Human Factors Issues in Designing Alarms and Monitors for Critical Care Environments.

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Human factors issues in a clinical environment.

"Critical care units are not quiet and calm environments but ones with flashing lights, frequent alarms and highly technological equipment" (Bakalis & Watson, 2005, p. 35). ICU nurses must constantly deal with factors that negatively affect their cognitive ability: fatigue caused by sleep deprivation and long hours working hours, as well as continuously high levels of arousal and anxiety due to the nature of the environment and work overload.

One negative effect of working in this kind of environment is perceptual narrowing—inability to attend to all information sources that might be important for deciding on a proper course of action (Wickens et al., 2004, pp. 330). Another is cognitive tunneling—a tendency to focus on only one hypothesis or solution at a time and ignore other possibilities (Wickens et al., 2004, pp. 330). Yet another is working memory "loss," and absorption in particular, where a nurse may become so preoccupied with one task, he or she may become simply forget to attend to another (Raskin, 2000, p. 26). These factors limit the number of monitors and, therefore, patients nurses can manage concurrently, which places nurses at odds with the pressure that hospital administration might be putting on them to be more productive (Bogner, 1997, p. 63-64).

Decision making in a clinical environment.

Critical care nurses need to rapidly make multiple decisions that frequently draw on a complex set of variables (Bucknall & Bucknall, 2000, p. 25). In fact, one study showed that on average a critical care nurse makes a patient care decision every 30 seconds (Bucknall & Bucknall, 2000, p. 25). Naturally, a decision maker in this kind of environment will not have the luxury of generating and evaluating alternative courses of action and selecting the optimum choice. In this setting "decision makers are more concerned with sizing up the situation and refreshing their situation awareness through feedback, rather than developing multiple options to compare to one another" (Zsambok, 1997, p. 4). Developing good situation awareness requires (a) quickly and accurately gathering the all the relevant cues from the environment, (b) interpreting them correctly, and (c) projecting their status into the near future (Endsley cited in Wickens et al., 2004,

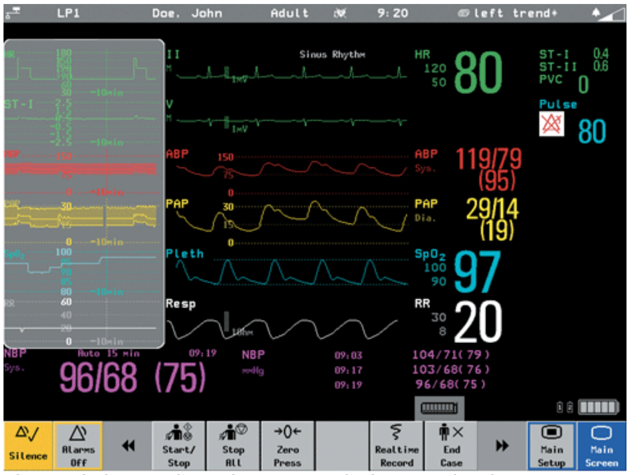
p. 143). While some of the cues will come from observing the patient, many of the cues on which treatment decisions are made come from the patient monitors. Therefore, effective display design can really enhance the quality of clinical decision making by clearly showing patient's current status, providing historical data, and indicating emerging trends.

Uses of numerical and graphical displays in monitoring devices.

The correct mix of numerical and graphical displays in a monitoring device will to a large degree be influenced by the enabling qualities of numbers and graphics. For example, the advantage of numerical displays over graphics is that they allow for precise readings of data (Wickens et al., 2004, p. 213). So when a clinician requires a precise reading of a patient's vitals at a given point in time, numerical displays are indispensable. Graphs, on the other hand, are better at indicating change over time (or some other continuous variable), such as, for example, a recent history of changes in patient's blood pressure or heart rate.

Another enabling characteristic of graphics is their ability to instantaneously convey complex characteristics of data visually (by drawing on the view's immense parallel processing capacity). For example, cardio-respirator monitors, such as the GE Medical Systems Solar® 8000M or Philips IntelliVue, include a wave display for each continuous variable being tracked. The shape of the wave can provide important diagnostic clues at a glance. There is no way to achieve this kind of instantaneous information transfer with a numeric display.

Since treatment decisions invariably involve a combination of historical and real-time data, effectively presenting both types of data becomes essential to decision making. Philips' ScreenTrends software does this effectively by using color and alignment (two of Gestalt principles of perceptual grouping) to relate the graphical trends, real-time waves, and current numerics. The size and font stroke thickness set the current numerics apart from all other items.



This vertical split-screen shows real-time waves, graphical screen trends, and current numerics on an IntelliVue MP50

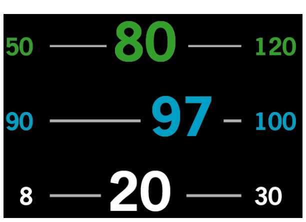
A few minor gripes:

Since the size the numbers is important for viewing them at a distance, this particular implementation makes the smaller numbers for ABP and PAP readings more difficult to make out. In addition, the chosen font's numbers "6", "8", and "9" can be confused with each other when viewed at a distance.

The small upper and lower threshold numbers (i.e. 120 & 50 for HR) require close examination to see how close the current metric is to either upper or lower bound. A graphical solution is suggested below.

In addition, common, aligned time scales for historical data make it easy to compare events across different parameters. For example, a rise in heart rate can be easily correlated with an increase in respiration rate. An absence of correlation—a diagnostic clue in itself—can also be easily observed.

One way this display could be improved, however, would be to indicate the relationship between the current numeric and its position relative to alarm threshold levels graphically. One way this could be done is by combining the numeric and graphical display into a "configural display," in which variables are arranged spatially so that a pattern would emerge and any deviation would become immediately noticeable as it would disrupt the pattern (Wickens et al., 2004, pp. 205-207):



The numerics (large numbers) form a straight vertical line when they're all near the middle of their ranges. This design makes it easy to scan the positions of the numbers to get an instant feel for where each variable is in relation to the upper and lower thresholds. In this example, 97 is clearly out of "line" – the position of the number disrupts the line and makes the deviation instantly recognizable: the viewer is not required to read the numbers to see that this number is on a high side and the patient may need attending to.

Of course, if the seeing these deviations is not important to the decision-maker, then the extra screen space required for this "solution" would make it inappropriate. This statement highlights the importance of a user-centered approach in designing patient monitors.

Role of experience. Research and anecdotal evidence shows that novice nurses tend to either (a) be overly reliant on technology to make treatment decisions or (b) hesitate to take action until they are certain that a trend is occurring and requires intervention (Bucknall & Bucknall, 2000, p. 25). On the other hand, experienced nurses make decisions based on intuition (Dreyfus and Dreyfus cited in Bakalis & Watson, 2005, p. 34), taking their cue from the patient. These differences make for important distinctions in the way nurses interact with monitors. For instance, a novice nurse may look to the monitor to provide clear trend information. If she can't see the trend clearly, she may delay care, putting the patient at risk. An experienced nurse, on the other hand may decide to ignore the monitor, and provide care based on how the patient looks, especially if the required information is difficult to see or is presented in the wrong format. User-centered approach is, again, essential here to ensure the data are presented in the most useful way.

The problem of incorrect default thesholds. Monitors are often designed with default pre-set thresholds for alarms that may not match an individual's age and medical condition. While it can be easy to change the settings, a nurse can simply forget to do so (especially considering the negative effects that the work environment can have on her cognitive ability) and leave the patient to be monitored under incorrect parameters. A solution for this problem can come in the form of an interlock, a forcing function where one action is required in order for the other to be possible (Norman, 1988, 132). In this case, the device can be designed so that it will not start monitoring until an alarm threshold set is selected.

Uses of audio displays and alerts.

Audio support in monitors often comes in the form of alarms. Since a nurse will not always be at the patient's side, visually monitoring the patient's "numbers," audio alarms serve an important alerting role. Some of the guidelines applicable to design of monitor alarms are (from Wickens, et al., 2004, p. 99):

- the alarm's onset should not be so abrupt as to startle the patient and the nurse;
- the alarm sound should indicate the event's severity and be easily distinguishable from other alarms. Not only is this a matter of convenience, it can impact the quality of care. For example, an alarm could go off while a nurse is with another patient. If the nurse

can judge the seriousness of the alarm by its sound alone, she can decide whether to stay with the current patient or to attend to the one "with" a new alarm.

- the device producing the alarm should be easily localized so that a nurse, especially a novice one who can't yet identify a monitor by its alarm sound, knows which of the myriad of monitors in the room is making the noise. In this particular situation, a visual echo of an alarm (i.e. a blinking numeric) can be helpful.

Monitor alarms are frequently discussed in literature in a negative context. A major culprit here is high incidence of false alarms, which causes (a) indiscriminate silencing of alarms, often without checking the patient's status, and (b) ignoring the alarms altogether (Davidson & Barber, 2004, p. 43-44). The danger of silencing all alarms, is obvious: a new alarm may go undetected. Even silencing a particular alarm is dangerous: given the "hectic" work environment, a nurse may simply forget to attend to the cause of an alarm, especially if she silenced it absent-mindedly.

One solution to this problem can come in the form of timed silencing, where a user would not be able to silence an alarm permanently. The only way to silence an alarm can be to select the amount of time it should be silenced for. While this adds an extra button press, it can be a life-saving feature if, for example, a "leads disconnected" alarm was silenced, a nurse went looking for new leads, got distracted, forgot about the leads, and the patient went into cardiac arrest.

In addition to alerts and alarms, audio can perform a feedback role, helping a clinician monitor an important variable if he or she is performing a procedure and can't attend to the visual display. For example, a doctor can monitor a patient's heart rate or blood oxygenation level when putting in a central line. In fact, both of these variables can be encoded and transmitted via the auditory channel simultaneously: heart rate can be encoded using the frequency of audio pulses, while the relative oxygen level can be represented by the pitch of the sound pulse. The important thing to remember, of course, is that while human perceptual system is great at detecting changes, it is poor at making absolute judgments (Kosslyn, 1994, p. 64), neither audio nor graphical displays should be relied upon to take precise value readings: there should always be a numeric alternative available where decision making relies on precise information.

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