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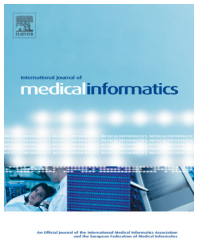

Review

Design of decision support interventions for medication prescribing

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ABSTRACT

Objective: Describe optimal design attributes of clinical decision support (CDS) interventions for medication prescribing, emphasizing perceptual, cognitive and functional characteristics that improve human–computer interaction (HCI) and patient safety.

Methods: Findings from published reports on success, failures and lessons learned during implementation of CDS systems were reviewed and interpreted with regard to HCI and software usability principles. We then formulated design recommendations for CDS alerts that would reduce unnecessary workflow interruptions and allow clinicians to make informed decisions quickly, accurately and without extraneous cognitive and interactive effort.

Results: Excessive alerting that tends to distract clinicians rather than provide effective CDS can be reduced by designing only high severity alerts as interruptive dialog boxes and less severe warnings without explicit response requirement, by curating system knowledge bases to suppress warnings with low clinical utility and by integrating contextual patient data into the decision logic. Recommended design principles include parsimonious and consistent use of color and language, minimalist approach to the layout of information and controls, the use of font attributes to convey hierarchy and visual prominence of important data over supporting information, the inclusion of relevant patient data in the context of the alert and allowing clinicians to respond with one or two clicks.

Conclusion: Although HCI and usability principles are well established and robust, CDS and EHR system interfaces rarely conform to the best known design conventions and are seldom conceived and designed well enough to be truly versatile and dependable tools. These relatively novel interventions still require careful monitoring, research and analysis of its track record to mature. Clarity and specificity of alert content and optimal perceptual and cognitive attributes, for example, are essential for providing effective decision support to clinicians.

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Contents

1. Introduction

Clinical decision support (CDS) systems can safely and effectively support medication prescribing when they deliver relevant, unambiguous and actionable advice well integrated into patient care [1–3]. Many contemporary installations, however, have poor interface design, use verbose or unclear language, non-standard terminology, alerts may be temporally misalignment with corresponding clinical tasks and their important human–computer interaction (HCI) attributes may be inadequate, making the receiving and responding to decision support interventions difficult.

There is a recognized and pressing need for high-performing CDS. Aside from an array of successes at specific sites in individual domains, few systems have substantially delivered on the promise to improve healthcare processes and outcomes [4]. The challenges of designing effective but potentially work-disruptive alerts and notifications are manifold and often require the reconciliation of contradictory goals, such as the need for succinctness with the need to adequately support complex medical decisions.

Designers and developers of health information technology (HIT) need a cohesive, widely accepted and reliable set of industry standards, recommendations and best practices to substantially increase the usability, effectiveness and safety of electronic health records (EHRs) and CDS systems. Such guidelines must be rooted in empirical evidence from biomedical informatics and HCI research, follow recognized usability principles and be informed by decades of software design and evaluation experience from other safety-critical domains.

This report describes design recommendations for CDS interventions that are activated during medication prescribing, such as alerts to drug and allergy interactions. We reviewed published reports on the successes, failures and lessons learned from CDS implementation in large hospitals and small clinics and interpreted the findings with regard to HCI principles and software usability. Emerging themes and specific suggestions were then formulated into a set of design recommendations for CDS interventions that would improve their effectiveness, safety and human interaction by, for example, reducing unnecessary workflow interruptions or allowing clinicians to make informed decisions quickly, accurately and without extraneous cognitive and interactive effort. A related methodological review of design approaches that are applicable to a wider range of decision support and EHR systems can be found in a recent JBI article [5].

This targeted review was focused on articles containing references to design features of CDS and therefore was not exhaustive. The recommendations, however, are not limited to specific CDS and EHR systems as they are partially derived from and reconciled with existing general usability principles. They are organized in the following sections according to specific design goals, with high-level principles and examples of their specific application.

2. Background

There is somewhat scant but increasingly more reported evidence of medical errors, adverse drug events, near misses and other patient safety problems that can be at least in part attributed to failures in human interaction with poorly designed EHR and CDS interfaces. Published reports include descriptions of decreased cognitive performance [6], medication prescribing errors [7–12], unsafe workarounds [13,14] and poor handling of safety alerts [15].

A common unintended consequence of CDS is frequent and disruptive alerting to minimal risks that may be irrelevant in a given clinical context or for the current task [2,16]. Excessive and repetitive interruptions are distractive, add to cognitive effort and rather than contributing to safety may in fact lead to the almost automatic dismissal of most alerts, including those that are safety-critical [17–20]. Poor specificity of warnings significantly lowers the perceived signal-to-noise ratio and limits the ability to differentiate between significant, relevant alerts (true positive, or "signal") and inconsequential, irrelevant ones (false positive, or "noise"), according to the signal detection theory [21,22]. This learned behavior not only

increases the risk of missing a dangerous interaction but also gradually weakens the confidence of clinicians in the merit and usefulness of any system-generated advice [19]. Somewhat paradoxically, it may at the same time foster a sense of complacency that an order must be "safe" when a system perceived as "oversensitive" does generate a warning message.

Overly inclusive dose limits and a large number of minor drug interactions present in commercial knowledge bases are primarily responsible for the high frequency of uninformative alerts [23] although inadequately maintained medication and allergy lists in EHRs also contribute significantly to their generally low specificity [24]. Clinicians working with systems that use only customized and curated subsets of trigger rules seem to override CDS interventions less frequently than those with off-the-shelf knowledge bases [25].

Safety-critical industries such as aviation or nuclear power generation rely heavily on set standards and shared knowledge of device and software usability [26–28]. Leaders in those fields have long recognized the close inverse relationship between usability levels and error rates and require their respective IT systems to have excellent usability characteristics [29]. Their impressive record of safety advancements is rooted in continuous improvements to information technology and steady support for research in human factors [30]. There is little published, reliable and accepted guidance in healthcare, however, to inform the choice of development processes, design goals, evaluation methods and standards that designers at vendor and academic institutions can directly follow. Existing standards [31–36] do provide an authoritative source of reference but are difficult to apply by designers without usability training.

3. Methods

Published studies concerning EHR and CDS systems report primarily on their implementation or the effect they have on the process of care and usually lack sufficiently detailed description of the interface, its design structure or observations about the interactive behavior of clinicians using them. However, they often do contain statements about design features and their usefulness within the context of care and indirect or anecdotal accounts of interface design quality and its effect on clinical work. We have therefore conducted a targeted rather than a fully systematic literature review so that we could gather and compare first-hand accounts and lessons learned by implementers and clinicians and analyze them within the context of established HCI and usability standards. Practical insights of clinicians gained form routine use of HIT can enrich the existing body of knowledge about usability design practices and inform a compendium of recommendations collected in this report.

We searched PubMed, Web of Science, PsychInfo, Books @ Ovid and ACM Digital library databases for peer-reviewed articles and trade literature and articles published online by private and public healthcare institutions and usability organizations. Keyword sets included: EHR; electronic health record; electronic patient record; electronic medical record; electronic prescribing; clinical computing; CPOE; computerized prescriber order entry; computerized prescriber order entry, physician order entry; provider order entry; electronic ordering; computerized ordering; CCDS; CDS; decision support; clinical decision support; computerized clinical decision support; alert system, design; development; implementation, usability principles; HCI; human–computer interaction; CHI; computer–human interaction; information design; cognitive engineering; adaptive display; cognitive workload; cognitive effort; UI; user interface; human interface; user-centered; human-centered; cognitive analysis; cognitive task analysis.

The search returned 1544 articles of which we reviewed 421 either in brief (abstract only) or in detail for statements about design, software development or lessons learned from implementation that described positive and negative findings related to specific design characteristics of EHR and decision support systems.

4. Reducing excessive alerting

Several design and approaches may help reduce the number of disruptive alerts of low clinical value. The degree of alert intrusiveness can be adjusted according to their level of importance, allowing only the most severe warnings to interrupt work [37]. Rules that trigger alerts can also be filtered and prioritized to suppress low-severity warnings by using more sophisticated algorithms that integrate patient context and provider-specific data into the decision logic [4]. Methods and strategies that help to reduce excessive alerting are described in the following sections.

4.1. *Alerts tiered by levels of interaction severity*

An alert is usually triggered automatically during ordering when a drug name is entered into a specified field and the rules engine determines that it interacts with another drug currently prescribed for the patient or with a recorded allergy. It is most often designed as an interruptive, modal dialog box requiring acknowledgement by a mouse click or a keystroke before any further interaction with the system can continue.

An approach taken by several institutions to limit unnecessary interruptions is to assign alerts to interaction severity categories, or "tiers," and to control how they are presented to clinicians. The most serious warnings still need an explicit response by a clinician but less important alerts are displayed less intrusively on the screen as messages not requiring any actions. Research evidence suggests that this approach may improve compliance rate for higher-severity alerts [37].

Drug–drug interactions may be stratified into three severity levels such as "high," "moderate" and "low". However, there is no clear consensus on categorization, terminology or taxonomy although a five-category operational classification has been suggested [38]. The Veterans Administration system, for example, uses only the ranks of "critical" and "significant"[39]; First DataBank identifies three levels but two are jointly considered as life-threatening and differentiated only by the availability of compelling empirical evidence [17].

Institutions implementing CDS usually decide by committee consensus how many severity levels will be used, which alerts are designed as interruptive dialogs and which

rules may be suppressed by filtering [40,41]. Judicious use of interruptive alerts should be considered, reserving this option only for interactions of the highest severity [42].

Design suggestions for more and less intrusive CDS interventions are described below.

4.2. *Interruptive high-severity alerts*

Warnings about the most serious interactions are intentionally interruptive to gain attention of clinicians and to present an option for a remedial action before the order is finalized. The dialog box, at minimum, offers a way to continue ordering (i.e., override the warning) or to cancel the order in progress (i.e., accept the suggestion) by clicking respective buttons. They may simply be labeled [Order] and [Cancel] although other verbs can be used (e.g., OK, Continue, etc.) to ensure clarity and ease of selection as verbose labels may preclude quick perceptual judgments [33,43]. Terminology should follow established local conventions but labels with more than two words (e.g., "continue with current order" or "override alert and continue order") are excessively long and may not clearly convey the effect of the action. "Discontinue" or "D/C," should not be used to cancel an order that has not yet been completely entered—the one that triggered the alert. The term applies to the creation of a new order to stop an active medication and may be therefore confusing.

An alternative drug to the one being ordered may be suggested as a third option. An action link with the drug name may be placed on the dialog box separated by enough blank space from the accept-override button pair not to visually compete with the primary actions. Clicking the link should close the dialog box and open a standard ordering form with the appropriate fields prepopulated with new values. A design example of two interruptive alerts with higher and lower severity levels is in Fig. 1. Their layout and interactive functions described in the legend are presented as one possible model of a design approach that closely follows usability principles described in this paper. For example, aesthetic and minimalist approach [44–46], controlled and meaningful color sets [28,47,48], concise wording and justification [49,50], clear response options with controls placed close to relevant text [51] and other principles summarized and referenced in Table 1 were used although their interpretation and instantiation may clearly vary depending on specific design goals.

Clinicians choosing to override an alert may be asked to give a reason for not following the advice. Although there is no empirical evidence that it may increase compliance rate, the collected data allow, on review, insight into the prescribing behavior of clinicians over time. Periodic reports on the number of alerts, proportion of overrides and the frequency of pharmacist intervention are necessary for refining trigger rules and making them more specific [42]. For example, some alerts may be consistently overridden by most clinicians, for similar reasons that may indicate possible problems with the rules logic or with the alert's relevance for certain clinical contexts or goals. The recorded justifications and possibly other annotations also allow nurses and pharmacists to understand the rationale for each override and reduce the need for further and potentially disruptive telephone inquiries [52].

The most common override reasons should be selectable from a list of no more than three or four with a single click as fast and convenient processing is essential for promoting use. Drop-down lists with too few (e.g., binary options) or too many (more than six to ten) selections should be avoided as they are slow to operate and require significantly more search time than index menus and are more likely to be ignored [53–55]. Override reason selections can be made mandatory for the most critical alerts but otherwise optional [56].

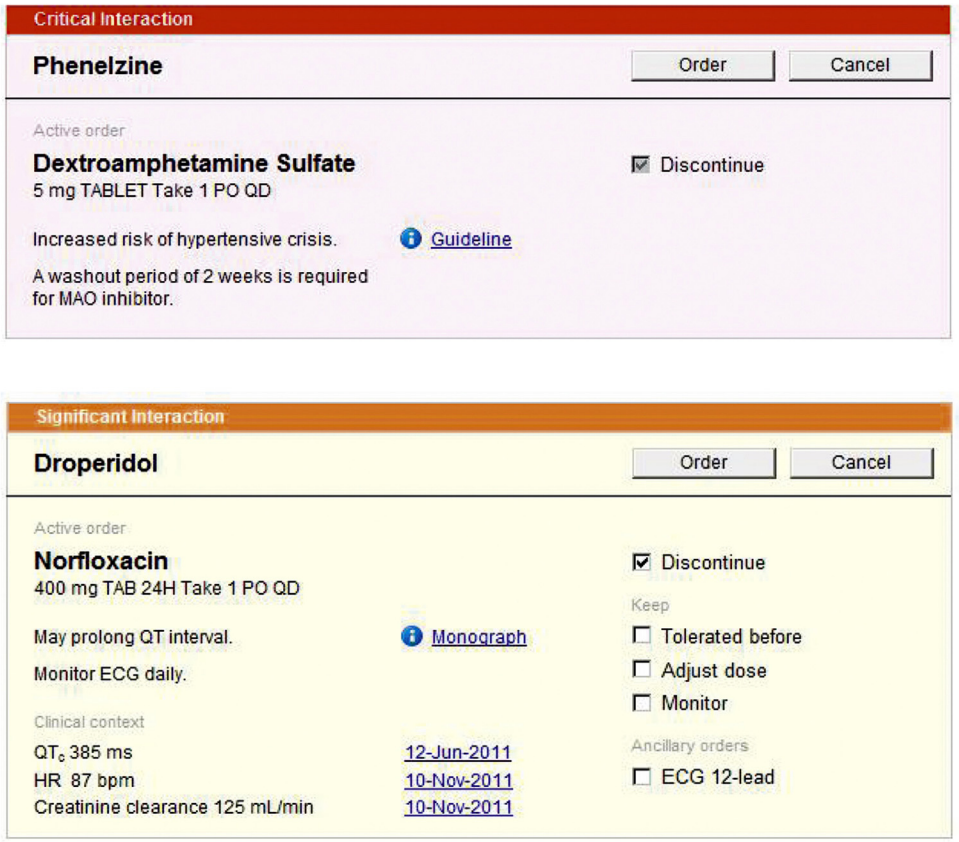
Some systems do not allow the overriding of possibly life-threatening interactions and the clinician is required to either cancel the new order or discontinue the pre-existing one (a "hard stop") [37]. There is no wide consensus on the merits of imposing this level of control over decision autonomy and clinicians often differ in their preference [57]. Many systems allow overriding in all instances but differentiate the level of required effort to override severe interactions by requiring a secondary confirmation action. In the example in Fig. 1, the hard stop is designed as a persistent checkbox selection to discontinue the existing drug. A less restrictive option may allow deselecting the checkbox but still require a subsequent confirmation to override.

The dialog box may be designed as a binary choice between (a) ordering the new drug while simultaneously discontinuing the existing drug of the interacting pair, and (b) canceling the new order. The first choice should close the dialog box, create a discontinue order for the existing drug and open a pre-populated entry from for the new one. The second choice should close the dialog box and place the focus back on the drug ordering screen. Alerts need to clearly state that the existing order will be discontinued if the new one is finalized. The dialog boxes should be displayed over the screen with currently entered orders (presumably the starting point for creating new orders that immediately preceded the alert) to provide sufficient context for the decision and allow clinicians to clearly see the outcome of their actions.

Even correct and refined medical logic rules may trigger inappropriate alerts when using data in the EHR that are outdated, not reconciled or inaccurate [58]. Maintenance of medication and allergy lists should be facilitated when an alert is being consistently overridden and the clinician is aware of the discrepancy between recorded and actual medications the patient is taking or has tolerated taking in the past [17]. For example, when a physician overrides an alert for the reason of "Patient tolerated", the system should prompt to edit (in a click or two) the appropriate list [2]. These prompts need to be non-intrusive (e.g., links within the alert body) as clinicians generally resent systems that require data entry at times that may conflict with their preferred workflows [59]. A direct action link such as "Remove from allergy list?" may also be used.

Drug–drug interaction alerts that are presented simultaneously with other warnings related to the same order (e.g., drug-allergy *and* therapeutic duplication *and* dose alerts) may have a diminished effect. The relative priority of concurrent alerts needs to be evaluated and those that do not absolutely contribute to improving the prescribing process should be suppressed or shown as low-importance messages [60]. Suboptimal priority and the presentation of multiple warnings in a long list had the unintended effect of increasing the number of duplicate medication orders in one study [12].

(A)



Checkbox selections	**[Order]** is clicked	**[Cancel]** is clicked
Discontinue ☑ Permanent selection	Phenelzine is ordered AND Dextroamphetamine Sulfate is discontinued	Phenelzine is **not** ordered AND Dextroamphetamine Sulfate remains active

(B)

Checkbox selections	**[Order]** is clicked	**[Cancel]** is clicked
Discontinue ☑ default	Droperidol is ordered AND Norfloxacin is discontinued	Droperidol is **not** ordered Norfloxacin remains active
Discontinue ☐	Droperidol is ordered AND Norfloxacin remains active	Droperidol is **not** ordered Norfloxacin remains active
One or more override (*keep*) reasons ☑	Discontinue is deselected ☐ ECG 12-lead is selected ☑ Droperidol is ordered AND Norfloxacin remains active Override reason is recorded ECG order will be prompted to finalize after Droperidol order is completed	Droperidol is **not** ordered Norfloxacin remains active
ECG 12 lead ☑	Discontinue is deselected ☐ Droperidol is ordered AND Norfloxacin remains active ECG order will be prompted to finalize after Droperidol order is completed	Droperidol is **not** ordered Norfloxacin remains active
ECG 12 lead ☐	ECG will **not** be prompted Droperidol is ordered AND Norfloxacin either remains active or is discontinued depending on Discontinue selection	Droperidol is **not** ordered Norfloxacin remains active

Fig. 1 – Example of dialog-style alerts for first and second level of drug interaction severity. (A) Critical interaction (hard stop, no overrides allowed) – effects of button clicks. (B) Significant interaction – effects of button clicks and checkbox selections.

Table 1 – Optimal design attributes of interruptive alerts.

Principle	Description
Color set [28,47,48,76–78]	√ *Parsimonious and consistent* use – red and orange are system "reserved colors" to denote two severity levels of warnings and abnormal values; the entire palette should have no more than five to six colors. √ Saturated hues are limited to headers; complemented by light background shading to *emphasize severity level* while maintaining text contrast. √ Blue links, black text, grey labels – *common web design conventions*. √ *Luminosity* ratio of text to background is high for good visibility on different screens and in variable ambient light conditions.
Dialog size [32,33]	√ *Variable* to accommodate content without appearing oversized or dense; collapsing and moving is allowed to see information underneath.
Layout [44–46]	√ *Blank space* is used rather than visible lines to visually indicate content relationships by controlling item proximity (low ink-to-content ratio). √ *Horizontal* dividing line denotes different types of content: a potentially ordered drug (above) and an existing, active drug (below). √ *Vertical* partitions aggregate informational content (drugs, advice, context) on the left, action controls (buttons, checkboxes) on the right and links to supporting details in the center. √ Strict adherence to *simple geometric alignment* structure of columns and rows allows fast and comfortable visual search.
Control placement [51]	√ Controls are in the *proximity* of corresponding (target) items: buttons are placed next to the ordered drug, checkboxes next to the existing drug.
Font [36,48,79]	√ Size conveys importance and *hierarchy* – dose and frequency are secondary to the drug name; labels are less important than content. √ The two drug names are the most important information on the screen; they are therefore the most *prominent* screen artifacts to draw visual attention. √ Labels (static information) are *deemphasized* (smaller, half-transparent) in order not to compete with content (dynamic information). √ *Capital* letters are entirely avoided to increase the speed of message reading, except for abbreviations and units.
Language [49,50]	√ *Concise* and unambiguous statements and directions. Directly visible messages are shorter than 10 words; details available on demand (links). √ Override reasons in a *selection lists* have 1–2 words; lists should contain less than five items. √ *Buttons* are labeled with unambiguous verbs [Order] and [Cancel].
Content [19,42,49,80]	√ *Rule* that triggered the alert and medical consequence are briefly described and a link to detailed explanation (monograph) is attached. √ Brief *instructions* (monitor ECG daily) are included. √ *Clinical context* shows relevant values from the patient record with a link to access further details. √ *Ancillary* order (ECG 12-lead) is included but not mandatory. √ *Override* is possible with one extra click (uncheck "Discontinue") for second tier alerts; not possible (if so designed) for critical alerts. √ *Reason* for override is selectable by one click but not mandatory.

4.3. *Non-interruptive alerts for low-severity interactions*

Alerts with lower urgency should be clearly noticeable, placed near the order for which they were triggered (i.e., not at the bottom of the screen) as spatial proximity of screen items visually implies their relatedness [43]. The fact that a new item "appears" on the screen in response to an action (i.e., entering a drug order) also further emphasizes the cause-effect association with the new order by temporal proximity and increases the likelihood that it will be noticed.

Messages about possible interactions that are considered merely informational (i.e., with the lowest severity rating) can be placed in regions on the screen that are not in the focused visual field of the clinician at the moment the order is entered. They can be in areas dedicated to warnings, in sidebars or in the main body section and expanded on demand [61]. These messages can also be aggregated and shown together in a single display to be reviewed all at once at a convenient point in the workflow such as at the end, during order signing. The messages can also be sorted and prioritized [4,12].

4.4. *Filtering of alerts and rule maintenance*

The lack of specificity of drug and allergy interaction pairs in many commercial knowledge bases inflates the number of alerts that have low predictive value of significant consequences to patients [62]. Consistent sets of definitions and editorial guidelines on what constitutes a severe interaction are also not readily available, impeding the determination of which alerts can be safely turned off. Several existing classification systems, however, have shown measureable improvements in alert specificity without compromising safety [38,61,63,64]. A document by the Office of National Coordinator (ONC) may help organizations develop an operational DDI list that can be practically implemented [65]. Large institutions with self and vendor-developed systems generally have in place a cyclical content-management process to maintain

their knowledge bases that follows an information lifecycle model [66]. A committee of experts systematically reviews, modifies, replaces or retires interventions with respect to new or changing clinical needs and recognized gaps in effectiveness, often with the use of collaborative and specialized knowledge-management tools [67]. Smaller-size clinics that purchase the knowledge content, however, may have to limit their periodic reviews to collected evidence of poor or abnormal function, report findings back to the vendors and rely on their maintenance agreements for updates.

Filtering of alerts means that rules triggering specific intervention modes (e.g., interruptive dialogs or non-intrusive messages) are modified not to activate when certain conditions apply. Suppressing alerts with little evidentiary basis or clinical relevance, or those that are redundant further increases their specificity [17]. An effective filtering method is to add to the decision logic, along with general drug–drug interaction rules, additional data from the EHR and thus making the rules more patient-specific. For example, a system could automatically prioritize recommendations according to a multi-attribute utility model by combining patient and provider-specific data [4]. Age, gender, body weight, mitigating circumstances, drug serum levels, renal function and comorbidity [68] may modify the severity of expected interaction for that patient and the system then selects appropriate warning level. Time intervals between interacting drugs should also be considered as earlier-prescribed drugs may have completely metabolized by the time a contraindicated drug is entered [50].

Redundant alerts can be suppressed when dose adjustments are entered for a specific patient and at times when a previously tolerated medication combination for the same patient is renewed [2,17]. There are conflicting opinions and evidence, however, on whether an entire class of alerts could be safely suppressed by system rules. For example, domain specialists may not need the same level of support as generalists but the purpose of CDS is not only to mitigate the effects of knowledge deficits but, perhaps more often, to monitor performance and vigilance deficits caused by distractions, interruptions and fatigue that are commonly experienced by specialists and generalists alike [69]. If the advice specificity is deemed high and alerts are triggered only in potentially unsafe situations, specialists usually do not consider them being superfluous or unwanted [70]. One of the primary objectives of CDS is to effectively remind clinicians of things they have truly overlooked and support corrections [71].

Physicians may be allowed to turn off individual alerts, with caveats, based on their practice, knowledge and comfort level [72]. For example, a psychiatrist comfortable prescribing antidepressants may choose to receive only the most critical alerts for antidepressants [73]. Clinicians may suppress alerts for medications that a patient had previously received and tolerated [74]. However, suppressing a drug–drug interaction alert after it has been overridden only once per patient, for example, was not favored by prescribers in one study and even less by pharmacists [60].

Specificity of alerts is dependent on the quality of rules in the knowledge base. A committee of physicians should periodically revise the rules and suggest safe and effective ways for filtering or changing the presentation format of frequently overridden alerts. Specificity or sensitivity will likely be improved as the result of consensus meetings between physicians and pharmacists [75].

5. Alert content, language and typography

Concise and clear recommendations are the most effective [49]. Verbose language may be difficult to interpret, the clinical consequences may become unclear and the clinician may not see the magnitude of the possible risk [50]. The message needs to have a succinct explanation of the interaction and its consequence, using recognizable and accepted terms, must be easily interpretable and generally shorter than ten words [4]. Triggering medical logic needs to be apparent and outlined in a few words accompanied by a link to further evidence [19]. A summary of optimal design characteristics pertaining to both visual and textual content of alerts is in Table 1.

Identification of an alert as a “drug–drug interaction”, for example, may be added to the top banner of the dialog box but the most important attribute is the severity level. It needs to be the most visually prominent item on the screen and clearly communicated by dedicated “code” words reserved for each level, such as “critical,” “significant,” “caution,” “recommendation,” or “note,” and used consistently for all warnings in the entire system. Other words and word combinations may include sets of gradual terms such as “contraindicated,” “provisionally contraindicated,” “conditional,” “minimal risk,” and “no interaction” [38]; or “absolute contraindication,” “relative contraindication,” “use caution,” and “notice” [81]. Terminology should follow local conventions but needs to be applied consistently.

Printing the text of the message, including the banner words, in all caps should be avoided as capitalized text is more difficult to read than lower-case print [79,82]. Bold text, larger font size or white space offsets are better choices for visually conveying emphasis (see Fig. 1).

The alert box should include an immediately actionable item [4,83] as physicians may resist suggestions not to carry out an action when an alternative is not offered [49]. It is generally more difficult to get clinicians to change their plans than to remind them of what they already intend to do [84]. Accurate suggestions of drug alternatives need to include dose and frequency but those may depend on clinical context. However, both medications must be considered, since either might be replaced to best ensure optimum patient outcomes for the condition being treated—it might be easier to alter one medication in the pair in some therapeutic situations and the other under different circumstances [85].

Appropriate contextual information from the patient record should be made available on demand (e.g., via a link) as the actual indications for a patient may be different from those considered by the decision logic [50]. The linked information source may show, for example, the last measured drug serum or creatinine levels, and other interacting drugs that taken together may further support the recommendation [86]. The text of the supporting information should be visually distinct (i.e., deemphasized) from the main message of the alert so that it can be easily ignored when not needed. It can be printed in smaller characters on the side or at the bottom of the alert box.

Systematic and consistently applied nomenclature and display formalisms may increase the speed of recognition and reading of drug names by allowing quick perceptual judgments [87]. For example, generic drug names may always be printed in lowercase letters while brand name equivalents may have the first letter capitalized, giving a distinctive visual cue to items in each group [42]. Drug names can be further made more distinguishable from one another to minimize errors among look-alike and sound-alike names. Tall man lettering is a useful practice of writing part of a drug's name in upper case letters [88]. For example, "chlorpromazine" and "chlorpropamide" may be written as "chlorproMAZINE" and "chlorproPAMIDE", respectively [89]. The Joint Commission has published a register of drugs with similar names that should not be adjacent in pick lists [90].

6. Visual and perceptual characteristics

Visual indicators such as color, font, or screen placement are powerful means of communicating to clinicians perceptually message importance before they read it, whether they need to pay attention to it immediately or if they can safely defer for a more convenient time. CDS is almost always integrated with EHR and prescribing systems. It is important that meaningful color schemes are consistently applied to all visual aspects of the entire system, not just to alerts and reminders. For example, if the color red signifies the highest level and orange a lower level of criticality, it should be consistently used for alerts as well as for values such as abnormal laboratory results and not for any other emphasis [91]. Cultural conventions should be followed to denote severity levels such as red and orange use for the highest and the second-highest levels, and neutral colors such as yellow, blue or white to indicate lowest abnormal or informational levels [48]. The use of green should be restricted to values, actions and states that are normal, completed or verified, not for low-level warnings.

As colors are the most salient visual aspects of screen layouts, their total number should be limited to no more than five to six for the entire EHR and no more than three to four on any single screen, if possible [78]. Overuse will significantly reduce their capacity to make objects distinct on the screen and will detract from mentally associating colors with severity designation. It is possible to use progressively more saturated shades of one color to indicate grades of importance if needed.

The font color should not be changed for emphasis and should remain either black or a deeply saturated, dark hue of another color to maintain visibility and good contrast with the background [77]. Rather, emphasis should be achieved by changing the background of the alert or a significant portion of it, such as a wide stripe across the top (Fig. 1). Luminosity contrast ratio, a calculated value between 1 and 21, measures the difference between the brightness of foreground and background colors, and is recommended to be at least 10:1 for comfortable reading without excessive eye strain [92]. "Reverse video" effects (e.g., white text on dark background) should be avoided for main text as it is less visually salient than dark-on-light background combinations. Font in white or light shades of gray is sometimes used to deemphasize labels and information that should not compete with the primary message [48].

Modal dialog boxes should be sufficiently large to contain the message, buttons and contextual data without appearing excessively dense and allow quick and comfortable reading. Oversized dialogs, however, may cover important contextual information on the screen below. For example, an alert may be superimposed over an ordering page that contains the list of currently active medications that clinicians may want to see. Dialogs should therefore be movable and resizable.

7. Discussion

Human factors and usability characteristics have been at the center of device and software design in high-risk domains for decades and safety has invariably improved as a result [93]. Healthcare has been incorporating best practices and proven design principles into IT development at a much slower pace than is necessary to maintain a high level of function and safety for increasingly more complex systems [29] and HIT is therefore often considered as having low reliability [30]. Basic HCI standards and guidelines that we review in this report need to be complemented by socio-technical, observational and ethnographic methods to give designers realistic insight into the conditions in which care is provided and the complexities of treating patients with a multitude of comorbid conditions [94,95]. For example, CDS algorithms not sufficiently sophisticated may give clinicians conflicting advice for patients requiring complex drug therapy with many medications or when data stored in the electronic records are unavailable, outdated or incorrect [96,97]. Safety analyses should not look for a single cause of problems but should consider the system as a whole when looking for ways to make a safer system and avoid unintended consequences of poorly designed HIT [98].

The high rate of drug interaction alerting to even minor possibility of personal discomfort or adverse reaction may in practice counteract the primary objective of CDS to safeguard patients from severe drug injuries [10,62]. Filtering the overinclusive lists of drug–drug interactions represented in commercial databases to a subset of clinically meaningful pairs may ameliorate the "alert fatigue" effect but also create liability concerns for vendors and physicians who would be reluctant to adopt a system that they perceive as exposing them to liability [99]. However, endorsement of a consensus-based DDI list by relevant professional societies or regulators like the ONC would provide professional and government imprimatur to the risk-management priorities the list embeds and constitute a collective affirmation that the risk is managed through formal standard-setting efforts rather than by tort liability after the fact [23].

8. Conclusion

This report suggests methods and practices to improve the visual and interactive design characteristics of CDS interventions used in medication ordering. Good performance of CDS and its benefit to clinicians can be significantly reduced by poor interface design, incorrect implementation and

inadequate data maintenance and may even become a disruptive factor contributing to medical error [17]. Specificity and clarity of alerts and quick ways of responding to suggestions are key to changing the prescribing behavior of clinicians [25,100].

Decision support is still a relatively novel form of intervention into traditional flows of clinical work that is seldom conceived and executed well enough to be a truly useful, time-saving tool. As any new technology, it requires years of research and comprehensive analysis of its track record to mature. Appropriate design approaches and adherence to principles of optimal human–computer interaction and usability are essential for developing safe and effective CDS systems. Careful implementation and continuous performance monitoring are required to meet the grand challenges [4] of providing decision support in complex clinical care. Basic HCI principles are not entirely novel and have been followed routinely and closely especially by developers of safety-critical IT. The magnitude of the potential effect of these core principles on patient safety is not yet at the forefront of HIT development although national regulatory bodies (ONC, NIST) and the scientific community have been advocating the use of safer software, for example by following upon the 2001 Institute of medicine with a report in 2011 that is solely focused on HIT safety [98]. The AMIA Board of Directors provides guidance and leadership by outlining research agenda and recommendations for policy and industry efforts that include a call for a minimum set of design patterns to be shared among vendors that improve the usability for patient-safety sensitive functions within and across EHRs [101]. Excellent usability characteristics of HIT are highly valued by clinicians and are among the decisive factors promoting their acceptance and routine use [102].

Summary points

Already known:

- Excessive alerting that leads to high override rates is distractive to clinicians and contributes to the risk of inadvertent dismissal of a serious warning.
- The performance level of many EHR systems with decision support may be substantially increased by designing their human interfaces according to established principles that emphasize user-centered design.

Contribution of this review:

- A compendium of design recommendations applicable to alerts and reminders based on a combination of evidence from CDS implementation reports and HCI principles.
- Collection of best practices and methods to reduce excessive alerting, prioritize and filter alerts rules, suppress redundant warnings and increase alert specificity.
- Suggestions based on established software usability principles to guide designers on the content, language, typography, layout and use of color that optimize interaction and visual characteristics of alert dialogs and messages.

Authors' contributions

All authors contributed to the conceptual design of the study, data collection planning and initial drafting of the manuscript. Drs. Bell and Middleton provided substantial help in revising and critiquing the manuscript.

Conflict of interest

None of the authors report any conflict of interests with respect to this study.

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