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Review article

Interface design features of clinical decision support systems for real-time detection of deterioration: A scoping review

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ABSTRACT

Background: Clinical decision support systems (CDSS) can support clinicians with the timely detection of patients' clinical deterioration, however, less than half of clinical decision support (CDS) systems implemented for clinical deterioration are used by clinicians. Poor design of CDS systems has emerged as a contributing factor.
Objective: The aim of this study was to 1) identify interface design features that have been used in CDS systems for real-time detection of clinical deterioration; (2) determine which interface design features are preferred by clinicians; and (3) examine other design features (external to the interface) which influence CDS acceptance.
Methods: Three databases (Medline, Scopus and CINAHL) were searched to identify relevant studies. All studies that met the eligibility criteria were included. A qualitative narrative synthesis was undertaken.
Results: Of 24 eligible articles, 17 described CDS systems in the form of a dashboard and 7 described alerts. Of the 17 dashboards, graphs and tables were the most used interface design features to display vital signs. Colour was the most frequently used interface design feature to signal the presence of deterioration with half of colour-coded dashboards using a traffic light schema to classify patient risk level. Clinicians preferred dashboards that included both graphs and tables. Clinicians have expressed that they were disinclined to use CDS systems with manual recording of vital signs and high alert frequency.
Conclusions: This scoping review uncovered wide variability in design features across CDS systems for real-time detection of deterioration. Our research calls for better adherence to reporting checklists when reporting on interface designs, and the development of design guidelines to guide interface designs of CDS systems for detecting deterioration in real-time. Our scoping review may serve as a preliminary guide for the design of future CDS systems for detecting deterioration.

1. Introduction

Clinical deterioration occurs when a patient's clinical state worsens [1]. Deterioration increases a patient's individual risk of morbidity, including organ dysfunction, protracted hospital stays, disability or death [1]. One key indicator of clinical deterioration is vital sign derangement, with most patients who suffer from in-hospital adverse events displaying abnormal physiological signs hours before these events [2]. As such, timely recognition and response can greatly improve patient outcomes and reduce the incidence of serious adverse events [2].

Clinical decision support (CDS) systems can facilitate timely detection of deterioration through the monitoring of patients' vital signs [3]. CDS tools link patient-specific data to a computerised knowledge base [4] and have been used to display a patient's risk of deterioration and produce patient-specific assessments and recommendations, assisting clinicians in forming a clinical judgement [3–5]. This information can be presented to users via a range of features and functions, such as alerts, reminders and dashboards [5].

Despite the potential benefits CDS tools may provide, widespread uptake of these tools is not often seen. A recent *meta*-analysis of 55 studies revealed that overall CDS system uptake was 34.2 % [6]. Several factors contribute to low CDS uptake, such as lack of knowledge or confidence with the CDS system, workflow disruption and CDS usability, including poor CDS system design [6–8]. This latter issue can include the use of unfamiliar icons, inappropriate use of colour and small font size in dashboard interfaces. Furthermore, difficulty in switching between displays, visual screen clutter, and inability to customise information have also been shown to contribute to decreased clinician satisfaction

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with dashboards resulting in poor uptake [7].

While existing studies have identified several implementation barriers to the uptake of CDS tools, there remains a gap in understanding whether and how effective CDS system designs can impact uptake and outcomes [9–11]. A recent scoping review examined the effect of deterioration displays on process and patient outcomes [12] and determined that CDS interface display type impacted patient outcomes, with shorter hospital lengths of stay and lower in-hospital mortality rates [13]. However, he impact of specific CDS interface design features on clinician acceptance has not yet been explored.

This scoping review aimed to: (1) identify interface design features that have been used in CDS systems for real-time detection of clinical deterioration; (2) determine which interface design features are preferred by clinicians; and (3) examine other design features (external to the interface) which influence CDS acceptance.

2. Methods

2.1. Overview

The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (Supplementary Appendix A) were followed for the method and reporting of this review. As this was a scoping review, no ethics committee approval was required.

2.2. Eligibility criteria

Our inclusions were peer-reviewed research publications and case studies which reported on design features of CDS systems for clinical deterioration detection in real time. CDS systems needed to have been implemented within hospital or hospital-in-the-home settings. CDS systems could target any health condition or patient group, and we included CDS systems used by all clinician groups. The articles were restricted to those available in English and published after January 2013. The timeframe of our search was chosen to capture the latest evidence given the rapid advancement in technological innovations with advanced interface design methods. There was no restriction on study type (mixed-methods, qualitative or quantitative). Our exclusions were publications which measured the effectiveness of CDS implementation without any description of design features. See Supplementary Appendix B for further explanation of our eligibility criteria. The outcomes extracted from papers included ‘interface design features’ and ‘other design features’. We defined ‘interface design features’ of CDS systems as user-interface elements such as trends, colour-codes, icons, numerical values, text and alerts and notifications. These were typically presented in figures or images in papers describing CDS systems. We defined ‘other design features’ as design elements external to the interface (e.g., whether a CDS system was stand-alone or connected to another clinical system) and categorised these as facilitators and barriers to the acceptance of CDS. These latter design features were extracted from the interview quotes and survey responses in papers.

2.3. Information sources

Three online bibliographic databases, Medline, Scopus, and Cumulative Index to Nursing and Allied Health Literature (CINAHL), were searched with the assistance of an academic liaison librarian. Four sets of concepts were used for the search relating to (1) CDS, (2) clinical deterioration, (3) hospital setting and (4) acceptance. With the help of the librarian, we developed search queries consisting of a comprehensive set of keywords and MeSH (Medical Subject Headings) terms related to each concept for each database to retrieve eligible studies. Data range was restricted from 2013 to 2024 to capture the most current publications related to CDS systems. The original search was conducted on the 3rd May 2023. An updated search was then conducted on the 4th November 2024. Supplementary Appendix C outlines an example of our Medline, CINAHL and Scopussearch string.

2.4. Selection of sources of evidence

All search results were exported into Endnote 20 [14] and duplicates identified via Endnote were removed. The remaining references were imported into Covidence to conduct title and abstract, and full-text screening [15].

2.5. Title and abstract screening

Title and abstract screening was performed independently by two researchers (TJ and ABA) and conflicts were resolved through meetings until consensus was reached.

2.6. Full-text screening

Full text screening was performed independently by two researchers (TJ and ABA). Conflicts based on justifications for exclusions were discussed and resolved through meetings.

2.7. Data extraction and synthesis

Data were extracted using Microsoft Excel software. A template was created by two researchers (TJ and ABA) and pilot extractions was performed independently by both researchers with 20 % of the included articles. Following this, the researchers held meetings to review the data extracted for each articles. Discrepancies identified were discussed until consensus was reached. Thereafter, one researcher (TJ) extracted data from the remaining articles, while the second researcher (ABA) reviewed all data extractions for accuracy.. Data items were grouped into three categories: paper characteristics, interface design features, and other design features influencing acceptance of CDS systems. Paper characteristics included: author, country, study type (quantitative, qualitative, or mixed methods), data source (system data, survey, interviews, focus groups), clinician type (doctors, nurses, health professionals), CDS type (alert, dashboard, or both), CDS integration with a clinical information system (standalone or integrated), vital signs data entry approach (manual entry or continuous monitoring of vital signs), study phase (design, evaluation or implementation). Data items related to interface design features were separated according to CDS system type. Data items for dashboards were text-based information, display of hazard, colour, use of icons, display of information, layout, steps to access dashboard. Data items for alerts were layout of content, prioritisation, colour, text-based information, complete/relevant information, corrective actions. Other design features items which influenced acceptance of CDS tools were classified as facilitators or barriers.

Interface design features for alerts were categorised based on elements of the Instrument for Evaluating Human Factors Principles in Medication-Related Decision Support Alerts (I-MeDeSA) tool, while the interface design features of the dashboards were mapped to these categories, where possible [16]. We customised I-MeDeSA to identify elements which addressed the use of interface design features within alerts targeting clinical deterioration, as this tool is primarily used for medication-related CDS [15]. See Supplementary Appendix D for the application of this tool across alert and dashboard design. Other design features which influenced the acceptance of CDSS were presented narratively.

3. Results

3.1. Study selection

A flow diagram of the study selection process is displayed in Fig. 1. The database search from Medline, Scopus and CINAHL retrieved 923

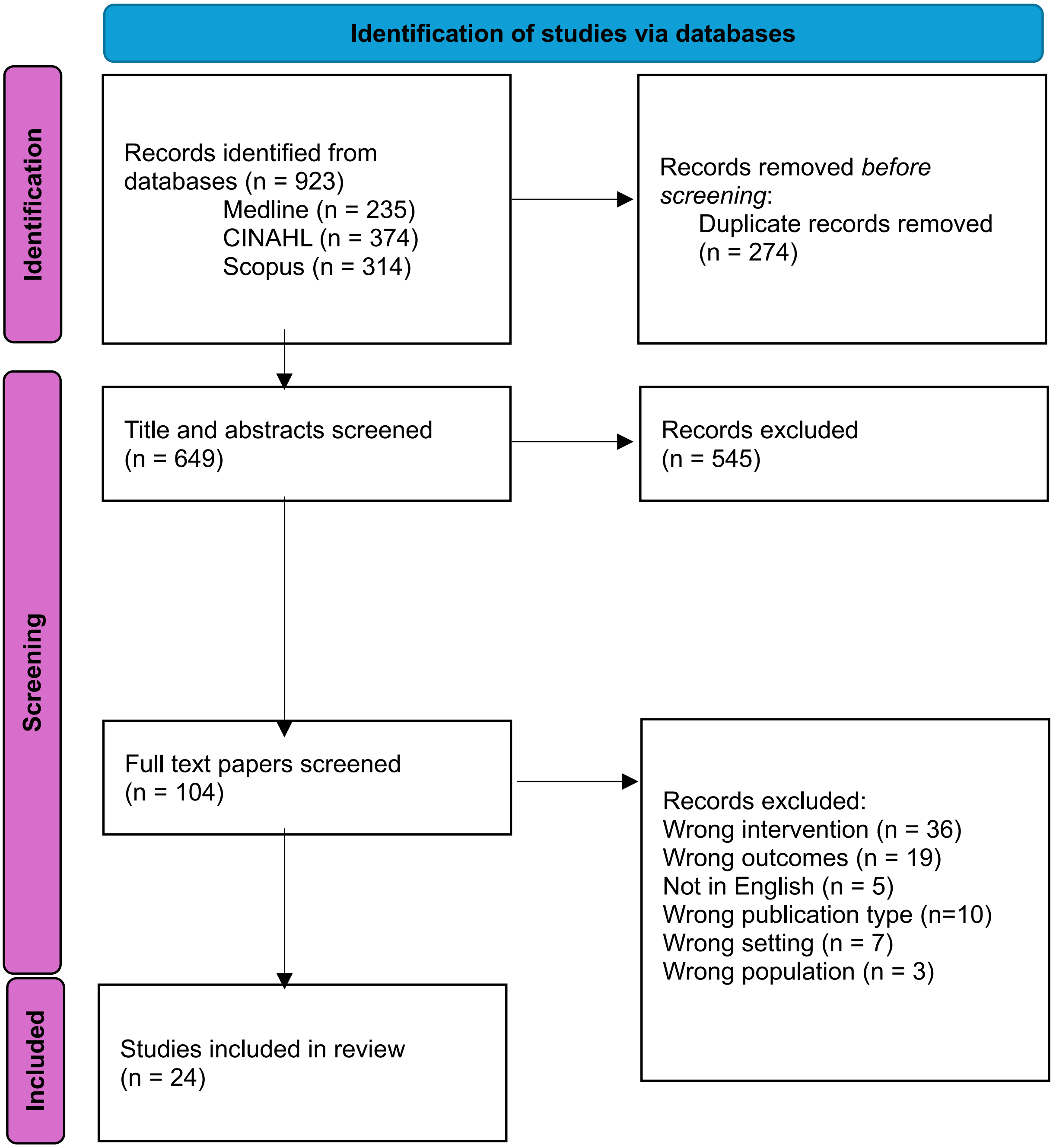

Fig. 1. Flow diagram of the study selection process.

studies. After title and abstract screening, 104 studies were eligible for full-text review. Of those, 24 studies met the inclusion criteria and were included for data extraction.

3.2. Study characteristics

Study characteristics are presented in Table 1. The year of publication ranged from 2017 to 2024, with most studies published after 2019 (n = 17). Two studies described the use of the same CDS system, resulting in 23 unique CDS systems described in the 24 studies [17,18]. Of the 24 studies, 42 % described dashboards only (n = 10), seven studies (29 %) described alerts only [19–25], and the remaining seven (29 %) described CDS systems that included both alerts and dashboards [17,18,26–30]. Most studies were conducted in a hospital setting (n = 15) and nearly all studies included doctors and nurses as their target audience [17]. Many studies were conducted in Europe (n = 8) or Asia (n = 6).

3.3. Interface design features of dashboards for real-time detection of deterioration

Interface design features of dashboards are presented in Table 2. Overall, the most frequently used interface design features were graphs (n = 7) and tables (n = 6). Of the 17 dashboards, vital signs were displayed solely in tables in three studies [29,31,32], in graphs (n = 2) [27,33] and as a numerical value (n = 1) [34]. A combination of interface design features to display vital signs were used in most dashboards, and these included graphs and tables (n = 2) [35,36] graphs and tiles (i.e. large numerical values representing vital signs in square-shaped boxes); (n = 2) [28,37], graph, tiles and tables (n = 1) [38],

Table 1
Paper Characteristics (n = 24).

Author and Year	Country	Setting	Study Type	Method	Target Audience for CDSS	CDS Type	Number of CDS Images
Ahmed *et al* (2022)	India	Hospital	Quantitative	Review of system data	Doctors	A and D	0
Alhmoud *et al* (2022)	United Kingdom	Hospital	Mixed-Methods	Interviews and review of system data	Nurses	D	1D
Bae *et al* (2020)	South Korea	NR	Quantitative	Survey	Doctors and Nurses	D	3D
Balamuth *et al* (2017)	United States	Emergency Department	Quantitative	Review of system data	Doctors and Nurses	A	4A
Braun *et al* (2022)	United States	Hospital	Qualitative	Focus groups	Nurses	A and D	0
Burns *et al* (2018)	United States	Hospital	Qualitative	Semi-structured interviews	Nurses	A	0
Carter *et al* (2022)	United Kingdom	Hospital	Qualitative	Survey	Allied Health Professionals, Doctors, and Nurses	A and D	0
Carter *et al* (2022)	United Kingdom	Hospital	Quantitative	Semi-structured interviews	Doctors and Nurses	A and D	0
Chua *et al* (2023)	Singapore	Hospital	Mixed-Methods	Interviews and survey	Nurses	A	0
Connell *et al* (2019)	United Kingdom	Two Wards	Qualitative	Interviews	Doctors and Nurses	A	0
Harsha *et al* (2019)	Canada	Hospital	Quantitative	Review of system data and survey	Nurses	A	0
Ibrahim *et al* (2020)	United Arab Emirates	Hospital	Quantitative	Review of system data	Doctors	D	2D
Kartika *et al* (2021)	Indonesia	One Ward	Quantitative	Review of system data and survey	Nurses	D	1D
Kazankov *et al* (2023)	United Kingdom	One Outpatient Clinic	Quantitative	Review of system data and survey	Doctors	A and D	2
Kuznetsova *et al* (2024)	United States	Hospital	Mixed-Methods	Observations, semi-structured interviews and review of system data	Nurses	A	1A
Lazzarino *et al* (2024)	United Kingdom	Hospital	Qualitative	Observations and semi-structured interviews	Doctors and Nurses	A	0
Leenen *et al* (2021)	Netherlands	One Ward	Mixed-Methods	Focus groups, review of system data, and survey	Doctors and Nurses	D	0
O'Brien *et al* (2020)	United States	Hospital	Quantitative	Review of system data	Nurses	A and D	1
Park *et al* (2019)	United States	Hospital	Quantitative	Review of system data	Doctors and Nurses	D	1D
Poncette *et al* (2020)	Germany	Hospital	Mixed-Methods	Interview and survey	Doctors and Nurses	A and D	0
Prutsachainimmit *et al* (2020)	Thailand	Hospital	Case Study	NR	Nurses	D	2D
Santos *et al* (2021)	United Kingdom	One Ward	Quantitative	Review of system data	Nurses	D	4D
Tan *et al* (2023)	Singapore	Hospital	Qualitative	Focus groups	Doctors and Nurses	D	2D
Tomasi *et al* (2020)	Canada	Hospital	Mixed-Methods	Interviews, review of system data, and survey.	Nurses	D	0

Note. A = Alert; CDS = Clinical Decision Support; D = Dashboard; NR = Not Reported.

and graphs and numerical values (n = 1) [39].

Many dashboards used numerical values, based on pre-defined thresholds, to signal deterioration (n = 10), with other studies using line graphs (n = 8), early warning scores (EWS) (n = 6), icons (n = 3) and bars (n = 1). EWS are numerical values which reflects a summation of weighted scores representative of vital signs [40]. Colour was used to signal the presence of deterioration in most dashboards in combination with other design features (n = 12), or solely used as a risk classification system in 10 studies. The traffic light colours (i.e. green, yellow and red) were used in half of the dashboards which used colour as a risk classification system (n = 5) with green as low risk, yellow as medium risk and red as high risk [26,29,32,36,39]. The remaining dashboards used unconventional colour-coding systems, with the inclusion of colours such as orange to signify medium risk of deterioration (n = 3) [33,34,38] and grey to signify low to no risk of deterioration (n = 2) [27,37]. An example of a dashboard that was reviewed is shown in Fig. 2.

3.4. Interface design features of alerts for real-time detection of deterioration

Design features of alerts are shown in Table 3. Of the seven studies which depicted the use of alerts, only three described their interface design features [17,19,24]. Colour, icons, and signal words were used in two alerts [19,24]. Colour was used to differentiate between alerts for CDS systems with multiple alert interfaces [19] and to signify risk of deterioration for those with a single interface [24]. Signal words such as 'Critical Advisory' [18] and 'Low' were also used to display risk of deterioration to clinicians [24]. Icons were used to visually describe a vital sign, such as a heart icon for heart rate, and lungs icon for respiratory rate [24]. Alerts displayed recommended actions and access to relevant information through hyperlinks [19] or through prompts which enabled access to pre-existing patient information [17]. Corrective actions included the use of action buttons of 'accept', 'stay', 'cancel' [19], 'save', 'clinical prompt acknowledgement' [17] 'suspend' and 'resume' [24]. An example of an alert that was reviewed is shown in Fig. 3.

3.5. Interface design features preferred by clinicians

Of the 24 CDS systems described in studies, five studies reported findings related to clinicians preferred interface design features. The interface design feature most frequently preferred was graphs, reported in four studies [17,20,33,38]. Clinicians' preferred method for signalling hazards was trends in graphs. For example, semi-structured interviews with nurses showed that graphs were seen to enhance nursing care as "*the trend lines give you a visual and you can see if the values are dropping or going up*"[16] and "*makes it easier… to consider whether the*

Table 2
Design features of dashboard interfaces (n = 17).

Author and Year	Number of Dashboard views*	Display of vital signs *Graph, table, numerical value, tiles*	Position of vital signs on screen	How hazard is signalled *EWS, numerical value, line graph, dot plots, icons, and whether they were coloured*	Risk classification system *What colour represents the level of risk?*	Use of EWS
Ahmed *et al* (2022)	NR	NR	NR	EWS (coloured)	• Green (Low risk) • Yellow (Medium risk) • Red (High risk)	Yes
Alhmoud *et al* (2022)	1	Graph and numerical value	Numerical values located above graph	EWS, line graph (coloured) and numerical value	• Green (Low risk) • Yellow (Medium risk) • Red (High risk)	Yes
Bae *et al* (2020)	2	View 1: Tiles View 2: Graph and Tiles	View 1: Multiple tiles across screen. View 2: Tiles on the right of graph	View 1: Icon (coloured) View 2: Line graph and numerical value	• Grey (No risk) • Green (one or more symptom of deterioration) • Red (chest x-ray abnormalities)	No
Braun *et al* (2022)	1	Graph	NR	Numerical value and line graph (coloured)	• Grey (Low risk) • Red (High risk)	Yes
Carter *et al* (2022)	NR	NR	NR	EWS	NR	Yes
Carter *et al* (2022)	NR	NR	NR	NR	NR	NR
Ibrahim *et al* (2020)	1	Numerical value	Numerical Values on the right of screen	Bars (coloured), line graph and numerical value	• Yellow (Low Risk) • Orange (Medium Risk) • Dark Orange (High Risk) • Red (Very High Risk)	No
Kartika *et al* (2021)	1	Table	Table at centre of screen	EWS and icon (coloured)	NR	Yes
Kazankov *et al* (2023)	2	View 1: Tiles View 2: Graph	View 1: Centre of screen View 2: NR	View 1: Numerical value View 2: Line graph	No	No
Leenen *et al* (2022)	NR	Graph	NR	Dot plot (coloured), EWS and numerical value	• Green (Low Risk) • Orange (Medium Risk) • Red (High Risk)	Yes
O'Brien *et al* (2020)	1	Table	Table at centre of screen	EWS and icon (coloured)	• Green (Low Risk) • Yellow (Medium Risk) • Red (High Risk)	Yes
Park *et al* (2019)	1	Graph and Table	Graph positioned on left and table on the right	Line graph	No	No
Poncette *et al* (2020)	NR	NR	NR	NR	NR	NR
Prutsachainimmit *et al* (2020)	1	Table and Graph	Table is at bottom of screen, Graph at top	Line graph and numerical value (coloured)	• Green (Low Risk) • Yellow (Medium Risk) • Red (High Risk)	No
Santos *et al* (2021)	3	View 1: Tiles View 2: Tiles and Graph View 3: Tiles, Table, Graph	View 1: Centre of Screen View 2: Tiles to the right, Graph to the left View 3: Tiles to the right, Graph to the left	Line graph (coloured) and numerical value (coloured)	• Yellow (Slightly High Risk) • Orange (High Risk) • Red (Very High Risk)	Yes
Tan *et al* (2023)	1	Table	Table with numerical values positioned on the right of screen	Numerical value (coloured)	• Green (Low Risk) • Yellow (Medium Risk) • Red (High Risk)	No
Tomasi *et al* (2020)	NR	NR	NR	Numerical value (coloured)	NR	NR

Note. EWS = Early Warning Score; NR = Not Reported; Tile = large numerical value of observations (e.g., temperature, oxygen saturation) in square-shaped boxes; *Views = the number of screens used in a dashboard.

trend actually deviates and promotes communication with the doctor"[16]. In a survey study, clinicians "*liked being able to see graphs as it shows trends easily*" [30]. Furthermore, survey responses highlighted that nurses were able to respond faster to deterioration and act earlier on vital sign trends and better monitor the effect of interventions on vital signs [33]. In another study, clinicians reported that their dashboard, with the inclusion of graphs and tables, was "*well received*", contributing to the uptake of the system [35]. Only one study described a disliked interface design feature, which was the use of EWS [20]. Semi-structured interviews revealed that users of EWS felt this feature was inadequate in signalling the presence of deterioration, with one participant stating that EWS was "*never enough*" to recognise clinical deterioration [20].

3.6. *Other design features influencing acceptance of CDSS*

In addition to interface design features, other design features, external to the interface, which influenced the acceptance of CDS were described in six studies. Three of these studies described the manual entry of vital sign data to be a design feature which decreased acceptance of CDS systems [18,31,41]. Participants in these studies expressed having difficulty populating vital sign parameters, saving vital sign data and performing data entry, which were reported to be time-consuming and tedious [18,31,41]. Continuous monitoring of vital signs, where data is automatically captured and fed into the CDS system, was reported to be a preferred CDS feature [42]. One study described how most participants in their study (65 %) agreed that the use of continuous monitoring allowed them to "*be more productive*" and that it was "*effortless use of technology*"[33]. Furthermore, most participants (76 %) in that study agreed with the statement of "*easily remembering how to use the continuous monitoring system*", signifying it was easy to learn and use [33].

Another design feature which influenced the acceptance of CDS was the frequency of alerts, known to result in 'alert fatigue', reported in five studies [23–25,30,33]. In a survey study, 93 % of participants agreed with the need for a "*reduction in alarm frequency*" for future patient

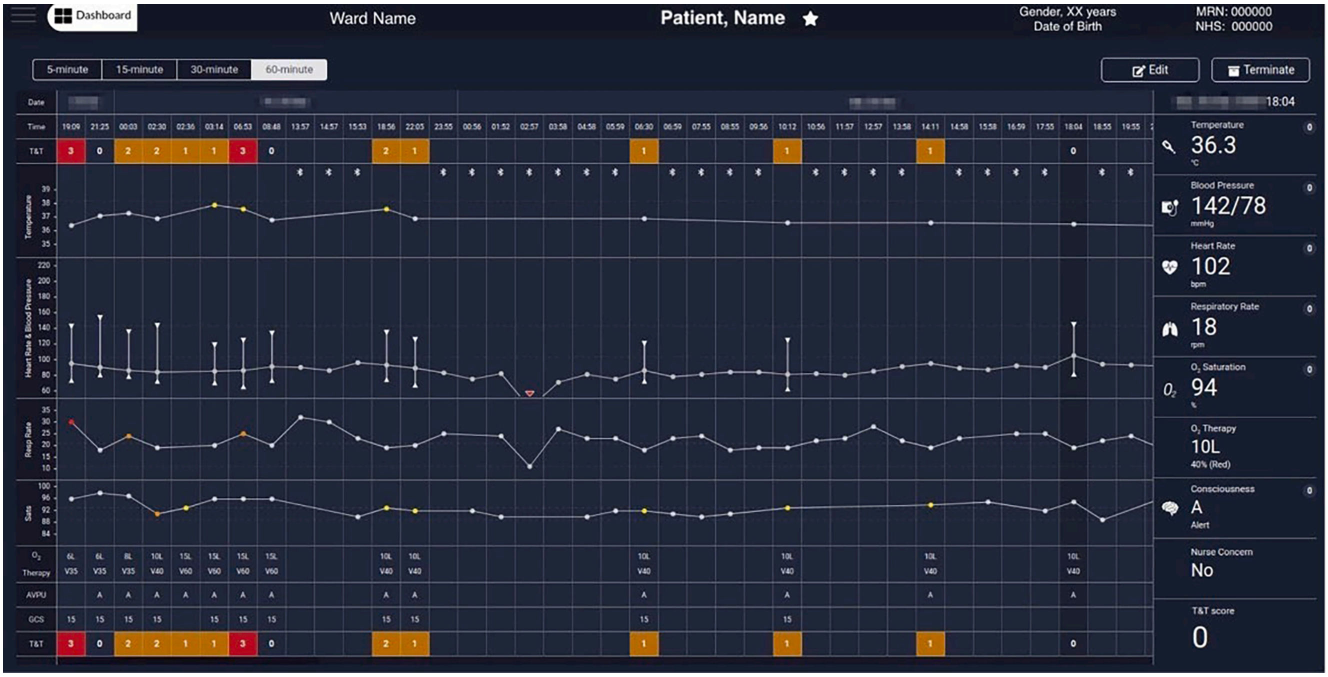

Fig. 2. Dashboard screenshot.
Screenshot of a dashboard's interface used for an ambulatory monitoring system to monitor COVID-19 patients. Interface design features found in this dashboard screenshot are; Tiles to display numerical values of vital sign data and graphs to display trends in vital sign derangement. Colour (red, orange and yellow) is used in the graphical display to represent and identify points in time in which the patient was at risk of deterioration. Colour (red and orange) is also used in highlight a number which reflect a patient's risk of deterioration. *Source:* Santos et al. [38].

Table 3
Design features of alert interfaces (n = 3).

Author and Year	Number of alerts	Layout of critical information (nature of hazard, risk to patient, recommended action)	How prioritisation is signalled	Use of colour	Text-based information (signal word, nature of hazard, recommended actions)	Complete/relevant Information	Corrective actions
Balamuth *et al* (2017)	3	1) Nature of hazard; First line 2) NR 3) Nature of hazard; First line, recommended action; centre of Screen	Colour, icon, signal word	Alert 1 = yellow, Alert 2 = purple, Alert 3 = red	1) No signal word, no recommended action, hazard was displayed 2) NR 3) Signal word: "Critical Advisory", hazard and recommended actions are displayed	Access to relevant information through hyperlinks	Action buttons include Accept, Stay and Cancel
Carter *et al* (2022)	NR	NR	NR	NR	Recommended actions: "Do you want to contact clinician?"	Access to 'Pre-existing risk information is displayed" through prompts	"Save" and "clinical prompt acknowledgement"
Kuznetsova *et al* (2024)	1	Nature of hazard; First line, risk to patient; second line. No recommended action	Colour, icon, signal word	Yellow	Signal word: "Low"	NR	"Suspend" button used to silence alarm for 15 min. "Resume" button used to resume vital sign monitoring

Note. NR = Not Reported.

monitoring [27]. Furthermore, a randomised controlled study explored the implementation of continuous monitoring of vital signs and wireless clinician notifications, and found that 31 % (318/1030) of patients experienced at least one false alarm [22]. These false alarms resulted in notifications being sent to the nursing staff, which ultimately disrupted clinician workflow [23]. False alarms in another qualitative study were mainly attributed to the oversensitivity and specificity of alerts, which was seen to potentially lead to over-triaging of patients or alerts being overridden and ignored [25]. One survey study also reported that the use of alerts was not the most preferred method of detecting deterioration, as clinicians conveyed preferences for continuous monitoring of vital signs via trend assessments and EWS [30]. Despite raised concerns of alert fatigue in pre-implementation interviews, in post-implementation interviews participants described infrequent alarms, reporting limited disruption to clinician workflow [24].

4. Discussion

This scoping review identified 24 studies that described design features of CDS systems used by clinicians to detect deterioration in real-time in hospital settings. Dashboards and alerts were primarily implemented, and targeted doctors and nurses. The most common interface design features of dashboards were graphs and tables, with clinicians preferring trends in line graphs than the visual comparison of bar and

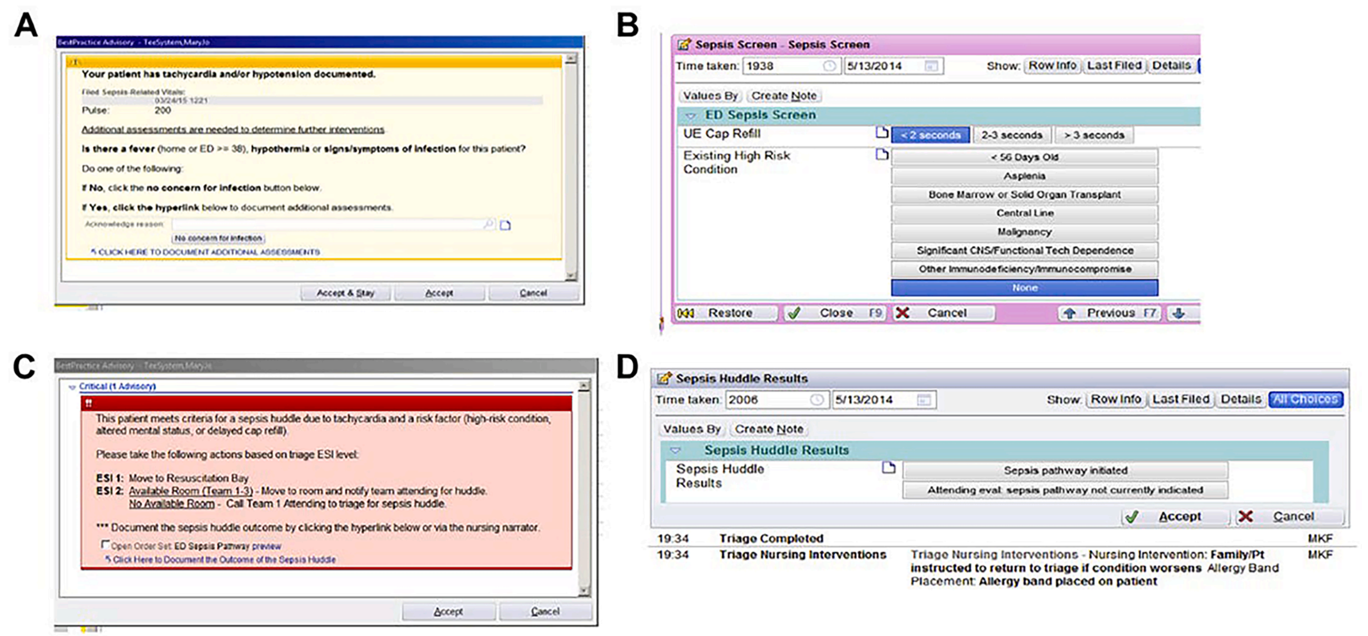

Fig. 3. Alert screenshot.

Screenshot of multiple alert interfaces used for detection of paediatric sepsis in an emergency department. Interface design features found in this screenshot are; 1) Layout of critical information is shown through nature of hazard 'Your patient has tachycardia and/or hypotension documented' in A, risk to patient 'this patient meets criteria for a sepsis huddle due to tachycardia and a risk factor (high-risk condition, altered mental status, or delayed cap refill)' in C and recommended action 'Please take the following actions based on triage ESI level' in C. 2) Prioritisation is signalled through colour (yellow, purple, red), icons (warning sign in A and exclamation points in C) and signal words ('Critical Advisory' in C). 3) Complete/Relevant information can be accessed via a hyperlink 'CLICK HERE TO DOCUMENT ADDITIONAL ASSESSMENTS' in A. 4) Correction action buttons such as 'Accept and Stay', 'Accept' and 'Cancel' are shown in A. *Source:* Balamuth et al. [19].

column graphs. Clinicians preferred a combination of graphs and tables in their interface display, to graphs or tables alone. Only three studies reported interface design features of alerts, and these included the use of colour, icons and signal words, as well as recommended actions through hyperlinks and prompts. Other design features which influenced the acceptance of CDS were automatic data input, continuous monitoring of vital sign data, and low numbers of alerts.

Line graphs were the most reported interface design feature in our study, found in eight of the nine dashboards which included graphical display of vital sign data. Line graphs highlight individual values and emphasise patterns or trends in the data while bar graphs only emphasise comparisons [43], making it unsurprising that line graphs were perceived as more useful for detecting deterioration. This finding is consistent with those from a recent comparative usability evaluation, where participants preferred a trended risk (line) graph in a predictive CDS model, rather than a single time point risk value [44]. However, line graphs alone have been reported to be insufficient to effectively present patient state and support decision making, with clinicians finding a combination of graphical and tabular presentation of data to be more useful [45]. Tables may be beneficial when it is imperative to search for individual values or when precision is key, while graphs may be beneficial when the information to be displayed lies in the patterns, trends and exceptions of the data [43]. This may explain why our study revealed a combination of graphs and tables to be preferred by clinicians than each feature alone.

Colour-coded schemas signalling the presence of deterioration were the most frequently reported interface design feature in our study. This aligns with existing literature as a systematic review reported that 80 % of general dashboards used colour as a visual variable to encode and categorise data [46]. We found a wide range of variability in colour-coding schemas used in included papers. Whilst half of the dashboards used traffic light colours (red, yellow, green), the other half used unconventional colour-coding schemas (e.g. orange, grey). Red was the most consistent colour used in dashboard design to indicate 'high risk', displayed across all dashboards, likely because this colour captures attention and is frequently associated with danger and risk [46]. However, dashboards which used an unconventional colour-coding schema displayed colours such as orange to indicate 'medium risk' [33,34,38] or 'high risk' [36] and grey to depict 'low risk' or 'no risk' [27,37]. The prompt recognition of colour transition is particularly important when detecting deterioration as change in colour may reflect a change in patient state. A comparative usability study on nurses preferences for risk information visualisation designs revealed that many of their participants did not initially notice a change in colours [44]. Our study adds to this work and calls for further research to guide future CDS system designs to better support timely detection of clinical deterioration by using consistent colour-coding schemas and ensuring colour transition can be clearly recognised.

In our review, alerts were less frequently described than dashboards for detection of deterioration in real-time. Although half of the studies we identified described the use of alerts (or combination of alerts and dashboards), only three reported on their interface design features [17,19,24]. Consistent with the literature [44], colour and icons were used to signal prioritisation in the alerts described in the two papers, but effectiveness of these design elements is not known. Although the use of alerts is common for real-time detection of clinical deterioration, our review shows that there is little evidence available on their interface designs and their impact on clinician acceptance and uptake. We also identified alert fatigue, a consequence of high volumes of alarm sounds or alerts, [47] to be a barrier to acceptance of CDS systems in five papers [21–23,28,31], highlighting the complexity of getting alerts right in practice. In addition, manual data input emerged as a key barrier to acceptance of CDS systems for detecting deterioration [17,30,40], revealing the need for interoperable systems to enable automatic data capture and ease of use. This finding is consistent with the literature, with one study, with limited description of their CDSS, reporting that automated documentation of vital sign measurement reduced workload in clinicians and decreased their levels of frustration [48]. These findings therefore indicate a need for the redesign of deterioration alerts based on interoperable clinical information systems to improve clinician uptake, minimise alert fatigue and support the timely detection of clinical deterioration.

The CDS tools identified in our scoping review were heterogeneous in their design. In dashboards, variability was found in graphical and tabular display, colour-coding schemas, and number of design features. This variation may be due to a lack of guidelines to inform interface design features. Although there are some proposed guidelines for information visualisation of data which may be used in dashboards outside of a healthcare setting [49], currently there is limited guidance available for selecting interface design features specifically for dashboards used in detecting deterioration. Guidelines to inform design of paper-based observation charts are available, with the development of Between the Flags (BTF) in hospitals in New South Wales (NSW), Australia [50]. The Clinical Excellence Commission (CEC) produced recommendations from evidence-based research, which became the foundation for the design of paper-based observation charts, and later electronic BTFs, for detecting clinical deterioration across all NSW hospitals [50,51]. However, similar guidance for selecting interface design features specifically for computerised dashboards used for detecting deterioration remains limited. This suggests the need for interface design guidelines to support consistent and bed-practice design of CDS tools for detecting clinical deterioration.

In addition to the lack of guidelines for design of CDS tools for detecting deterioration, our review highlighted inconsistent and inadequate reporting of the design features in papers, why they were selected, clinician uptake of the CDSS, and the impact of the interface design on both clinician and patient outcomes. The CONSORT-EHEALTH extension was published in 2011 as a checklist to provide guidance in reporting electronic health interventions such as CDS systems, and does specify a requirement to describe interface design principles for CDS interventions [52]. Although most studies in our scoping review included screenshots and images of their dashboard design, limited studies described their interface design features and little to none explained the rationale for why those design features were selected. This was also the case for alerts for detecting deterioration, as only two studies included screenshots of their alert interface, and provided limited description of the interface design and the supporting rationale for the included design features. Our findings call for greater adherence to the existing reporting checklists.

5. Limitations

Quality assessment of included papers was not conducted, in line with PRISMA-ScR reporting guidelines for scoping reviews. We acknowledge that our review commenced from 2013 to capture the latest evidence. Consequently, design and clinician preferences from antiquated CDS systems may have been missed. When applying the I-MeDeSA tool to classify alert design features, difficulties were encountered in assigning data to certain principles due to the lack of information included in papers on alert interface designs. Although we used this tool in classifying alert interface design, we also encountered difficulties when using it for classification of dashboard interface design, given the tool's focus on alerts. Furthermore, the I-MeDeSA tool was designed to evaluate drug-drug interaction alerts, not alerts used to detect deterioration [16], however, we could not identify any other available tools for classifying alert elements.

6. Conclusion

Our scoping review identified 24 studies that described the design features of 23 unique CDS systems for real-time detection of clinical deterioration in hospitals. Dashboards, displaying graphs and tables, and alerts, including colour, icons and signal words, were primarily implemented to support detection of deterioration. Our review uncovered wide variability in the design of CDS systems and poor reporting of interface design features making it difficult to ascertain why designs were used. To improve future designs of CDS systems for detecting deterioration, we recommend the development of design guidelines for CDS systems, further research on the design and evaluation of CDS, and better reporting of this research to enable optimal design elements to be identified.

7. Summary Table

What was already known on the topic	What this study added to our knowledge
• Clinical decision support (CDS) tools can assist in timely detection of clinical deterioration. • CDS tools monitor vital signs and alert clinicians when risk of clinical deterioration is high. • CDS uptake by clinicians is often poor due to factors like workflow disruption, poor design, and usability issues.	• CDS tools used for clinical deterioration mostly take the form of dashboards • The most frequently used interface design feature in dashboards is colour for risk classification. • Clinicians prefer trends in line graphs than the visual comparison of bar and column graphs • Design factors external to the interface such as high alert volume, alert fatigue, and manual entry of vital sign data can deter clinicians from using CDS systems

8. Contributorship

ABA and MB contributed to the conception and design. TJ and ABA, with assistance from an academic liaison librarian, developed the search strategy. TJ conducted the database searches. TJ and ABA conducted title/abstract and full-text screening. TJ and ABA conducted data extraction. TJ, ABA and MB conducted data analysis and interpretation of the results. TJ wrote the initial draft and ABA and MB provided critical review. All authors approved the final version for publication.

CRediT authorship contribution statement

Tamasha Jayawardena: Writing – review & editing, Writing – original draft, Visualization, Project administration, Investigation, Formal analysis, Data curation. **Melissa Baysari:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Adeola Bamgboje-Ayodele:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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