Heuristic Analysis of 25 Australian and New Zealand Adult General Observation Charts

Human Factors and Observation Chart Research Project: Phase 1.1

Report prepared for the Australian Commission on Safety and Quality in Health Care's program for Recognising and Responding to Clinical Deterioration

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September 2009

Preface

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Acknowledgments

First, we would like to thank all of the interested parties who provided us with observation charts from their hospital or area health service for inclusion the current study.

Second, our thanks go to the Project's Reference Group, who made suggestions regarding the content of the report.

Finally, we would also like to thank Nicola Dunbar from the Commission for her support throughout the Project, Alexandra Sonsie for assembling the majority of the observation charts, John Manly for research assistance, and Kelly Ryan for administrative support.

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Executive Summary

The current study was the first stage of a project aimed at developing an evidence-based adult general observation chart for Queensland and for national use. The project aim is to generate an evidence base regarding the design and use of observation charts in recognising and managing patient deterioration.

Improving the recognition and management of patients who deteriorate whilst in hospital is a frequently cited goal for patient safety. Changes in physiological observations or 'vital signs' commonly precede serious adverse medical events. Paper-based observation charts are the chief means of recording and monitoring changes to patients' vital signs. One approach to improve the recognition and management of deteriorating patients is to improve the design of paper-based observation charts.

There is considerable variation in the design of observation charts in current use in Australia and a lack of empirical research on the performance of observation charts in general. Consequently, the aim of the current study was to evaluate the quality and extent of design problems in a sample of 25 existing observation charts from Australia and New Zealand.

The evaluation was completed using a technique for systematically identifying design problems known as heuristic analysis. In such an analysis, the main output is a list of usability problems identified by evaluators' expert judgment. A total of 1,189 usability problems were identified in the 25 observation charts. Usability problems were identified as affecting the observation charts' page layout, information layout, recording of vital signs, integration of track and trigger systems, language and labelling, cognitive and memory load, use of fonts, use of colour, photocopying legibility, and night-time legibility.

In compiling lists of the various usability problems present in the observation charts reviewed, this report has produced a de facto manual for designing better observation charts. No such guide presently exists to help those charged with designing observation charts. The next step in the project will be to design a user-friendly adult general observation chart that adheres to the usability principles developed through the current study.

The observation charts included in the heuristic analysis are listed in Table 2. Common usability problems identified in the observation charts are listed in Tables 3 to 13 in the Results Section. The Results section also includes Figures 1 to 15 illustrating common design problems taken from the (de-identified) observation charts.

1. Project Background

Improving the recognition and management of patients who deteriorate whilst in hospital is a priority both at the national and state level. The Australian Commission on Safety and Quality in Health Care (ACSQHC) has launched a national program for 'Recognising and Responding to Clinical Deterioration'[1]. In Queensland, Queensland Health's Patient Safety Centre recently released a discussion paper highlighting gaps in the recognition and management of the deteriorating patient [2].

Changes in physiological observations or 'vital signs' commonly precede serious adverse events such as cardiac or respiratory arrest, unplanned Intensive Care Unit (ICU) admission, or unexpected death [3-8]. Several studies report that derangements in vital signs are observable up to 48 hours before the adverse event [3, 5, 6, 9]. This suggests that if deterioration is recognised early and approppropriately managed, then complications arising from delayed diagnosis could be reduced (e.g. morbidity, unexpected ICU admissions, extended length of stays in hospital), and some serious adverse events could potentially be avoided altogether [2, 10-12].

Paper-based observation charts are the principal means of recording and monitoring changes to patients' vital signs. However, vital signs are not always correctly recorded or appropriately acted upon [2, 3, 6, 9]. The design of the observation charts themselves may contribute to failures in the ability of medical and nursing staff to record vital signs and recognise deterioration.

There is considerable variation in the design of observation charts in current use in Australia. They vary in both the number and selection of vital signs monitored. Observation charts also display diversity in the way in which they display information. For instance, respiration rate may be displayed on one chart as a row with boxes for writing the number of breaths taken by a patient per minute for each time-point, while on another chart it may be plotted as a graph over time. Finally, observation charts also vary in the degree to which they incorporate track and trigger systems based on clinical criteria to help users recognise a deteriorating patient and respond appropriately.

There is presently a lack of empirical research on the design and use of observation charts. In Australia, observation charts tend to be designed at the local hospital or individual health service area level (resulting in a nationwide duplication of effort) [2]. Some observation charts appear to have been trialled in specific wards before full implementation or evaluated by means of a staff survey. Rigorous empirical evaluation is lacking in most cases.

There are indicative findings that efforts to improve the design of observation charts can produce benefits for patients, staff, and the hospital. In the United Kingdom, Chatterjee et al. carried out an empirical evaluation of 5 observation charts in use at a district general hospital [13]. They reported that the design of the charts had a significant effect on the ability of staff to recognise patient deterioration (with a detection rate as low as 0% for one vital sign), and that no single existing chart was best for all vital signs. As a result, they designed and implemented a new chart incorporating a track and trigger system. They found that there was a significant improvement in staff's ability to recognise deterioration (all detection rates over 90%), after the re-design and implementation of the new chart. Their new chart produced improvements in the detection of four forms of deterioration, hypoxia (45% increase in detection), tachypnoea (41% increase in detection), tachycardia (29% increase in detection), and fever (16% increase in detection). Similarly, a recent Australian effort to improve the design of observation charts has produced statistically significant gains in the frequency of recording vital signs, as well as decreasing unplanned ICU admissions, decreasing the rate of cardiac arrests, and decreasing rate of hospital deaths [14].

The current study was the initial phase of a project aimed at developing an evidence-based adult general observation chart for Queensland and for national use. The project aim is to generate new knowledge regarding the design and use of observation charts in recognising and managing patient deterioration. It is part of the ACSQHC's programme 'Recognising and Responding to Clinical Deterioration'. The findings of the project will inform the development of a nationally agreed upon adult general observation chart for Australia.

Before designing a new observation chart, it was important to gauge the quality and extent of design problems in existing observation charts. This was completed using a technique for systematically identifying design problems known as heuristic analysis. Existing observation charts were collected by the ACSQHC or provided directly to the Research Team by interested parties. Out of the 45 observation charts received, a representative subset of 25 observation charts were subjected to a systematic heuristic analysis by 5 trained evaluators.

2. Heuristic Analysis

Heuristic analysis is a form of usability inspection in which evaluators examine the usability-related aspects of a system or how well the average user can successfully interact with the system [15, 16]. It is also frequently referred to as a type of "discount usability engineering" as it is easy to learn (one can be trained as an evaluator in a half-day workshop) [17], quick to do (one can evaluate a system in 1 day), and relatively inexpensive to run [18]. Consequently, it is frequently employed in the information technology domain, including in the design life-cycle of new electronic devices, computer software and corporate websites.

Heuristic analysis relies on evaluators' expert judgment as the primary source of feedback [15, 16]. In judging the usability of a system, the evaluators consider a number of points, including: how easy it is for new users to learn to use the system, how efficiently the system can be used, how pleasant it is to use the system, and how frequent and severe user errors are likely to be. In sum, how "user-friendly" the system appears to be.

The analysis is usually conducted by a number of evaluators. This is because evidence exists that while a single evaluator finds about 35% of the usability problems in a system, five evaluators identify 60% to 75% of the problems (with additional evaluators finding fewer and fewer additional problems; i.e. the best cost/benefit ratio is achieved with five evaluators) [17, 19].

2.1 General procedure for a heuristic analysis[1]

In a heuristic analysis the evaluators *independently* examine the system and, in the main, decide for themselves how they undertake the analysis. However, the evaluators are required to determine the system's compliance with a set of general usability principles (or "the heuristics"). The usability principles are usually derived from published lists.

If the system under investigation is domain-dependent (i.e. requires some level of specialised knowledge) or some of the evaluators are not domain experts, then the heuristic analysis can benefit from the inclusion of a typical usage scenario. For example, observation charts are arguably domain-dependent systems as a layperson would not necessarily know how to use or interpret a chart correctly. Therefore, providing the evaluators with the steps users would take to record information on the observation chart or representative physiological data plotted on a chart can facilitate the evaluators' task.

The output generated from a heuristic analysis comprises a list of usability problems identified by the evaluators. Each usability problem identified is also usually characterised in terms of which usability principles it violated. In a heuristic analysis, it is not sufficient for an evaluator to identify an aspect of the system as problematic just because he or she does not like it, an evaluator must always justify problems identified with reference to usability principles.

After all evaluations are completed, evaluators communicate with each other about the heuristic analysis and the individual analyses are aggregated. It is at this point that a debriefing session can be conducted with all the evaluators present. Debriefing sessions usually seek to mediate any disagreements between the evaluators (e.g. Evaluator A rated feature 1 as a usability problem when Evaluator B saw feature 1 as an advantageous feature), and such sessions can act as a brainstorming session to produce re-designs to address the major problems identified.

2.2 General usability principles used in heuristic analyses[2]

In heuristic analysis, the evaluators are required to determine a system's compliance with a set of general usability principles derived from published lists. The usability principles all aim to promote a satisfying experience with the system for the average user [19].

This section presents a summary of published usability principles. Please note that some usability principles are not relevant to observation charts and so have been excluded (for example, "clearly marked exits" is relevant to software but not a paper-based chart).

[1] This section summarises relevant information taken from Nielsen's book chapter 'Heuristic Evaluation' [18]
[2] This section summarises relevant information taken from Nielsen's book chapter 'Heuristic Evaluation' [18] with supplementary information from Nielsen's book 'Usability Engineering' [20]

Simple and natural ‘dialogue’

- The aim of any system should be to present exactly the information the user needs (and no more) at exactly the time and place that it is needed.
- The system should match the user’s task in as natural a way as possible. Operations should be in a sequence that matches the way the user does things if appropriate.
- Information that will be used together should be displayed close together.

Aesthetic and minimalist design

- The system should not contain information that is rarely needed (as such information competes with relevant information for the user’s attention).
- The system’s graphic design and colour should be carefully considered, e.g.:
    - Avoid unrelated elements being formatted in a such a way that they seem to belong together and vice versa (otherwise the user will need more search time) [21]
    - Information presented in the top left of a display normally gets more attention
    - Avoid over-using upper-case text, it attracts attention, but is 10% slower to read than mixed-case text
    - Avoid more than seven colours (on a webpage), or the display will look too “busy”
    - If colour is to be used, the system requires redundant cues so that colour-blind users are able to use the system with ease.

Speak the users’ language

- Words, phrases, and concepts used should be familiar to the user.
- The system should have a good match between the display of information and the user’s mental model of the information.

Minimise the users’ cognitive and memory load

- Reduce the time spent assimilating raw data [21].
- Automate unwanted workload, i.e. eliminate mental calculations, estimations, comparisons, and unnecessary thinking, to free cognitive resources for high-level tasks [21].
- Bring together lower level data into a higher-level summation if appropriate [21].
- Present new information with meaningful aids to interpretation [21].
- The system should be memorable. Users should be able to use the system easily even after a period of not using it [19].
- The system should be based on a limited number of pervasive rules that apply throughout.
- The system should allow the user to rely on recognition rather than recall memory.
- Users should not have to remember information from one part of the system to another (i.e. avoid mental comparisons).
- When users are asked to provide input, the system should describe the required format and, if possible, provide an example.
- Basic functionality should be understandable in 1 hour.

Consistency

- Users should not have to wonder whether different words or actions mean the same thing.

Prevent errors

- The system should produce minimal errors.
- Practice judicious redundancy [21].

Precise and constructive error messages

- Messages should be phrased in clear language and avoid obscure codes (the user should not have to refer to elsewhere, e.g. the manual).
- Messages should help the user solve the problem.
- Consider multi-level messages; it is possible to use shorter messages that will be faster to read, as long as the user has access to a more elaborate message.

Help and documentation

- Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.
- Consider different levels of documentation, e.g. short reference cards vs. introductory manual for new users.

2.3 Usability analyses in health care

Despite their apparent applicability to improving patient safety, usability inspections have seldom been used in the health care domain. When such methods have been employed, it has usually been to assess the usability of a mechanical medical device or new computer software [22]. Martin et al. reviewed the literature on usability testing in medical device development [22]. Though they noted that there was little published work in this field, they report that several successful usability tests have been carried out in health care, including a heuristic analysis of the design and development of an infusion pump and the development of design principles for medication packaging [17, 23].

Martin et al. highlight several conditions that might make usability inspections in the health care domain particularly challenging [22]. First, medical devices differ from many other devices in that the needs of multiple types of users in varying environments must be considered. Second, purchasers or commissioners of new medical devices are rarely the primary users of the device, resulting in the risk that important factors such as usability and user satisfaction may be overlooked when procuring or commissioning a new device. Third, one study reviewed reported that novice users may generate more useful suggestions for system requirements for initial learning [24], whereas another study found that experienced users may be more critical of new devices but simultaneously provide more suggestions for improvements [25]. This suggests that it may be important to include users with a range of experience.

Zhang et al. successfully adapted heuristic analysis to evaluate the patient safety of infusion pumps [17]. They developed 14 usability principles (from the information technology domain), which they applied to two infusion pumps. Their four evaluators found 142 usability problems for the two infusion pumps. However, infusion pumps are computer-based devices and Zhang et al. noted that many of the usability problems they found were generic human-computer interaction issues rather than issues unique to the health care domain [17]. The applicability of heuristic analysis to non-computer-based medical systems is still yet to be determined [22].

A collaboration in the United Kingdom between the National Patient Safety Agency and the Helen Hamlyn Research Centre at the Royal College of Art resulted in a set of design principles in order to maximise patient safety in medication packaging [23]. The guidelines resulted from a review of existing guidelines, consultation of experts in graphic design and patient safety design, consultation of key stakeholders and end-users, observational research in users' environments, and a review of common problems evident in a sample of currently available medication packaging. The guidelines include a packaging design checklist, annotated with good and bad examples of each principle.

3. Method

3.1 Description of evaluators

Five evaluators participated in the heuristic analysis. Evaluators were selected in order to incorporate applied psychology, human factors, and medical expertise in the team (see Table 1 for a summary of each evaluator's background). As a minimum qualification, the evaluators had to be postgraduates in psychology or a health-related discipline. Three of the evaluators had previous experience with using observation charts.

Table 1: Profile of the 5 Evaluators

	Sex	Age in years	Domains of expertise
Evaluator 1[a]	Female	24	Applied cognitive psychology, hospital-based research methodology
Evaluator 2	Male	34	Applied cognitive psychology, human factors, comparative cognition, research methodology
Evaluator 3[b]	Male	39	Applied cognitive psychology, human factors, psychometrics, statistics
Evaluator 4[a]	Male	41	Human factors, medical education, cognitive systems engineer
Evaluator 5[a]	Female	34	Hospital medicine (gastroenterology)

Note. [a]Evaluators had previous experience with observation charts. [b]This evaluator was red/green colour-blind.

3.2 Representative sampling of observation charts

Forty-five observation charts that were in use or about to be implemented in Australia and New Zealand were obtained for consideration in the heuristic analysis. Observation charts were collected by the ACSQHC or provided directly to the Research Team by interested parties. See Appendix A for a list of the hospitals or area health services that provided an observation chart for inclusion the current study.

Evaluators 1 and 2 identified a subset of 25 observation charts to be subjected to the heuristic analysis (see Table 2 for the included observation charts). The observation charts were selected to represent the full range of designs submitted.

Table 2: List of 25 Observation Charts in the Heuristic Analysis

Hospital or area health service	Title of chart supplied
ACT Health	Compass General Observation Chart
Cabrini Hospital	Cabrini Hospital Observations & Fluid Balance Summary
Cairns Private Hospital	Composite Record
Caloundra Private Hospital	Close Observation Chart
Capital & Coast District Health Board	Adult Observation Chart
Clinical Excellence Commission	General Observation Chart
Counties Manukau District Health Board	Observation Chart
Epworth Freemasons Hospital	Observations
Hunter New England Area Health Service	Adult Observation Chart
Linacre Private Hospital	Temperature General Observations
Noarlunga Hospital	Observations Graphic Chart
Noosa Hospital	Modified Early Warning System
North Coast Area Health Service	Observation Chart
Northern Sydney Central Coast	General Observation Chart
Peninsula General Hospital	Observation Chart
Princess Alexandra Hospital	Temperature and General Observations Chart
Royal Adelaide Hospital	Observation Chart – Composite Graphic
Royal Prince Alfred Hospital	General Observation Chart
St George Private Hospital	Modified Early Warning System Observation Chart
Sydney Adventist Hospital	Adult Observation Chart
Sydney West Area Health Service	SWHR-2570W Observation Chart
The Prince Charles Hospital	General Observation Chart
Wangaratta Private Hospital	Observation Chart
Western Health	Observation Chart
Westmead Private Hospital	General Observation Chart

3.3 Procedure for heuristic analysis of 25 observation charts

Preparation

Evaluator 1 prepared the procedural requirements and materials for the heuristic analysis. Usability principles are usually derived from published lists [18]. However, no such published usability principles exist either for observation charts or even for the health care domain generally (note that the usability principles used by Zhang et al. [17] were not adapted to the health care domain). In light of this, Evaluator 1 (in discussion with the other evaluators) developed a set of specific principles sensitive to the usability challenges posed by paper-based observation charts. Before the main analysis, Evaluators 1, 2, and 3 each trialled the new set of usability principles on 4 observation charts. Evaluator 1 reviewed their analyses and any additional principles that were identified in the trials were added to the set. The trial of the new set of usability principles took each evaluator about 4 hours. The final set of 67 usability principles included in the current analysis and the rationale for their use are listed in Appendix B.

The materials for the heuristic analysis comprised (see Appendix C for copies of the materials):

- A Microsoft Excel© spreadsheet listing the usability principles to be used by the evaluators. Each column in the spreadsheet was framed as a question about a specific usability problem, to which evaluators could reply *Yes*, *No*, or *Not applicable*. Underneath their reply, the evaluators could type in a comment describing the problem in more detail. There was also room in the spreadsheet for additional comments if a unique problem was found that was not reflected in the set of principles.
- An instructional briefing detailing the procedure that evaluators were to follow
- A font size guide
- The 25 observation charts

The observation charts were each presented in two formats, a full-size ‘blank’ colour copy and another full-size colour copy with a case of patient deterioration plotted on the chart. The Research Team decided that since the observation charts were domain-dependent systems (i.e. their use required a level of specialised knowledge), the heuristic analysis would benefit from a typical usage scenario [18]. A Staff Specialist gastroenterologist provided a representative case of patient deterioration due to a post-operative infection plotted across 30 time-points for 8 vital signs. The 8 vital signs were: respiration rate, oxygen saturation, blood pressure, pulse, temperature, urine output, pain, and level of consciousness. Evaluator 1 transcribed this case by hand on to the 25 observation charts using a black pen (unless the chart specified the use of a different colour).

Heuristic analysis

The materials listed above were distributed to the 5 evaluators. The evaluators independently performed the heuristic analysis for each of the 25 charts. The evaluators were encouraged to draw on their knowledge of cognition, human factors, and health care, not just confining themselves to the set of usability principles provided. The length of time spent analysing an individual observation chart varied from 0.5 to 1.5 hours depending on the chart's complexity. The average length of time spent on the whole analysis was 30 hours per evaluator.

Debriefing

After all evaluators returned their individual analyses, a combined heuristic analysis was produced for each observation chart. Then, a 2 hour debriefing session was held with all 5 evaluators present. The main aim of the debriefing session was to identify and discuss instances of evaluator disagreement in the heuristic analyses. For example, 1 evaluator rating an aspect of an observation chart's design as a problem (i.e. answering *Yes* in a certain column of the spreadsheet), whereas the other evaluators did not consider it problematic. Such an instance could be a false positive (i.e. a typo) on the part of the dissenting evaluator or a true positive that the other evaluators had not indentified.

After reviewing potential false positives in 5 representative analyses of charts, it was decided that Evaluator 1 should go through all the combined analyses and ask for clarification from sole or dual evaluators who identified a problem but did not provide a commentary on what the problem was. Such an approach reduced the number of false positives in the results. The data-cleaning took 9 hours for Evaluator 1 and approximately 1 hour each for the other evaluators.

Additional usability tests

The Research Team decided to conduct several other usability tests on the observation charts alongside the heuristic analysis. These tests are described below.

Count of labels and abbreviations. A research assistant identified all the labels used in the sample of 25 observation charts for 8 vital signs. The 8 vital signs were: respiration rate, oxygen saturation, blood pressure, pulse, temperature, urine output, pain, and level of consciousness. The research assistant also counted the number of abbreviations used in each observation chart.

Test of charts' ability to be photocopied. A research assistant photocopied all master-copies of the 25 observation charts (i.e. the copies which included the physiological data plotted by hand) at several light/dark settings on a Fuji Xerox Document Centre 336. The photocopied charts were first inspected to determine if all chart elements photocopied legibly at the various settings. When it was decided that a chart's elements were not reproduced legibly, the specific vital signs' data or labels that were illegible were recorded.

Night-time hospital light level simulation. Evaluator 1 and a research assistant tested legibility of the 25 observation charts in realistic night-time hospital light levels. All charts were viewed at < 1 metre reading distance by Evaluator 1 at an illuminance of 9 lux [26].

4. Results

A total of 1,189 usability problems were identified in the heuristic analysis and other usability tests of the 25 observation charts. The number of usability problems identified in an individual observation chart ranged from a minimum of 35 to a maximum of 63 problems. The average (arithmetic mean) number of usability problems identified in a particular chart was 48 problems. The following divisions in this section will describe the main types of problems identified in the charts.

It should be stressed that heuristic analysis is a problem-focused usability inspection and it only raises negative issues regarding the systems under investigation. Consequently, the following sub-sections will appear to be highly critical of the observation charts.

4.1 Page layout

Well-designed observation charts should incorporate principles of good page layout. The main usability problems identified regarding the charts' page layout are presented in Table 3.

The majority of charts used too much space for the hospital name or logo and contained bureaucratic codes (e.g. form numbers). Compared to the importance of correctly recording vital signs, the hospital name and bureaucratic codes are less relevant to the clinical care of a patient. Including and formatting such items in a prominent fashion causes such 'irrelevant' information to compete with the relevant information for a user's attention. It is acknowledged that from an organisational perspective, such 'clinically irrelevant' items usually need to be displayed on charts. However, such items should be presented in such a way that they are not prominent or overly distracting.

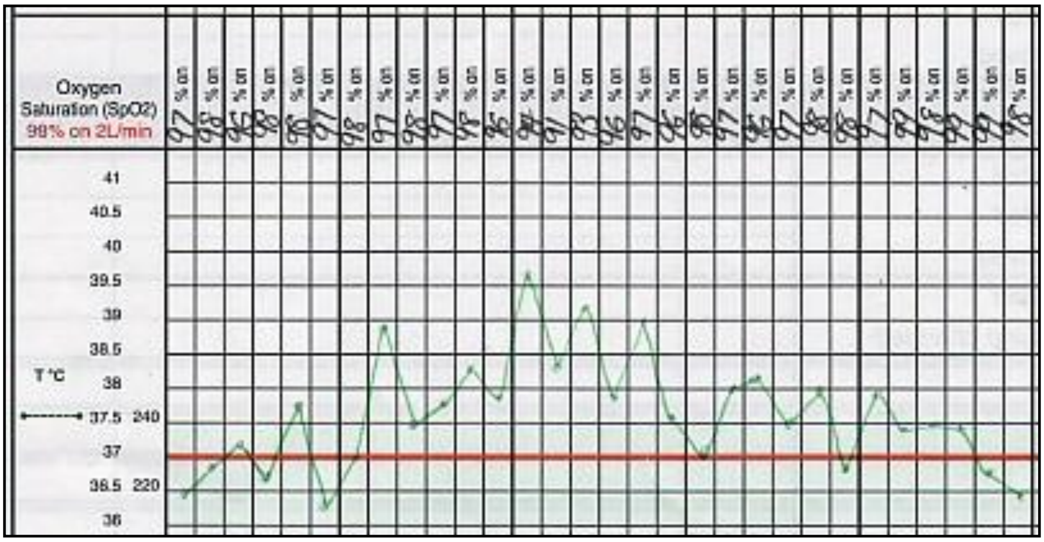
Mixing vertical and horizontal data points affected the legibility of the data. For example, one chart required oxygen saturation to be entered vertically, while all other data were plotted horizontally (see Figure 1). This made the oxygen saturation data more difficult to read than it would otherwise have been.

Several charts included either the hospital or the printer's address and contact numbers. Again, such irrelevant information will compete with relevant data for attention. Also, one chart placed a graph's legend in the binding margin (i.e. information about the graph would not be visible if the chart was bound in a medical file).

Table 3: Proportion of the 25 Charts Affected by Usability Problems Related to Page Layout

Usability problem	Percentage of charts affected
Too much space used for hospital name or logo	92%
Bureaucratic codes present that do not relate to the chart's clinical usage	92%
Portrait orientation	72%
Page margins too small (left 2 cm, all others 1 cm)	64%
Page margins too big (left 2 cm, all others 1 cm)	64%
Mixture of vertically-oriented & horizontally-oriented data points	52%
Page not A4 size	24%

Figure 1: Mixture of vertically-oriented and horizontally-oriented data points



4.2 Information layout

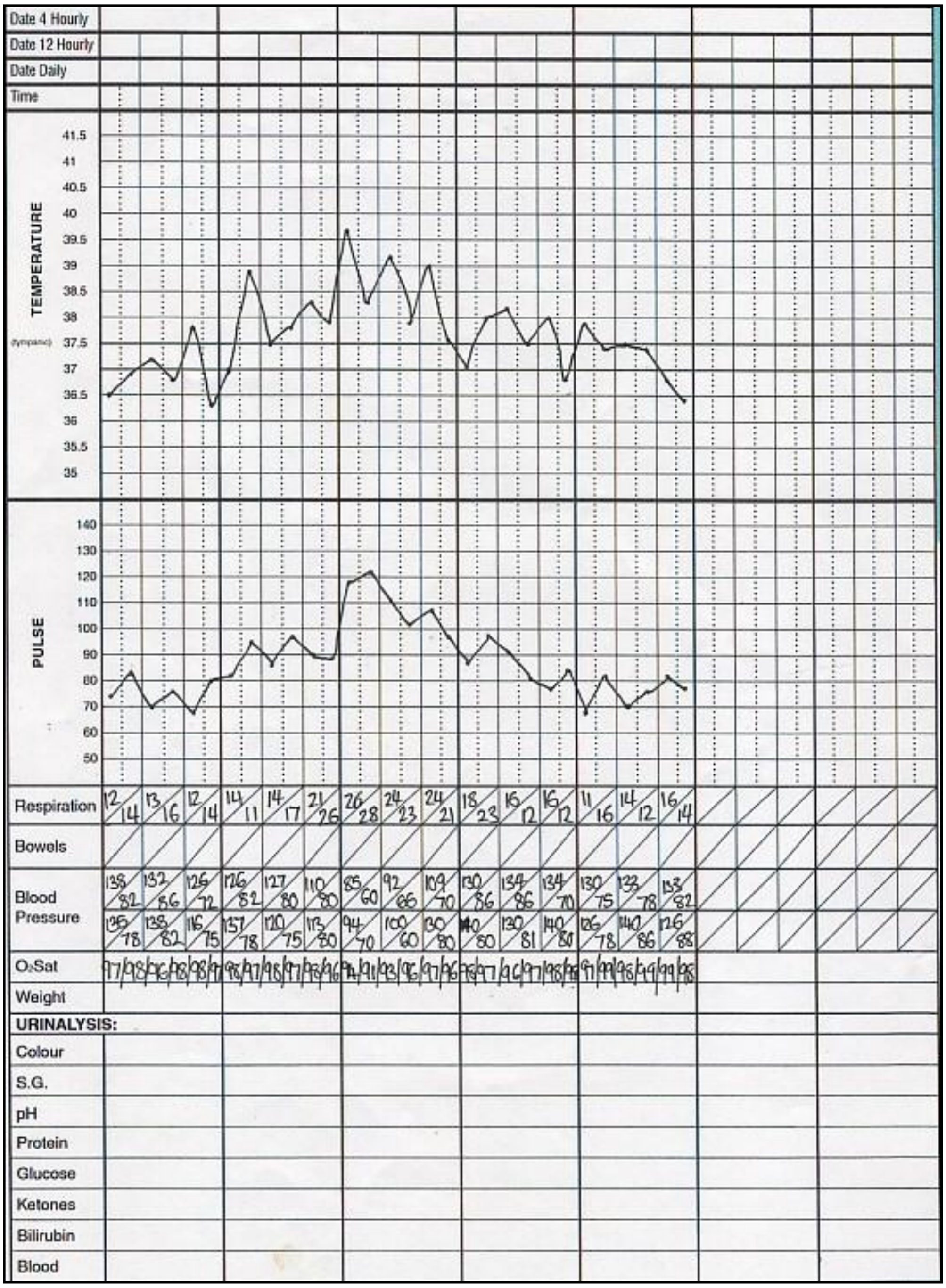
As with page layout, well-designed observation charts should order information in a logical manner and format such information appropriately. The most frequently identified usability problems regarding the charts' layout of information are presented in Table 4. All 25 charts were seen as having problems with using the available space to present information in a logical order and an appropriately formatted manner. Common examples of this general problem include important vital signs being placed towards the bottom of a page (see Figure 2) or even on side two of a double-sided chart. The formatting of vital signs' labels was often inconsistent.

Similarly, the evaluators concluded that all the charts included redundant or irrelevant information. For instance, one chart included information on paediatric vital signs even though it is generally accepted that adult and paediatric charts should be treated separately. In other charts (including the example shown in Figure 3), the same information or required action was sometimes repeated up to four times. Most of the charts also devoted too much space to unimportant items. As shown in Figure 2, a typical problem involved a large space being devoted to a temperature graph at the top of a chart (given that temperature is not generally considered to be the most important vital sign). If such additional information was omitted or reduced, then there would be more space available to present more critical information in a user-friendly manner.

Table 4: Proportion of the 25 Charts Affected by Usability Problems Related to Information Layout

Usability problem	Percentage of charts affected
Information not displayed in decreasing order of importance	100%
Eight vital signs not all on 1 side of a page	100%
Redundant or irrelevant information present	100%
Two vital signs or track & trigger scores "joined" instead of separated by a small space or double line	100%
Area for writing is too small (cannot accommodate 14 point font)	100%
Amount of space devoted to something is too big	92%
Labels of the same level of importance are formatted differently	88%
Too many time-points for chart to be used for 3 days (assuming 4-hourly monitoring)	88%
Important information not displayed in top left of page	76%
Basic functionality not understandable in 1 hour	28%
Too few time-points for chart to be used for 3 days (assuming 4-hourly monitoring)	8%

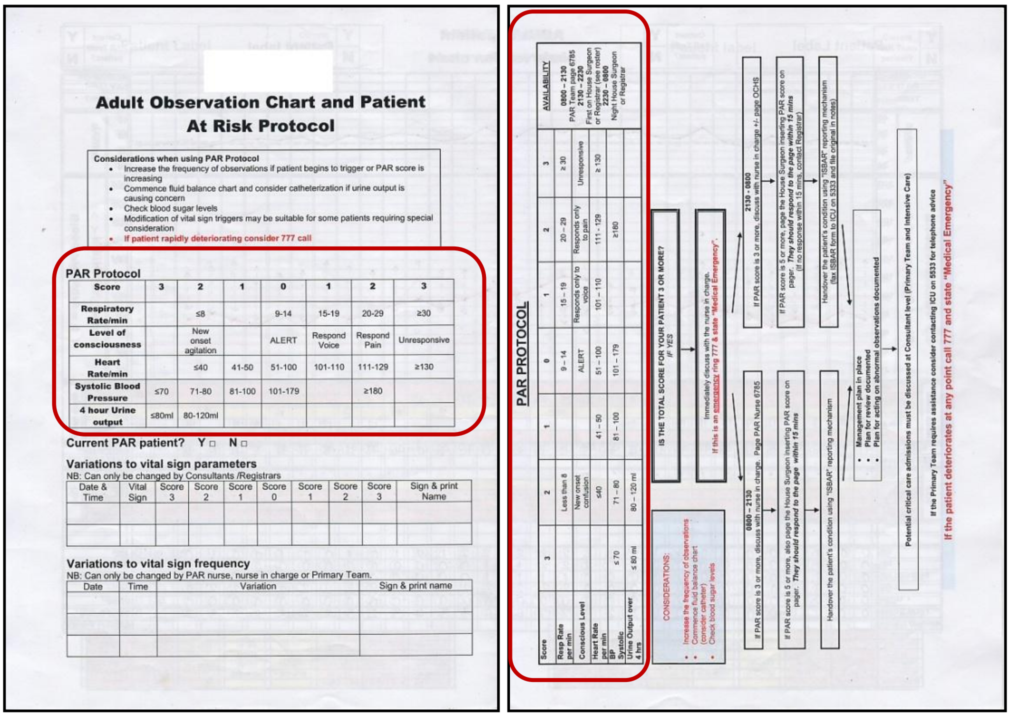
Figure 2: Poor information layout



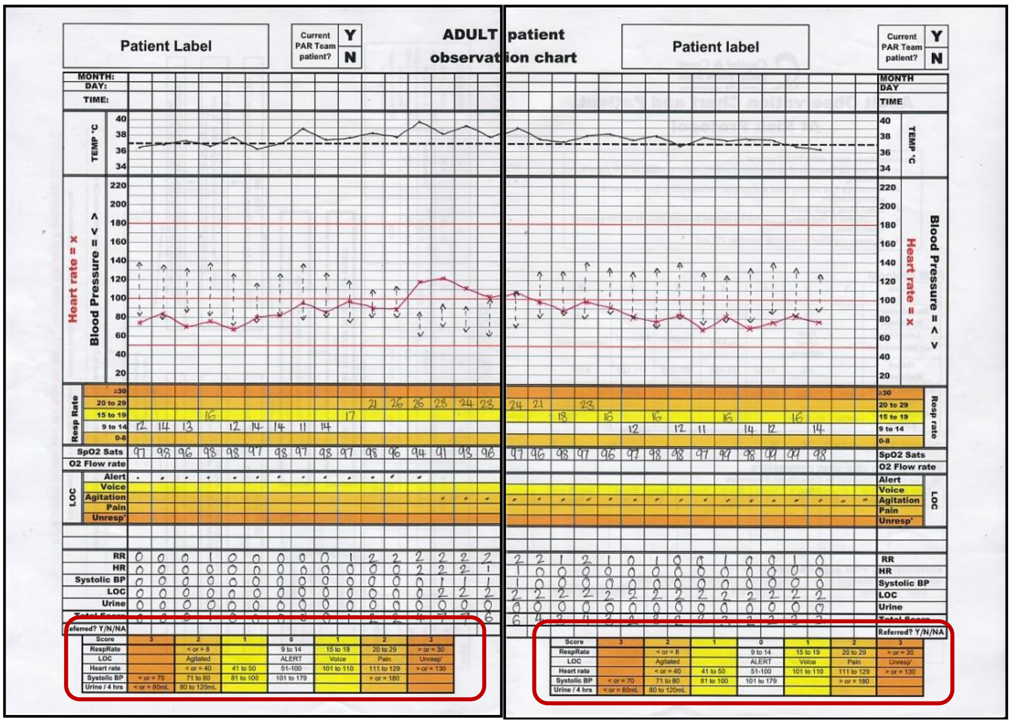
Commentary: Information is not displayed in decreasing order of importance. Temperature is the first vital sign in the top left of the display, while more sensitive indicators of deterioration (respiration, O_2Sat, blood pressure) are in the bottom half of the page. Also, the vital signs' labels are inconsistently formatted. Temperature and Pulse are in capitals, but Respiration, Blood Pressure, O_2Sat are not. When plotting data, the dots on the temperature and pulse graphs compete for the user's attention with the data points. Boxes for blood pressure are stacked one on top of the other and diagonally split into two triangles. This could cause confusion regarding the correct order for plotting data across time.

Figure 3: Inclusion of redundant information

Outside faces of an A3 sheet



Inside faces of an A3 sheet



Commentary: Information is repeated. Two sides of an A3 size chart are shown above. The red rectangles highlight show where the chart's track and trigger scoring system (PAR Protocol) is repeated.

4.3 Recording of vital signs

Perhaps most important facet of observation charts in helping users to recognise a deteriorating patient is how the the vital signs are to be recorded and displayed. Table 5 lists the most commonly identified usability problems regarding the recording of vital signs on the 25 observation charts.

All of the charts were seen as having the potential for two vital signs' data to be confused. A common example of this was pain and level of consciousness scales being placed on consecutive rows (see Figure 4). As both scales usually employ some identical values (e.g. *0* to *5*), a user could confuse the information unless he or she paid careful attention to the row's label and position. Another common issue was for two or more vital signs to be plotted on the same graph. This led to both the potential for the vital signs to be confused (or at least for reading to be slowed) and for deterioration to be obscured (see Figure 5 for an example of problematic design in which multiple plots are presented the same graph and Figure 6 an example of good practice in which the plots are kept separate).

Table 5: Proportion of the 25 Charts Affected by Usability Problems Related to Recording Vital Signs

Usability problem	Percentage of charts affected
Data points for 2 vital signs could be confused	100%
Label does not specify unit of measurement	100%
Label is not clear & descriptive	96%
Graph looks too small or cramped	96%
Thick vertical lines not placed every 3-4 columns	96%
Time boxes too small (cannot accommodate 14 point font)	96%
Date boxes too small (cannot accommodate 14 point font)	92%
Information is not displayed as a graph	92%
Vertical axis of a graph not labelled on the left & right of the page	88%
Label does not provide an example of how data are to be recorded (e.g. • or **x**)	80%
More than 1 vital sign recorded on the same graph or area	72%
Graph label formatting exactly the same as the vertical axis values' formatting	72%
Scale of the vertical axis values changes	52%
Vertical axis values are misaligned	52%
Date is a blank row, instead of ruled off every 24 hours	52%
Instructions specify the use of different coloured pens	28%
Vertical axis values are not mutually exclusive	24%
Label is written vertically with upright letters	8%

Figure 4: The potential for pain and level of consciousness to be confused

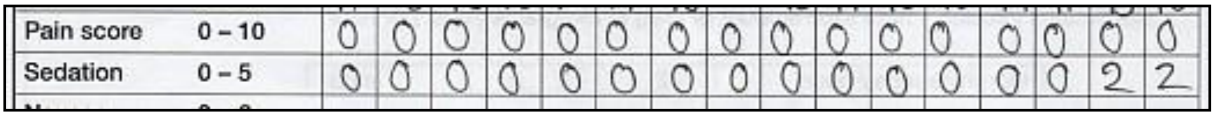


Figure 5: Three vital signs (temperature, blood pressure, and pulse) plotted on the same graph

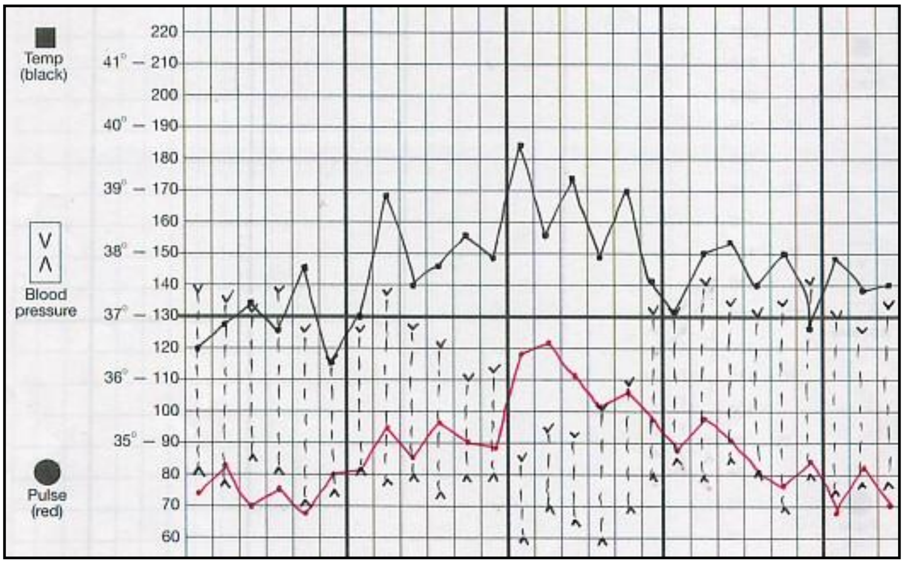
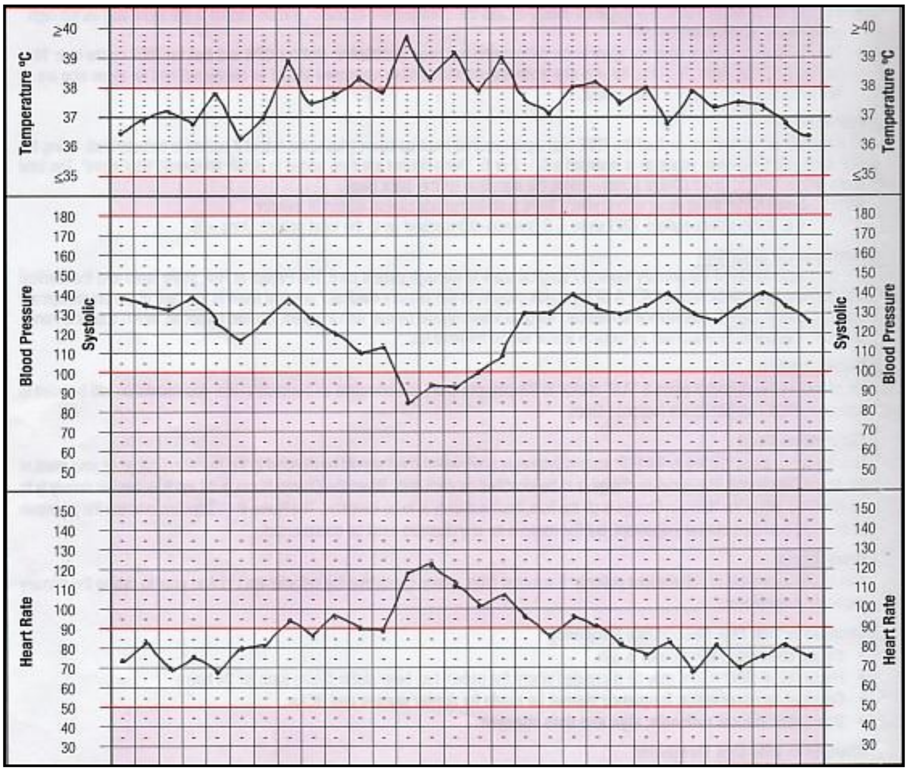
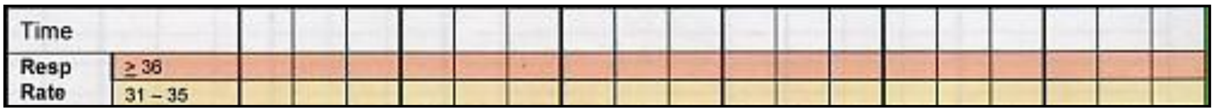


Figure 6: Three vital signs (temperature, blood pressure, and pulse) plotted on separate graphs



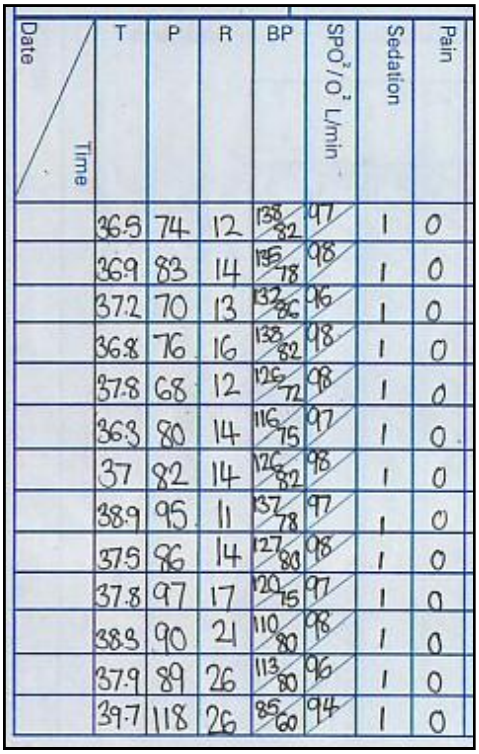
Two features of chart layout were considered to be important to prevent a user from losing her or his place in the display. First, thick vertical lines should be placed every three to four columns (as in Figure 7). This prevents 'column shift', i.e. a user placing a data point to the left or right of the correct column. Thick vertical lines every 3 columns mean a user can track down a column to the correct row relatively easily as the column will either have a thick line on the left or right, or no line at all (and columns on either side will look different to the correct column). Second, the vertical axis of a graph should be labelled on the left *and right* of the page (such as in Figure 6). This reduces the chance of 'row shift' (and may allow left-handed users to plot data more quickly).

Figure 7: Thick vertical lines prevent 'column shift'



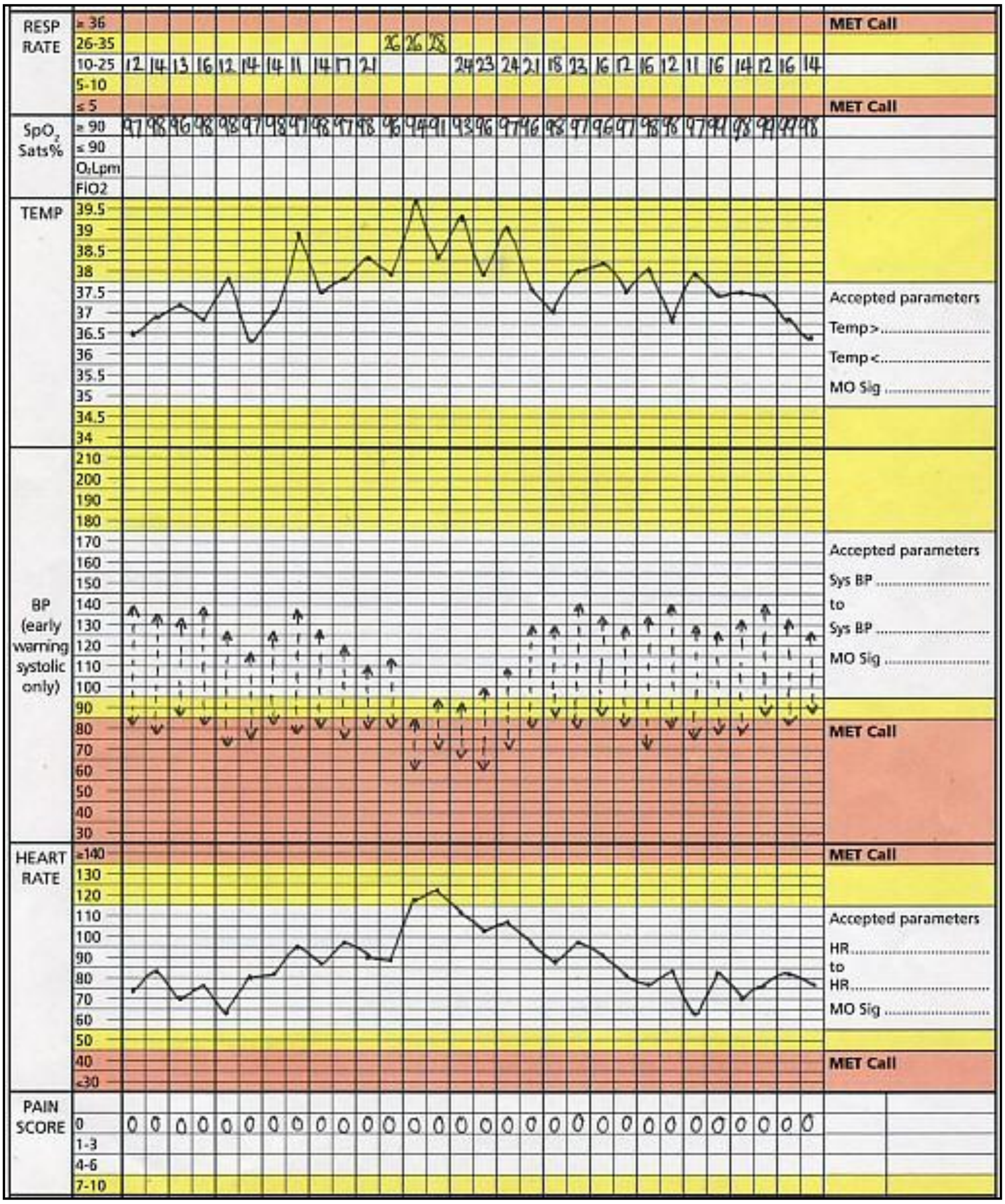
The majority of charts did not display all the vital signs' data as a graphs. Displaying data in a tabular form makes it very hard to recognise that a patient is deteriorating (Figure 8, cf. Figure 9). In fact, to see the trend a chart user must mentally visualise the data as a graph. It is debatable how complex a display a user can mentally visualise. It was considered preferable to require a user to plot the vital signs as a graph to preclude the need for complex mental visualisations.

Figure 8: A chart with tabular display of data



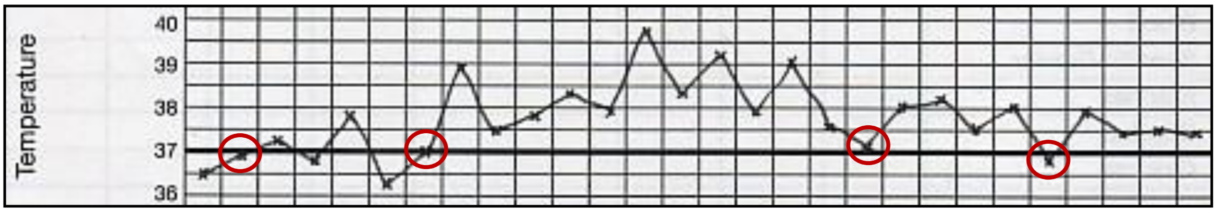
Date / Time	T	P	R	BP	SPO2/O2 L/min	Sedation	Pain
	36.5	74	12	138/82	97	1	0
	36.9	83	14	135/78	98	1	0
	37.2	70	13	132/86	96	1	0
	36.8	76	16	138/82	98	1	0
	37.8	68	12	126/72	98	1	0
	36.3	80	14	116/75	97	1	0
	37	82	14	126/82	98	1	0
	38.9	95	11	137/78	97	1	0
	37.5	86	14	127/80	98	1	0
	37.8	97	17	120/75	97	1	0
	38.3	90	21	110/80	98	1	0
	37.9	89	26	113/80	96	1	0
	39.7	118	26	85/60	94	1	0

Figure 9: A chart displaying data via graphs or 'quasi-graphs'



A number of issues regarding data plotting were noted by the evaluators. In the chart displayed in Figure 2, dots on the graph area for temperature and pulse competed for attention with the dots entered to plot the graphs. In the same chart (and in other charts with the same design), boxes for entering data were diagonally split into two triangles for each time-point. This caused confusion regarding the correct order for plotting values across time. Finally, in a few charts, thick black lines across the graph's area (either indicating a "normal" value or a cut-off) would cover the dots drawn by Evaluator 1, making it unnecessarily difficult to plot the graph (see Figure 10).

Figure 10: A thick normative line obscuring data points



4.4 Integration of track and trigger systems

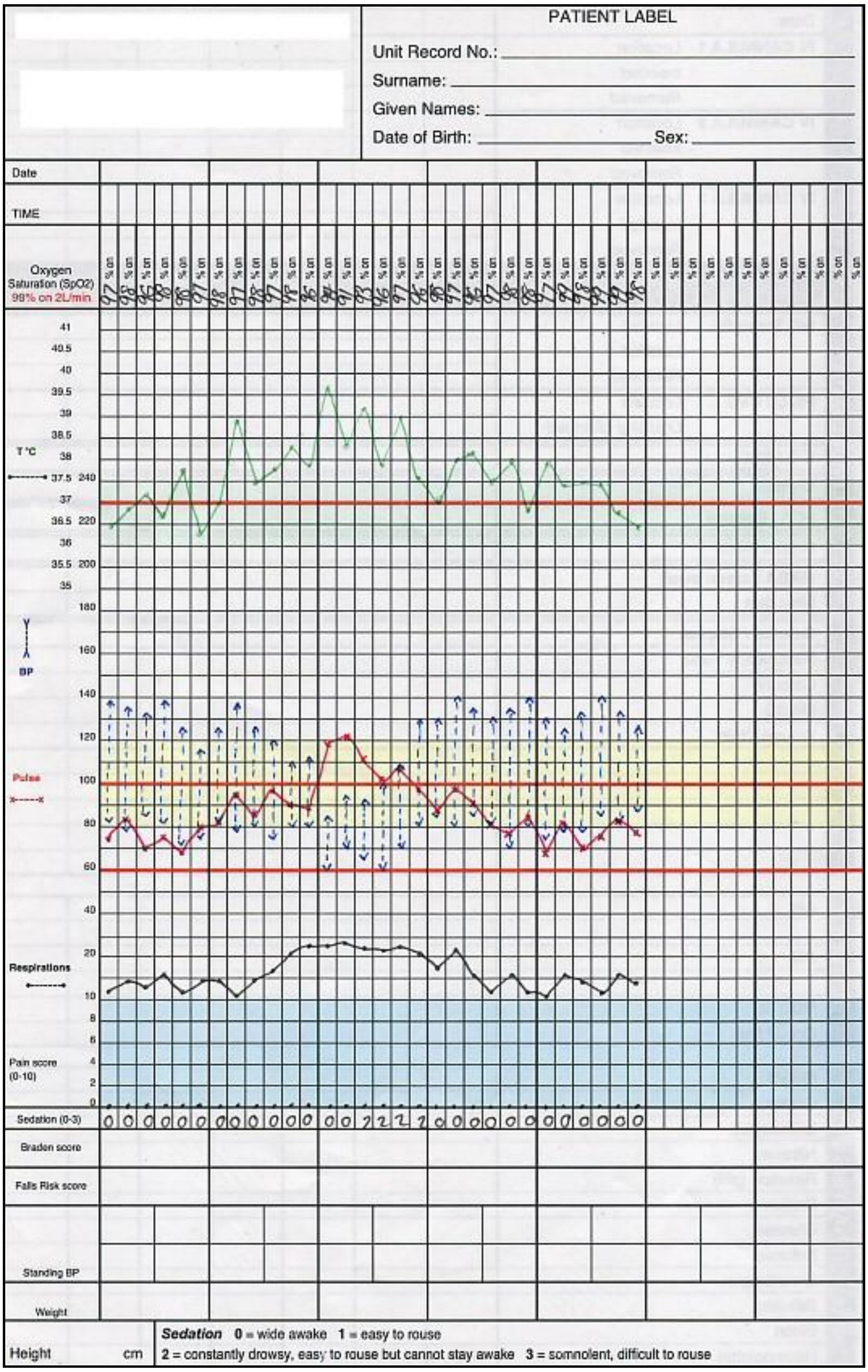
From a human factors perspective, track and trigger systems are beneficial in that they can bring together lower-level data (e.g. a patient's individual vital signs' observations) into a higher-level summation (e.g. a single score that represents the patient's degree of physiological abnromality) and automate much unnecessary workload. Track and trigger systems therefore arguably help users to recognise a deteriorating patient and escalate responses appropriately, and such a system should be included in a well-designed observation chart. However, only 36% of the 25 charts reviewed included any sort of a track and trigger system (e.g. even just listing the Medical Emergency Team's call criteria). Furthermore, several problems were identified with the implementaton of such systems in charts (see Table 6 for a list).

Almost three-quarters of the charts included instances of track and trigger system instructions not being clear and descriptive. For example, one chart included the instuction "Report Temp <36 or >37.5", but no detail as to whom or where to report temperature deviations. Similarly, another chart did not define what actions to take in a "clinical emergency", or what a "sudden change in LOC [level of consciousness]" meant. The most severe case was a chart with possible criteria defined by multi-coloured lines and backgrounds but the colouring was not explained on the chart (see Figure 11).

Table 6: Proportion of the 25 Charts Affected by Usability Problems Related to Track and Trigger Systems

Usability problem	Percentage of charts affected
Action instructions are not clear & descriptive	72%
No system or system is present in a non-meaningful way	64%
Scoring guide for each vital sign is listed on another part of the chart	52%
Action guide for the total score is listed on another part of the chart	52%
System does not allow for modification of the threshold scores for a particular patient	52%
System is not multiple parameter or aggregated weighted scoring	44%
Colour scheme does not correspond to the system	44%
Score for each vital sign is recorded on another part of the chart not beside the vital sign itself	32%
Basic functionality not understandable in 1 hour	12%

Figure 11: A chart with no instructions as to how to use its colour-coded system



Commentary: Lack of instructions. For instance, at the bottom of the graph area, five rows are shaded blue. The evaluators did not know whether this signified the "Pain score area" or that less than 10 respirations per minute were clinically significant.

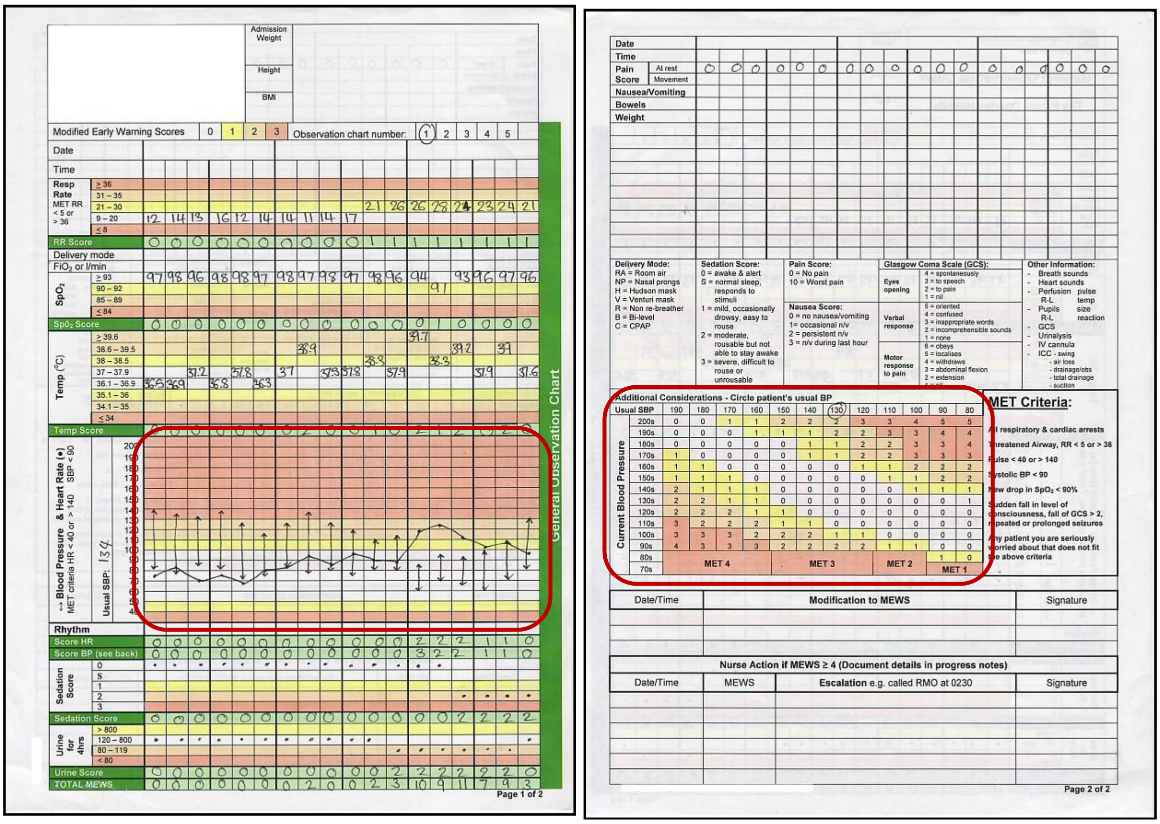
Several problems were observed in the use of colour in track and trigger systems. In three charts, the progression of colouring for the data recording areas differed from the clinical cut-offs listed in another part of the chart. For example, temperatures 38 C to 38.5 C were coloured as being “moderate risk”, but a temperature greater than 38.5 C was listed as moderate risk elsewhere on the same chart. Such inconsistency is clearly problematic.

In a similar vein, one chart used different colours to signify cut-offs for different variables. For blood pressure, respiratory rate and oxygen saturation, blue corresponded to "bad", but for pulse, red corresponded to “bad". This inconsistent colouring was seen as being confusing and having the potential to cause errors. There were also two charts that required pulse and blood pressure to be plotted on the same graph area, while the colouring of the area was only relevant to scoring pulse. In order to score blood pressure, the user had to turn over the chart to refer to a separate table (see Figure 12).

Figure 12: Potentially confusing use of colour in a track and trigger system

Front of an A4 sheet

Back of an A4 sheet



4.5 Language and labelling

Clarity, consistency, and familiarity in the language and labelling used in an observation chart can improve the way in which users interact with the chart. Table 7 shows the main problems found in the observation charts regarding the use of language and labels.

The vast majority of charts had instances where expressions could be made clearer. For example, "If patient begins to trigger…" (should read "If patient triggers…", "begins to" is unnecessary). The most memorable instance of unclear labelling was a sedation scale asking users to score how "easily arousable" a patient was. Changing the wording to "easily roused" or "easily awakened" would avoid such potential for embarrassment.

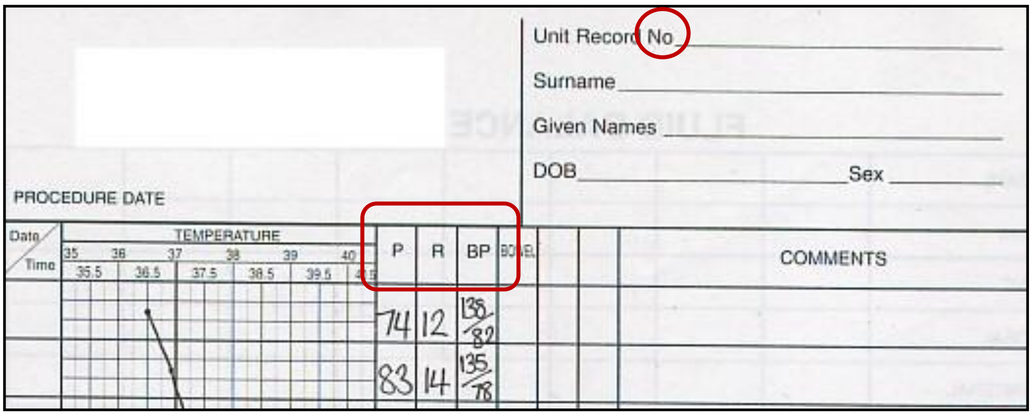
Table 7: Proportion of the 25 Charts Affected by Usability Problems Related to Language and Labelling

Usability problem	Percentage of charts affected
Expressions used could be made clearer	96%
Abbreviations used could be misinterpreted	80%
Spelling or grammatical errors	68%
Not Australian English spelling[a]	4%

Note. [a]The instance of non-Australian spelling observed was in a chart from New Zealand.

The majority of the charts included a large number of abbreviations. The average number of unique abbreviations (i.e. discounting repetitions of the same abbreviation) in a chart was 19. The minimum number of unique abbreviations in a chart was 3. However, the chart with the maximum number had 51 unique abbreviations. Many charts also included abbreviations that could be misinterpreted (see Figure 13). For instance, the one chart using the symbol 'R' to denote different things ('respiration' and 'right'). A related problem seen in many charts was the inconsistent use of labels, such as the one chart using 'O2 Saturations', 'SaO_2', and 'SaO^2' interchangeably to refer to oxygen saturation.

Figure 13: Language and labelling that could be improved



Commentary: To the top, there is a grammatical error. The label should read "Unit Record No." not "Unit Record No", as "No." is the correct abbreviation for number. The abbreviations for pulse, respiration rate, and blood pressure are 'over abbreviated' and thus could be misinterpreted. For instance, "P" could mean pulse or pressure.

When considering the labelling used in the observation charts as a whole, many differing terms were used for the one vital sign. Table 8 shows the terms used for eight main vital signs. Pain, pulse and temperate tended to be appropriately labelled. On the other hand, oxygen saturation and level of consciousness had many permutations (with some being incorrect).

Table 8: Terms Used in the 25 Charts for 8 Vital Signs

Vital sign	Terms used in charts	Total number of terms used
Respiration rate	R, RESP, Resp Rate, Respiration, Respirations, Respiratory Rate, Resps, RR	8
Oxygen saturation	O^2 saturation (%),O2 Saturations, O_2Sat, O_2Sat%, O_2Sat., Oxygen - Saturation %, Oxygen Saturation, Oxygen Saturation (SpO2), SaO_2, Sat O_2, SATS (SpO2), Saturation, SpO Sats%, $Sp0_2$, SpO_2, SpO2 Sats, SpO2%, SPO^2	18
Blood pressure	B.P., Blood Pressure, BP, SBP, Systolic Blood Pressure, Systolic BP	6
Pulse	Heart Rate, HR, P, Pulse	4
Temperature	T, T˚C, TEMP, Temp (˚C), Temp ˚C, Temp Score, Temperature, Temperature (˚C), Temperature ˚C, Temperature C˚	10
Urine output	4 Hour Urine Output, HOURLY URINE FOR PAST 2 HOURS IN CATHERISED PATIENTS, Other, Output Urine, Urinary Output, Urine, Urine for 4hrs, Urine Output, Urine Score	9
Pain	Pain, Pain Scale, Pain Score, Pain Score – M, Pain Score – R, Pain Score (0-10), Pain Score 0- 10	7
Level of consciousness	Alertness, CNS, Conscious Level (AVPUC), Levels of Alertness, LOC, Neurological, Sedation, Sedation Score	8

4.6 Cognitive and memory load

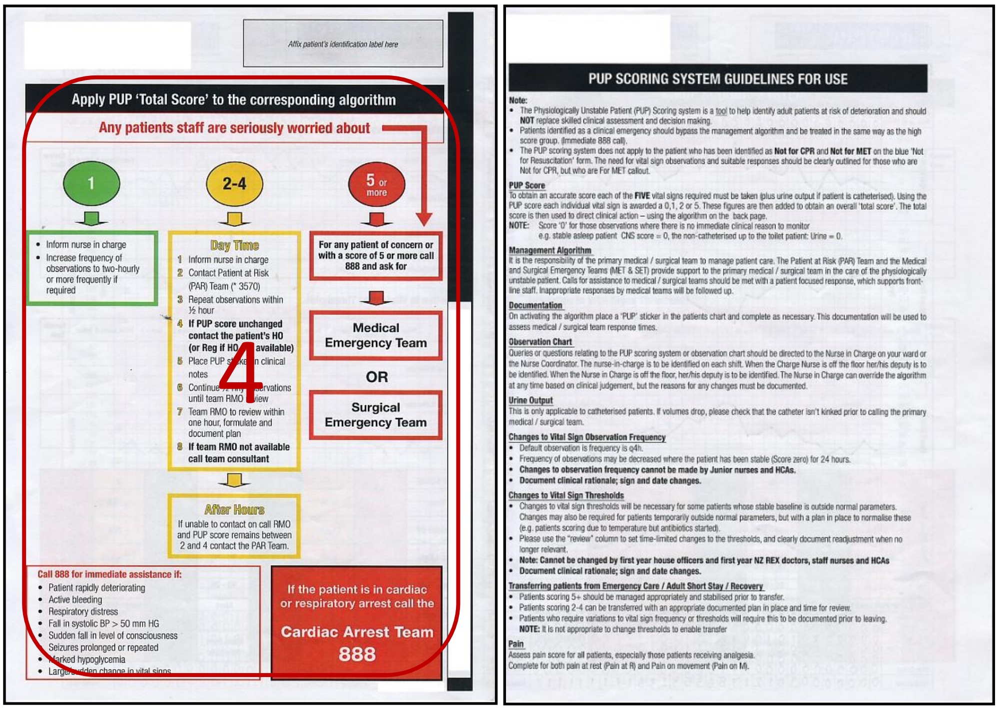
Minimising the cognitive and memory requirements for the user of an observation chart is necessary to promote user satisfaction and decrease the number of errors made. Cognitive and memory load problems that were frequently identified in the 25 charts are listed in Table 9. Comparing information over different areas of the one page or even comparing information over two pages requires a mental comparison (i.e. at least 1 piece of information must be held in the mind, as all the required information for the comparison is not visible on one area of the page). See Figure 14 for a flow chart overlaid on a chart showing the memory loads present in recording observations. Also, wherever possible, the need to write in data should also be avoided (e.g. hospital name, sex) as chart users must think about the required response format and recall from memory the correct response, rather than just recognising and circling the correct datum. Additional problems cited regarding the cognitive and memory loads associated with charts were the inclusion of vague directives such as "check unit policy" (omitting detail regarding what specific policy was to be checked or where it could be found, and directing the user away from the chart itself), or not providing any instructions for cut-off lines on graphs for vital signs (again requiring users to know or remember what the lines signified, as in the chart shown in Figure 11).

Table 9: Proportion of the 25 Charts Affected by Usability Problems Related to Cognitive and Memory Load

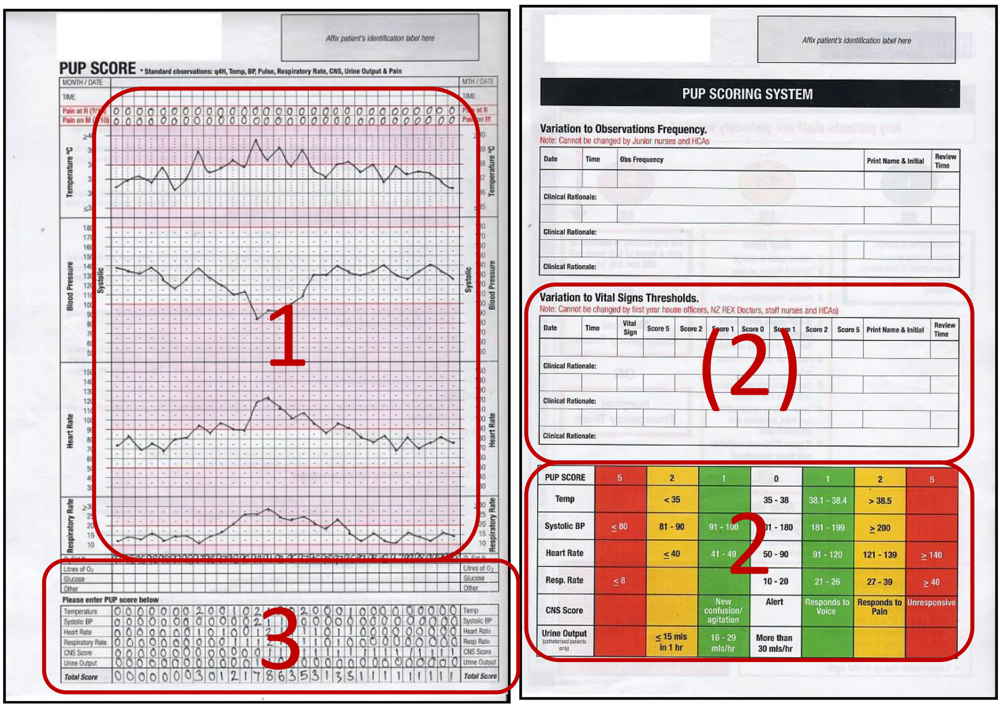
Usability problem	Percentage of charts affected
Information must be compared over different areas of the 1 page	80%
Writing is required when chart could provide response options to circle	72%
Information must be transcribed or compared over 2 pages	48%

Figure 14: Example of the multiple cognitive and memory loads present in filling in a chart

Outside faces of an A3 sheet



Inside faces of an A3 sheet



Commentary: The process is (1) record data on the left-hand side of the bottom A3 sheet, (2) compare data with scores in the PUP score table on the right-hand side of A3 sheet (plus check for Variations to Vital Signs Thresholds), (3) Copy PUP score to the table at the bottom of the left-hand side sheet & calculate total PUP score, (4) Feed total PUP score into flow-chart on the left-hand side of the top A3 sheet to identify actions.

4.7 Use of fonts

As shown in Table 10, all the observation charts contained text that was regarded as being too small. Most of the charts' text was as small as 7 or 8 point (which is about this big), but one chart used 4 point font (which is this big). However, it is acknowledged that in producing a relatively compact observation chart, a small text size may have to be employed in some of the chart's components.

On the whole, the charts avoided using more than one font for the bulk of their text. In all cases where more than one font was employed, it was to format the chart title or hospital name differently. Similarly, the 4 charts which used serifs only used serifs in the chart title, hospital name or patient label area.

Almost a quarter of the charts were rated as having employed fonts where the ohs/zero or els/one look very similar. This may be due to the correct design decision to avoid the use of serifs, which slows reading speed for text that is not lengthy or is displayed on a computer screen (such as in Times New Roman). However, a related problem observed in several charts was the substitution of 0 for O in SpO_2 (resulting in the incorrect '$Sp0_2$').

Two additional problems were identified by the evaluators regarding font usage. One chart was described as having lot of different font sizes and formatting styles on the one page, which made the chart appear unnecessarily "busy" or complicated. Another chart was criticised for using ***Arial Black*** for all of its labelling, which was considered as reducing legibility.

Table 10: Proportion of the 25 Charts Affected by Usability Problems Related to the Use of Fonts

Usability problem	Percentage of charts affected
Text too small (smaller than 11 point font)	100%
Capitalisation used too often	76%
Text size misleading (e.g. important information very small & vice versa)	76%
More than 1 font type present	48%
Font appears compressed (e.g. Arial Narrow)	32%
Ohs/zero or els/one look very similar	24%
Text too big	16%
Serifs used	16%

4.8 Use of colour

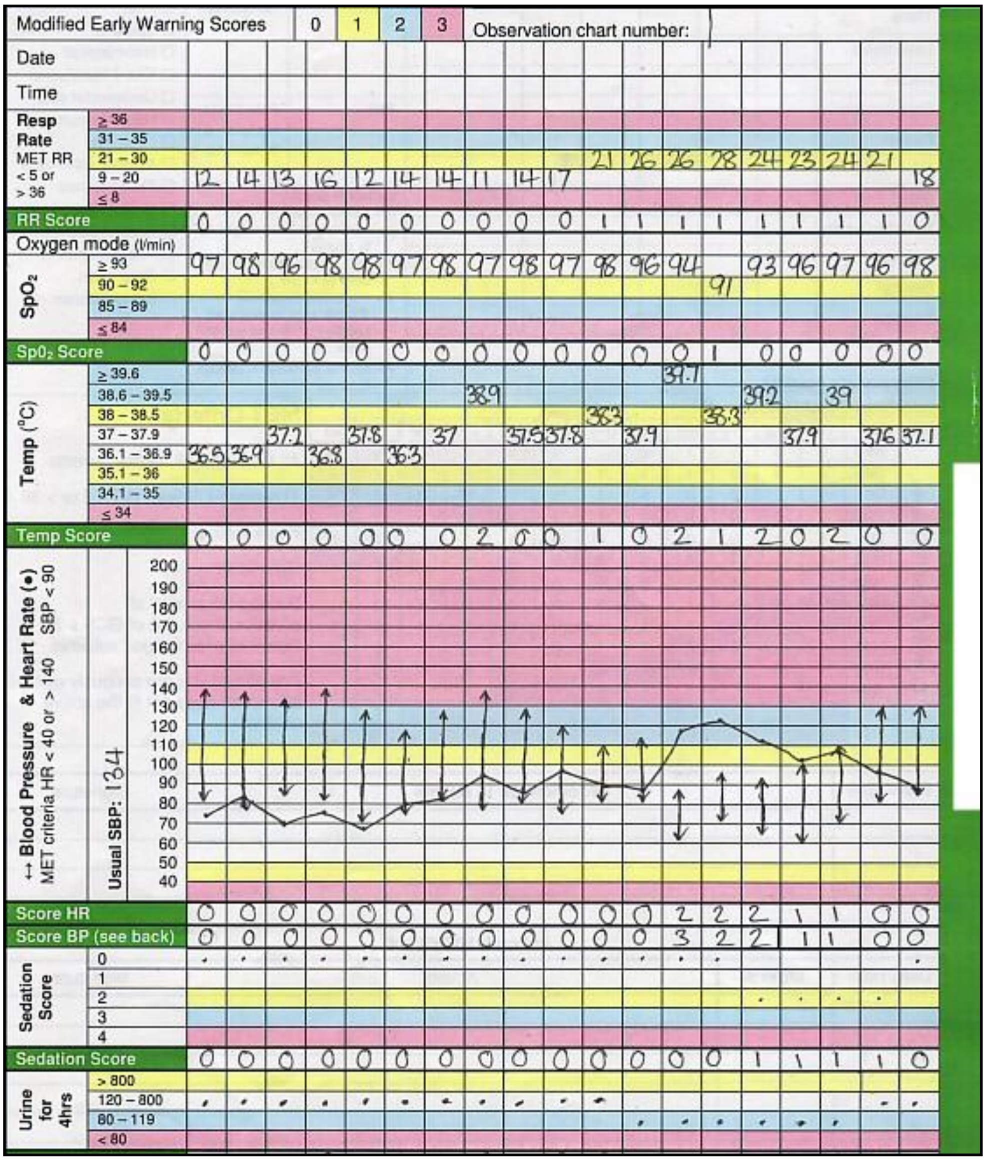
Judicious use of colour can enhance the usability of an observation chart. For example, colours can signify different track and trigger system scores on the vital signs' graphs. However, just over two-thirds of the charts either did not use colour at all or used colour in non-meaningful ways (such as to indicate progressively more deranged vital signs). Table 11 presents the results of the heuristic analysis on the use of colour in the 25 observation charts. Common problems were colour schemes not accommodating for colour-blind users (i.e. using green and red colours with very similar densities), not providing redundant cues if the track and trigger system was colour-based (Figure 9 shows a chart that does use redundant cues), and not using pastel colouring. In general, there were few problems with the use of too many colours (where it is generally considered that using more than five colours can lead to a cluttered design) and using colours in ways that could lead to confusion (e.g. green signalling "moderate deterioration" cf. a more logical warning colour such as yellow, orange, or red).

Several additional problems related to the use of colour were cited by the evaluators. For one chart, a lack of the use of colour as part of a track and trigger system was considered to make the scoring of the vital signs difficult. Another chart, which did use colour for a track and trigger system, was described as "cluttered and confusing" due to a lack of progression of colouring between the different levels of severity (for example, an appropriate progression, where severity is correlated with choice of colour could be **yellow** → **orange** → **red** → **purple** → **black**; see Figure 15 for an example of what was considered an inappropriate colour scheme, where colour choice was less obviously related to severity). Two charts were formatted entirely in **dark** or **medium** blue. This was seen as advantageous if users used a black ink to write on the charts (entered data would stand out against the chart background), but the value of such formatting would be negated if a blue ink was used. Finally, one chart used a pink colour to show when a vital sign's value was outside the normal range. However, using one colour to signify "value is outside the normal range" meant users would still have to refer to a scoring table to enter a track and trigger score for the value (see Figure 14). Using a progression of colouring could eliminate this unnecessary step. Furthermore, it was argued that the pink colour could be confused with the red colour in the table that indicated a score of 5.

Table 11: Proportion of the 25 Charts Affected by Usability Problems Related to the Use of Colour

Usability problem	Percentage of charts affected
No colour or colour present in a non-meaningful way (e.g. in logo only)	68%
Colour-blind users will perhaps struggle with the colour scheme	56%
No redundant cues, scheme cannot be used without the colours	44%
Colours not pastel	36%
More than 5 colours in chart as a whole (including white space, text, logos)	32%
One or more colours could be deceptive	28%
More than 5 colours in vital signs' area (including white space)	12%

Figure 15: A chart with no progression of colouring



Commentary: This chart has no logical progression in its colouring, though each colour does correspond to a different track and trigger score. There is no convention whereby pink is considered more serious than blue, and blue is considered more serious than yellow.

4.9 Photocopying legibility

When photocopied, just under half of the 25 observation charts were legible at a number of light/dark settings. As seen in Table 12, a few charts tended to have illegible data for vital signs when photocopied. However, only one chart had an instance of illegible labelling for vital signs when photocopied. In addition to the figures reported in Table 12, a few charts were reported as being less legible or harder to read when photocopied, but without becoming completely illegible.

Table 12: Proportion of the 25 Charts Affected by Usability Problems Related to Photocopying

Usability problem	Percentage of charts affected
Some chart elements not visible in photocopies[a]	56%
Vital signs' data not visible in Normal setting photocopy	4%
Vital signs' data not visible in +1 Darker setting photocopy	8%
Vital signs' data not visible in +2 Darker setting photocopy	4%
Vital signs' data not visible in +1 Lighter setting photocopy	4%
Vital signs' data not visible in +2 Lighter setting photocopy	4%
Vital signs' labelling not visible in Normal setting photocopy	0%
Vital signs' labelling not visible in +1 Darker setting photocopy	0%
Vital signs' labelling not visible in +2 Darker setting photocopy	4%
Vital signs' labelling not visible in +1 Lighter setting photocopy	0%
Vital signs' labelling not visible in +2 Lighter setting photocopy	0%

Note. [a]Results were exactly the same for an individual chart at Normal, +1 Darker, +2 Darker, +1 Lighter, +2 Lighter settings.

4.10 Low light legibility

All 25 observation charts were legible with realistic night-time hospital light levels at less than 1 metre reading distance. However, almost a third of the charts took longer to read in night-time lighting conditions compared with day-time lighting. Table 13 lists the chart features that affected night-time legibility.

Table 13: Proportion of the 25 Charts Affected by Usability Problems Related to Low Light Legibility

Usability problem	Percentage of charts affected
At least 1 important part of the chart is less legible	32%
Small font size affects legibility	16%
Font style or font colour affects legibility	12%
Colour scheme affects legibility	4%
Values or plotted data for 1 vital sign are less legible	4%

5. Discussion

Improving the recognition and management of patients who deteriorate whilst in hospital is a frequently cited priority for improving patient safety [1, 2]. One way to improve the recognition and management of deteriorating patients is to improve the design of paper-based adult observation charts. The aim of the current study was to evaluate the quality and extent of design problems in a sample of 25 existing observation charts from Australia and New Zealand.

Heuristic analysis was chosen as the methodological approach, as it quickly and easily generates information regarding design problems for a chosen system [17, 18]. In heuristic analysis, the main output is a list of usability problems identified by evaluators' expert judgment. The five evaluators in the current study had expertise in applied psychology, human factors, and medicine; and three had previously used observation charts.

The 25 observation charts were each analysed in two formats, a full-size 'blank' colour copy and another full-size colour copy with a case of patient deterioration plotted on the chart. A total of 1,189 usability problems were identified in the observation charts. Usability problems were identified as affecting the observation charts' page layout, information layout, recording of vital signs, integration of track and trigger systems, language and labelling, cognitive and memory load, use of fonts, use of colour, photocopying legibility, and low light legibility.

While the nature of heuristic analyses means that they tend to raise negative issues, there are positive facets to this particular analysis that should be mentioned. First, the material presented in the Results section may give the impression that the evaluators were highly critical of all of the observation charts. This is not true. The evaluators acknowledge that many of the observation charts demonstrated good design practice. Second, this report has generated valuable material that could be used to produce a manual for designing more user-friendly observation charts. To the Research Team's best knowledge, no such guide presently exists to help those charged with designing observation charts, apart from very general guidelines such as Queensland Health's Clinical Form Design Standard Guidelines [27].

This analysis has also highlighted that it may well be impossible to produce an observation chart that conforms to all usability principles. For instance, accommodating graphical displays for all vital signs on a landscape A4 page may be very difficult to achieve. Similarly, a small text size may be a necessary evil in producing a compact chart. However, problems that were frequently identified in the 25 observation charts analysed such as making spelling or grammatical errors, including vague instructions, not using colour, and using more than one font, can and should be avoided. In designing a user-friendly observation chart, instances of usability problems should be minimised as much possible. Furthermore, when considering breaking a usability "rule", there should be careful consideration of the relative importance of the competing usability principles and what the alternative chart designs would actually look like.

With regards to the usability testing literature, this study demonstrated three important points. First, heuristic analysis can be successfully implemented in a usability test of up to 25 separate systems (i.e. the 25 observation charts). Second, usability principles can be specifically developed for paper-based systems, as opposed to computer systems or mechanical devices. Third, heuristic analysis can be successfully employed to evaluate paper-based observation charts in the health care domain. As mentioned previously, previous to this study the potential applicability of heuristic analysis to non-computer-based medical systems had yet to be determined [22].

This study also complements other nascent efforts to improve the design of observation charts. In line with Chatterjee et al. [13] and Australian efforts led by ACT Health [14], the heuristic analysis showed that many usability problems are present in current observation charts. While the previous two studies focused on improving their hospital's particular observation chart, this study reports on the type and quantity of design problems present in a sample of Australian and New Zealand observation charts.

In the near future, the project will emulate Chatterjee et al. [13] and ACT Health [14] in designing a user-friendly adult general observation chart. A draft of the new observation chart's design will be initially evaluated against eight other observation charts by means of an online survey of relevant health professionals. The survey will also gather data on general issues related to observation charts, for example what terms health professional prefer for various vital signs (out of the correct terms found in Table 8). After the survey, the new observation chart will be empirically evaluated (again, by comparison against a number of other observation charts) in terms of how well staff perform at recognising simulated patient deterioration (Simulation Study 1), and recording simulated deteriorating physiological data and responding appropriately (Simulation Study 2).

6. References

1. Australian Commission on Safety and Quality in Health Care, *Recognising and responding to clinical deterioration: Background paper*. 2009, Australian Commission on Safety and Quality in Health Care, Department of Health and Ageing, Commonwealth of Australia.
2. Lim, P., *Reconition and management of the deteriorating patient*. 2009, Patient Safety Centre, Queensland Health.
3. Franklin, C. and J. Mathew, *Developing strategies to prevent inhospital cardiac arrest: Analyzing responses of physicians and nurses in the hours before the event.* Critical care medicine 1994. **22**(2): p. 189-191.
4. Buist, M., et al., *Association between clinically abnormal observations and subsequent in-hospital mortality: A prospective study.* Resuscitation, 2004. **62**(2): p. 137-141.
5. Hillman, K.M., et al., *Antecedents to hospital deaths.* Internal Medicine Journal, 2001. **31**(6): p. 343-348.
6. Goldhill, D.R., S.A. White, and A. Sumner, *Physiological values and procedures in the 24 h before ICU admission from the ward.* Anaesthesia, 1999. **54**: p. 529-534.
7. McQuillan, P., et al., *Confidential inquiry into quality of care before admission to intensive care.* British Medical Journal, 1998. **316**(1853-1858).
8. Kause, J., et al., *A comparison of antecedents to cardiac arrests, deaths and emergency intensive care admissions in Australia and New Zealand, and the United Kingdom-the ACADEMIA study.* Resuscitation, 2004. **62**: p. 275-282.
9. Endacott, R., et al., *Recognition and communication of patient deterioration in a regional hospital: A multi-methods study.* Australian Critical Care, 2007. **20**(3): p. 100-105.
10. Bristow, P.J., et al., *Rates of in-hospital deaths and intensive care admissions: the effect of a medical emergency team.* Medical Journal of Australia, 2000. **173**: p. 236-240.
11. Bellomo, R., et al., *A prospective before-and-after trial of a medical emergency team.* Medical Journal of Australia, 2003. **179**(6): p. 283-287.
12. Bellomo, R., et al., *Prospective controlled trial of medical emergency team on postoperative morbidity and mortality rates.* Critical Care Medicine, 2004.
13. Chatterjee, M.T., et al., *The "OBS" chart: An evidence based approach to re-design of the patient observation chart in a district general hospital setting.* Postgraduate Medical Journal, 2005. **81**: p. 663-666.
14. ACT Health. *Compass - background*. No date 26/8/09 [cited; Available from: http://www.health.act.gov.au/c/health?a=&did=11026450.
15. Mack, R.L. and J. Nielsen, *Executive summary*, in *Usability inspection methods*, J. Nielsen and R.L. Mack, Editors. 1994, John Wiley & Sons: New York.
16. Nielsen, J. and R.L. Mack, eds. *Usability inspection methods*. 1994, John Wiley & Sons: New York.
17. Zhang, J., et al., *Using usability heuristics to evaluate patient safety of medical devices.* Journal of Biomedical Informatics, 2003. **36**: p. 23-30.
18. Nielsen, J., *Heuristic Evaluation*, in *Usability inspection methods*, J. Nielsen and R.L. Mack, Editors. 1994, John Wiley & Sons: New York.

19. Zhu, W., K.-P.L. Vu, and R.W. Proctor, *Evaluating web usability*, in *Handbook of human factors in web design*, R.W. Proctor and K.-P.L. Vu, Editors. 2005, Lawrence Erlbaum Associates: Mahwah, NJ. p. 321-337.
20. Nielsen, J., *Usability engineering*. 1994, San Diego, CA: Morgan Kaufmann.
21. Gerhardt-Powals, J., *Cognitive engineering principles for enhancing human-computer performance [Abstract].* International Journal of Human-Computer Interaction, 1996. **8**(2): p. 189-211.
22. Martin, J.L., et al., *Medical device development: The challenge for ergonomics.* Applied Ergonomics, 2008. **39**(3): p. 271-283.
23. Swayne, T., *Design for patient safety: A guide to the graphic design of medication packaging*. 2007, National Patient Safety Agency.
24. Garmer, K., J. Ylvén, and I.C.M. Karlssona, *User participation in requirements elicitation comparing focus group interviews and usability tests for eliciting usability requirements for medical equipment: A case study.* International Journal of Industrial Ergonomics, 2004. **33**(2): p. 85-98.
25. Garmer, K., et al., *Application of usability testing to the development of medical equipment. Usability testing of a frequently used infusion pump and a new user interface for an infusion pump developed with a Human Factors approach.* International Journal of Industrial Ergonomics, 2002. **29**(3): p. 145–159.
26. Higgins, P.A., et al., *Light measurement in the hospital: A comparison of two methods.* Research in Nursing & Health, 2007. **30**: p. 120-128.
27. *Queensland Health data management policy: Queensland Health clinical form design standard guidelines*. 2003, Queensland Health.
28. Yu, D., et al., *Reading horizontal and vertical english text [Abstract].* Journal of Vision, 2008. **8**(6): p. 629a.
29. Australian Institute of Health and Welfare, *Australian hospital statistics 2007–08*, in *Health Services Series*. 2009, Australian Institute of Health and Welfare, Australian Government: Canberra.
30. Bernard, M.L., et al., *Comparing the effects of text size and format on the readability of computer-displayed Times New Roman and Arial text.* International Journal of Human-Computer Studies, 2003. **59**(6): p. 823-835
31. Lorch Jr. , R.F., E. Pugzles Lorch, and M.A. Klusewitz, *Effects of typographical cues on reading and recall of text.* Contemporary Educational Psychology, 1995. **20**(1): p. 51-64.
32. Frascara, J., *Typography and the visual design of warnings*, in *Handbook of Warnings*, M.S. Wogalter, Editor. 2005, Lawrence Erlbaum Associates: Mahwah, NJ. p. 385-406.
33. Pelli, D.G., et al., *Crowding and eccentricity determine reading rate.* Journal of Vision, Journal of Vision. **7**(2): p. 1-36.
34. Tinker, M.A. and D.G. Paterson, *Studies of typographical factors influencing speed of reading. V. Simultaneous variation of type size and line length.* Journal of Applied Psychology, 1931. **15**(1): p. 72-78.
35. Yager, D., K. Aquilante, and R. Plass, *High and low luminance letters, acuity reserve, and font effects on reading speed.* Vision Research, 1998. **38**(17): p. 2527-2531.

Appendix A: List of Organisations that Supplied Observation Charts

Hospital or area health service	Title of chart supplied	Hospital or area health service	Title of chart supplied
ACT Health	Compass General Observation Chart	Northern Sydney Central Coast	General Observation Chart
Cabrini Hospital	Cabrini Hospital Observations & Fluid Balance Summary	Northside Clinic	General Observation Chart
Cairns Private Hospital	Composite Record	Peninsula General Hospital	Observation Chart
Caloundra Private Hospital	Close Observation Chart	Pindara Private Hospital	Observation Chart & General Observations
Capital & Coast District Health Board	Adult Observation Chart	Prince of Wales Private Hospital	Observation Chart
Clinical Excellence Commission	General Observation Chart	Princess Alexandra Hospital	Temperature and General Observations Chart
Counties Manukau District Health Board	Observation Chart	Royal Brisbane & Women's Hospital	Observation Chart With Medical Emergency Call Criteria
Epworth Freemasons Hospital	Observations	Royal Adelaide Hospital	Observation Chart – Composite Graphic
Figtree Private Hospital	Four Hour Temperature & Observation Charts	Royal Prince Alfred Hospital	General Observation Chart
Greater Southern Area Health Service	Colour Coded Observation Chart (Adult)	Southern Highlands Private Hospital	General Observation Chart
Hillcrest Hospital	Observation Chart	St George Private Hospital	Modified Early Warning System Observation Chart
Hunter New England Area Health Service	Adult Observation Chart	Sydney Adventist Hospital	Adult Observation Chart
Kareena Private Hospital	Observation Chart	Sydney West Area Health Service	SWHR-2570W Observation Chart
Lake Macquarie Private Hospital	4 Hourly Temperature Observation Chart & General Observation Sheet	Sydney West Area Health Service	SWHR-2570EC Observation Chart
Linacre Private Hospital	Temperature General Observations	Sydney West Area Health Service	SWHR-2570bm General Observation Chart
Lyell McEwin	Observation Chart	Tamara Private	Clinical Observation Chart

Hospital		Hospital	& EWS and Escalation Protocol
Mitcham Private Hospital	Frequent Observation Chart & Temperature General Observations	The Avenue Hospital	Observations Chart
Noarlunga Hospital	Observations Graphic Chart	The Prince Charles Hospital	General Observation Chart
Noosa Hospital	Special Observation Sheet	Wangaratta Private Hospital	Observation Chart
Noosa Hospital	Modified Early Warning System	Western Health	Observation Form
Noosa Private Hospital	Special Observation Sheet	Western Health	Observation Chart
North Coast Area Health Service	Observation Chart	Westmead Private Hospital	General Observation Chart
North Shore Private Hospital	Observation Chart		

Appendix B: Usability Principles Used in the Current Analysis with the Rationale for Their Use Explained

Each usability principle specific to paper-based observation charts that was used in the current analysis is listed below. In order to be relatively concise, only the most applicable rationales (adapted from the more general published usability principles listed in Section 2.2 of the report) are listed for each usability principle. For some principles related to formatting (page margin size, pastel colouring, and font size), Queensland Health's Clinical Form Design Standard Guidelines were used [27].

Usability principle	Rationale
Page layout	
Minimal space should be used for hospital name or logo	The system should not contain information that is rarely needed
Bureaucratic codes that do not relate to the chart's clinical usage should not be present	The system should not contain information that is rarely needed
Landscape orientation preferred	Increases the size of the display that a user can simultaneously attend to
Page margins should be: left 2 cm, all others 1 cm	Queensland Health's Clinical Form Design Standard Guidelines
Should not have mixture of vertically-oriented & horizontally-oriented data points	The system's graphic design & colour should be carefully considered – chart should not have to be turned during use & vertically-oriented text takes longer to read [28]
Page should be A4 size	The system should match the user's task in as natural a way as possible
Information layout	
Information should be displayed in decreasing order of importance	Information presented in the top left of a display normally gets more attention
Eight vital signs should all be on 1 side of a page	The aim of any system should be to present exactly the information the user needs at exactly the time & place that it is needed
No redundant or irrelevant information	The system should not contain information that is rarely needed
Two vital signs or track & trigger scores should be clearly separated	Avoid unrelated elements being formatted in a such a way that they seem to belong together
Areas for writing should accommodate 14 point font	Queensland Health's Clinical Form Design Standard Guidelines
Amount of space devoted to something should not be too big	The system should not contain information that is rarely needed
Labels of the same level of importance should be formatted the same	Avoid related elements being formatted in a such a way that they seem to belong to different categories
Enough time-points for chart to be used for 3 days (assuming 4-hourly monitoring)	The system should match the user's task in as natural a way as possible (i.e. average length of stay in hospital = 3.3 days) [29]

Important information should be displayed in top left of page	Information presented in the top left of a display normally gets more attention
Basic functionality should be understandable in 1 hour	Basic functionality should be understandable in 1 hour
Recording vital signs	
Data points for 2 vital signs should not be able to be confused	The system should produce minimal errors
Labels should specify unit of measurement	The aim of any system should be to present exactly the information the user needs at exactly the time and place that it is needed
Labels should be clear & descriptive	The system should have a good match between the display of information and the user's mental model of the information
Graph should not be too small or cramped	The system's graphic design and colour should be carefully considered – smaller or cramped graphs may be less legible (i.e. trends flattened)
Thick vertical lines should be placed every 3-4 columns	Reduce the time spent assimilating raw data
Time boxes should accommodate 14 point font	Queensland Health's Clinical Form Design Standard Guidelines
Date boxes should accommodate 14 point font	Queensland Health's Clinical Form Design Standard Guidelines
Information should be displayed as a graph	Bring together lower level data into a higher-level summation
Vertical axis of a graph should be labelled on the left & right of the page	Reduce the time spent assimilating raw data
Labels should provide an example of how data are to be recorded	When users are asked to provide input, the system should describe the required format and, if possible, provide an example
More than 1 vital sign should not be recorded on the same graph or area	The system should produce minimal errors
Graph label formatting should differ from vertical axis values' formatting	The system's graphic design and colour should be carefully considered – graph label should stand out from the graph values
Scale of the vertical axis values should not change	Reduce the time spent assimilating raw data
Vertical axis values should not be misaligned	The system should produce minimal errors
Date should be ruled off every 24 hours	Reduce the time spent assimilating raw data
Chart should not require the use of different coloured pens	Reduce the time spent assimilating raw data
Vertical axis values should be mutually exclusive	The system should produce minimal errors
Labels should not be written vertically with upright letters	The system's graphic design and colour should be carefully considered - vertically-oriented text takes longer to read [28]
Integration of track and trigger systems	
Action instructions should be clear & descriptive	Messages should be phrased in clear language and avoid obscure codes (the user should not have to refer to elsewhere, e.g. the manual). Messages should help the user solve the

	problem
Chart should include a track & trigger system	Bring together lower level data into a higher-level summation if appropriate
Scoring guide for each vital sign should not be listed on another part of the chart	Users should not have to remember information from one part of the system to another (i.e. avoid mental comparisons)
Action guide for the total score should not be listed on another part of the chart	Users should not have to remember information from one part of the system to another (i.e. avoid mental comparisons)
System should allow for modification of the threshold scores for a particular patient	The system should match the user's task in as natural a way as possible
System should be multiple parameter or aggregated weighted scoring	Bring together lower level data into a higher-level summation if appropriate
Colour scheme should correspond to the system	Automate unwanted workload. The system should allow the user to rely on recognition rather than recall memory
Score for each vital sign should be recorded beside the vital sign itself	Information that will be used together should be displayed close together
Basic functionality should be understandable in 1 hour	Basic functionality should be understandable in 1 hour
Language and labelling	
Expressions should be clear	Words, phrases, and concepts used should be familiar to the user. Users should not have to wonder whether different words or actions mean the same thing
Abbreviations should not be able to be misinterpreted	Words, phrases, and concepts used should be familiar to the user
No spelling or grammatical errors	Words, phrases, and concepts used should be familiar to the user
Australian English spelling	Words, phrases, and concepts used should be familiar to the user
Cognitive and memory load	
Information should not need to be compared over different areas of the 1 page	Users should not have to remember information from one part of the system to another (i.e. avoid mental comparisons)
Writing should not be required when chart could provide response options to circle	The system should allow the user to rely on recognition rather than recall memory
Information should not need to be transcribed or compared over 2 pages	Users should not have to remember information from one part of the system to another (i.e. avoid mental comparisons)
Use of fonts	
Text no smaller than 11 point font	The system's graphic design and colour should be carefully considered – 10 point font can be less legible [30]
Ohs/zero or els/one should not look very similar	Users should not have to wonder whether different words or actions mean the same thing
Capitalisation should be used sparingly	Avoid over-using upper-case text, it attracts attention, but is slower to read than mixed-case text [31-32]
Text size should not be misleading (e.g.	The system should have a good match between

important information very small & vice versa)	the display of information and the user's mental model of the information.
Should not use more than 1 font type	The system's graphic design and colour should be carefully considered – may slow reading as user must 'switch' between fonts
Should not use compressed font (e.g. Arial Narrow)	The system's graphic design and colour should be carefully considered – crowding the letters in words slow reading [32-33]
Text should not be too big	The system's graphic design and colour should be carefully considered – larger fonts (12 & 14 point) can be less legible [34]
Serifs should not be used	The system's graphic design and colour should be carefully considered – serifs slow reading of short pieces of text [35]
Use of colour	
Colour should be used in a meaningful way	Reduce the time spent assimilating raw data
Colours should be distinguishable to colour-blind users	If colour is to be used, the system requires redundant cues so that colour-blind users are able to use the system with ease
Redundant cues should be included, i.e. scheme can be used without the colours	If colour is to be used, the system requires redundant cues so that colour-blind users are able to use the system with ease
Pastel colours preferred	Queensland Health's Clinical Form Design Standard Guidelines
Should not be more than 5 colours in chart as a whole (including white space, text, logos)	Adapted from: avoid more than 7 colours (on a webpage), or the display will look too "busy"
Colour choice should not be potentially deceptive (e.g. green = bad)	The system should have a good match between the display of information and the user's mental model of the information
Should not be more than 5 colours in vital signs' area (including white space)	Adapted from: avoid more than 7 colours (on a webpage), or the display will look too "busy"
Photocopying legibility	
Chart should be reproduced legibly at a range of photocopier settings, especially vital signs' data and labels	The system should match the user's task in as natural a way as possible
Low light legibility	
Chart should be legible in realistic low-light levels	The system should match the user's task in as natural a way as possible

Appendix C: Copies of the Materials Developed for the Heuristic Analysis

Microsoft Excel© spreadsheet listing the usability principles for the heuristic analysis

Coding 0 = no, 1 = yes, 4 = not applicable	Page layout					
	Too much space used for hospital name/logo	Barcode (if not a part of the pt label) in an awkward location	Mix of landscape & portrait data points (i.e. chart needs to be turned during use)	Cryptic codes present (e.g. form no. for bureaucratic purposes), NOT related to chart's use	Not A4 size (QH preferred)	Portrait
CHART AS A WHOLE						
Respiration rate						
Oxygen saturation						
Blood pressure						
Pulse/heart rate						
Temperature						
Urine output/volume						
Pain						
Level of consciousness						
Open-ended comments (e.g. where you recorded "yes" in any of the cells above, give examples of the problem identified when you feel it's necessary)						

Page 1

			Information layout		
Margins too small (QH rules = 2cm left hand side of form, others 1cm)	Margins too big (QH rules = 2cm left hand side of form, others 1cm)	Other comments	Important information NOT in top/left of 1st page (e.g. respiration rate)	Information NOT in order of importance (see order of 8 vital signs in Column A)	8 vital signs not all on 1 page

Page 2

Are 2 vital signs' info/track & trigger scores "joined" instead of separated by a small space or double line?	Too few boxes/columns for the chart to be used for 3 days (assuming 4-hrly monitoring)?	Too many boxes/columns for the chart to be used for 3 days (assuming 4-hrly monitoring)?	Headings/labels of the same level of importance are formatted differently	Box for writing something is too small, i.e. not size 14 font

				Font		
Box/amount of space devoted to something is too big (e.g. 8 rows for "action if MEWS ≥ 4" for a 3-day chart)	There is redundancy /irrelevant info taking up space	Basic functionality is not understandable in 1 hour	**Other comments**	Font looks compressed (e.g. arial narrow)	Too small (smaller than 11 point)	Too big

						Colour scheme			
Size misleading (e.g. important info v. small & vice versa)	Capitalization used too often	Ohs/zero or els/one look very similar	More than 1 font type present	Serifs	Other comments	Absent (or present in a non-meaningful way)	Not pastel	1 or more colours could be deceptive (e.g. blue meaning "moderately bad",	Colourblind users will struggle with the scheme

				Recording vital signs		
Scheme cannot be used without the colours (no redundant cues)	More than 5 colours (incl. white!) in vital signs' area, ignore text/logos	More than 5 colours in chart as a whole (incl. white, text, logos)	Other comments	Is information not displayed as a graph?	Is more than 1 vital sign to be recorded on the same graph/area	Could the graphs/data points for 2 vitals signs be confused?

Does the graph look too small/cramped?	Graph label is not clear & descriptive	Graph label is written vertically with upright letters	Graph label does not specify unit of measurement	Graph label does not provide an example of how data is to be recorded (e.g. ● or X)	Graph insts specify use of different coloured pens

Page 7

Graph label font/formatting exactly the same as the Y-axis values font	Is the vertical axis (vital sign's values) NOT labelled on the left & right of the page	Scale of Y-axis values changes (e.g. going from .5 intervals to 1 intervals for the same length of the Y-axis)	Are the Y-axis values not mutually exclusive (e.g. "5-10", "≤5")?	Do the Y-axis values "jump around" - sometimes next to a line vs middle of a box

Page 8

					Track & trigg
Are thick vertical lines NOT placed every 3-4 boxes	Are the date boxes unnecessarily small (should accommodate size 14 text)	Is the date box a blank row, instead of ruled off for every 24 hrs?	Time boxes too small (should accommodate size 14 text)	**Other comments**	Absent (or present in a non-meaningful way)

Page 9

Track & trigger system					
System is not multiple parameter or aggregated weighted scoring system (e.g. MEWS)	Colour scheme does not correspond to the track & trigger system	Score for each vital sign is recorded on another part of the chart (not beside the vital sign itself)	Scoring guide for each vital sign is listed on another part of the chart	"Action guide" for the total score is listed on another part of the chart	System does not allow for modification of the trigger scores for a particular pt

Page 10

		Minimise the user's 'memory' load		
Instructions are not clear & descriptive	Basic functionality is not understandable in 1 hour	Writing is required, when could provide options to circle, e.g. having to write hospital name, male, female	Does info have to be transcribed/refered to over 2 pages	Does info have to compared over different areas of the 1 page

Page 11

	Language					
Other comments	Grammatical errors	Not Australian spelling	Expressions used could be made clearer/less jargonistic	Abbreviations used could be misinterpreted	**Other comments**	

Page 12

Instructional briefing for the heuristic analysis

The following instructions were distributed to the 5 Evaluators:

Full Heuristic Analysis

1. 5 evaluators independently examine the 25 charts to judge their compliance with usability principles
    a. The 25 charts will have 2 versions: blank & with data plotted for the 8 vital signs of interest. The same "case" will be plotted across the 25 charts
2. Evaluators decide on their own how they want to proceed with evaluating the charts. But a general recommendation would be to go through the charts at least 2 times, i.e. once with the blank chart & once with data plotted on the chart
    a. There is no need to do a separate analysis on both versions of the chart, just fill in extra comments/problems re: filled-in chart

Debriefing

1. Discussion of the major problems identified in the Heuristic Analysis

Font size guide

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Physiological data for the case of patient deterioration

Time point			3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Respiration rate			13	16	12	14	14	11	14	17	21	26	26	28	24	23	24	21	18	23	16	12	16	12	11	16	14	12	16	14
Oxygen saturation			96	98	98	97	98	97	98	97	98	96	94	91	93	96	97	96	98	97	96	97	98	98	97	99	98	99	99	98
Blood pressure	Systolic		132	138	126	116	126	137	127	120	110	113	85	94	92	100	109	130	130	140	134	130	134	140	130	126	133	140	133	126
	Diastolic		86	82	72	75	82	78	80	75	80	80	60	70	66	60	70	80	86	80	86	81	70	80	75	78	78	86	82	88
	Usual systolic BP																													
Pulse			70	76	68	80	82	95	86	97	90	89	118	122	111	102	107	97	87	97	91	81	77	84	68	82	70	76	82	77
Temperature			37.2	36.8	37.8	36.3	37	38.9	37.5	37.8	38.3	37.9	39.7	38.3	39.2	37.9	39	37.6	37.1	38	38.2	37.5	37.7	36.8	37.9	37.4	37.5	37.4	36.8	36.4
Urine output (mL/hour)			>120	>120	>120	>120	>120	>120	>120	>120	>120	<80	<50	<50	<80	<80	<80	>120	>120	>120	>120	>120	>120	>120	>120	>120	>120	>120	>120	>120
Pain Score			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Level of consciousness																														
Eyes open		4	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
		3													X	X	X	X												
		2																												
		1																												
Best verbal response		5	X	X	X	X	X	X	X	X	X	X	X																	
		4												X	X					X	X	X	X	X	X	X	X	X	X	X
		3														X	X	X	X											
		2																												
		1																												
Best motor response		6	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X
		5													X		X													
		4																												
		3																												
		2																												
		1																												
Total GCS		15	15	15	15	15	15	15	15	15	15	15	15	14	12	12	11	12	13	14	14	14	14	14	14	14	14	14	14	14
Sedation score			0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0