Extending clinical information systems design in the ICU

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Miller and Sanderson (2003b) presented promising results for a prototype clinical information design developed according to Ecological Interface Design principles, but the size of the prototype made it impractical for onscreen display. This paper replicates the previous study using an onscreen presentation of the original EID divided according to functional systems. As in the original study, nurses' ability to detect patient change events was enhanced using the onscreen EID. However, there are differences between doctors' performance using the original and using the onscreen EID. Unlike the original participants, doctors were better able to agree about physiological systems failure, but also unlike the original participants, showed no significant differences in their ability to agree about the patients' current diagnostic state using the onscreen EID or conventional charts. This later ability is clinically more important. It was concluded that while dividing the original EID had no appreciable effect on nurses and enhanced some abilities among doctors, this was at the expense of more clinically significant abilities. It may be necessary to rethink the appropriateness of limited real-estate, office style computer terminals in intensive care units.

INTRODUCTION

Electronic Clinical Information Systems (CIS) are being implemented to replace paper-based patient records. Until now onscreen user-interface design has borrowed information representations from paper-based media. In the short term this has undoubtedly eased the transition from paper to electronic media. However, information representations designed for paper may not capitalise on the representational options afforded by computerisation. In addition, paper-based designs have not been based on evidence about their effects on clinical decision making, and recent publications suggest that while networked technology affords substantial improvements in information access and security (Fraenkel et al, 2003), new problems attributed to interface design are emerging that may increase the risk of adverse patient events (Koppel et al 2005; Ash et al, 2004).

Miller and Sanderson (2003b) presented the results of an empirical evaluation of a proof of concept paper prototype designed for Intensive Care Units (ICU) according to principles of ecological interface design (EID). (Burns & Hajdukiewicz, 2004; Vicente, 1999; Rasmussen et al, 1994). The experimental tasks used in the study were based on a previous analysis of doctors' and nurses' information use. The results were that nurses were better able to detect patient change events using the EID display and there were significantly higher mean proportions of agreement among doctors about the patients' current state when using the EID prototype compared to the conventional display. These results were despite the foreignness of the EID compared to conventional displays and the rudimentary nature of the early paper prototype. Participants did, however, comment that many of the individual display elements were unusual and that the use of design devices such as perspective was disorienting.

Performance differences were attributed a) to the whole-part grouping of information that allowed clinicians to a) scan horizontally across different physiological systems at the same level of analysis; b) which allowed clinicians to scan vertically through different levels of the same physiological system and finally c) the abstract-concrete grouping of patient data (sensed information) in close proximity to patient management information (e.g., effectors such as drugs and other treatment modalities) and goals.

The next phase in design development is to move the display from a paper to an onscreen prototype while preserving the EID characteristics of the original display. This is no mean challenge. The original display measured in excess of 1x1metre and included all patient related information on the one page (Miller & Sanderson 2003a). The computer screens used at ICU patient bedsides are similar in size to standard office computers. Small screen sizes, low resolution and limited screen real estate present significant problems for large data displays. Clearly the original prototype needed to be divided. While maximising consistency with underlying design principles there are at least three ways to do this which are as follows.

1. Divide the design according to functional systems. This option involves allocating each physiological system of the whole-part dimension of the patient work domain (e.g., circulation, respiration [Miller, 2004]) to a screen of its own with all levels of the parts of each function displayed in this screen or in direct association with it. The trade off is increased difficulty in scanning across different physiological systems (e.g., between circulation, respiration and renal systems).

2. Divide the design according to levels of analysis. Display each level of whole-part analysis (system, organ, molecular levels) for all physiological functions on separate screens. The trade-off in this approach would be the loss of direct association between hierarchical levels of analysis within physiological functions. While grouping all highest levels of analysis information together may be useful, the value of grouping lower molecular levels out of context with higher levels may be more problematic.

3. Divide the design according to time. Conventional paper-based designs use this approach; all or the majority of patient information is represented on large charts but only for one day. The trade-off in this approach is difficulty seeing patient dynamics that have trajectories lasting more than one to two days.

The first approach appeared to be the most promising. Thus the purposes of the study reported in this paper were: 1 to report the results of an empirical evaluation of the original EID divided according to functional systems and presented as an onscreen EID prototype and 2. by using a similar evaluation protocol to compare the results of the onscreen EID to those of the original paper-based EID.

METHOD

Participants

A convenient sample of eight senior ICU nurses and eight senior ICU registrars recruited from two Melbourne hospitals volunteered to participate. The demographic profiles of the participants were similar to those of the original study in terms of age, length ICU work experience, qualification and hours of bedside contact with patients per week. There were, however, more male nurses (62.5% [5]) included in this study compared to male nurses (37.5% [3]) in the original study.

Materials

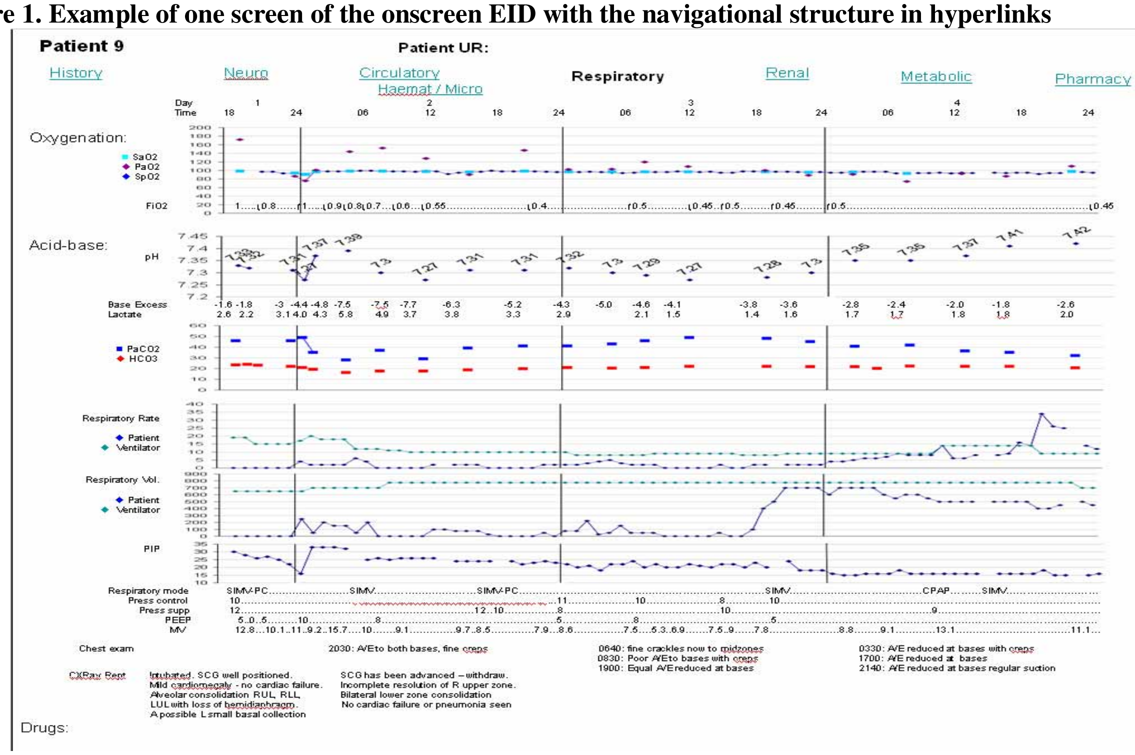
With the exception of the onscreen design, the materials used in the original study were used in this study and are as follows:

1. Demographic surveys and experimental task completion sheets.
2. Four completely de-identified patient data sets collected from patient archives with Ethics Committee approval.
3. Each of the four patient data sets was represented in the standard paper-based charts used at one of the hospitals. The chart designs did not differ substantially from those used in the original study or across the ICUs from which the participants were recruited. The four patient data sets were also represented as an onscreen EID developed in Microsoft PowerPoint (slideshow format) and displayed to clinicians on a laptop computer. PowerPoint hyperlinks allowed participants to navigate freely between the screens but they could not enter or change data. An example of one screen with navigational hyperlinks is shown in Figure 1. The graphical elements used in the original display (Miller & Sanderson 2003a) could not be used in the onscreen design, so more conventional graphic elements were used while retaining the original grouping of patient information.
4. A post-evaluation questionnaire designed to elicit participants' comparative assessments of the two designs.

Procedure

The experimental procedure followed exactly the procedure used in the original study (Miller & Sanderson, 2003b). Following a preliminary briefing, participants were presented with the first patient data set in either the conventional charts or the onscreen displays. The displays were presented using a fully counterbalanced experimental design that accommodated display and the patient data set effects.

Figure 1. Example of one screen of the onscreen EID with the navigational structure in hyperlinks



Participants were not offered training though they were given a brief walkthrough of the major sections of the onscreen design to illustrate the hyperlinked navigational behaviour.

Four days of data from each patient were presented. Nurses, consistent with their information use patterns (Miller & Sanderson 2005), were asked to detect patient change events by identifying the day, time and parameters associated with the change event, and doctors consistent with their information use patterns (Miller Sanderson 2005) were ask to identify a) the physiological systems that had failed over the four days of patient data, b) the patient's overall diagnosis on day 4 and c) the goals the doctor would suggest to guide future management for that patient on day 5. This final task was not included in the original study.

Participants were given 14 minutes to complete the first set of patient tasks before being presented with the second patient data set in the same design format. When two designs had been presented the second design using the third patient data set was presented and the same procedure and time limits used. At completion of the fourth patient data set participants were interviewed from the post –task questionnaire. Data was collated as discussed by Miller and Sanderson (2003b).

RESULTS

The data was initially tested for differences associated with gender and learning effects associated with the design presentation. No significant differences were identified.

Nurses' patient change detection

Nurses' responses were analysed using Student's t-tests for differences in signal detection theory's d' and β for changed parameter detection (Proctor & Van Zant, 1994; Green & Swets, 1966).. Table 1 presents the summary statistics for d' and β for the onscreen EID and chart designs for the original and the current study, for nurses' changed parameter detection and shows that nurses using the onscreen EID were better able to detect changed patient parameters as indicated by a significant difference in d' using a one-tailed, matched sample Student's t-test (t_6=3.143; p<0.01). Also using a one-tailed, matched sample Student's t-test, nurses using the onscreen EID demonstrated a significantly more conservative response bias using the onscreen design than they did when using the charts (t_6=1.943; p<0.05). These results support the hypothesis that nurses using the onscreen EID were better able to detect changed patient parameters that they were able using conventional charts despite a significantly more conservative response bias. Nurses' mean d' and βs were also analysed for differences between the original EID and the onscreen EID using two-tailed Student's t tests for samples with equal variance.

There were significant differences between the group's d's when using the EID ($t_{(df=6)}$ =5.959; p<0.0005), and when using the paper-based charts ($t_{(df=6)}$ = 3.707; p<0.005). Nurses in the current study appeared to be better able to detect patient change events using the onscreen EID and the paper charts than their colleagues in the original study. There where, however, no significant differences in response bias for nurses' using either design format.

Agreement among Doctors

1. Doctors' agreement about failed physiological systems. Like the original study agreement among doctors was evaluated using inter-participant agreement (Miller & Sanderson 2003). Agreement was calculated based on the paired responses of participants using the same designs for the same patients. In the current study doctors using the onscreen EID (mean=0.51, sd=0.11) were able to achieve higher proportions of agreement about the physiological systems that had failed over the course of the patients' admissions than they were able to achieve using the conventional charts (mean =0.36, sd=0.14), ($t_{(df=3)}$ = 4.1; p<0.01). These results are contrary to the results in the original study where there were no significant differences in doctors' agreement about physiological systems failures using either the EID or the conventional charts.

There were significant differences in failed physiological systems agreement between the original EID (mean proportion = 0.27; sd=0.08), and the onscreen EID ($t_{(df=10)}$ = 3.169, p<0.01, 2-tailed t-test for two samples with unequal variance). There were no significant differences between the levels of agreement achieved by the doctors in either group using the conventional charts.

2. Doctors' agreement about patients' current state diagnoses. There were no significant differences in agreement among doctors about the patients' diagnosis using the onscreen EID or using the conventional charts. This finding is again contrary to the findings of the original study, where there were significantly higher mean proportions of agreement among doctors using the original paper EID. There were statistically significant differences between the mean proportions of diagnostic agreement achieved by the doctors using the original EID (mean = 0.32, sd =0.01) and those using the onscreen EID (mean=0.31sd = 0.2) ($t_{(df=10)}$ = 3.169; p<0.01). There were no significant differences in mean proportions of agreement for current state diagnosis using conventional paper charts.

3. Doctors' agreement about the patient goals for the next 24 hours. The hypothesis that doctors' using the onscreen EID would achieve higher levels of agreement about the patient's goals for the next 24 hours was not evaluated in the original study.

Table 1 Mean d' and β for event detection and parameter identification for EID and conventional designs

Changed parameter detection – Original study					Changed parameter detection – Current study				
	d' EID	d' chart	B EID	B chart		d' onscreen EID	d' chart	B onscreen EID	B chart
Mean	1.9375	1.7125	138.186	76.878	Mean	2.8977	2.3463	204.5098	135.5272
SD	0.2402	0.2355	59.6044	50.751	SD	0.3836	0.4478	68.0779	89.1531
	$t_{(6)}$=1.943	p = 0.0369*	$t_{(6)}$ =2.863	p= 0.012*		$t_{(6)}$= 3.143	p= 0.009**	$t_{(6)}$ = 1.943	p=0.02*

Among the doctors in this study there were no significant differences between mean proportions of agreement about patient goals depending on whether the onscreen EID or conventional charts were used. The surprisingly low proportions of goal agreement for the EID and the conventional charts were, however, notable (mean EID = 0.11, sd= 0.09; mean charts = 0.12; sd = 0.12).

Post-evaluation questionnaire results

1. The representativeness of patient data. All nurses and all doctors maintained that the patient data sets were representative of patients they had cared for in the past six months, although one doctor commented that the case mix was slightly different and two nurses commented that the patients were more representative of surgical rather than the medical patients they typically cared for.

2. Advantages and disadvantages of conventional chart designs. The participants identified four broad categories of advantages and disadvantages for conventional chart designs and their responses were similar to the responses of the original study participants:

1. Putting information together to extract meaning: Advantages- all information for one day is on one page which makes it easier to extract meaning, this also makes it easier to scan information and easier to home-in in detail on small areas in time. Disadvantages: it's difficult to see trends that emerge over days; it's difficult to find information – it isn't intuitively grouped; it's more difficult to see past critical events.
2. Familiarity: Advantages - I'm used to the conventional chart design
3. Handwriting: Advantages – changes in handwriting mark changes in shifts and often changes in management; progressive progress notes provide a narrative around the numbers. Disadvantages: handwriting can be difficult to read; "it's the same old gumph, I don't read it unless I'm looking for a particular report.
4. Data integrity and security: Disadvantages – pages can be lost, manual charting is often inaccurate, charts are voluminous

3. Advantages and disadvantages of the onscreen EID. Participants identified five broad categories of advantages and disadvantages of the onscreen EID.

1. Access to information: Advantages – the graphic formal allows you to see four days of data without page flipping; you can see trends over hours and days; the functional systems headings help to organise and integrate data; I had no difficult finding information despite that the design was unfamiliar; you don't have to go looking for information.
2. Putting it together to extract meaning: Advantages- variations are easy to identify; results and tests are integrated with patient observations (e.g. blood pressure, heart rate); treatments and observations are grouped together so that you can see treatment effects; it was easier to interpret historic events and to go back and see how things change over time. Disadvantages: Some information was in unexpected places but this made sense and was easy to get used to; couldn't see all physiological functions at the same time.
3. Issues with the media: Advantages- large amounts of information can be displayed in a smaller number of places; can store and send information to other people when its online.
4. Familiarity: Disadvantages – it [the EID] was unfamiliar; you have to unlearn what you know and relearn it.
5. Information presentation format: Disadvantage: too much information on one page and the writing is too small.

While broadly similar to the responses of participants in the original study, the current study participants identified the separation of physiological systems as a disadvantage whereas the original EID participants commented that having all information on a single page was the original EID's major advantage. This advantage is clearly lost in the onscreen EID given that physiological functions were displayed on different screens.

DISCUSSION

The results presented in this paper extend the findings of previous research which provided some early promising results for a EID inspired clinical information system for the ICU. The results of this present study highlight some particularly difficult problems in translating the original EID to the office computer screens typical of current bedside clinical information systems.

There were two major differences between the original EID and the onscreen EID that was the subject of the current study. These differences included: 1. the division of the original EID according to physiological systems each displayed on separate screens; the original EID included all functional systems on a single but large display and, 2. the original graphical elements could not be displayed electronically, thus more conventional graphical displays were used that retained the proximal groupings of related information that were characteristic of the original display (Miller & Sanderson, 2003a).

The onscreen EID was evaluated using exactly the same procedure used to evaluate the original EID (Miller & Sanderson 2003b). The results of the evaluation show similarities and differences to the results of the previous study. Nurses were better able to detect patient change events using the original EID, and onscreen EIDs compared to using conventional charts, despite that the EIDs were unfamiliar. Like their original study colleagues, nurses attributed this to the ease with which they could identify deviations from parameter base-lines in the onscreen EID, and the ease with which they could extract meaning from information that was grouped to highlight relationships between parameters and between patient observations and treatment modalities. The division of the original EID did not appear to affect nurses change detection abilities in general. However, nurses using the onscreen EID and the conventional charts were significantly more able to detect patient change events than their colleagues in the original study. There were no significant differences in response biases. The only notable demographic difference between the samples was that more male nurses were included in the present study than in the original, although there were no significant differences between male and female nurses' performance. An alternative explanation, particularly for the differences noted for the conventional displays, may lie in the fact that nurses in the current study were presented with patient data using charts from their own ICU, whereas the original study nurses were presented with charts that did not, for example, have their hospital logo or colours included. T hese differences are however, superficial. In all other respects the charts used in both studies were the same.

The doctors' results suggest differences that are more directly related to the effects of dividing the original EID. Unlike their counterparts in the original study who showed no significant differences in mean proportions of agreement about failed physiological systems, the doctors in this study demonstrated significantly higher mean proportions using the onscreen EID. There were no significant differences between the current and previous groups associated with conventional charts.

This finding is not surprising given that the electronic design was divided according to physiological systems. This division is more likely to focus doctors' attention within physiological systems, where it becomes easier to identify within-systems failures. However, this is at the expense of the more holistic information integration required to make a more general diagnosis - the second task. In ICUs patients often experience multiple systems pathologies. Thus failure in circulation (e.g., perfusion) may have consequences that are manifest across a number of other physiological systems (e.g., neurological, respiratory and renal). Assessing and diagnosing a patients' current state involves assimilating information across these different physiological systems. Doctors' in the current study were not as able to do this, as demonstrated by their lower mean proportions of agreement patients' current states, compared to their counterparts in the original study who were able to achieve significantly higher mean proportions of current state agreement using the original EID.

It may be argued that agreement about a patient's current state is clinically more important than agreement about what has occurred in the past in separated physiological systems. Agreement about a patient's current state may lead to better integrated care delivery especially over multiple changes of work shift. In summary, neither the original EID nor the onscreen EID provides an optimal solution, though from a clinical perspective agreement about patients' current diagnoses is arguably more important and this is better supported by undivided information representation.

The barriers to developing clinical information systems designs that allow doctors to better integrate patient related information are a) the sheer volume of information that must be represented and b) the size of current bedside computer screens. The volume of available patient information is not likely to get smaller, thus the ultimate solution will reside in the provision of screen real-estate that accommodates this information and the horizontal (between systems) and vertical (within systems) scanning that is required to detect patient change and to ensure that physicians can comprehensively apprehend and assimilate patient related information.

Interim solutions may lie in additional options for dividing information in the original EID. Three options were proposed: 1. to divide information according to functional systems and include all levels of physiological analysis within the function in one screen; 2 to divide information according to different levels of analysis, or 3. to divide information temporally. One participant suggested in relation to the disadvantages of conventional charts that while it is difficult to assess two to three days of data that only a few variables might be required (e.g., Temperature, blood pressure etc). These parameters are functional indicators at the systems level. It may therefore be possible to use these as launching points within a navigational structure that provides a holistic overview and a means for within functional systems views for secondary assessments.

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