The Effectiveness of Hillrom's Display Design on Cognitive Processing

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Abstract

This paper is an assessment of Hillrom’s bedside continuous heart rate and respiratory rate monitor in effective display design for cognitive processing. The principles of display design are documented extensively in research papers and experiments, yet the execution of effective design proves to be a complicated process. Despite the subjection of medical devices to regulations ensuring safety and effectiveness, the nature of the device’s purpose imposes limitations on creative display design. Medical displays have the power to communicate important information, and the imperative to support clinicians and patients in making decisions about healthcare outcomes. I begin the paper by highlighting the importance of display design in healthcare settings, eventually identifying the impact of different design strategies on cognitive processing. I use Mayer’s SOI (select-organize-integrate) model to describe the foundations of information processing. Then, I describe the primary screens of Hillrom’s monitor, evaluate their simplicity or complexity in communicating information, and provide recommendations for improvement.

Display design can have real world consequences when operationalized in hospitals and other healthcare settings. Healthcare providers must receive timely and accurate information about their patients, allowing them to use that information to make critical decisions about a patient's care. Information that is difficult to find, hard to read, or not deemed useful could create unnecessary cognitive strain when making decisions, potentially leading to misdiagnosis. If the display design is unsatisfactory due to its mode, size, color, and layout, users will bear the excessive psychological and physiological strain, resulting in difficulty with identification of important information, judgment, and operational control. This has the potential to cause unintended human error during operation (Wang et al, 2021).

The usability of a display interface can mitigate the occurrence of human error, especially for less experienced workers. Usability can be defined through efficiency, learnability, memorability, minimized errors, satisfaction, usefulness and perceived ease of use (Mishra, 2016). In dynamic environments such as hospitals, healthcare professionals must contend with limited human capacity for memory and concurrent sensory information competing for their attention. Visual displays can draw attention to important information by using external stimuli such as color, light, or text size. The knowledge of the user can also be utilized to highlight a display's graphics or features by leveraging its expected usefulness to the viewer.

The ability to focus on specific stimuli or locations is a significant aspect of attention, while selective attention filters relevant information from distractions (Goldstein 2018). Mayer's SOI (select-organize-integrate) model is pertinent to the discussion regarding cognitive processing of visual displays. In the selection stage, a user directs attention to specific contents of a display, thus processing the information into working memory. *Signaling* entails the use of cues to increase the salience of important information by leveraging colors, arrows, underlining words, large print, movement, contrast, and segmentation of text (Mayer 2009). Participants of a study on signaling (Ozcelik et al, 2010) were found to direct more attention to, and locate the relevant information more effectively, when viewing instructional messages containing signals. Signaling is an important element of selection that can affect the processing and comprehension of information, thus supporting effective organization of information into coherent representations.

Organization facilitates encoding and storage through relationship inference of different pieces of information. Visual displays can employ different types of organizational inference such as temporal, hierarchical, and relational. Temporal inference captures the dynamic relationship between variables, such as diagrams displaying sequential steps or images of chronological events, to infer cause and probablity. Hierarchical inference refers to structural relationships between concepts, with displays using diagrams to spatially organize concepts according to their position in the structure (McCrudden et al., 2017). Relational inference refers to comparisons between concepts, with visual displays presenting concepts close together in the form of matrices and outlines. The cognitive process of organization is strengthened when users can connect prior knowledge to the details of a display.

Integration, whether active or passive, engages prior knowledge with a display's message whereby both are stored in memory. Active integration occurs when a user consciously attempts to identify a relationship between a display's message and their own prior knowledge. Passive integration occurs when a user unconsciously associates a display's message with information retrieved from their own memory, thus informing perception of the new information. Integration can lead users to either modify or enhance existing knowledge with the new information. Ideally, visual displays in healthcare environments should not only inform the present state of a patient, but also provide relevant information to assist clinicians when making decisions about a patient's care.

I will now assess the strength of Hillrom's bedside continuous heart rate/respiratory rate monitor in facilitating information processing. The goal of Hillrom's monitoring system is to detect patient deterioration through continuous monitoring, resulting in early intervention and better patient outcomes. The monitoring system uses sensors in the mattress to detect cardiac and respiratory motion, updating the HR/RR (heart rate/respiratory rate) values twice per second, in addition to compiling the values to display historical trends. As shown in Figure 1, the monitoring system display is located on the left side of the patient's bed. The bed does offer multiple methods to display alerts when HR/RR exceeds one of the set thresholds, but the focus of this paper will be to discuss the impact of Hillrom's user interface screens on information processing and decision-making.

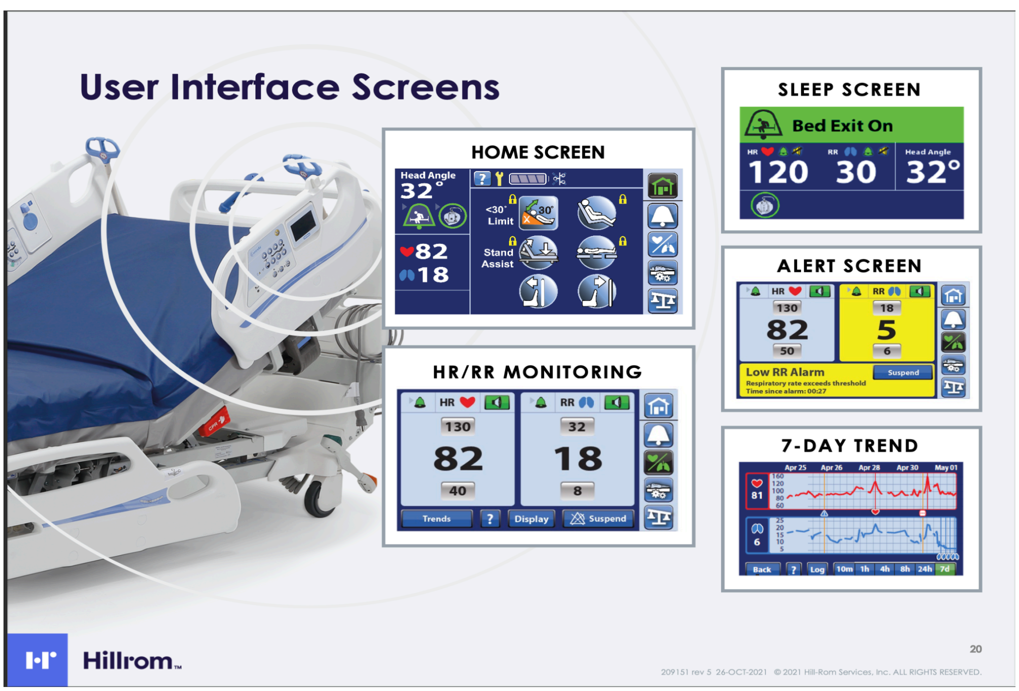

Fig. 1 Taken from Hillrom's brochure showing available screens

The home screen is similar to a settings page, allowing users to modify alert settings, bed settings, as well as provide information about the patient. The interface is clearly delineated into four sections, in addition to a vertical navigation bar placed on the right side of the screen. Hillrom compensates for the display's small size by utilizing semantic design, employing symbols to convey information and describe button control. The navigation bar provides quick access to the home screen, alerts menu, scale menu, and mattress menu represented by icons of a house, bell, scale, and mattress, respectively. The icon images are white with a blue background, turning green with a black background to indicate the current screen.

Given the most screen space are the buttons to change the bed length and angle, located at the center of the screen. This choice highlights their frequency of use, simplifying the process of adjusting the bed with each new patient. The upper left corner of the screen shows the angle of the bed, with symbols below it to indicate monitors for patient bed exit and foley limit. The symbols are surrounded by a green circle if the alert is active, while a yellow circle signifies that the alert is silenced. The symbol for bed exit changes accordingly when a patient moves positions, is in a position to possibly exit the bed, or is out of the bed. The bed exit icon is explicit in its image of a person on a bed, limiting any perceptual errors when viewed by hospital staff. However, the image for the foley limit icon is difficult to decipher, exacerbated by its small size, leading to greater probability of being misunderstood.

Color combinations can have a considerable effect on the user's accuracy and speed when reading a display. Hillrom's home screen display uses a dark blue background with white text and icons, not including the heart and lung icons which are colored red and blue, respectively. Studies have shown that the color of a display background can significantly influence its perceptibility and acceptability threshold, with white and black backgrounds producing the best results, while images viewed against a white background show a larger perceived color difference than viewed over other colored backgrounds (Perez et al, 2020). Grozdanovic et al. (2017) explain that negative contrast (dark symbols on a white background) have better readability than positive contrast (white symbols on a dark background) for the following reasons: adaptation is better, reduction in unpleasant screen brightness relative to ambient light, and a reduction of reflections from the screen. Although Hillrom's display panel can be flipped up for better view, its small size and color combinations could lead to eye strain, as well as negative effects on readability and ease of use.

The HR/RR monitoring screen displays heart rate and respiratory rate on the left and right section, respectively. Each section is labeled, includes a corresponding icon, with labels turning white and blue if monitoring is off. A bell icon is located to the left of each label, indicating if the alarm *outside* of the patient's room is turned on. A green icon indicates that the alarm is on, while a yellow icon with a line over it indicates that the alarm is off. The speaker icon located to the right of the label has similar features as the bell icon, but indicates if the alarm *inside* the patient's room is on. Hillrom's use of the bell and speaker does not conform to the conventional wisdom of their meaning. Users familiar with smartphones and touchscreens may expect the bell to represent notifications, and the speaker to represent volume control. Furthermore, the severity of an alarm is not conveyed by the usage of icons that normally represent mundane tasks. The icons themselves can bear similar meaning in terms of representation of sound, neither showing any indication of the relationship to the inside or outside of the room.

The HR/RR sections are displayed with a light blue background and bold black text. The patient's current heart rate and respiratory rate values are displayed in large text, with the higher and lower threshold values displayed above and below in smaller text. Hillrom's use of negative contrast on this screen may be an indicator that they understand the importance of contrast and its ability to communicate correct information, as heart rate and respiratory rate monitoring is the display's primary goal. The navigation bars surrounding the heart rate and respiratory rate sections continue the same pattern as the home screen by using buttons with white text/icon over blue background. The contrast of the heart rate and respiratory rate values directs them into foveal view, while the navigation bars seemingly recede to peripheral view.

The alert screen maintains the same design as the HR/RR monitoring screen, excluding the bottom navigation bar which is replaced by a yellow threshold alarm alert. The value that exceeds threshold changes from a blue background to yellow, providing the clinician the option to silence the alarm by pressing a "suspend" button. This suspends the alarm for 15 minutes and displays a timer with a countdown. After 15 minutes, the system will automatically resume heart rate and respiratory rate monitoring. The Hillrom manual indicates that the threshold alarm is also used to display alerts for problems with the signal and sensor. When those alerts are activated, the heart rate and respiratory rate sections remain blue, while the alert below them is yellow. By using the same color for alarms and alerts, the message being delivered becomes convoluted, increases the cognitive load to interpret the message, and has a risk of being ignored. From a design standpoint, the severity of a threshold alarm would seem to warrant immediate action, and the use of red instead of yellow may communicate the message better.

When a user directs attention to a display, the contents and spatial arrangement are processed in memory (McCrudden et al, 2017). The process of allocating memory for essential knowledge is disrupted when presented with interesting but unimportant information, and in this case, may undermine the objective of early intervention. A simplified alert screen should focus on the severity of the patient's current state, provide options regarding the alarm, and support the caregiver in making decisions. Moreover, cognitive perception may improve with separate screens for threshold alarms and alerts. Likewise, quick access to a patient's historical trends would be a useful addition to the alarm screen, providing the clinician valuable information before deciding on a course of action.

The heart rate/respiratory rate trend screen shows a patient's measurements over time - 10 minutes, 1 hour, 4 hours, 8 hours, 24 hours, or 7 days. The screen displays the heart rate measurement as a red line graph, surrounded by a red border. On the left side of the graph is a heart icon with the patient's current beats per minute (BPM) below it. The respiratory rate is displayed similarly to heart rate, except the line graph and border is blue. Breaks in the line graph can occur when service alerts disrupt the measurement, indicated by an orange vertical line. A red vertical line in the heart rate graph indicates a heart rate alarm event, while a blue vertical line in the respiratory rate graph indicates a respiratory rate alarm event. Hillrom also uses additional icons to indicate certain events such as an exclamation mark inside a triangle to indicate service required, an ellipsis to indicate multiple service alerts, as well as the heart and lung icons below the alarm events.

Maintaining the red and blue color scheme for HR/RR enables users to effortlessly identify the graphs. However, the use of icons below events seems unnecessary and introduces additional complexity to the graphs. This could lead to extraneous cognitive load, distracting the user's attention away from the important measurements. The events themselves are significant data points to help clinicians interpret the graph, already denoted by the vertical lines, that the addition of icons contributes marginal informational value. The color scheme for the vertical lines can continue to serve as event markers, and the help button can be used to display a legend.

The display in sleep mode is an overview of the patient's heart rate, respiratory rate, and alert settings. The screen is divided into three vertical sections, with the top section indicating the status of the bed exit alert, the middle section displaying HR/RR and status of corresponding alerts, while the bottom section indicates the status of the foley limit alert. In this screen, Hillrom chose white text over a dark blue background to display the heart rate and respiratory rate. The bed exit status is illuminated in green if the alert is on, capturing the user's attention when glancing at the screen. Rather than displaying the bed exit icon next to the foley limit icon, as shown in the home screen, Hillrom isolates the bed exit status to a more prominent position. Assuming that the sleep screen is displayed after a period of inactivity, a clinician would likely glance at the display to check the patient's status, without needing to interact with the display. Affording the heart rate and respiratory rate the most screen space highlights them as essential information, while presenting the bed exit icon next to the foley limit icon achieves the same message of its status, without detracting from more important messages.

In conclusion, when designing displays for medical devices, designers should prioritize efficient retrieval of essential information and reducing the user's cognitive load. In high-pressure environments such as hospitals, overstimulation can affect a clinician's response time and quality of decisions. A clinician's experience can also greatly affect how they perceive display information, and their ability to quickly react before patient deterioration. Understanding the knowledge and limitations of a display's users is crucial in developing interfaces that will meet their expectations. The analysis of Hillrom's bedside HR/RR monitor highlights the importance of text/background color combinations, utilizing symbols to convey information when limited by a small screen, continuity of symbols throughout the various screens, and organization of information.

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