# The Impact of CPOE Medication Systems' Design Aspects on Usability, Workflow and Medication Orders

## A Systematic Review

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**Keywords**
CPOE, medication systems, medication errors, assessment-evaluation, design aspects, user-computer interface, usability evaluation, human factors

**Summary**
**Objectives:** To examine the impact of design aspects of computerized physician order entry (CPOE) systems for medication ordering on usability, physicians' workflow and on medication orders.
**Methods:** We systematically searched PubMed, EMBASE and Ovid MEDLINE for articles published from 1986 to 2007. We also evaluated reference lists of reviews and relevant articles captured by our search strategy, and the web-based inventory of evaluation studies in medical informatics 1982–2005. Data about design aspects were extracted from the relevant articles. Identified design aspects were categorized in groups derived from principles for computer screen and dialogue design and user guidance from the International Standard Organization, and if CPOE-specific, from the collected data.
**Results:** A total of 19 papers met our inclusion criteria. Sixteen studies used qualitative evaluation methods and the rest both qualitative and quantitative. In total 42 CPOE design aspects were identified and categorized in seven groups: 1) documentation and data entry components, 2) alerting, 3) visual clues and icons, 4) drop-down lists and menus, 5) safeguards, 6) screen displays, and 7) auxiliary functions.
**Conclusions:** Beside the range of functionalities provided by a CPOE system, their subtle design is important to increase physicians' adoption and to reduce medication errors. This requires continuous evaluations to investigate whether interfaces of CPOE systems follow normal flow of actions in the ordering process and if they are cognitively easy to understand and use for physicians. This paper provides general recommendations for CPOE (re)design based on the characteristics of CPOE design aspects found.

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## 1. Introduction

Computerized physician order entry (CPOE) systems can have a significant impact on the safety and quality of drug management, and they have been identified as being vital to reducing serious medical errors [1]. Studies on CPOE have shown reductions in incomplete and inappropriate prescriptions [2–6], and in adverse drug events [7], improvements in antibiotic ordering patterns [7, 8], and decreases in length of stays and costs [9]. In contrast, evidences point at reluctance of physicians to use CPOE systems [10, 11], due to increasing time for ordering, decreasing interaction with patients and nurses, and lack of integration with workflow, reducing the ultimate success of CPOE. Complex CPOE systems that place heavy cognitive demands on the users may result in suboptimal use of system features designed to support physicians in the medication ordering tasks [12, 13]. CPOE interface designs that do not conform to physicians' task behavior and decision-making processes may obscure the appropriate order entry strategy [14, 15] and, in turn, lead to inefficient workflow and user frustration. Moreover, poor CPOE interface design induces lack of usability and facilitates medical error and may even lead to disaster if critical information is not presented in an effective manner. Both quantitative and qualitative studies have highlighted CPOE system design flaws that led to errors in orders. Many adverse drug events for example resulted from poor CPOE interface design rather than from human error [16–18]. Thus, the design of a CPOE medication system will influence its ease of use and the final outcome of the medication ordering process.

Usability is often referred to capability of a product to be used easily. This corresponds with the definition of usability as a software quality put forward by the International Standard Organization (ISO) in ISO/IEC 9126 [19]: "a set of attributes of software which bear on the effort needed for use and on the individual assessment of such use by a stated or implied set of users". Based on ISO 9241 [20] usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfac-

tion in a specified context of use. Physicians as users of CPOE medication systems have to accomplish a series of sequential tasks to achieve the goal of setting out a medication order as a part of their workflow. Workflow itself is a step-by-step process including a linear sequence of activities, to be executed by certain users, to provide the necessary input for the next step [21]. Effectiveness of a CPOE system can be defined as the accuracy and completeness with which physicians achieve the ordering of medications. Errors in medication orders affect accuracy whereas incomplete orders influence completeness. Efficiency can be defined as resources expended in relation to the accuracy and completeness of a medication order. In the context of CPOE usability, efficiency is related to the cognitive demands put on the physician in setting out the medication order supported by the CPOE system. Satisfaction can be defined as the physicians' attitudes towards using a CPOE system and be specified as subjective ratings of (dis)comfort experienced with CPOE use, or the extent to which system efficiency and learnability have been achieved.

Despite the impact of CPOE design on the medication ordering process, no literature review has focused specifically on the influence of CPOE design aspects on usability, physicians' workflow and medication orders. Current review studies [22–27] on CPOE systems investigated the effect of these systems on outcomes such as medication safety, costs, adverse drug events, adherence to guidelines, and work efficiencies. Determining design aspects of CPOE systems exerting a positive or negative influence on system usability, physicians' workflow and final outcomes of medication ordering might give clues about how to optimize the design of these systems to be easy to use, aligned with physicians' ordering processes, and effective in ordering medications.

The main objective of this study is to answer the following research questions. What design aspects of CPOE medication systems influence their usability, physicians' workflow, and medication orders? And how the design of CPOE could be changed to improve usability, workflow and medication ordering process? To answer these questions, we reviewed the literature for studies describing original data on a (usability) evaluation of CPOE mediation systems' design aspects. Based on the results we provided recommendations, benefited from principles for computer screen and dialogue design and user guidance of ISO, to enable CPOE system designers to create systems that are more user-friendly, more efficient, and safer to use.

## 2. Methods

We searched the literature from 1986 to 2007 using PubMed, EMBASE and Ovid

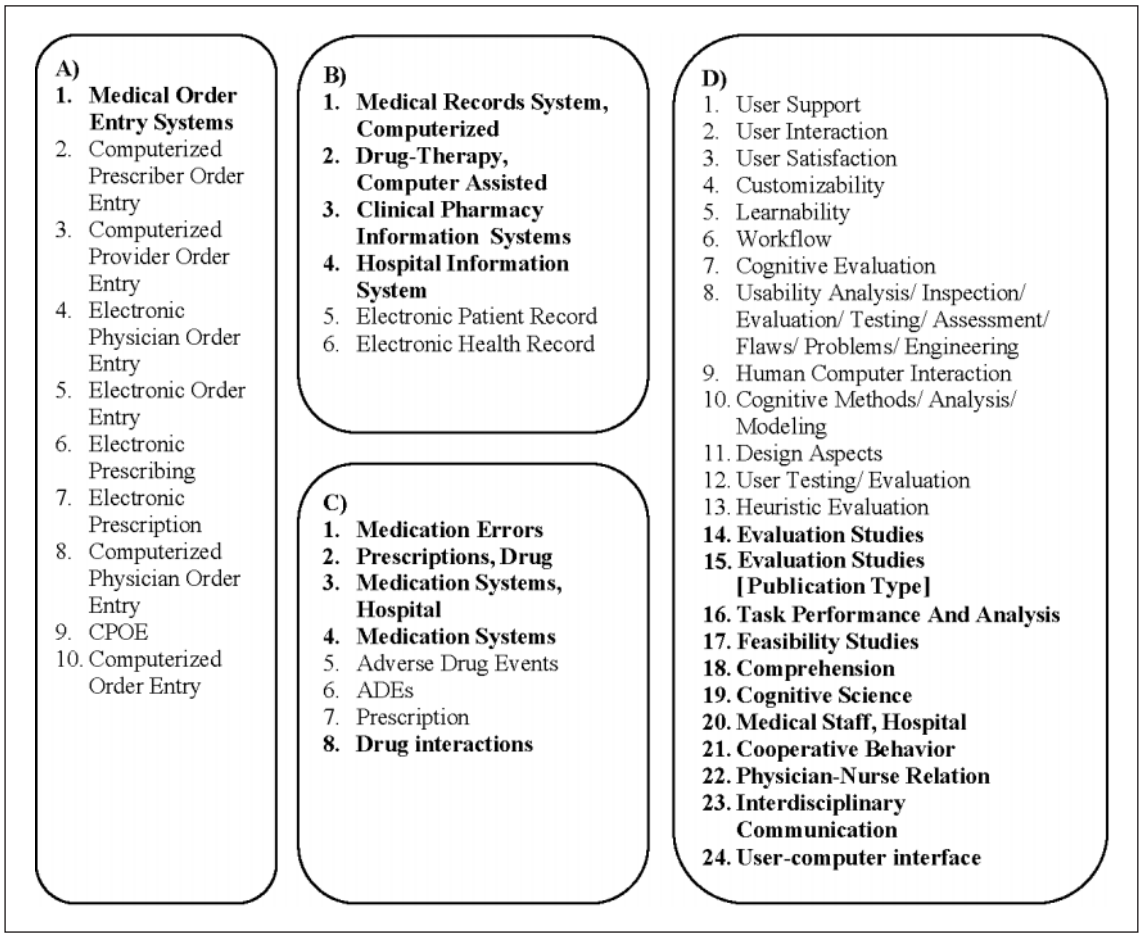


**Fig. 1**
Groups of keywords and MeSH terms used in the search strategy (MeSH terms are in bold)

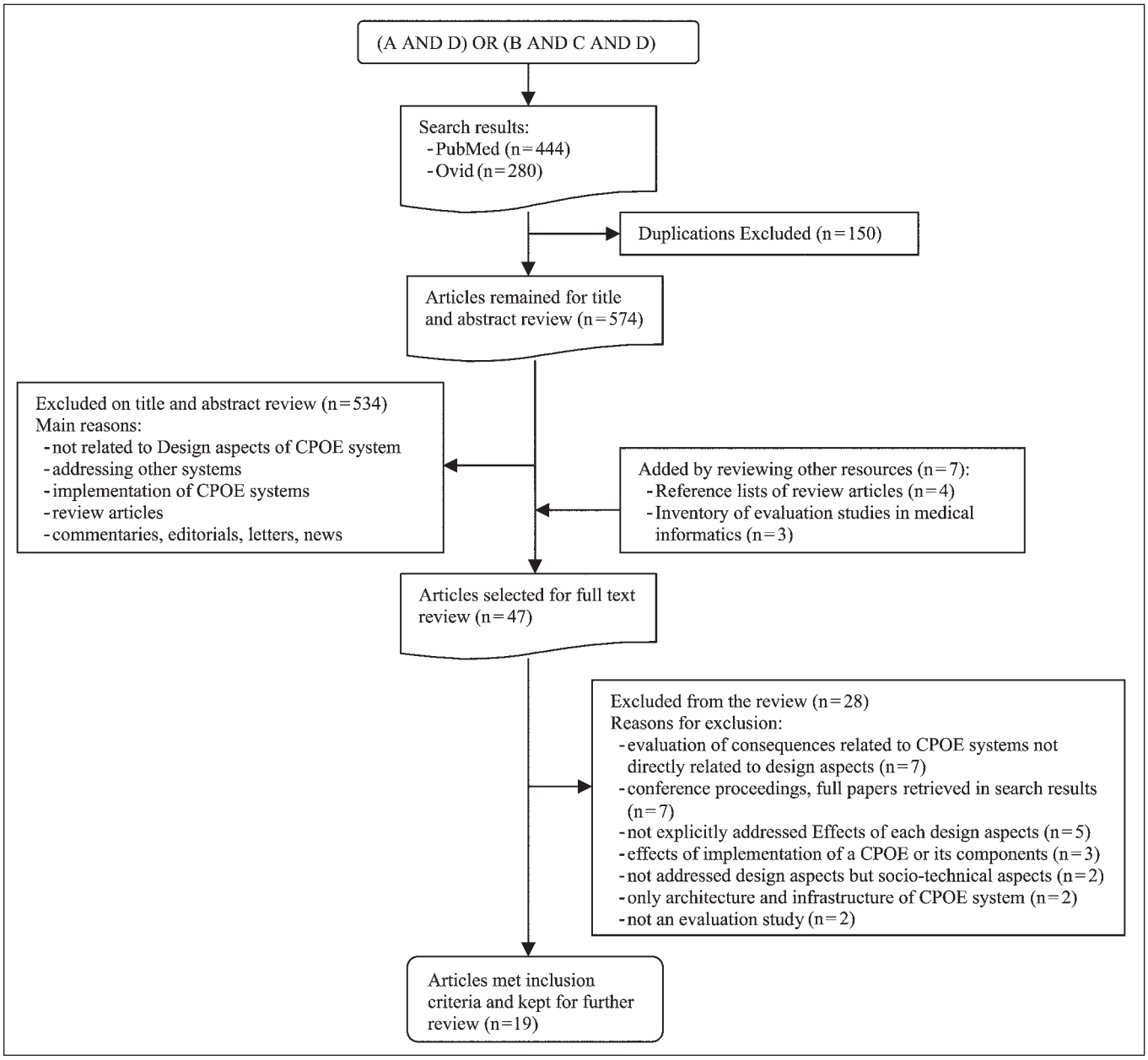


**Fig. 2** Search flow

MEDLINE for English-language publications reporting on (usability) evaluation studies of CPOE medication systems in both inpatient and outpatient settings. In searching these databases, four groups of key terms were constructed related to: A) CPOE and Electronic Prescribing Systems, B) Computerized Patient Records, Computer-Assisted Drug Therapy and Pharmacy Systems, C) Medication Ordering, D) Evaluation Studies, Usability, and Workflow. ▶Figure 1 shows the keywords and ▶Figure 2 shows the search strategy used to identify relevant articles. We used these clusters of key terms in the following 4-step process to automatically retrieve as many as possible publications on CPOE systems for medication ordering. 1) Key terms in each group were combined by the operator "OR"; 2) groups A and D were combined using "AND" to capture studies about CPOE medication system usability, task behavior and workflow; 3) groups B and C were combined with "AND" to retrieve articles addressing CPOE medication systems not indexed by CPOE-related keywords. We then combined the resulting set of articles with group D; 4) results of steps 2 and 3 were added using the "OR" operator to accumulate all of the evaluation studies associated with usability of computerized physician medication order entry systems and physicians' task behavior or workflow. Generally we used the following combinations in the search strategy to extract relevant studies: (A AND D) OR (B AND C AND D).

Two reviewers independently reviewed and assessed titles and abstracts of the result-

ing papers against predefined inclusion and exclusion criteria. First, editorials, letters, commentaries and conceptual papers were excluded. Articles in proceedings were excluded if a more comprehensive article of that study was retrieved from an international journal.

Articles were selected if they reported original data from a (usability) evaluation study of a CPOE medication system used in ambulatory or inpatient health care settings and if they reported on effects of design aspects of CPOE on usability, physicians' workflow and final influence on medication orders set out. We considered all computerized systems; both stand-alone or integrated with other systems, used for ordering medication for a patient, as CPOE medication systems. Articles concerning the use of CPOE other than for medication ordering, for example concerning laboratory and radiology ordering systems, retrieved in the first step, were manually excluded. Feasibility evaluation studies on CPOE medication systems and studies on deployment and technical infrastructures of CPOE medication systems not directly related to design aspects of CPOE were excluded. Studies that reported on the impact of general CPOE components (such as decision support tools), or impact of CPOE on patient outcomes were also excluded, unless they described that certain effects were related to specific CPOE design aspects. In the absence of an abstract or when inclusion of an article could not be decided upon on the basis of the abstract, full texts of the articles were reviewed. We additionally evaluated reference lists of relevant articles and of review articles captured by our search strategy for relevant publications. We finally searched the web-based inventory of evaluation studies in medical informatics 1982 to 2005 [28] for studies not captured by our search strategy. Any disagreements between reviewers concerning the selection of articles were resolved through discussion. Subsequently, from the selected articles data was extracted by two reviewers using a standard report form (▶ Fig. 3).

Each of the design aspects found in the articles was matched to the ISO principles and recommendations for computer screen- and dialogue design and user guidance [29–32]. Subsequently, corresponding information from the ISO standards was added to the data collection form. To facilitate data presentation, this standard report form was used to cluster the CPOE design aspects into seven groups. Groups were formed based on similarity and homogeneity of design aspects, and of corresponding ISO recommendations by the consensus of two reviewers. The groups were determined so that all extracted design aspects could be placed in one group without any ambiguity. Recommendations for optimizing design aspects of CPOE user interface were articulated, using guidance and requirements put forward by ISO for those corresponding with the ISO recommendations.

| Article ID: | | Authors: | | Reviewer: | |
|---|---|---|---|---|---|
| **Study characteristics** | | | | | |
| Study year: | | Participants (if applicable) | Number: | | |
| Study location | | | Computer expertise: | | |
| Setting: | | | Domain expertise: | | |
| System: | | Evaluators (if applicable): | | | |
| Phase in system development: | | Outcomes measures: | | | |
| Study methods: | | | | | |
| ☐ qualitative ☐ Quantitative | | | ☐ Summative ☐ Formative | | |
| Data analysis: | | | | | |

| Outcomes (designs and effects) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Design aspects | Matched ISO recommendations | Effects on usability | Effects on workflow | Effects on medication orders | Other contributing causes | Actions - Recommendations | Reviewer comments |
| | | | | | | | |

**Fig. 3** Data extraction form

**Table 1** Selected publications on evaluation of CPOE medication systems' design aspects

| | Study | CPOE system | Method | Qualitative/ Quantitative | Summative/ Formative * | Setting | User groups |
|---|---|---|---|---|---|---|---|
| 1 | Bradly et al., 2006 [38] | CPOE with CDS integrated in EMR | Pre-post test descriptive study | Quantitative | Summative | Inpatient | Not applicable |
| 2 | Ash et al., 2007 [16] | CPOE integrated in HER vendor-supplied | Ethnographic study, observation and interview | Qualitative | Summative | Outpatient | Clinicians |
| 3 | Horsky et al., 2005 [43] | Commercial CPOE | Think aloud method | Qualitative | Formative | Laboratory setting | Internal medicine residents |
| 4 | Banet et al., 2006 [35] | CPOE added to a commercial emergency department information system | Pre-post test repeated time-motion studies, questionnaire survey | Qualitative, quantitative | Summative | Inpatient, Outpatient | Registered nurses |
| 5 | Zhan et al., 2006 [13] | Full CPOE | Analysis of medication errors reported | Qualitative, quantitative | Summative | Inpatient , outpatient | Not applicable |
| 6 | Beuscart-Zephir et al., 2005 [37] | CPOE integrated in patient care information system (PCIS) | Activity analysis, heuristic evaluation, think-aloud method | Qualitative | Formative | Inpatient | Nurses and physicians |
| 7 | Horsky et al., 2005 [42] | – | Analysis of order entry logs, visual and cognitive evaluation, semi structured interviews | Qualitative | Formative | Inpatient | Clinicians |
| 8 | Koppel et al., 2005 [17] | A widely used CPOE system | Structured interviews, real-time observations, focus groups, questionnaire survey | Quantitative , qualitative | Formative | – | House staff, pharmacists, nurses, nurse-managers, attending physicians, and information technology managers |
| 9 | Horsky et al., 2004 [12] | Development version of a commercially POE system, with DSS | Cognitive walkthrough, think-aloud method | Qualitative | Formative | Laboratory setting | Physicians |
| 10 | Cheng et al., 2003 [14] | CPOE integrated in an EMR | Observational case study | Qualitative | Formative | Inpatient | Physicians, nursing staff, two pharmacists, and one respiratory therapist (RT) |
| 11 | Horsky et al., 2003 [15] | A development version of a commercially POE system with DSS integrated in an EMR | Cognitive walkthrough, think-aloud method | Qualitative | Formative | Laboratory setting | Internal medicine physicians |
| 12 | Bates et al., 1999 [36] | CPOE with DSS, integrated in home-grown BICS (Brigham integrated computing system) | Prospective time series analysis | Quantitative | Summative | Inpatient | Not applicable |
| 13 | Caudill-Slosberg and Weeks, 2005 [39] | – | Case study using cause-and-effect/fishbone analysis | Qualitative | Summative | Inpatient | Not applicable |

**Table 1** Continued

| | Study | CPOE system | Method | Qualitative/ Quantitative | Summative/ Formative * | Setting | User groups |
|---|---|---|---|---|---|---|---|
| 14 | Ash et al., 2003 [34] | In two sites (the first and third site) a commercial system, in the second a home-grown system with CDSS | Observation, focus groups, and interviews | Qualitative | Summative | – | Clinicians, clinical pharmacist, administrators, information technology personnel, chief clinical information officer, clinical system specialist |
| 15 | Glassman et al., 2002 [41] | POE included in computerized patient record system (CPRS) | Cross-sectional survey | Quantitative | Summative | Outpatient | Attending physicians, licensed nurse practitioners, physician assistants |
| 16 | Ahearn and Kerr, 2003 [33] | Pharmaceutical decision-support (PDS) systems within prescribing software or as stand-alone systems | Focus groups | Qualitative | Summative | Outpatient | General practitioners |
| 17 | Feldstein et al., 2004 [40] | CPOE with DSS | Semi-structured, in-dept interviews | Qualitative | Formative | Outpatient | Primary care prescribers |
| 18 | Teich et al., 2000 [45] | CPOE with DSS, integrated in home-grown BICS (Brigham integrated computing system) | Time series analysis | Quantitative | Summative | Inpatient | Not applicable |
| 19 | Mullette et al., 2001 [44] | Anti-infective decision support tool integrated in a fully integrated hospital information system (HELP) | Pre-post study, questionnaire survey | Quantitative | Summative | Inpatient | Resident physicians and pediatric nurse practitioners |

* Formative evaluation: Evaluation and usability analyses carried out early and throughout system development with the goal of guiding CPOE design. Summative evaluation: Evaluation and usability analyses carried out at the end or at milestones during system development with the goal of assessing how well the system has met its usability objectives.

# 3. Results

## 3.1 Study Design, Setting

The online databases' searches identified 724 publications (Fig. 2). After removal of duplicates (n = 150), initial screening of titles and abstracts of 574 remaining articles excluded 534 articles and rendered 40 articles eligible for further full-text review. Four additional articles were identified by reviewing reference lists of review articles and an additional three papers from the web-based inventory of evaluation studies in medical informatics, yielding a total of 47 articles. Based on the full-text review, 28 studies were additionally excluded among them five out of seven articles not identified by our first online databases' searches. Seven conference proceedings were excluded because we could find a published journal paper reporting on the results of these studies. Seven other publications were excluded because they evaluated impact of CPOE systems on outcomes not related to design aspects of CPOE system, five because they did not address any effects of CPOE design aspects, and three because they only reported on the outcomes following implementation of CPOE or its components. Six additional articles were excluded, describing CPOE architecture or infrastructure or socio-technical aspects surrounding a CPOE implementation. Finally, a total of 19 papers published from 1999 onwards [12–17, 33–45] met our inclusion criteria and were used for detailed analyses. One of the 19 articles we retrieved [16] was ahead of print in 2006 but was finally published in the following year. The main characteristics of the studies are summarized in ▶Table 1. Our results show that a variety of study methods have been used to evaluate CPOE systems' usability, including ethnographic studies [16], time series analyses [36, 45], questionnaire surveys [17, 35, 44], focus groups [17, 33, 34], analyses of medication errors [13, 38], observations and

 

**Table 2** Effects of CPOE documentation and data entry components (+: positive effect, –: negative effect)

| Type | Effects on | | | ISO recommendation* |
|---|---|---|---|---|
| | Ease of use | Workflow | Medication order | |
| Documentation templates | – Difficulty in structured data entry (14)<br>+ Efficiency of documentation (35) | – Different cognitive model for classifying orders than physicians (14) | + Standardization of documentation (35) | 5.8.2 (32)<br>5 (30) |
| Predefined order sets | | + Time saving for straightforward orders (34)<br>+ Improving workflow (34) | + Reduction in medication errors (36) | 6.3.1 (30) |
| Clinical pathways | | + Physicians need to be called less often (34) | | |
| Selection menus with recommended drug dosage and frequency highlighted | | + Increase in the use of approved frequencies (45)<br>+ Increase in the use of approved dosages (34) | + Decrease in the proportion of doses that exceeded the recommended maximum (45) | 8.1.1 (29)<br>8.1.6. a (29) |
| Multiple route options | | | – Increase in medication errors (36) | 4.1 (29)<br>8.1.9 (29) |
| Data entry fields | | – Prolonging the ordering (12)<br>– No data entry, where it is required (37) | – Increase in medication dose errors (12;42) | 5.10.1, 5.10.4, 7.5.3 (32)<br>5.3.3 (30) |
| Pre-set global schedules | | – Nurses uncertainty about time of medication administration (37) | | |
| Punctuation sensitive fields | | | – Increase in ordering failures (13) | 7.2.3 (29) |
| Availability of copy-and-paste function | + Reduction in physicians' typing burden (39) | | – Promulgation of the distribution of inaccurate data (39) | |
| Dosage change generating new prescription | | – Leading users to workaround (39) | -Increase in dosing errors (39) | |
| Limited space for clinician notes | | – Leading users to workaround (34) | | 6.2.6 (30) |

* The figures in this column refer to the (sub)heading numbers of matched ISO recommendations to each of the design aspects.

interviews [14, 16, 17, 34, 40, 42]. Of the 19 studies, five applied usability evaluation methods from the human-computer interaction domain (heuristic evaluation, cognitive walkthrough, and think aloud) [12, 15, 37, 42, 43]. Sixteen used qualitative evaluation methods [12, 14–16, 33, 34, 36–39, 41–45] and three used both qualitative and quantitative methods [13, 17, 35]. Eight out of the 19 studies were formative studies [12, 14, 15, 17, 37, 40, 42, 43) whereas 11 studies were summative studies [13, 16, 33, 39, 41, 44, 45). Formative studies are studies with the primary intent of improving the CPOE system under study by providing the developers with feedback or user comments. Summative studies are studies designed primarily to demonstrate the value of a mature CPOE system. Eight studies were carried out in an inpatient setting [36–39, 42, 44, 45], four in an outpatient setting [16, 33, 40, 41], and two of them in both inpatient and outpatient settings [13, 35], and three in a laboratory setting [12, 15, 44]. Two studies did not specify the setting [17, 34].

## 3.2 CPOE Design Aspects

Review of the 19 articles gave us sight on specific design aspects of CPOE that influence CPOE usability, the ordering behavior of physicians or subsequent workflow and the final medication orders set out. In total 42 CPOE design aspects were found, of which nine were CPOE-specific and the rest general design aspects. Eighty-five percent of the identified general design aspects were matched to ISO principles and recommendations. Below we describe the effects of identified CPOE system design aspects based on predefined seven categories.

Wherever relevant, we provide the number of the corresponding ISO principle(s) and recommendation(s) in a column next to each design feature in Tables 2–7.

### 3.2.1 Documentation and Data Entry Components

A total of 10 studies reported on CPOE documentation and data entry components, of which three studies discussed the impact of these CPOE design features on CPOE ease of use, six on physicians' workflow, and seven on medication orders (▶Table 2). Banet et al. [35] reported that documentation templates, prompting users to enter certain information, improved efficiency and standardization of documentation, e.g., use of these templates prevented double/triple charting. In another study [14] CPOE templates likewise provided many convenient orders, but the CPOE interaction structure providing these templates relied upon a cognitive model of classifying orders which the physicians did not always share. This introduced difficulty in navigation and data entry of orders, prolonging this procedure. Predefined order sets and clinical pathways are considered as facilitators in the medi-

**Table 3** Effects of CPOE alerting (+: positive effect, –: negative effect)

| Type | Effects on | | | ISO recommendation* |
|---|---|---|---|---|
| | Ease of use | Workflow | Medication order | |
| Real time alerts | | + Triggering when it was most needed (12)<br>+ Improve in physicians' medication choices (44) | + Increase in the likelihood that the dose was on target (44)<br>+ Decrease in the number of orders (44)<br>+ Reduction in the likelihood of adverse drug events (44) | 9.5.8 (31) |
| Wrong timing of alerts | | – Unnecessarily prolonging the process (12)<br>– Shifting the responsibility to others (17)<br>– Encouraging alert overridden (40) | – Drug interaction alert after the patient had gone (16) | 9.5.8 (31) |
| Alert failures | | | – Missing warnings about interactions (13) | 7 (30)<br>7.3 (30) |
| Too many false-positive alerts | – Alert fatigue (41) | – Limited use of automated alerts (41)<br>– Alert overriding (33)<br>– Desensitization to alerts (33) | – Missing an important interaction alert (33) | 5.2.4 (31)<br>5.2.2 (31) |
| Sensitivity settings for alerts | | + Preventing from alert overriding (33) | | |
| Non-patient-tailored alerts | – Cause users' frustrations (40) | – Encouraging alert overridden (40)<br>– Desensitization to warnings (33)<br>– Limited use of automated alerts (41) | | |
| Difficult-to-interpret alerts | – Cause users' frustrations (40) | – Encouraging alert overridden (40)<br>– Slow down prescribers work (40) | | 5.3.7, 9.5.3 (31) |
| Repetitive alerts | – Cause users' frustrations (40) | – Encouraging alert overridden (40) | | 5.2.3, 5.2.5 (31) |
| Too long text alerts | – Cause users' frustrations (40) | – Encouraging alert overridden (40)<br>– Slow down prescribers work (40) | | 5.3.5 (31) |

* The figures in this column refer to the (sub)heading numbers of matched ISO recommendations to each of the design aspects.

**Table 4** Effects of CPOE visual clues and icons (+: positive effect, –: negative effect)

| Type | Effects on | | | ISO recommendation* |
|---|---|---|---|---|
| | Ease of use | Workflow | Medication order | |
| Screen icons | | + Help to organize and time order tasks (35) | | 6.3.5 (30) |
| Poorly designed icons | | – Hindering notification about new orders (35) | | 6.1.1 (32)<br>8.4 (29)<br>8.4.2 (29)<br>8.4.3 (29) |
| Lack of visual cues and information | | – Engaging in demanding order tasks (43)<br>– Insufficient users support of order tasks (37; 43) | – Increase in misidentification of errors (34) | 7.2.1, 7.2.7 (31) |
| Computer's recommendation of a consequent order | | + Increase in likelihood of o rdering consequent orders (45) | | 6.2.2 , 6.2.5 (31) |
| Obscure orders hierarchies | – Increase of trial and error task behavior (15) | – Time delay (15) | – Selection of wrong order set (15) | 8.1 (29)<br>6.1 (29) |

* The figures in this column refer to the (sub)heading numbers of matched ISO recommendations to each of the design aspects.

cation ordering process. Order sets have shown to improve workflow, to save time for straightforward orders [34] and to contribute in reducing medication errors [36]. These predefined order sets and clinical pathways are helpful to physicians because, if required (e.g. in circumstances where the specialist primarily responsible for the patient cannot be reached), the ordering physician can use order sets of other medical disciplines and is not obliged to define the medication orders himself [34]. Clinical pathways outlining the entire care plan for the patient were welcomed by nurses because these allowed them to rely on their own judgment, once a physician had put a patient on the care plan. As a result, nurses needed to call physicians less often, resulting in a more efficient workflow of the medication ordering process [34]. Teich et al. [45] found that computer screens displaying a menu for selecting medication dosage and frequency, with recommended dosage and frequency highlighted, changed physicians' ordering behavior in a positive sense and resulted in a decrease in the proportion of drug doses that exceeded recommended maxima. Meanwhile, unintelligent design of selection lists and options can lead to medication errors. For instance when physicians have to select a drug route from multiple drug routes options provided by the CPOE system, they may still select a route that is not in accordance with the medication dose or not feasible for a certain medication [36].

Certain fields, specifically adjacent ones in a data entry screen, can be mistakenly used [12, 42]. CPOE users, for example, mistakenly entered rate value (e.g. 18 U/kg) in the data entry field for complete dose (e.g., 1800 U/h – the rate multiplied by weight) [12]. These kinds of misinterpretations can, in the most positive sense, generate alerts prolonging the ordering process. In the absence of alerts or in the case a physician would override such an alert, medication errors lie in wait. One study [37] showed that the use of grey boxes for highlighting preferred time-slots for drug dispensing by nurses, that were to be activated by physicians, were misinterpreted by the same physicians as fields in which no data could be entered. In the rest of the CPOE application the color grey was used for non-active fields: fields that could not be used for data entry; as a result physicians would avoid using these pre-selected time-slots in the time-table. When physicians nevertheless used the global pre-set schedules, the CPOE system registered the corresponding exact times, confusing nurses about the primary intention of the physician as to whether the medication was to be administered at the exact time or whether they were allowed more flexibility in administration of the specific medication. Another study [13] showed that punctuation sensitivity of data fields ("TID" entered by physician instead of "T.I.D." suggesting dosing three times a day) during ordering caused ordering failure because the CPOE system did not recognize "TID" as a valid entity.

Caudill-Slosberg and Weeks [39] found that displaying a patient's medication dosing information recorded in the EMR caused physicians not to question the accuracy of the drug information derived from the EMR though it was inaccurate. Physicians' confidence in the accuracy of the drug dosage information displayed and the availability of a copy-and-paste function led to distribution of inaccurate medication dosages data. The entering of data concerning a change in medication dose in the CPOE generated a new medication prescription thus liability of the patient for a new co-payment. As a result, physicians resorted to "working around" this system limitation to overcome the economic impact of dosage changes to the patient. They tended to list the tablet dosage but not necessarily the total drug dosage, replacing these details by entering "take as directed" in the CPOE. Unavailability of accurate dosing information in the system may re-

sult in dosing errors and increasing the probability of adverse drug events [39]. Limited space for patient notes in a CPOE generating discharge summaries led users to use workarounds using the space for free text under the 'diet' data entry field, forcing the nutritionist to read all kinds of non-diet comments listed under the diet [34].

### 3.2.2 Alerting

A total of eight studies reported on the impact of the timing, unclear information content, and sensitivity and specificity of alerts on creating conditions for medication errors. Two of these studies discussed impact of these design features on CPOE ease of use, six of them on physicians' workflow and four on opportunities for ordering errors (▶Table 3). In a study [12] providing alerts when they were most needed, e.g. at the time medications are ordered, increased the likelihood that the dose was on target for the given age, weight, and renal function of the pediatric patient. Providing real time alerts decreased the number of redundant orders and improved physicians' medication choices as well as their awareness of impairments in patients' renal function, reducing the likelihood of adverse drug events [44]. Three studies [12, 16, 17] reported that alerts which showed up too early or too late in the workflow of CPOE users, e.g. a drug interaction alert after a patient has gone, were annoying to physicians and subject to overriding [40]. Wrong timing of alerts can lead to errors from which users cannot recover. Users may indeed search for information provided by the alert but at a different moment in time than the moment the alert is actually given, unnecessarily hampering and prolonging the ordering process [12]. Post-hoc alerts persuaded users to shift the responsibility of drug interaction checking to the pharmacist [17]. In another study [13], failure to alert in the proper time caused deactivation of orders with a future activation date and prevented physicians to be aware of a drug interaction related to documented allergy information.

Too many false-positive warnings (non-relevant alerts) [41], and annoying or unhelpful prompts such as very repetitious, and time-consuming ones [33], induce alert fatigue. All these encourage physicians to skip or ignore them, ultimately resulting in desensitization to alerts. Sensitivity settings for drug interaction alerts, having the default setting on the "cancel" button to prevent the user from intentional or accidental overriding the alert, and presenting important warnings in red were found helpful by physicians [33]. In conclusion, alerts which are not patient-tailored, have little clinical significance, are too long or difficult to interpret; and alerts with low-priority information cause user frustration and slow down the medication ordering task. They all cause, among other factors, alert overriding and desensitization to alerts. When physicians miss an important alert or important patient information patient safety is at risk.

### 3.2.3 Visual Clues and Icons

In total, six articles evaluated effects of clues and guidelines provided on the CPOE systems' screens. One of them addressed effects of this features on CPOE ease of use, five on physicians' workflow and two on errors in the medication process (▶Table 4). One of the articles reported that icons on the screen reminding users of forthcoming tasks helped them to organize and time their tasks [35]. Yet, nurses' recognition of new medication orders was hampered when the status of these kinds of icons remained unchanged until all ordered doses of all medications were administered [35]. This finding suggests that a series of icons is required enabling nurses to recognize each new order that could be dismissed as soon as a nurse has acknowledged a new order. Nurses likewise can be confused by CPOE systems displaying exact times for drug administration without providing clues as to whether these specific times are critical or not. Without such clues, they may have no means to determine the initial intentions of the physician ordering the drug [37]. It has been shown that on-screen computer recommendations for consequent orders, directly after a first order has been entered, increases the likelihood that physicians immediately set out the consequent order. For example, physicians followed computer recommendations to order heparin after they had advised bed rest for certain patients [45]. Lack of clear visual cues on CPOE screens can lead to errors of misidentification [34]. Horsky et al. [43] found that screens providing few clues on availability of dose calculation functionality and insufficient guidance to support users in their natural workflow necessitated users to carry out a series of cognitively demand-

**Table 5** Effects of drop-down lists and menus (+: positive effect, –: negative effect)

| Type | Effects on | | | ISO recommendation* |
|---|---|---|---|---|
| | Ease of use | Workflow | Medication order | |
| Proximate screen items | | | – Juxtaposition error (16) | 5.7.2 (32)<br>7.5.2 (29) |
| Lengthy list of menu items | – Requiring users to scroll down (37) | – Engaging in a time consuming search process (15;37) | – Wrong item selection (13;15;38) | 5, 5.1.4 Note, 5.2.1 (29)<br>6.3.4 b (30) |
| Ambiguity of items on the medication order lists | | – Inaccurate interpretation of dose and administration (39) | – Faulty drug administration (39) | 5.9.2 (32) |

* The figures in this column refer to the (sub)heading numbers of matched ISO recommendations to each of the design aspects.

ing estimations and comparisons of heparin dosing required to accomplish medication ordering. Suboptimal guidance of the CPOE users during the CPOE interaction added time and recovery effort to the task. Obscure hierarchical structuring of orders or order sets required novice CPOE users to involve in a prolonged trial and error task causing time delay, failures to find an appropriate drug order set and selection of wrong drug sets [15].

### 3.2.4 Drop-down Lists and Menus

Six articles reported on drop-down lists provided on the screen of CPOE medication systems. Of these articles one focused on CPOE ease of use, three on physicians' workflow and five on medication orders (▶Table 5). From the literature, it is evident that illegible handwriting in paper charts is replaced with selection errors from drop down lists [15, 38], with picking wrong items from multiple choice lists on the computer screen and with failure to differentiate look-alike patient names [13]. For example, CPOE users may unintentionally select a wrong patient, a wrong drug, or wrong drug routes. Close proximity of selection items on the screen, e.g. items on the drop down list for order routes and order time, may cause juxtaposition errors ( that is selecting an adjacent, but wrong item) [16]. Lengthy lists of items in menus, with few of the items visible at once, were difficult to use [37] and compelled users to engage in a time-consuming and lengthy scroll down to see the other items [15, 37]. Ambiguity of the medication items (warfarin dosing) on the medication order list led to inaccurate interpretation of medication dose and faulty drug administration [39].

### 3.2.5 Safeguards

A total of eight studies focused on CPOE medication system safeguards, of which two studies evaluated the effects of these design features on ease of use, four on physicians' workflow and five on medication orders (▶Table 6). One of these studies [36] showed that an ordering checking system including drug allergy, duplicate medication, drug-drug interaction, and drug-laboratory checks had a considerable effect on reduction of non-missed-dose medication errors. Ash et al. [34] reported that checks on errors in patient identification prevent communication of wrong orders but burden physicians as they have to reenter the same orders all over again for the correct patient. Mullet et al. [44] found that a CPOE providing calculations tailored to patient conditions increased the likelihood that the dose was on target for the given age, weight, and renal function of the patient. Automatic daily estimations and updates of the patient's body functions, calculations of suggested doses with adjustments for evidence of impairment, automatic factoring of patient age and prematurity considerations, and doses calculations all decreased pharmacy interventions for erroneous doses. They also caused

**Table 6** Effects of CPOE safeguards (+: positive effect, –: negative effect)

| Type | Effects on | | | ISO recommendation* |
|---|---|---|---|---|
| | Ease of use | Workflow | Medication order | |
| Drug-allergy , duplicate medication, drug-drug interaction, and drug-laboratory checks | | | + Decrease in medication errors (36) | 6.5.2 (30)<br>9.2.1 (31) |
| Checks on patient identification | | + Notifying physician about wrong patient (34) | | 9.2.1 (31) |
| Calculations of suggested doses tailored to patient conditions | | + Decrease in pharmacy interventions (44)<br>+ Decrease in number of extra therapeutic days (44) | | |
| Automated computations without provision of underlying algorithmic bases | | – Increase in manual calculation by physicians (12) | | |
| Lack of safeguards | | | -Increase in rate of intercepted potential ADEs and dosage errors (36)<br>– Duplicate therapy (38; 42)<br>– Gaps in antibiotic therapy (17) | 9.2.1 (31) |
| Inconvenient log-in procedures | – + Using the logged-in sessions of other physicians (14;17) | – Adaptation to circumvent the safety features of the system (14) | – Physicians signing the orders of other physicians (14)<br>– Wrong medication (17) | |

* The figures in this column refer to the (sub)heading numbers of matched ISO recommendations to each of the design aspects.

**Table 7** Effects of CPOE screen displays (+: positive effect, –: negative effect)

| Type | Effects on | | | ISO recommendation* |
|---|---|---|---|---|
| | Ease of use | Workflow | Medication order | |
| Poorly conceptualized graphical representations | – Requiring extra interpretation of information (12)<br>– Inability to have a simple visual review of orders (12)<br>– Requiring scrolling through screens (15)<br>– Hard to read for novice users (34)<br>– Hard to find certain information (34) | – Relying on memory (15)<br>– Limited use of automated alerts (41) | – Errors of (information) omission (15) | 5.4.2, 5.5.1, 5.6.1, 5.6.2, 5.6.3 (32)<br>5, 5.1.5 (30) |
| Extraneous details in templates | – Visual barriers to identifying important information (39) | | | 5.5.1 (32) |
| Multiple screen displays | | – Deviation from normal workflow (34) | – Medication discontinuation (17)<br>– Selection of wrong medications (17) | 5.5.2 (32) |
| Faulty screen displays | – Cognitively exhausting (15) | – Difficult to identify physician and patient (15;17) | – Error-prone task of ordering (15)<br>– Overdose (13;17)<br>– Erroneous interpretation of medication stop times (42) | 5 (30) |
| Suboptimal displayed measures | | | – Overdose (13)<br>– Medication under-dose (17)<br>– Users misinterpretation of duplicate order (38) | 5.9.2 (32) |

* The figures in this column refer to the (sub)heading numbers of matched ISO recommendations to each of the design aspects.

reductions in the number of days of therapy that fell outside recommended therapeutic ranges. Although automated dose calculation facilities can assist users in deciding on a drug dose, computations that were represented without their algorithmic basis forced users to hand calculation to enable them to "validate" the reasoning of the system, which complicated the CPOE-user interaction [12]. Lack of timely duplicate checking when physicians ordered a new dose of the same medication [38], or when physicians ordered the same medication in another form, or when physicians reordered a medication prescribed earlier by another physician [42] resulted in duplicate medication orders. Likewise, a failure to warn CPOE users that antibiotic drugs had to be preapproved caused delays in approval, and resulted in gaps in antibiotic therapy [17]. Moreover, lack of safeguards concerning the infusion rate of intravenous medication (potassium) led to an increase of potential ADEs and dose errors requiring interception by nurses [36].

Inconvenient logging procedures, especially when the log-out takes time because of security measures, incited many physicians to order medications at computer terminals not yet "logged out" by other physicians [14, 17]. As a result, physicians signed orders which they did not enter themselves. Apparently, physicians adapted their behaviors to circumvent the inconvenience of the logging procedures [14]. Using another physician's logged-in session can yet result in either unintended patients receiving certain medications or patients not receiving the intended medication [17].

### 3.2.6 Screen Displays

Nine studies reported on the effects of suboptimal screen displays of medication ordering systems. From these studies, four reported on effects of these features on CPOE ease of use, four on physicians' workflow, and five on medication orders (▶Table 7). It has been shown that poorly conceptualized graphical representations, e.g. graphical representation of the dosing suggestion window, and rigid hierarchical user interfaces make it hard for physicians to find certain information, leading to inefficient searches, particularly by novice CPOE users [12, 34]. Besides reported effects related to alerts not triggered at the right time in the physicians' workflow, poor conceptual presentation of alerts likewise increased cognitive effort of users who were

forced to engage in an extensive search for this information, unnecessarily prolonging the ordering process and potentially leading to limited use of alerts [12, 41]. Moreover, a poor display of entered orders does not allow for simple visual reviews of these orders [12], necessitating users to scroll through several screens or forcing them to rely on their memory in retrieving the history of orders set out [15]. These problems could lead to medication errors. A suboptimal display of a patient's current medications can make physicians feel uncertain about the actual medications and doses the patient is on, increasing the likelihood of overdoses or drug-drug interactions. Multiple-screen displays of a patient's medications prevented physicians from seeing a patient's complete medication record, resulting in medication discontinuation and selections of wrong medications [17]. High numbers of screens that physicians had to access to get the order task done, deviated users from normal workflow and required them to "think like a computer" to place an order [34]. Huge amounts of information displayed on one computer screen forced physicians into a cognitively exhausting and error-prone ordering task. Fragmented CPOE displays made it difficult for physicians to identify the patient they were actually ordering for [15, 17], increasing the likelihood for "wrong patient" medication orders. Use of templates with extraneous details raised visual barriers to identifying important information and made it hard to find relevant information among irrelevant information [39].

Subtle differences in layout and appearance of data labels and values for bolus entry forms and drip entry forms of potassium chloride, while their default stop times were calculated differently by the system, led to erroneous interpretation [42]. For instance, one user used volume specification in an entry screen for medication drips in the way that it was to be used for the intravenous bolus entry screen. From the information presented on the screen the distinction between time-limited (drips) and amount-limited (boluses) was not clear. Moreover, lack of an explicit indication that a laboratory result was not from the same day, as the day of the drug ordering, led a physician set out another drug order, leading to an overdose [42]. One study [38] evaluating medication errors before and after CPOE implementation found that invisibility of administration dates on printouts concerning a patient's medication confused pharmacists, who assumed that two printouts for a similar medication represented a duplicate order, whereas in reality these concerned two different orders. Suboptimal labeling of medication dose, for example for 'package' instead of 'tablets' [13], or displaying drug dosages according to pharmacy warehousing and purchasing decisions, rather than according to clinical guidelines [17], can lead to medication overdosing or underdosing.

Table 8 Effects of CPOE auxiliary functions (+: positive effect, –: negative effect)

| Type | Effects on | | |
|---|---|---|---|
| | Ease of use | Workflow | Medication order |
| Laboratory results on the ordering screen | | | + Reduction in non-missed-dose medication errors (36) |
| Selection from hospital-approved standard medication lists | | | + Reduction in non-missed-dose medication errors (36) |
| Computerized guideline for medication selection | | | + Increase in orders of recommended drug (45) |

### 3.2.7 Auxiliary Functions

Two studies reported on the effect of accessibility to other resources such as: laboratory results, automated medication lists, and automated clinical guidelines on medication orders (▶Table 8). Bates et al. [36] reported that displaying relevant laboratory results on the screen and accessibility to hospital-approved standard lists for selecting medication names, doses, and frequencies both resulted in a decrease in medication errors. In another study by Teich [45], a computerized clinical guideline extremely increased orders of recommended drugs instead of other less favored drugs.

## 4. Discussion

A total of 42 CPOE design aspects were found that exert a positive or negative influence on CPOE usability, physicians' ordering behavior, workflow and on the final medication order. Despite some positive effects of CPOE systems on reduction of medication errors, adverse drug events, costs and length of stays [2–9], we unexpectedly found mostly negative effects related to particular CPOE designs. However it can not be concluded that CPOE medication systems induce, rather than prevent, errors, and the results of this review should be interpreted with caution. This is because most studies we identified performed usability evaluations of certain CPOE systems with the objective to improve CPOE system design on the basis of identified design flaws. As a consequence, researchers might unintentionally have not paid attention to or not have reported on those CPOE design features that positively influenced CPOE usability, physicians' ordering behavior or may have decreased the likelihood for medication ordering errors. Moreover, eight out of the 19 articles we identified represent formative evaluation studies [12, 14, 15, 17, 37, 40, 42, 43) indicating that poor CPOE designs might have been optimized in an iterative process.

There are a number of limitations in this study. First, "usability" is not a MeSH term so we may have missed some publications on this topic. To validate our search strategy, we evaluated reference list of relevant articles, and review articles; and the web-based inventory of evaluation studies in medical informatics 1982–2005 [28]. Only

two articles were added to the list of 17 articles we identified by our search strategy: one from the reference list of a review article and one from the web-based inventory of evaluation studies in medical informatics. Further investigation revealed that our search strategy did not capture these two articles because they were indexed under MeSH headings not relevant to our subject; none of the keywords from group "D", related to Evaluation studies, Usability, and Workflow, were used for indexing these two articles. Second, despite our extensive search we found a few usability studies investigating CPOE design aspects. Moreover, the studies we identified used several methods to evaluate design aspects of CPOE systems, from interviews and think aloud usability tests with end users to cognitive walkthroughs by usability experts. Therefore we reported on both actual effects of CPOE designs experienced by users, and potential effects of CPOE designs perceived by usability experts. Third, certain data in the method sections of some articles , including information on study location, type of CPOE system studied, settings of implementation, phase in CPOE system development, and computer experience and domain expertise of participants, were missing. This makes it hard to generalize the results of our study among different types of CPOE systems, different stages of CPOE development, settings, and different groups of users.

To our knowledge, this is the first review focusing on design features of CPOE medication systems and their (potential) influence on usability, physicians' ordering behavior and workflow, and outcomes of the medication ordering process. Five systematic reviews [22, 23, 25–27] preceding this review have summarized the effects of CPOE medication systems on patient outcomes, (medication safety [22, 23, 25], costs [22, 25, 26], adverse drug events [22, 26, 27], work efficiencies [26], and adherence to guidelines [22]). Lehmann and Kim [25] additionally described organizational, technical and financial aspects of CPOE. One more review study [24] reported on outcome variables (health care variables, costs, clinicians satisfaction, and time spent on ordering) that were associated with CPOE implementation or some features of CPOE. Moreover the last review considered all types of CPOE systems for laboratory, radiology and medication ordering.

Based on our review, we can provide general recommendations for (re)designing CPOE systems, for a part matching general recommendations for computer screen design, dialogues and user guidance of ISO [29–32], and for the remaining, CPOE design-specific recommendations. Our results show that in designing CPOE systems, it is of utmost importance to consider that physicians require interfaces that explicitly map to their workflow patterns, so as to keep the ordering process as less cognitively complex as possible. Therefore presentation of the data on different screen sections, e.g. in templates, should follow physicians' normal flow of actions in the medication ordering processes, e.g. when using paper forms [30, 32]. The optimal method for ordering medication would be preferably made explicit to users by clues in the interface. These external clues on the screen display can fulfill a central role in controlling the CPOE-user interaction. Menu dialogues should be provided to better support physicians who have little or no experience with the CPOE system [29], thereby minimizing training needs. In designing multiple selection menus, e.g. multiple route options, visual cues should be provided to the user in a consistent screen position and manner to indicate that multiple selection is allowed [29]. Priority should be given to the critical items which should be continuously displayed, whereas the cursor should be placed on to recommended items or items with higher probability of selection, particularly in selection lists [29], directing physicians toward picking the most appropriate item. For example, one study [45] showed that highlighting recommended medication dosage on the screen positively influenced physicians' ordering behavior to pick the recommended option, decreasing the proportion of dosages outside the recommended range. CPOE systems should be flexible so that dosage changes do not generate new medication orders. The length of a non-scrolling fixed-length entry field should be clearly indicated [32] whereas enough space should be provided for text fields to accommodate the majority of anticipated physician entries [30]. This would prevent users from workarounds by using other data entry fields provided by the CPOE system, forcing other health care professionals to extra tasks. A mechanism should be provided enabling the physician to view and select available order sets [30]. Options should be used that are selectable by typed input in either lower case, upper case or mixed case [29], by adjusting punctuation and case sensitivity of data entry fields. Entry fields and read-only fields should be visually distinct by appropriate coding, e.g. by label, format, shape, and color [30, 32]. Color should yet be used sparingly and consistently, giving important elements (e.g. alerts) prominence through contrast, making it easier for physicians to notice information intended to arrest their attention. Each color should only represent one category of information. If the same color is used for different categories of information (e.g. fields that can be modified and those that cannot) the physician's recognition of the intended meaning may be hindered [32].

In supporting physicians in their daily medication ordering and reducing pharmacy intervention in the ordering process, data validation checks should be considered when there are dependencies among different fields of data entry forms [30]. For example, physicians should receive an alert when ordering "Tenormin", a beta blocker, for a patient with hypertension, if the entry in the field "comorbidities" is "COPD or asthma". Therefore, as far as possible, intelligent checking of drug-drug, drug-allergy interactions, and drug dose calculations based on patient condition should be implemented. Error prevention should be used to the maximum, as drug ordering requires correctly sequenced input from physicians who are likely to be interrupted during ordering. Particularly, when ordering tasks have critical consequences for errors or if errors are frequently occurring, more attention should be given to error prevention [31]. Following error detection, physicians should be allowed to easily undo and edit or cancel the erroneous actions rather than being forced to cancel the whole ordering process and reenter the entire order [30, 31]. It is furthermore highly

recommended to present automated calculations with their underlying arithmetic basis, so that physicians can easily validate the system calculations. Log-in and check-out procedures should be as fast as possible to take less time of physicians and to prevent using log-in session of other physicians leading to "wrong patient" medications.

The results of this review also suggest the need for displaying information that allow users to control the interaction, recognize their errors, and determine their next course of actions [30]. The navigation issues revealed in the studies can be traced back to the concept of task efficiency viewed upon as essential for a successful CPOE system. This is also consistent with the study results showing that for certain CPOE systems physicians report a loss of overview when they are forced to navigate through too many different screens to review a patient's current medication status. Deep navigational structures should therefore be prevented, especially when a physician has to discern some relationship between separately displayed sets of information [32]. Physicians should be kept aware of orders set out and the state of the system through visualization of orders and ordering steps previously carried out in a single screen. Beside multiple-screen displays, extraneous details on screens provide visual barriers to recognize important information necessitating the display of relevant information only. Required information should be structured into subsets corresponding to task steps so that it is meaningful to the users. Another recommendation would be the clustering of the information on the screen in distinct groups helping physicians to perceive, find, and interpret information more easily. Grouping of information should follow common formats and conventions and should support the task sequence [32]. Presentation of the information should reflect users' needs rather than the computer process. An overview of the complex form structures or a visual presentation of the structure should be presented to users [30]. Access should be provided to information resources that are essential for decision making during ordering, such as a patient's lab results with their exact date and times. This could be realized by on-time presentation of this information or by providing efficient links to the suitable resources.

Long lists should be presented in the appropriate logical order (e.g. alphabetical, numeric, chronological) [30] and a mechanism should be provided so that physicians can rapidly navigate through these lists. For example, the user should be able to enter a search string or several strings to find what is of interest. Searches should not be restricted to searching from the beginning of the items, and each item in the list should be retrievable by typing any of its constituting characters. Since scrollable lists are time-consuming for the physicians, an alternative is to reduce the length of a menu items list at least to the height of the screen. This could be realized by designing menu structures (hierarchical, network, or other logical structures) and logical grouping of items [29] so as to prevent users from exhausting searches for information not directly visible. In labeling menu items familiar vocabularies should be used and labels should explain the purpose and the content of the designated menu item [32] to prevent users from misinterpreting label terms. Use of terms throughout the CPOE system should be consistent and terminology should be related to the task. Close proximity of active user interface items may yet lead users inadvertently click the wrong options. Therefore, active screen elements should be visually distinctive from one another to support visual scanning [32] and enough space between selectable items should be provided to prevent selection of undesired items [29].

Use of screen buttons should be considered to sufficiently support users in selecting from a small number of values that need to become effective immediately after selection [30]. Icons labeling these screen buttons should be unambiguous, conform to user expectations, and be suitable for the ordering task to enhance user recognition of the option's action, object or name [29]. Active and passive screen elements should be easily distinguishable, requiring consistent use of tick boxes and pick lists. Likewise pressed push-buttons should be distinguishable from non-pressed push-buttons using different shadows [32]. More cognitive resources seem to be needed, and consequently more time is spent in processing information of screen elements that are unrelated or too close positioned on the screen. Screen elements that are related should therefore be physically grouped together yet not too close, so that the layout of these elements on the screen would guide the CPOE users to the information they are looking for. CPOE designers should therefore organize screen elements into logical groups, visually separated by space and alignment, and their meaning should be easily recognized by users [29]. Every input by the physician should produce timely and predictable visual feedback [31]; especially feedback on completion of ordering tasks is required. When ordering tasks require sequenced steps, which is the case with most CPOE systems, specific prompts for the required steps should be displayed [31] to remind physicians of consequent orders. In preventing obscurity of order hierarchies, ordering options should be displayed according to the requirement of the task at hand. Moreover navigational cues should be provided which can help users learn the ordering menu structures and orient and move within the menu structures [29].

Alerts should be displayed as quickly as possible after a physician has entered data that are crucial and should be corrected to prevent medication ordering errors [30, 31]. This is the moment that a physician would himself search for this information. Alerts should also be displayed in a consistent location, either close to the field of user entry that caused the alert; or a single consistent location in the display windows, in order to be easily noticeable for the physicians. Alerts message should keep as short as possible while their content should be easily understandable for the physicians [31]. They should convey what is wrong, what corrective action can be taken, and what caused the error, using the same terminology that physicians use to perform their tasks [31]. In situations of drug-drug, drug-allergy interactions, and wrong drug dose calculations, the evidence underlying the alert should likewise be presented. Repetitive alerts and high numbers of non-relevant alerts could however lead to physicians becoming insensitive to alerts, alert fatigue and alert overriding. These negative effects could be prevented by providing pa-

tient-specific alerts containing specific information relative to the prescribing task, applicable to the current system state of user actions [31]. Defining sensitivity settings for alerts, adjusting default settings of serious drug interaction alerts on "cancel" buttons rather than on "ok" buttons, and tailoring them to patient conditions, would increase physicians' usage of alerts' information and could prevent them from overriding the alerts. User-initiated guidance should stay under the control of physician and should not disrupt the user's task and the continuum of ordering [31].

Reviewed studies reported on other factors influencing physicians' task or workflows or medication errors, beside CPOE design aspects. Among them are human errors such as typing errors, which are hard to detect automatically [13, 17], but lead to medication errors, and geographical distance of work-stations from bedsides and printers, resulting in disruptions in workflow of the care team and delay in delivery of orders (14). It seems that apart from CPOE design aspects, socio-technical issues surrounding the implementation of these systems can play a role in successful CPOE implementation. Successful implementation of CPOE is a socio-technical activity which often is more influenced by the organizational setting than the specificities of the CPOE system itself [16, 46–53]. For example implementation of the same CPOE system failed in one Dutch hospital and somewhat succeeded in another Dutch hospital due to differences in technical issues and organizational conditions [54]. Therefore when studying the influence of CPOE design and usability aspects on its success or failure, these aspects should likewise be considered in the context of the specific clinical workflow [25] and organizational setting.

Our literature search for studies published in the last 20-year period resulted in only 19 relevant articles with none of them published before 1999. This could mean that very little researches have been done on CPOE design features influencing the medication ordering process. In the studies we reviewed, there were few reports on the final impact of CPOE redesign efforts on their success. This indicates that a research agenda is needed for conducting evaluation studies after redesign efforts of CPOE systems.

## 5. Conclusion

Characterization of consequences associated with certain CPOE design aspects provides insight into how CPOE system designs can be improved for certain settings. Despite the fact that CPOE systems facilitate medication ordering processes by the range of functionalities provided in their interface, they can play the role of a two-edge sword so that suboptimal CPOE interface designs can result in usability problems, workflow interruptions and finally in medication errors. Therefore in (re)designing CPOE interfaces and implementing new functionalities, the subtle design of screen elements should be observed. To gain physicians' acceptance of CPOE, system designers should focus on system usability early in the design process by following recommendations and principles of computer user interface design. This should be followed by continuous evaluation of the system after (re)designing, and feedback from CPOE users to guide CPOE systems' evolutions to improve the medication ordering process and to warrant patient safety.

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