank fields) 3. Display of information that interferes with user's ability to actually carry out the action (e.g., drop down list is excessively long, items in drop down list are not in an easy to use order, no separation between items, function demands excessive scrolling, inactionable fields) 4. Lack of salient cue that indicates that there WAS a response to an action (e.g., screen does not appear to change, font too small to read, poor screen layout) 5. Lack of salient cue that indicates HOW to perform an action (e.g., Do I need to click? do I need to double click? do I need to type into the box?) 6. Lack of information to assist the user in carrying out their intended or needed next steps (e.g., user needs to calculate when the dose of drug will be given in order to enter the order for drug level to be done at the correct time)
Issue distance = Goal Shift „WHAT DO I DO NEXT?" Can also be thought of as consistency with the users steps in approaching the task	1. Timing of information that forces user to alter their task process (e.g., renal dosing alert happens AFTER the clinician has already calculated and entered the renal dose; alerts that are repeatedly displayed during the same order entry session). 2. Lack of salient cue to guide user to the next step such that the task process is altered or interrupted (e.g., lab history shows an elevated serum creatinine which might require a different drug or a renal dose of a drug, but the interface does not provide the user with the possible options) 3. Information that the user mistrusts or disagrees with and which forces them to alter their task process. (e.g., computer dose does not match users own calculation, forcing them to recalculate)

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Table 5 Frequencies of cognitive distance categories and sub-categories

Cognitive Distance Type	Sub-categories of cognitive distance	n
Issue Distance	Information timing that alters task process	29
	Lack of recommended actions that alters task process	9
	Information mistrust that alters task process	17
	Total	**54**
Articulatory Distance	Lack of cue to next step	22
	Lack of clear function cues	0
	Confusing information display	11
	Lack of cue to indicate system response to actions	0
	Lack of cue to indicate how actions are performed	5
	Lack of assistance with task activities	9
	Total	**48**
Semantic Distance	Words/icons that interfere with forming intention to act	15
	Words/icons that interfere with action evaluation	4
	Irrelevant/excess information	13
	Total	**32**
	Overall Total	**134**

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Table 6 Cognitive distance problems and suggested design solutions

Cognitive Distance Type	Sub-categories of cognitive distance	Suggested design solutions
Issue Distance	Information timing that alters task process	integrate task-related information into single screen
		split screen views
		widget-based display (drag and drop)
	Lack of recommended actions that alters task process	affordances (i.e.; highlight appropriate button to indicate next step)
	Information mistrust that alters task process	visible information sources (i.e; drug dose calculations)
Articulatory Distance	Lack of cue to next step	guidance through task steps (i.e; automatic cursor advance)
	Confusing information display	widget-based display
	Lack of cue to indicate system response to actions	messages in user language to indicate results of actions
	Lack of cue to indicate how actions are performed	screen language consistent with user's language
		clear icons tested with users
	Lack of assistance with task activities	incorporate on-screen instruction
Semantic Distance	Words/icons that interfere with forming intention to act	eliminate unnecessary text/icons
		clear icons tested with users
	Words/icons that interfere with action evaluation	clear icons
		screen language consistent with user language
	Irrelevant/excess information	eliminate unnecessary text/icons

Table 7 Frequency of cognitive distance problems by subject

Role	Years Experience	Semantic Distance	Articulatory Distance	Issue Distance	Total
NNP1	23	9	14	10	33
NNP2	2	1	2	4	7
NNP3	4	0	5	1	6
Hosp1	3	5	3	10	18
Res1	<1	2	5	9	16
Res2	<1	7	5	7	19
Res3	2	4	3	7	14
PA1	1.5	4	10	7	21
Total		32	47	55	134

Note: NNP: neonatal nurse practitioner, Hosp: hospitalist, Res: resident, PA: physician assistant

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