Prescribers’ interactions with medication alerts at the point of prescribing: A multi-method, in situ investigation of the human–computer interaction

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ABSTRACT

Purpose: Few studies have examined prescribers’ interactions with medication alerts at the point of prescribing. We conducted an in situ, human factors investigation of outpatient prescribing to uncover factors that influence the prescriber–alert interaction and identify strategies to improve alert design.

Methods: Field observations and interviews were conducted with outpatient prescribers at a major Veterans Affairs Medical Center. Physicians, clinical pharmacists, and nurse practitioners were recruited across five primary care clinics and eight specialty clinics. Prescribers were observed in situ as they ordered medications for patients and resolved alerts. Researchers collected 351 pages of typed notes across 102 hours of observations and interviews. An interdisciplinary team identified emergent themes via inductive qualitative analysis.

Results: Altogether, 320 alerts were observed among 30 prescribers and their interactions with 146 patients. Qualitative analysis uncovered 44 emergent themes and 9 overarching factors, which were organized into a framework that describes the prescriber–alert interaction. Prescribers’ ability to act on alerts was impeded by the alert interface, which did not adequately support all prescriber types.

Conclusions: This empiric study produced a novel framework for understanding the prescriber–alert interaction. Results revealed key components of the alert interface that influence prescribers and indicate a need for more universal design. Actionable design recommendations are presented and may be used to enhance alert design and patient safety.

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1. Introduction

The Institute of Medicine estimates at least 1.5 million preventable adverse drug events (ADEs) occur annually in the United States [1]. Automated, computerized alerts can warn prescribers about potential problems during medication ordering (e.g., drug interactions, drug-allergy warnings) and are intended to reduce ADEs. Proponents of alert systems hope these warnings will mitigate harmful orders before medications are dispensed to patients [2,3].

However, alert systems have not reached their full potential for supporting prescribers [4,5]. Prescribers are overwhelmed by the number of alerts [6–8], and studies suggest that alert designs do not fully support prescriber decision-making [6,7]. In one survey, 41% of clinicians indicated that ‘insufficient information’ was a barrier to alert use [9]. Enhanced medication alert designs could benefit patients, prescribers, and healthcare organizations.

Researchers have conducted surveys of providers [10–12], examined alert frequencies [13,14], and quantified alert override rates [7,15,16]; only a handful of studies have collected data on alerts via focus groups or interviews [17–19]. Directly observing prescriber behavior may provide a robust picture of the prescriber–alert interaction and reveal additional factors that influence alert success [15]. One study conducted disguised observations with six residents as they resolved alerts [20]. Medication alerts occurred for one-third of orders on the internal medicine wards, and override rate frequencies were high for several types of alerts. Another study examined alert resolution under simulated working conditions to assess prescriber accuracy [21]. Most alerts were resolved accurately, but incorrect rules or reasoning was used to justify responses to 36% of alerts. A systematic review of computerized alerts found substantial gaps in the literature with respect to human factors issues and how to display alerts at the point of prescribing [22]. Human factors principles may inform alert design [23], but information on prescribers’ actual interactions with medication alerts is lacking. The objective of this investigation was to observe prescribers during their work, conduct inductive, qualitative analysis to uncover factors that influence prescriber–alert interactions, and identify strategies to enhance alert design. To our knowledge, this is the first in situ investigation of the human–computer interaction between prescribers and naturally-occurring medication alerts.

2. Methods

2.1. Setting

This study was conducted at a large, academic Midwestern VA Medical Center (VAMC). The VA’s electronic health record (EHR), the Computerized Patient Record System (CPRS), includes computerized provider order entry (CPOE) with automated medication alerts [6,24]. VA medication alerts, more formally known as ‘order checks’, appear real-time in pop-up windows during the medication ordering process (Fig. 1). In general, the alert system we studied does not incorporate parameters such as patient age, gender, lab results, or medication dose into the alert system logic. Exceptions to this include a small handful of alerts, such as an alert that is triggered if the system calculates an estimated creatinine clearance less than 50 as well as an alert that displays the renal function for patients over 65 years of age. These two alerts appear when initiating an order, but before a specific medication has been entered. Table 1 compares VA alerts to other systems. The alert system in our study is used by VA prescribers nationwide.

2.2. Participants

We recruited outpatient prescribers, including physicians, nurse practitioners, and clinical pharmacists between August 2008 and August 2009. Study methods were approved by an Institutional Review Board and participants gave informed consent. We purposefully recruited four prescribers from each of five primary care clinics and 1–2 prescribers from each of eight specialty clinics. All nurse practitioners and clinical pharmacists who work in these clinics were invited to participate. (Clinical pharmacists did not dispense medications to patients, rather, they were physically integrated into each of the clinics; served as clinic resource; and/or had prescribing privileges to help manage specific conditions, such as hypertension.) Snowball sampling [34] was used to identify physician participants. Specialty clinics included those for anticoagulation, infectious diseases, organ transplant, psychiatry, nephrology, endocrinology, gastroenterology, and oncology. These specialty clinics were chosen since they work with medications that have a high likelihood of generating medication alerts.
2.3. Observations and interviews

Researchers conducted interviews and in situ, half-day observations with each prescriber. Data collection was completed by two independent researchers (AR, MM). Observations were conducted to directly examine prescribers’ interactions with alerts, understand how alerts are integrated into patient care, and uncover system factors that influence prescriber–alert interactions. Prescribers were observed as they ordered medications for patients and resolved any subsequent medication alerts. Interviews were conducted during natural breaks, and researchers consistently asked three questions across participants: (1) In what ways do medication alerts help with your work? (2) In what ways do medication alerts hinder your work? (3) If you could change the medication alerts, what, if anything, would you change? As time allowed, researchers asked other questions to gather additional information.

2.4. Qualitative analysis

Observations and interview data were analyzed inductively, without a pre-determined coding scheme, to identify emergent themes [35,36] with respect to the prescriber–alert interaction. The qualitative analysis team consisted of four individuals: a pharmacist (AZ), practicing VA nephrology nurse practitioner (MM), human factors engineer (JS), and a biomedical engineer/human factors specialist (AR). This team guided the analysis by identifying initial themes, discussing possible new themes, and meeting as a group to review and refine themes until reaching consensus on final results. Specifically, each team member read through notes from the first two participants, recorded their impressions, proposed initial themes based on the data, and discussed potential themes until the entire team reached consensus. Then, one researcher (AR) reviewed the entire data set and coded the data with consensus themes using MAXQDA software. Data were assigned multiple codes if they clearly related to two or more distinct themes [37,38]. Throughout the analysis, notes that were challenging to code or appeared to represent new themes were brought to the analysis team and discussed until reaching consensus. To maintain quality, periodically during the analysis, the full set of notes collected from a single participant were independently reviewed and coded by every team member. Notes from 20% of participants were reviewed and coded by the entire team, and each coding discrepancy was discussed until the team reached agreement. A similar “sampling” technique for analysis has been used in other qualitative investigations [39,40]. To account for variation among participants, the 20% sample included primary care and specialty clinic participants and represented each prescriber type. Themes were further abstracted into overarching, emergent factors. Themes and factors were iteratively refined by the team throughout data analysis.

After 27.5 hours of discussion across 30 meetings, the entire team reached consensus on factors and themes. To further confirm that the team’s interpretation of the data was correct, at several stages of the analysis, participants were invited to provide feedback on how well the findings captured their experiences with alerts. The methodological approach remained consistent throughout the analysis, but it became apparent that case examples [41] in the data related to previous model work in human factors. After factors and themes were finalized, results were integrated with models work from Norman, 1990 [42].

3. Results

3.1. Data collection

Researchers observed 320 naturally-occurring alerts among 30 prescribers and 146 patients. Thirty-seven prescribers were invited to participate, and we successfully recruited 20 primary care and 10 specialty clinic prescribers (18 physicians, 7 nurse practitioners, and 5 clinical pharmacists). Researchers recruited both men (14) and women (16). Participants’ average VA experience was 10 years (range less than 1 year to 24 years); and their average age was 42 years (range 27–63 years). Researchers collected 102.8 hours of combined observation and interview data, yielding 351 pages of typed notes.

3.2. Framework, emergent factors, and themes

Qualitative analysis revealed 9 factors that influence the prescriber–alert interaction. Factors were integrated with Norman’s work on mental models [42], yielding an emergent framework for the prescriber–alert interaction (Fig. 2). These factors were associated with 44 themes (Table 2). Each factor is summarized below, along with select themes (underlined) and participant quotes (italics). Details on each individual theme can be found in the Supplemental Files, Tables A–D.

### Table 1 – Overview of how VA alerts compare to other alert systems.

<table>
<thead>
<tr>
<th>Similar to the VA, some alert systems...</th>
<th>Unlike the VA*, some alert systems...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Require a response for each alert [8,16,25]</td>
<td>Include some passive alerts that do not require acknowledgement [26,27]</td>
</tr>
<tr>
<td>Require a rationale for some alert overrides [16,28]</td>
<td>Prevent alert overrides for serious warnings, such as allergies [29] (i.e., use a hard stop)</td>
</tr>
<tr>
<td>Classify alerts by levels of severity [31] (VA: 2-tiered severity for drug interactions)</td>
<td>Use color to help indicate alert severity* [31,32]</td>
</tr>
<tr>
<td>Present multiple alerts on one screen [8,21]</td>
<td>Provide guidance for prescribers on actions to take* [26,33]</td>
</tr>
</tbody>
</table>

* In addition, some features may be unique to the VA: (1) most alerts are presented twice during order entry, as described in Fig. 1 legend; and (2) medications are compared against those prescribed at other VA facilities and can generate alerts.

** In 2011, after study data had been collected, the VA alert system was modified to include more of these features.
3.2.1. Alert system logic and alert redundancy

‘Alert system logic’ was associated with nine themes representing different facets of alert system rules that influenced the prescriber–alert interaction (Table 2). The alert system checked against medications prescribed at other VAMCs, but prescribers wanted additional, external cross-checks for medications filled by other pharmacies. Prescribers wanted more patient-specific alerts, and were particularly appreciative of alerts triggered by a patient’s laboratory values. These included an alert that was triggered by a metformin

<table>
<thead>
<tr>
<th>Factor</th>
<th>Associated themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alert System Logic (201)</td>
<td>Allergy logic (24)</td>
</tr>
<tr>
<td></td>
<td>Consistency (11)</td>
</tr>
<tr>
<td></td>
<td>Design transparency (39)</td>
</tr>
<tr>
<td></td>
<td>Detection (33)</td>
</tr>
<tr>
<td></td>
<td>Dosing logic (9)</td>
</tr>
<tr>
<td>2. Alert System Redundancy (80)</td>
<td>Duplicate work processes (3)</td>
</tr>
<tr>
<td></td>
<td>Repetition across encounters (30)</td>
</tr>
<tr>
<td>3. Alert Content (146)</td>
<td>Evidence (25)</td>
</tr>
<tr>
<td></td>
<td>Information quantity (28)</td>
</tr>
<tr>
<td></td>
<td>Patient information (25)</td>
</tr>
<tr>
<td>4. Alert Display (95)</td>
<td>Format (36)</td>
</tr>
<tr>
<td></td>
<td>Level of intrusiveness (23)</td>
</tr>
<tr>
<td></td>
<td>Retrievability (8)</td>
</tr>
<tr>
<td>5. Cognitive Factors (114)</td>
<td>Alert fatigue (37)</td>
</tr>
<tr>
<td></td>
<td>Awareness (32)</td>
</tr>
<tr>
<td>6. Pharmaceutical Knowledge (63)</td>
<td>Experience with alert systems (6)</td>
</tr>
<tr>
<td></td>
<td>Medication expertise (16)</td>
</tr>
<tr>
<td>7. Medication Management (97)</td>
<td>CPOE care coordination (19)</td>
</tr>
<tr>
<td></td>
<td>CPOE design (11)</td>
</tr>
<tr>
<td></td>
<td>Medical complexity (7)</td>
</tr>
<tr>
<td>8. Workflow (63)</td>
<td>Alert resolution time (27)</td>
</tr>
<tr>
<td></td>
<td>Computer delays (23)</td>
</tr>
<tr>
<td>9. Alert System Reliability (147)</td>
<td>Alert priority (54)</td>
</tr>
<tr>
<td></td>
<td>Common care practices (52)</td>
</tr>
</tbody>
</table>

Fig. 2 – Overview of factors that influence the prescriber–alert interaction. In this study, 9 factors were identified and relate to mental model components [42] including the programmer mental model; system design and corresponding image; and prescriber mental model. Ideally, these components should be aligned to promote effective prescriber–alert interactions. As found in this study, several factors influence this alignment and how prescribers interact with medication alerts.
order if there was no recent serum creatinine in the EHR and an alert that appeared before medication selection if the patient’s estimated creatinine clearance was below a given threshold. Prescribers wanted more of these types of alerts and suggested additional alerts for: metoprolol and heart rate; colchicine, allopurinol, non-steroidal anti-inflammatory drugs (NSAIDS) and the patient’s renal function; along with medications that affect or utilize enzymatic pathways in liver metabolism (e.g., terbinafine) and the patient’s liver function.

Another factor, ‘alert redundancy’ was defined as alerts that duplicate themselves or other processes. Prescribers proposed several strategies to reduce inapplicable alerts, especially alert repetition across encounters: designing a system that is “smart enough to remember” the patient and number of alert appearances; entering an alert override justification that is “tagged and sent to pharmacy”, where the alert can be reviewed and removed if pharmacists agree; and creating a system where alerts only appear for a given patient if one or more of the drugs is “new” or if there has been a “dosing change”.

3.2.2. Alert content and alert display
Specific components of the ‘alert content’, i.e., information provided or not provided by the alert, were important for prescribers to be able to interpret alerts and make decisions. Some alerts failed to adequately explain why they were triggered: prescribers were sometimes unsure why an alert was appearing or what an alert was attempting to convey. In fact, data collected from 21 of the 30 prescribers revealed that this lack of alert specification was a barrier to interpreting alerts. In other instances, the alert did not provide essential patient information for the prescriber, even though it existed elsewhere in the EHR. For example, decision-making for some drug interaction alerts (e.g., amiloride and lisinopril, which can cause hyperkalemia) depend on patient labs (e.g., potassium). This missing, or more accurately, ‘hidden’ patient data triggered varying responses. Some prescribers relied solely on their memory of the patient profile, while others overrode the alert, proceeded with the order, and spent time searching for information in the EHR afterwards to validate their decision.

Another influential factor was the alert interface style, which we termed ‘alert display’. A physician described how the timing of alerts during order entry can impede cognitive processes: “Instead of answering the alert right away, it’d be nice to be able to choose whether to respond to it now, or later, before signing [the order]. When it comes up during order entry, you lose your concentration. I’m ordering and it shows up, and I’ll forget the second medication that I was going to order.” Sometimes, prescribers wanted a way to retrieve an alert that had been displayed, but the alert system did not support this function.

3.2.3. Cognitive factors and pharmaceutical knowledge
‘Cognitive factors’ contributed to prescribers’ interactions with alerts; that is, alerts supported or hindered certain types of cognitive processes. Sometimes, an alert did not result in a medication change, but influenced other forms of decision-selection (i.e., prescriber behaviors). Prescribers voiced that although some alerts may not result in a medication change, they are still valuable for patient counseling. For example, although the following alert was overridden, it prompted an important conversation with the patient: After the nurse practitioner (NP) sees the [terazosin and vardenafil] alert, s/he has a discussion with the patient… tells the patient to separate these two out—don’t take [them] close together. NP explains that both medications vasodilate and can cause a drop in [blood] pressure. NP says not to take [them] with alcohol. This phenomenon is unlikely to be captured by electronic databases that log prescribers’ response to alerts.

Another factor, ‘pharmaceutical knowledge’, was defined as pharmaceutical training, tools, and resources that influence prescribers’ understanding of alerts and their reaction to them. Alerts did not adequately support all prescriber types. Clinical pharmacists expressed more confidence in their ability to address alerts, whereas physicians and nurse practitioners found it helpful, and sometimes necessary, to have real-time, face-to-face communication with clinical pharmacists to be able to interpret and resolve alerts (pharmacist consultation and proximity). These findings were derived from both primary care and specialty clinic prescribers, and examples from each of the three prescriber types are below:

Nurse practitioner: “[One helpful alert is] simvastatin and amiodarone. I’ll ask the pharmacist in the clinic: ‘Is this an important interaction?’ Pharmacist says, ‘Yes.’”

Physician: “I talk to the clinical pharmacist to resolve order checks. I like having the pharmacist in the room here with me. This pharmacist works with two different [clinic] pods. The other pod doesn’t have [one sitting] over there. The pharmacist sits in our pod. I am lucky that way.”

Clinical pharmacist: “If I’m not in the room, the doctors don’t know what to do with the alert.”

3.2.4. Medication management and workflow
‘Medication management’, or clinical care processes to review, order, and update medications, also influenced the prescriber–alert interaction. Prescribers revealed that the larger CPOE design sometimes impeded alert resolution. In one observation, a prescriber wanted to stop azathioprine, which was prescribed by a provider at another VA facility, and replace it with mycophenolate. When ordering mycophenolate, s/he received a duplicate drug class order alert for the immunosuppressants mycophenolate and azathioprine. After overriding the alert, the physician explained: ”I couldn’t discontinue the [azathioprine] because it’s coming from [another VA]. It still triggers an alert, but it’s not an active medication here in this hospital. I can only tell the patient to stop it.” In addition, while alerts demand an immediate response, in reality, prescribers sometimes needed to consult with the patients’ other care providers (CPOE care coordination) to make a decision.

‘Workflow’ was defined as aspects that influence the flow through medication alerts, specifically in terms of prescribers’ available time and the efficiency of alert resolution. A primary care physician illustrated how ‘workflow’ themes in Table 2 contributed to a workaround: “[Providers] tried to bypass the medication order checks in [non-VA system X]. [It] took up to 2-3 minutes to do the order check [ing]. There’s not time to do this in a 15 minute patient visit. I learned to discontinue the [old] medications first, to decrease the order check time. We found a way to order medications in [system X] without checking against the whole medication list. We want to comply, but we only have so much time with...
the patient." At the time of this study, prescribers at this VAMC were typically allotted 60 min for a new patient appointment and 30 min for returning patients. Similar to the example above, computer delays sometimes occurred between the VA medication entry screen and subsequent alert. When possible, these delays were timed by the observer. Prescribers voiced frustration for delays of 10–15 s, the most common delay time noted, but times ranged from essentially no delay to 60 s.

3.2.5. Alert system reliability
Four themes shaped prescribers’ views of the ‘alert system reliability’, or credibility and trustworthiness of the alert system. Study results revealed that some alerts were not simply inapplicable for a specific patient, but inappropriately warned against common care practices that apply to broad patient populations (Fig. 3), degrading alert system credibility. This theme was evident across primary care and specialty care clinics and was derived from physicians, nurse practitioners, and clinical pharmacists. Medications in Fig. 3 are commonly used together, and evidence-based clinical practice guidelines [43] recommend using some of these drug combinations.

Fig. 3 – Prescribers pointed out several alerts that inappropriately warned against common treatments intended to aid patient health, as shown in the examples above. Examples 1–6 and 7–10 were obtained from primary care and specialty clinics, respectively. Abbreviation: NPH – Neutral Protamine Hagedorn.

4. Discussion

To our knowledge, this is the first in situ study to specifically investigate the prescriber–alert interaction. This study provides a more in-depth understanding of prescribers’ interactions with medication alerts at the point of prescribing. Data were qualitatively analyzed by a diverse team of professionals representing clinical, pharmaceutical, and human factors engineering expertise. This strengthened the rigor and breadth of the findings.

4.1. Framework

This study produced a novel, emergent framework for understanding the prescriber–alert interaction. In Fig. 2, factors that are situated near each other are more closely related. For example, the logic and redundancy of the system are similar since both are driven by the rules of the system design. Factors also tend to depend, in part, upon those that precede them. For instance, the system logic and design produces a corresponding system image (i.e., alert interface), where alert content and display are prominent factors. This framework may guide future studies and be useful when designing, evaluating, or advancing medication alert systems.

4.2. Actionable recommendations

Study results inform actionable recommendations for alert designers. Recommendations for select themes are outlined in Tables 3 and 4, and additional recommendations are described in detail below.

4.2.1. Expand alerts that leverage patient labs

Medication alerts that were triggered by the patient’s laboratory findings were viewed positively by prescribers and study participants wanted more of these types of alerts (see ‘alert system logic’ section). These alerts are especially useful as a safety mechanism: front-line prescribers can adjust medication orders based on lab results, whereas most pharmacists who verify and fill prescriptions work outside of an integrated healthcare system and do not have access to patients’ problem lists or laboratory findings. This is a nontrivial safety benefit of laboratory related alerts that appears to be underemphasized in the literature.
Table 3 – Recommended actions for the design of alert systems. Example challenges were derived from study data.

<table>
<thead>
<tr>
<th>Select factors and themes</th>
<th>Example challenge(s)</th>
<th>Actionable recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert System Logic: Design transparency</td>
<td>Prescribers were unsure what types of medications the system can evaluate</td>
<td>Add visual cues to medications during order entry or EHR medication list, such as status indicators or highlighting, to warn prescribers about any medication(s) that are not reviewed by the alert system (e.g., free-text meds, herbal).</td>
</tr>
<tr>
<td>Alert System Logic: External cross-checks</td>
<td>Prescribers wanted alerts to assess medications filled at other pharmacies</td>
<td>Enhance alert systems so they can cross-check for problems across these lists.</td>
</tr>
<tr>
<td>Alert System Logic: Patient-specific</td>
<td>Prescribers wanted to see more alerts linked to patient labs</td>
<td>Expand drug-disease alerts and incorporate lab values and other EHR data into alert system rules to increase the specificity of alert logic.</td>
</tr>
<tr>
<td>Alert System Redundancy: Repetition across encounters</td>
<td>Repeat alerts appear for a patient across one or medication renewals</td>
<td>Design alert systems to remember prescribers’ previous actions and suppress specific, overridden alerts after a period of time; allergy alerts may be an initial starting-point for designing such systems.</td>
</tr>
<tr>
<td>Cognitive Factors: Awareness</td>
<td>Prescriber awareness of alerts is particularly important for: new prescriptions; medications rarely prescribed by the provider; patients that are new to the prescriber; allergies entered by another individual</td>
<td>Ensure all applicable alerts are triggered in these cases. If any alert(s) have been turned off via customizable settings (prescriber-level or higher), temporarily override the settings in these instances to ensure alerts appear and to help maximize prescriber awareness.</td>
</tr>
<tr>
<td>Pharmaceutical Knowledge: Experience with alert systems</td>
<td>Differences across alert systems can promote prescriber confusion and safety gaps</td>
<td>Develop best practice guidelines for alert system logic. Standardize alert interface designs across systems to reduce confusion for prescribers who work at multiple institutions or transfer from one to another.</td>
</tr>
<tr>
<td>Medication Management: CPOE Design</td>
<td>Prescribers were sometimes unable to discontinue medications in response to an alert since they were prescribed by a provider at another VA</td>
<td>Create a shared, real-time, active medication list. Redesign CPOE systems so that, in response to an alert, prescribers can electronically discontinue medications prescribed by other individuals and notify the original prescriber.</td>
</tr>
<tr>
<td>Alert System Reliability: Alert Priority</td>
<td>There was frequent disagreement between the severity assigned by alerts and prescribers’ views</td>
<td>Keep the number of severity levels to a minimum and create at-a-glance alerts that prescribers can interpret and act on quickly (see Table 4).</td>
</tr>
</tbody>
</table>

4.2.2. Reduce alerts that contradict broadly accepted clinical practices
Several studies have shown that many alerts are overridden because they are not applicable for a specific patient [7,8,30]; however, this investigation also demonstrated that some alerts conflict with prescribing practices that are common, and thus, are not applicable for broad patient populations (Fig. 3). These alerts were not simply irrelevant, but offered poor advice by warning against common care practices. More effort is needed to reduce alerts that contradict accepted clinical practices, especially those that apply to large patient populations or conflict with evidence-based guidelines.

4.2.3. Design alert interfaces to support both pharmacist and non-pharmacist prescribers
Results indicate the programmer mental model for the alert interface more closely matches pharmacists’ mental models [41], and the interface does not adequately support non-pharmacist prescribers. Medication alert systems initially originated from the field of pharmacy. Pharmacists have navigated these types of electronic alerts long before medication alerts were introduced to nurse practitioners, physicians, and other prescribers. In this study, non-pharmacists were more uncertain about how to address alerts and took extra steps in their decision-making process (see ‘pharmaceutical knowledge’ section). Prescriber training might be proposed as a potential remedy, and while prescribers may benefit from formal EHR training, it is well known from human factors, specifically the hierarchy of hazard control [44], that education and training are weak approaches to promoting safety compared to changing the system’s design. Results indicate a need for a more ‘universal design’ of the alert interface to support a wider range of prescribers. Adapting this human factors concept, universal design [45] can be defined for medication alerts as: alerts that have functions that can be accessed and used efficiently across all prescriber types (e.g., professional training, clinical experience, etc.); are presented in a pleasing manner; and are easy for prescribers to understand, learn, and effectively use. To work towards a more universal alert interface design, actionable items for alert content and alert display (Table 4) should be combined with general human factors guidelines for warning design [23,46]. To help achieve this goal, future research should focus on comparing different alert interface redesigns by conducting formal usability testing with a variety of prescriber types. Efforts to accommodate
Table 4 – Recommended actions for a universal alert interface design. Example challenges were derived from study data.

<table>
<thead>
<tr>
<th>A. Alert display</th>
<th>Example challenge(s)</th>
<th>Actionable recommendations for the interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timing</td>
<td>Some prescribers wanted alerts as they ordered each medication, others found this intrusive and distracting for decision-making and the patient visit</td>
<td>Give prescribers options – not just for what types of alerts they receive – but at what point they receive alerts during the prescribing process (e.g., real-time after each medication, or in one summary at the end of the ordering session for the patient).</td>
</tr>
<tr>
<td>Level of Intrusiveness</td>
<td>Clinical pharmacists wanted to increase the invasiveness of some alerts to reduce medication errors</td>
<td>Work with medication safety leaders and leverage scientific evidence about adverse drug events to inform the invasiveness of individual alerts.</td>
</tr>
<tr>
<td>Retrievalability</td>
<td>Prescribers forced to ignore or accept alerts, but in reality, they are not always able to immediately address alerts – waiting on incoming lab results or need input from patient’s other provider(s)</td>
<td>Add an option for prescribers to temporarily place the order and associated alert on hold and easily retrieve them; add mechanism so prescribers can review alerts on-demand for a given patient.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Alert content</th>
<th>Example challenge(s)</th>
<th>Actionable recommendations for the interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification</td>
<td>Prescribers unsure what the alert is attempting to convey</td>
<td>Clearly indicate the alert triggers and potential problem (e.g., “potentially causes hypotension”).</td>
</tr>
<tr>
<td>Evidence</td>
<td>Prescribers question the quality and strength of the alert evidence and want guidance on actions</td>
<td>Indicate how well each alert is supported by the literature, cite references and provide links to evidence; include advice on actions.</td>
</tr>
<tr>
<td>Risk</td>
<td>Prescribers wanted a more clear indication on the level of risk</td>
<td>Develop a standardized, numeric rating for risk that can be used across alert systems.</td>
</tr>
<tr>
<td>Patient Information</td>
<td>Additional patient-specific information from the EHR was needed to resolve alerts</td>
<td>Display essential EHR data (e.g., patient labs) on the alert itself; provide ways for prescribers to access other, related information from the alert.</td>
</tr>
<tr>
<td>Terminology</td>
<td>Language of the alerts was difficult for the prescriber to interpret</td>
<td>Eliminate the use of technical, programmer-specific and pharmacist-specific language. Use language commonly known by all alert recipients.</td>
</tr>
</tbody>
</table>

A wider range of prescribers may generate innovative designs that benefit all prescriber types and may have other potential advantages [47,48], including reduced dependency on pharmacists for alert resolution, increased alert resolution efficiency, and enhanced patient safety.

4.2.4. Balance the strengths of computer automation and human cognition

Results also indicate that the alert system is not fully utilizing the advantages of computer automation. Alerts could be designed to automatically present specific, applicable EHR data such as labs and adverse reaction documentation, but instead, prescribers were burdened with this task or ‘function’ of retrieving data. The concept of ‘function allocation’ has evolved over several decades of human factors research, and the general goal is to allocate functions, or tasks, to maximize the performance of the human-machine (i.e., prescriber-alert) interaction [49]. In our observations, when patient information was lacking on the alert interface, prescribers relied on recall or spent additional time searching in the EHR to validate their alert override decision.

Interestingly, we did not identify any cases where the prescriber looked up the information before proceeding past the alert. This likely requires more time and effort on the part of the prescriber and may fit unnaturally with his/her workflow. This may also have potential safety implications if the prescriber becomes distracted before the search for patient data is complete. Presenting relevant patient data on the alert interface may aid decision-making and help prescribers process alerts more efficiently.

4.2.5. Prepare alert systems for increased EHR interoperability

Within and outside of the VA, patients often receive care from multiple providers and facilities. Each VA facility maintains a separate medication list for the patient, and the VA alert system can detect potential issues by comparing prescribed medications across these lists. Thus, study results and recommendations in Table 3 offer insight on how to prepare alert systems to support prescribers as data exchange becomes more commonplace. As medication data are shared, prescribers will need to be informed about whether problems can be detected across different medication lists. Ideally, prescribers will be able to share one medication list for each patient. Alert systems should also be enhanced, as outlined in Table 3, to foster communication among the patient’s different prescribers and reduce the risk of medication errors.

4.3. Limitations

Although this investigation provides a more comprehensive understanding of prescribers’ interactions with medication alerts, there are some limitations to consider when interpreting results. This study was conducted at a major VAMC and results may not always be applicable across medical centers, even though the same alert system is used by VA
prescribers nationwide. The VA alert system may also have different strengths and weaknesses compared to other systems although literature indicates that they face similar design challenges [11,12,16]. Table 1 may be useful when interpreting how study findings relate to other system designs. The framework in Fig. 2 has intrinsic validity since it is based on empirical study data from prescribers and builds upon well-established mental models work [42] that applies broadly to information technologies [50]. Future research could help assess the framework’s validity in other CPOE systems, through assessing whether the framework is consistent with other validated measures (construct validity) and is useful in predicting results (predictive validity) from systems that either address or fail to address these issues. Validation approaches might include: examining whether these factors are consistent with qualitative data from other alert systems; using the themes to develop a questionnaire for reliability and validity analyses [51]; or translating findings into scales and employing other validation approaches [52]. Factors and themes themselves, rather than specific examples, are more likely to generalize to other alert systems. For instance, the content presented by some alert systems may aid prescribers more or less than the VA system, but ‘alert content’ is likely important across organizations. We expect that many factors and themes may be relevant for other alert systems. For example, studies from other systems have also indicated that alert intrusiveness [26,53] and repetition across encounters [18,54,55] are important issues along with providing supportive clinical evidence [18,56] for prescribers. In addition, an example from a recent non-VA study (i.e., “there is no button to get it [the alert] back”) [21] indicates that the inability to retrieve alerts may be problematic across multiple alert systems. One research group compared six CPOE systems [57], and found wide variation in alert sensitivity and specificity. Research comparing other design features could provide a valuable assessment of alert design and may uncover some unique design strategies. Themes in Table 4 may inform what design aspects to compare across systems. Within the VA, clinical pharmacists, physicians, and nurse practitioners use the same alert system, but this may or may not be true for other systems. Finally, this study focused on the prescriber–alert interaction and does not capture all of the challenges that organizations and software designers face when developing medication alert systems. This study does not reveal factors that influence the programmer mental model, but it demonstrates the complexity of the prescriber-medicine alert interaction and the findings herein may be useful for informatics designers.

4.4. Conclusions

To our knowledge, this is the first in situ investigation of the prescriber–alert interaction. Through this effort, a framework emerged that provides insight on prescribers’ interactions with alerts. Results reveal that, in addition to the underlying rules of an alert system, prescribers’ ability to act on alerts was impeded by several barriers including inadequate alert interface design. This empiric study provides several actionable recommendations for alert system design and outlines specific components of the alert interface that warrant additional attention. Redesign efforts should include a more universal interface that supports a wider variety of prescribers. Findings may ultimately be used to enhance decision support for prescribers and medication safety for patients, and future studies should be directed towards conducting usability tests of alternative alert designs, to qualitatively and quantitatively evaluate prescribers’ interactions with alerts.

Summary points

What was already known on the topic

- Few alerts lead to medication changes, and alert fatigue poses a substantial barrier to alert effectiveness.
- Prescribers are often unaware of important medication conflicts, but alert designs have not reached their full potential for aiding decision-making.
- For all types of software systems, the interface plays a vital role in the human–computer interaction and can be challenging to design.

What this study has added to our knowledge

- A richer understanding of prescribers’ interactions with alerts at the point of prescribing along with actionable recommendations to improve alert design.
- A framework that describes prescribers’ interactions with alerts.
- Evidence that alert designs more closely match clinical pharmacist mental-models than the mental models of physician and nurse practitioners in outpatient primary care and specialty clinics.
- Specificity to knowledge about the user interface of alerts, including detailed components that should be evaluated and enhanced to support non-pharmacist prescribers.

Author contributions

All authors contributed to the study design. AR and MM collected the data. AR, AZ, MM, and JS conducted the qualitative analysis. AR drafted the initial manuscript, and all authors contributed to and approved the final version of the manuscript.

Conflict of interest statement

The authors report there are no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ijmedinf.2012.01.002.

REFERENCES

