

Don't set and forget: Optimising Digital Early Warning Tools through upgrade and evaluation

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Abstract

Objective

Digital early warning tools (DEWTs) use clinical information and models to assist in early detection of clinical deterioration. Just like the ever-changing landscape of best practice guidelines and clinical workflows, DEWTs require active monitoring and intervention to remain current. This study aims to answer the research question “What are the issues experienced by clinicians and users with a Digital Early Warning Tool?”.

Methods

We studied 15 public hospitals in Australia, pre- and post-DEWT upgrade. The upgrade included changes to graphical views, altered calling criteria (ACC) and recording changes in mental status. We conducted a mixed methods study, including stakeholder focus groups, surveys, and quantitative system use metrics.

Results

Stakeholder focus groups and surveys identified a lack of awareness of specific functionality, issues with alert fatigue, technical challenges with the system, the need for training and concerns around over-reliance on the system by junior staff. System usage metrics revealed vital sign compliance and graphic-view-page usage increased post-upgrade. The number of chronic ACC reduced significantly post-upgrade; while compliance with early warning score generation increased significantly for acute ACC cases. Changes in mental state documentation reduced post-upgrade.

Conclusion

DEWTs have potential to improve patient outcomes through enhanced surveillance, timely recognition of deterioration, and improved vital sign monitoring. Ongoing training, monitoring and evaluation post-implementation are key to ensure these systems continue to function as intended. Given the substantial resources invested in DEWTs, research is needed into how health services can incorporate continuous auditing and feedback to ensure clinical effectiveness and safety over time.

BACKGROUND

Clinical decision support systems are widely used in healthcare to support clinicians in their decision-making processes. Within electronic medical records, a clinical decision support system will match individual patient characteristics to a computerised clinical knowledge base to generate patient-specific assessments or recommendations at the point of care [1]. One type of decision support system used in acute care settings are early warning tools (EWTs) which assist in early detection of clinical deterioration

and identify patients at risk of an adverse event. These systems utilise clinical information such as vital signs along with statistical models and rules to create an early warning score (EWS) indicating the risk of an adverse event [1, 2]. EWTs then trigger an alert that prompts clinicians to monitor and respond in a timely manner, enabling intervention before deterioration progresses to serious outcomes such as cardiac arrest or the need for intensive care [3–5]. EWTs can be implemented as paper or digital tools and use a variety of models and criteria [5–10].

EWTs have been shown to improve health outcomes [11, 12], however, there are also challenges in implementing and using these systems [13]. Users report limitations relating to areas such as data collection and quality [14, 15], lack of training [13], alert fatigue [16] and competing priorities [13]. As systems become increasingly digital, consideration must also be given for the human-computer interactions which influence both acceptance and functionality over time [17]. EWTs are likely to be more effective if they are developed in conjunction with users and organisational decision making processes [18]. While systems may incorporate user input at design stage, monitoring their usage post-implementation and ongoing is equally important, but is a less common practice [19, 20]. Just like the ever-changing landscape of best practice guidelines and clinical workflows, EWTs require active monitoring and intervention to remain current and useful in clinical practice [19].

OBJECTIVE

Given the need to understand how health care workers use digital EWTs (DEWTs) over time, to ensure continued effective functioning from technical, organisational and user perspectives, we studied 15 public hospitals in Australia, pre- and post- a DEWT upgrade. We aimed to conduct a mixed methods study, combining information from user focus groups and surveys, as well as quantitative system use metrics pre- and post-upgrade, to answer the research question “What are the issues experienced by clinicians and users with a Digital Early Warning Tool?”. We hypothesised that the DEWT upgrade would address existing issues experienced by users, while other challenges would remain pervasive. We also hypothesised that this study would elucidate new unanticipated usage challenges introduced by the system upgrade.

METHODS

Setting

The study was conducted within the public hospital setting across the state of Queensland, Australia. Queensland has a population of ~ 5.2 million and has the second largest land size of Australian states. This study considered 15 digital hospitals across the state (12 metropolitan and 3 regional sites [21]) ranging in size and acuity, from a small 28-bed facility to a large 1070-bed facility. All digital facilities share a single instance electronic medical record (EMR) and manage their National Safety and Quality

Health Service Standard (Recognising and Responding to Acute Deterioration) [22] via vendor-specific Managing Deterioration Digital Early Warning Tools (DEWT).

The DEWT has many features, including an EWS, which is calculated for each patient; as a patient's EWS increases, it is recommended to increase the frequency of patient observations and escalation to a more senior clinician. There is a managing deterioration graph-view page, which is a custom developed view where users can enter and interact with information visually (Fig. 1), in accordance with National Safety and Quality Health Service Standard requirements [23]. Authorised users can modify the typical parameters for escalation of abnormal vital signs, for the entire encounter (chronic conditions), or for a limited period (acute conditions), known as an altered calling criteria (ACC).

On 26–27 July 2023, the DEWT undertook a significant upgrade, following extensive engagement and collaboration between clinicians, health informaticians, human factors experts, and solution architects. The purpose of the upgrade was to assist clinicians with more robust early warning charts and workflows, improving visibility of a patient's physical, mental, and cognitive deterioration. Key updates included:

- Optimise clinical alerts (i.e., wording standardisation, more clinically informative, reduce unnecessary clinical alerts to reduce alert fatigue).
- Offer additional functionality to the Managing Deterioration graph-view page.
- Split out acute ACC from chronic, and introducing a 6-hours limit for acute ACC (previously ACC under 24-hours were assumed to be acute), and mandatory 1-hourly observation frequency.
- The AVPU (Alert, Verbal, Pain, Unresponsive) field changed to CAVPU (Changing Behaviour, Alert, Verbal, Pain, Unresponsive), the additional field allows clinicians to record any Changing Mental Behaviour or New Confusion observed in their patients.
- The introduction of new specialty charts, for example a Chronic Respiratory Adult chart with modified SpO2 scoring thresholds.
- Oxygen therapy table updated with relevant observation inclusions and label updates.

Study design

This system upgrade provided a 'natural experiment' from which to study the impact of the different features of the DEWT. We conducted a mixed-methods study comprised of three sub-studies, as described in Fig. 2. Ethical approval for this project was granted by the Metro North Health Human Research Ethics Committee (HREC) A (EC 00172).

Participants and recruitment

Stakeholder focus groups

Participants were eligible for recruitment if they were a member, or were nominated by a member, of an existing state-wide governance group for DEWTs, and work within a digital hospital using the DEWT. During the pre-upgrade period, only participants not yet exposed to the upcoming changes were asked to express their interest. Participants had the ability to volunteer for both the pre- and post-upgrade focus groups if eligible. Individuals unable or unwilling to complete the online consent form were excluded from the study. Voluntary participation in the focus groups was via self-selection. Due to the targeted approach of this research project, purposive sampling was used to identify participants. Emails were sent, containing an embedded link to the research participation consent form and short demographic survey. Participants were invited to attend a focus group via videoconferencing. Those who responded to the expression of interest were contacted directly to participate.

Survey of frontline clinicians

Participants were eligible to complete the survey if they were a health professional representing the clinical workforce from one of the study sites who had experience working with DEWT post enhancements. Voluntary participation in the survey was via self-selection. Due to the targeted approach of this research project, purposive sampling was used. Emails were sent, using nominated emailing lists and contained an embedded link to the survey. Digital recipients of the survey were encouraged to “snowball” the survey by distributing the link to personal contacts.

System usage measures

Routinely collected data related to patients whose treatment triggered an EWS were accessed via a centralised statewide database. A waiver of consent was granted by the ethics committee.

Data collection

Stakeholder focus groups

The semi-structured interview guide (Supplementary materials 1) contained questions pertaining to impressions of the DEWT, how the DEWT has affected practice and desired changes to the DEWT. Participants were invited to one focus group of up to 60 minutes, with two interviewers (JA, JL) and up to five participants present. Interviewers were a researcher with post doctorate qualifications and a research assistant with subject matter expertise in the DEWT; they had no prior relationship with the interviewers. Focus groups participants were notified the sessions were video recorded via Microsoft Teams. A digital transcription service supported transcribing, and the resultant transcripts were corrected and anonymised by one interviewer (JA). Transcripts were not returned to participants for comment or correction to assist with maintaining anonymity of focus groups members. No repeat interviews were conducted, and no field notes were made during or after focus groups.

Survey of frontline clinicians

The survey (Supplementary materials 2) was created and disseminated via the secure Qualtrics platform throughout March and April 2024. Basic demographic and work experience information was captured in a non-identifiable manner. The survey included a mix of questions relating to DEWT, including free-text responses and ranking responses via a 10-point Likert-type scale, with the option to state 'no opinion'. All survey data was stored, securely encrypted within Qualtrics.

System usage measures

A list of relevant system usage metrics was compiled by clinical subject matter experts (Supplementary materials 3). Data were accessed by a hospital employee via a centralised statewide database which contains clinical information from the EMR. Multiple bespoke Structured Query Language (SQL) queries were run to obtain data relating to the metrics. The pre-upgrade period spanned 12-months prior to upgrade (August-2022 to July-2023), and 12-months post-upgrade (September-2023 to August-2024), excluding August-2023 as a washout period. Note that for one metric (graph-view page views), data access limitations meant that the pre-upgrade period was only 8-months (January – August 2023) and included the wash-out period.

Data analysis

Stakeholder focus groups

The analysis was carried out using the Braun and Clarke method [24] to identify and analyse common themes across the focus groups. NVivo software version 12 was used to assist in the analysis, using a mixed inductive-deductive approach. The first two transcripts were coded inductively, independently by two researchers (JA, JL), through identification of recurring ideas, to organically derive preliminary codes from the data itself. Then, in a deductive approach, data from the remaining transcripts was applied to the preliminary codes to create a working theoretical framework. Any data that did not fit into the preliminary codes formulated a new code. Codes were discussed iteratively at each stage between the two independent researchers (JA, JL) and final codes were agreed upon by consensus. The final categories and codes were then applied deductively to the Knowledge-Attitudes-Practice (KAP) framework [25] to identify the stakeholder knowledge, attitudes and practices around the DEWT.

Survey of frontline clinicians

Survey responses from Qualtrics were analysed in Microsoft Excel. Descriptive statistics were used to report on quantitative data. Free-text results were thematically analysed by one researcher (JA) using an inductive-deductive approach and then presented back for comment by additional members of the research team (JL, VC, NM).

System usage measures

Metrics were calculated for the pre- and post-upgrade periods. We employed a Quasi-Poisson interrupted time series (ITS) design using segmented regression to evaluate the impact of upgrade on system usage measures. The model included terms for time, a binary indication for the intervention period, and an

interaction term to estimate changes in slope post-intervention. To account for variation in the number of days per month, we included an offset term equal to the natural logarithm of the number of days in each month. Pre-intervention trend stability was tested using generalized empirical fluctuation process based on a Quasi-Poisson regression. Autocorrelation was checked and accounted for if present. Rate ratios (or relative risks) and 95% confidence intervals comparing the two periods were derived from the ITS model. Proportions were compared using the Chi-squared test.

RESULTS

Stakeholder focus groups

Twenty-two participants (nursing and medical staff and patient advocates) were involved in eight focus groups, split evenly pre-and post-upgrade. Of these, two participants were involved across both the pre-and post-upgrade focus groups. An additional 11 individuals were enrolled but dropped out of the study (5 no-shows, 1 sent a substitute, 5 gave no reason). Themes and illustrative quotes are included in Supplementary materials 4.

Knowledge

The Knowledge themes were similar pre- and post-upgrade. The workforce highlighted the lack of awareness of specific functionality in the DEWT relating to the managing deterioration graph-view page and how to recognise when an ACC was in place. Pre-upgrade, suggestions were made regarding optimal training strategies which included consistent workflows, 'on-the-job' support and supporting critical thinking to minimise loss of foundational clinical knowledge. Post-upgrade the need for ongoing, re-education was identified, as was a more targeted focus on the input of appropriate clinical documentation removing the need for contemporaneous documentation of clinical observations and measurements that are captured elsewhere in the integrated electronic medical record (ieMR).

Attitudes

The workforce identified both pre- and post-upgrade certain aspects of DEWT functionality that are not suitable in all clinical settings. Pre-upgrade it was flagged that the EWS was not appropriate in a chronic disease setting. Post-upgrade the addition of the chronic respiratory chart was reported to have made a positive impact. However, graphing on the managing deterioration graph-view page was still not suitable in an outpatient setting and workarounds were routinely used, for example day therapy units used different encounters which required the data to be retrieved from other areas of the ieMR. In terms of the volume of pop-up alerts received, the overwhelming response pre-upgrade was that the volume of alerts was excessive. Post-upgrade, whilst comments were made echoing the ongoing issue with the volume of alerts, others were more neutral or positive, deeming the current volume of pop-up alerts manageable. Post-upgrade, comments surrounding enhanced usability of the system were reported, including being visually easier to read, faster to use and less room for error, whilst others still noted the difficulty at times in understanding how an EWS had been generated.

Practice

Some practices were consistent pre- and post-upgrade, suggesting that these DEWT practices related to the tool as a whole and not specific to system optimisation. There was a consensus that DEWT provides an outlet to prompt for escalation. The workforce flagged issues with the EWS not triggering due to the need to enter all parameters which is not always conducive to clinical workflows. Post-upgrade the workforce noted positive impacts on patient outcomes, specifically surrounding the addition of 'C' (Confusion) to the pre-existing 'AVPU' (Alert, Voice, Pain, Unresponsive) functionality. Others were neutral to the impact of the DEWT-upgrade on patient outcomes, and one reported detrimental effects related to EWS not triggering. Concerns were raised for the digital DEWT functionality 'dumbing down' the workforce. Pre-upgrade it was noted that the alerts may differ from clinical judgement, and post-upgrade the workforce flagged concerns with overreliance by junior staff.

With regards to process and procedures, pre-upgrade there were several reports of workarounds in place. ACC were adjusted to get a desired EWS to assist with discharge or ward transfer based upon local policies and procedures, deviating from best intended use and potentially introducing patient risk. Post-upgrade, positive comments were made around the impact to the Medical Emergency Team (MET) call process, whilst others were neutral to the change in processes resultant from the DEWT upgrade. Negative comments surrounded internet connectivity and the impact this has on entering vital signs simultaneously into the ieMR, impacting the ability for an EWS to trigger.

Survey of frontline clinicians

A total of 167 responses were received, 32 responses were excluded due to incompleteness, resulting in 135 responses for analysis, see Table 1.

Table 1
Frontline clinician post-upgrade survey respondents

Work setting*	n	%
Inpatient - Adult	85	63%
ED - Mixed	17	13%
ICU/ICU consults/MET	16	12%
Other	55	41%
Clinical role		
Registered nurse (RN) / Registered midwife (RM)	58	43%
Clinical nurse (CN)	32	24%
Clinical nurse consultant (CNC) / Nurse Unit Manager (NUM)	15	11%
Senior medical officer (SMO) – Experienced non-specialist doctor	10	7%
Other (e.g. Assistant in nursing (AIN), Director of Medical Services, Nurse Practitioner)	20	15%
Clinical experience		
< 1 year	3	2%
1–5 years	31	23%
6–10 years	29	21%
> 10 years	72	53%
Frequency of documenting vital signs in the EMR		
At least daily	89	66%
At least once per month	20	15%
Less than once per month	26	19%
Frequency of using managing deterioration page to view graphical trends		
Rarely	42	31%
Sometimes	32	24%
Most times I view the patient's chart	20	15%
Every time I view the patient's chart	20	15%
Only when I'm concerned / informed the patient is deteriorating	18	13%

Work setting*	n	%
Only at the patient's bedside on ward rounds	3	2%
Under normal circumstances, how would you describe your ability to manage the level of patient alerts^		
Easy: I can always manage	32	37%
Mostly easy: Only rarely to I find it difficult to manage	38	44%
Moderate: I frequently find it difficult to manage	12	14%
Hard: I usually find it difficult to manage	1	1%
Very hard: I always find it difficult to manage	3	3%
How frequently are you unable to complete alert activities for patients because of other priorities^		
Never	16	19%
Rarely	23	27%
Sometimes	24	29%
Often	15	18%
All the time	6	7%

* respondents could choose more than one option

^ missing responses removed

Gaps in integrating the Managing Deterioration graph-view page into clinical workflows was identified with respondents indicating they 'rarely' or only 'sometimes' use it, 31% and 24% respectively. The DEWT upgrade changes deemed most useful by respondents included the acute ACC being split out from chronic (n = 21, 16%), the new oxygen therapy separating FiO2 and L/min (n = 21, 16%), addition of 'C' (changing behaviour/new confusion) to 'AVPU' (alert, verbal, pain and unresponsive) assessment to contribute to the score (n = 20, 15%) and the EWS now graphed and visible on the Managing Deterioration graph-view page (n = 20, 15%), refer Fig. 3.

With regards to managing patient alerts and notifications, most respondents felt it was 'easy' (24%) or 'mostly easy' (28%) to manage. When asked to comment on what could be improved with the system (Table 2), a key theme was the desire for less pop-up alerts to reduce alert fatigue. Whilst the responses were varied, most respondents appear to be able to complete activities for patients alongside their existing tasks and workloads, with 18% of respondents 'sometimes' unable to complete activities for

patients because of other priorities. This was followed by 17% who were ‘rarely’ unable to complete activities, and 12% who were ‘never’ unable to complete activities for patients due to other priorities.

Table 2
Key themes emerging from free-text survey question “What could be improved?”

Key theme	Illustrative quote
Remove 6-hour limit to the acute ACC	“Remove the 6hr limit to acute ACC. We need to be able to alter them at least for overnight without a spurious mandatory-MET happening at 0200 because they expired. If a limit is absolutely unavoidably critically necessary, set it to 24hrs at minimum”
Quicker loading times needed	“Improve loading times. By my estimate, these have roughly tripled since the prior system and take significant time on ward rounds to load it then load it again after changing to a more suitable time display...”
Less pop-ups to reduce alert fatigue	“I find for our staff that the volume of alerts makes them click very quickly through alerts, so making important alerts that they really need to do something about eg. EWS of 6 and expected interventions should look different to the alert that pops up when the patient scores a 1. That would help staff to view the contents of the box as more important than just another pop-up...”
Need to simplify input of information and navigation	“Keep ieMR simple. Too many boxes to tick on certain tasks. Some things could be removed off main screen to simplify...”
Need the ability to adjust oxygen targets	“We are now unable to make any modifications to SpO2 other than "target > 92" or "target 88–92 permanently". Limiting the system to only allow for 2 options is incredibly clinically inappropriate and needs to be rectified...”
Improve on education	“Clinical education for detecting SIRS/Sepsis without the tool. The tool is literally a life saver for when staff miss the early signs, but it should be a fail safe, not a primary tool. Staff need more education on physical, hands-on assessment as well as vital sign surveys. Comprehensive patient examination extends far beyond a set of vitals...” AND “Education regarding updates and how to utilise new updates”

System usage metrics

System usage metrics are summarised in Table 3. There was a significant 3.7 times increase (95% CI: 3.68, 3.70) in views of the Managing Deterioration graph-view page post-upgrade. However, it is still only viewed in less than 2% of EWSs. Overall, the rate of EWS alerts per encounter was constant pre- and post-upgrade. However, there was a slight change in the distribution of EWSs. There was a small increase in the proportion of EWSs generated in alignment with EWS-based recommended frequency post-upgrade (RR = 1.03, 95% CI: 1.02, 1.05), this was most pronounced in EWS 6–7 (1.07 (1.04, 1.10)).

Significant changes were also observed in ACC episodes, with a statistically significant reduction in the number of chronic ACC episodes (RR = 0.22 (0.14, 0.34)). This is likely driven by the introduction of the ACC respiratory chart view, which was viewed 5,347 times post-upgrade, and removed the need to alter the calling criteria of patients with chronic respiratory disease to account for their usual respiratory status. We found that there were significantly less gaps of 60/90/120 minutes between EWS generated when acute ACC is in place, demonstrating higher rates of compliance with requirements to generate hourly EWS for acute ACC.

Pre-upgrade, clinicians used a drop-down to indicate a change in the patient's mental state, however this did not impact the EWS; post-upgrade, a new field for Changing Behaviour was added to the AVPU neurological state assessment, which contributed to the EWS. We compared the total number of mental state change records (which incorporates the pre- and post-upgrade methods) and found a significant reduction in the rates of mental change recorded per encounter (RR = 0.77 (0.76, 0.77)) post-upgrade. We used 2 indicators of actioned response to the recording of a mental state change, a) increased observation frequency due to an increase in EWS, and b) urine Microscopy, Culture and Sensitivity (MCS) to investigate for new delirium. When we restricted the analysis to the number of mental state change records with at least 1 follow up EWS within 90 minutes, we also observed a reduction in the rate per encounter post-upgrade (1.5 vs. 1.3; RR: 0.81 (0.80, 0.83)). This was also true for ordering Urine MCS within 4 hours of the first mental state change recorded in each admission, which reduced from 9% pre- to 7% post-upgrade ($p < 0.001$).

Table 3
System usage metrics

Measure	Pre-upgrade	Post-upgrade	Rate ratio ² / Relative risk ³ (95% CI)
Graph-view page views^{1,2}			
Views per month	108,095	398,897	3.69 (3.68, 3.70)
EWS alerts per encounter²			
All	10.8	10.9	1.02 (0.97, 1.07)
EWS 0	6.9	7.3	1.08 (1.04, 1.12)
EWS 1–3	7.1	6.7	0.96 (0.92, 1.00)
EWS 4–5	3.0	2.8	0.93 (0.87, 0.98)
EWS 6–7	2.4	2.2	0.92 (0.87, 0.98)
EWS >= 8	2.2	2.0	0.92 (0.86, 0.98)
EWS MET call	2.5	2.5	1.03 (0.98, 1.08)
Proportion of vital sign frequency aligned to EWS at time²			
All	76.8%	76.9%	1.03 (1.02, 1.05)
EWS 0	81.5%	81.2%	1.00 (0.99, 1.01)
EWS 1–3	77.3%	77.5%	1.00 (0.99, 1.02)
EWS 4–5	61.7%	63.2%	1.01 (0.99, 1.04)
EWS 6–7	47.0%	48.8%	1.07 (1.04, 1.10)
ACC episodes³			
All	40,930	19,032	0.55 (0.25, 1.18)
Acute ⁴	13,927	15,831	1.12 (0.60, 2.08)
Chronic	26,987	3,197	0.22 (0.14, 0.34)
ACC respiratory chart usage			
All	-	5,347	-
Rate of EWS time gap per acute ACC encounter³			
EWS gap > 60 minutes	2.6	1.6	0.68 (0.57, 0.82)

Measure	Pre-upgrade	Post-upgrade	Rate ratio ² / Relative risk ³ (95% CI)
EWS gap > 90 minutes	2.1	1.2	0.66 (0.49, 0.89)
EWS gap > 120 minutes	1.8	1.0	0.66 (0.44, 0.97)
Mental state change			
Rate of mental state changes per encounter ²	1.7	1.3	0.77 (0.76, 0.77)
Rate of mental state changes per encounter – limited to those with at least 1 follow up EWS < = 90 minutes ²	1.5	1.3	0.81 (0.80, 0.83)
Urine MCS ordered < = 4 hours of first mental state change recorded, N (%) ⁵	5,318 (9%)	2,751 (7%)	p < 0.001

Statistically significant rate ratios are **bolded and italicised**

¹ pre-upgrade period only had 8 months and included the transition period

² rate ratio was calculated using Quasi-Poisson interrupted time series model

³ relative risk was calculated using Quasi-Poisson interrupted time series model

⁴ acute ACC was defined as less than 24 hours between start and end time when ACC is in place

⁵ p-value compares % pre- and post-upgrade using chi-square test

DISCUSSION

This mixed-methods study of a deterioration digital early warning tool (DEWT) upgrade revealed clinician perspectives on features of the tool, changes in usage patterns and attitudes towards changes as a result of the upgrade. This represents one of the largest studies of DEWTs to date, encompassing 15 hospitals of varying sizes across both metropolitan and regional settings. While the upgrade did alleviate some challenges and clinical risks, our study also uncovered new unintended consequences created as a result of the upgrade. Our findings highlight the importance of continued monitoring of early warning tools, from both a technical, usage and stakeholder perspective. The following discussion of our results is organised highlighting key human, organisational and technology factors, in line with the HOT-fit framework for health information systems evaluation [26].

The key human factor identified through all three sub-studies was the need for user training, in both specific features of the DEWT, and in appropriately integrating its output with clinical judgement. These findings corroborate existing studies of other CDSS [27, 28]. Surveys revealed that a large proportion of

users didn't notice any differences in many features post-upgrade, highlighting those which require focused training. Usage metrics identified a reduction in recording mental changes post-upgrade, suggesting the need for training on this feature. Focus groups highlighted the need for junior staff members to receive training that enables building critical judgement. Literature highlighted the potential for EWS to hinder junior staff in developing critical thinking and maintain clinician autonomy to enable them to interpret the EWS [18, 29, 30]. While there are concerns for the overreliance by junior staff on the digital system, this point was seen as an enabler by junior staff to escalate their clinical deterioration concerns. Therefore, training programs must not only teach about the functionality of the tool but also reinforce foundational clinical knowledge that underpins the decision support and encourage practices in which decision support enhances rather than replaces clinical acumen.

Our study demonstrated changes made to the DEWT during upgrade can change organisational workflows. One key change in the upgrade was including confusion or acute mental status changes in the EWS, as an important signal for early clinical deterioration. Sudden confusion, delirium, or altered consciousness may be the first indication of serious underlying conditions such as sepsis, hypoxia, stroke, or metabolic imbalance—often preceding changes in vital signs [31, 32]. The addition of 'Confusion' to the existing 'AVPU' measure was rated useful by survey respondents. However, recording changes in mental state reduced significantly post-upgrade, as did urine MCS orders within the first 4 hours of documented mental change. This suggests a potential clinical risk, as studies show failure to recognise mental status changes can delay escalation and compromise outcomes [33]. While organisational workflows may change as the DEWT evolves, it is important this is monitored to avoid unintended or negative clinical impacts.

Technology limitations are having a clinical impact. Increasing digitisation of CDSS provides many opportunities but also poses clinical risks when the technology falters. Participants in our study flagged issues with internet connectivity, resulting in the inability for data to transfer automatically between the vital sign machines and the EMR, leading to EWSs not triggering. Additionally, slow loading times of the graph-view page post-upgrade impaired users' ability to provide efficient patient care. Rubins (2019) presented a case study of how slow CDSS response times create the potential for safety incidents, concluding that "it is critical to consider adding decision support-time generation to ongoing CDS system monitoring programs" [34]. Our findings support this suggestion. Speed and reliability are key enablers for CDSS use [35, 36], technology and internet connectivity need to be optimised to avoid negative clinical impacts.

Limitations

Whilst our study was conducted across 15 hospitals, including rural and urban settings, all sites were located in a single state, using the same DEWT model and configuration, which may limit the generalisability of some findings specific to this model. Users were recruited via purposeful sampling, so it may not be representative of the broader user group. However, the substantial size of our sample and inclusion across different disciplines, including nursing, medical and allied health, helped broaden our

sample. A complete case analysis was undertaken for the post-upgrade survey which may hinder generalisability of these results. The post-upgrade time period was relatively short, significant organisational changes can take years to realise their full impact. Additionally, for the graph-view page view metric, only 8-months of pre-upgrade data was available, potentially limiting the ability of this model to accurately capture seasonality. The mixed-methods approach incorporating quantitative system usage metrics, in combination with focus group and survey user input helped provide a robust response set. Combining these results with patient care outcomes would be ideal, for example number of ward deterioration events, unplanned ICU admissions, length of stay or hospital mortality. Whilst out of scope for the current study, capturing these metrics over time could offer valuable further insights into the clinical impact of DEWTs.

CONCLUSION

Digital early warning tools have potential to improve patient outcomes through, enhanced surveillance, timely recognition of deterioration, and improved adherence to vital sign monitoring protocols [11, 12]. However, their effectiveness is contingent not only on initial implementation, but also on sustained monitoring to ensure these systems continue to function as intended and fit with evolving clinical workflows, to avoid unintended consequences [19, 20]. Given the substantial resources invested in DEWTs, further research should be conducted into how health services can incorporate system usage metrics, technical performance measures and user feedback into continuous improvement cycles to ensure clinical relevance and technical reliability over time.

Declarations

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Competing interests: The authors declare no competing interests.

Ethics approval: Ethical approval for this project was granted by the Metro North Health Human Research Ethics Committee (HREC) A (EC 00172) (HREC/2022/QRBW/80550). The study is in accordance with the Declaration of Helsinki.

Consent: Informed consent was obtained for focus group participants and survey respondents. A waiver of consent was granted by the ethics committee for accessing system usage metrics.

Data availability statement: The data underlying this study are not publicly available due to privacy and confidentiality. Researchers interested in accessing the data must obtain appropriate ethics and governance approvals from the data custodians.

Author contributions:

Author	Contribution
Jodie Austin	Methodology, Investigation, Formal analysis, Project Administration, Writing – original draft, Writing – review & editing
Joshua McRae	Methodology, Investigation, Validation, Writing – review & editing
Jason Lynch	Investigation, Formal analysis, Writing – review & editing
Hai Pham	Data curation, Formal analysis, Writing – review & editing
Teyl Engstrom	Project administration, Validation, Writing – original draft, Writing – review & editing
Naitik Mehta	Project administration, Methodology, Writing – review & editing
Victoria Campbell	Conceptualization, Methodology, Writing – review & editing
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Figures

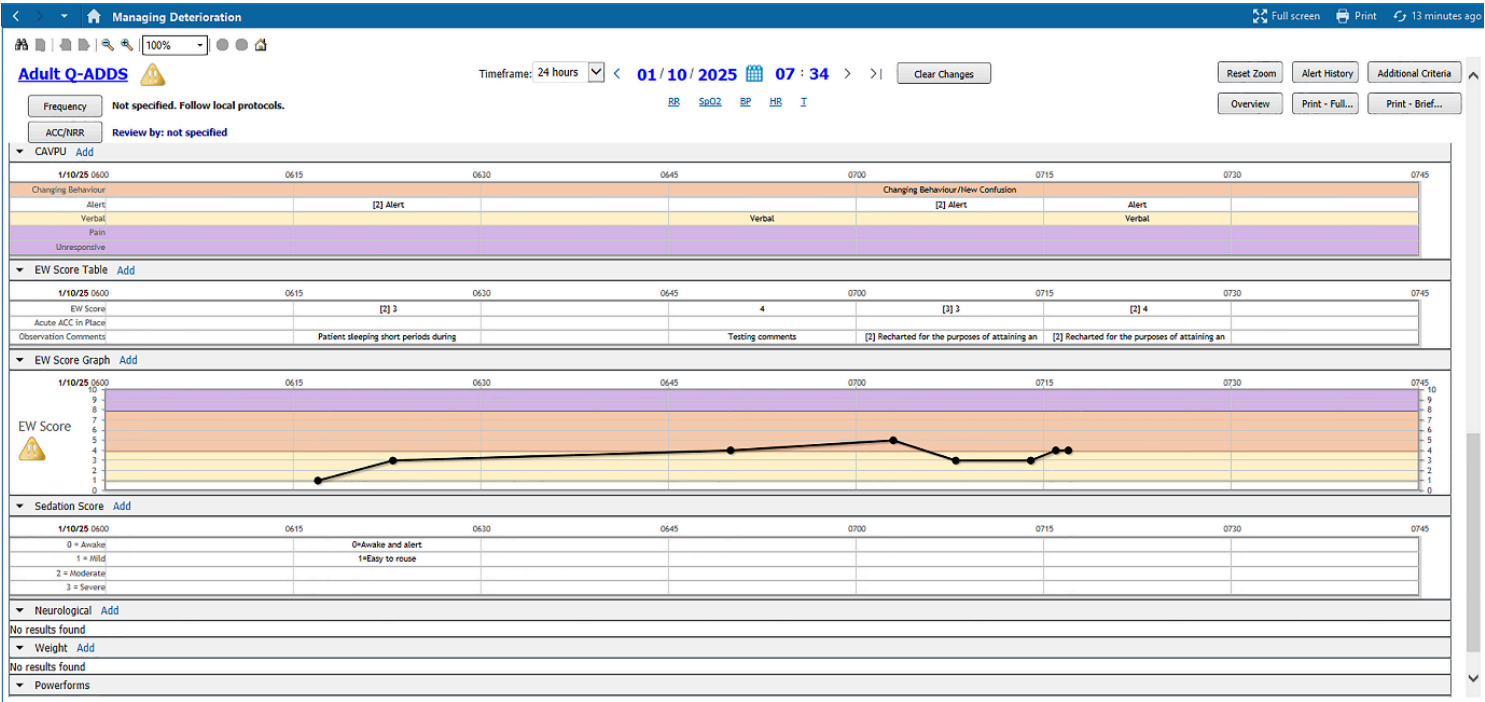


Figure 1
Managing deterioration graph-view page for a test patient

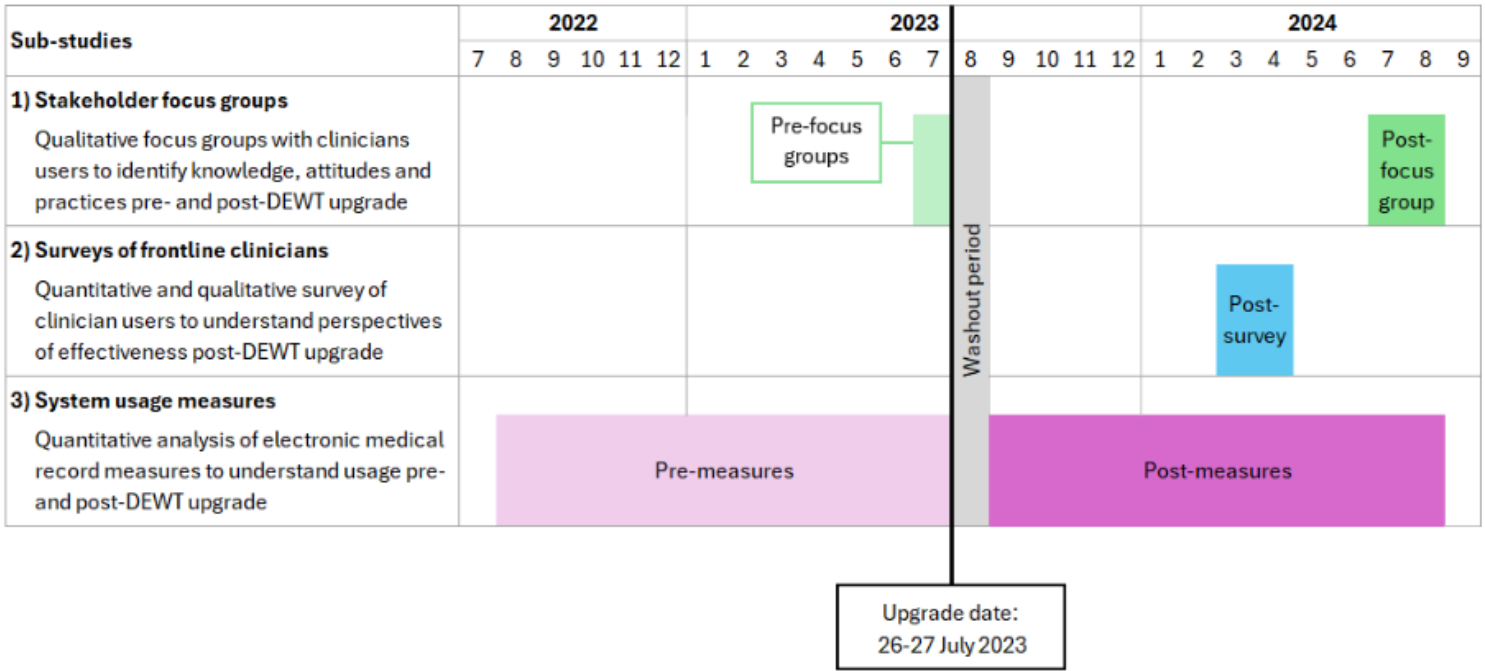


Figure 2
Overview of sub-studies and data collection dates, by year and month

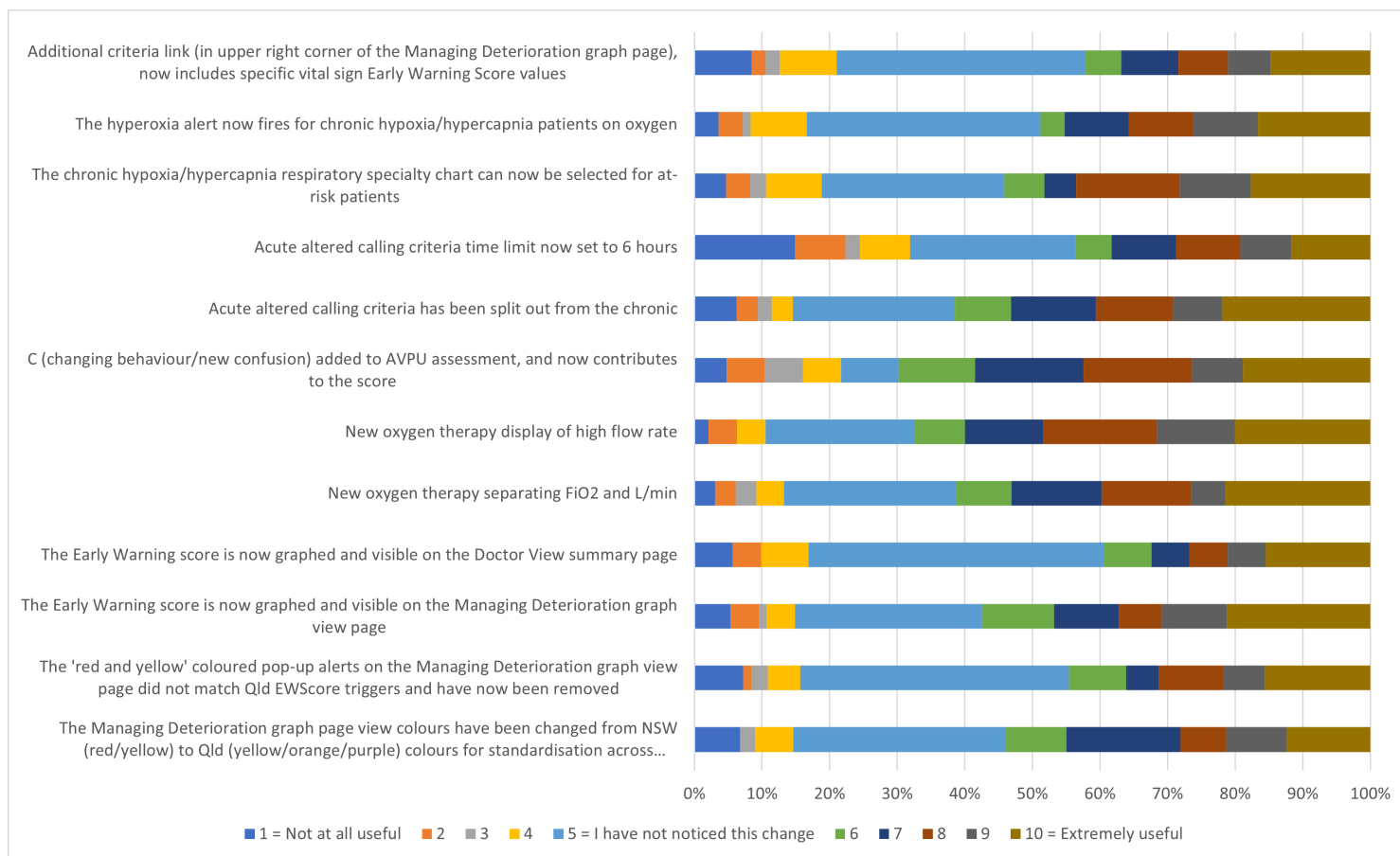


Figure 3

Survey responses to 'Grade the changes as to their usefulness', excluding 'no opinion' responses

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