Supporting Clinical Cognition: A Human-Centered Approach to a Novel ICU Information Visualization Dashboard

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Abstract

Advances in intensive care unit bedside displays/interfaces and electronic medical record (EMR) technology have not adequately addressed the topic of visual clarity of patient data/information to further reduce cognitive load during clinical decision-making. We responded to these challenges with a human-centered approach to designing and testing a decision-support tool: MIVA 2.0 (Medical Information Visualization Assistant, v.2). Envisioned as an EMR visualization dashboard to support rapid analysis of real-time clinical data-trends, our primary goal originated from a clinical requirement to reduce cognitive overload. In the study, a convenience sample of 12 participants were recruited, in which quantitative and qualitative measures were used to compare MIVA 2.0 with ICU paper medical-charts, using time-on-task, post-test questionnaires, and interviews. Findings demonstrated a significant difference in speed and accuracy with the use of MIVA 2.0. Qualitative outcomes concurred, with participants acknowledging the potential impact of MIVA 2.0 for reducing cognitive load and enabling more accurate and quicker decision-making.

Introduction

Several decades of emerging bedside monitoring devices (BMD) and electronic medical record (EMR) systems have provided intensive care unit (ICU) clinicians with a range of tools that display and intelligently filter data in ways that enhance patient diagnosis. As part of the greater decision-making process, clinical decision-support (CDS) systems have also provided diagnostic tools to identify and analyze patient data through the use of algorithmic rules within a knowledge base.[1-2] In spite of advances in display technology, the perceptual clarity of visually represented clinical data on LED[3] displays (associated context-sensitive information) continues to be of low quality. (Figure 1.) These constraints have added to ongoing cognitive overload for ICU clinicians, thereby increasing diagnostic error, particularly errors of omission.[4] Correlated to an annual mortality rate of 12-22%,[5] human factors studies have demonstrated that 80% of "user error" is attributable to cognitive overload.[6-7] These challenges create the potential for missing critical signs of an unrecognized deadly medical condition.

Figure 1. Four interfaces commonly seen in the ICU that present patient data in an array of visual configurations for various purposes: **(A)** BMD of patient vital signs, **(B and C)** EMR data and information displays that provide varying levels of clinical decision-support functionality, and **(D)** Medication pump display (top) and respiratory pump display (bottom).

The Institute of Medicine (IOM) states that the greatest contributor to cognitive load during data extraction and diagnosis is inadequately designed interfaces of bedside devices.[8-11] In addition to time constraints, work-place interruptions, and BMD alarm fatigue, cognitive filtering strategies are often applied by clinicians as workarounds that severely constrict their analytical capacity.[12] In each case, an assault on the clinician's visual recognition processor, working memory, and concentration is ongoing due to cognitive loads that exceed human capacity.[13] As a result, the clinical need to process patient information quickly and easily are unmet at critical times of diagnostic decision-making.[14]

Adding to clinician cognitive load is the complexity of the ICU environment, where patients require constant monitoring (by multidisciplinary team members) and support through continuous bedside-care, frequent intervention, and analysis of non-electronic and device-generated diagnostic testing data.[15] Although ICU patients are the most tested and examined of all hospital patients,[16] important medical conditions and physiological deteriorations are (at times) overlooked.[17-18] In sum, numeric and textual data analysis by clinicians results in excessive cognitive strain and irregular thinking patterns,[19-21] all of which impact the quality of care and patient safety. The domains of critical care medicine and health informatics have enormous potential for leveraging and transforming a plethora of patient data/information through the use of human-centered designed visualization technologies that are smart, mobile, and easy to extract relevant patient-centered knowledge.

With these challenges, this paper is a review of the design and testing of a novel ICU patient information visualization tool. Intended to support clinician cognitive load and reduce decision-making error, the tool was designed to spatially and temporally organize contextual patient data. We refer to this tool as MIVA 2.0 (Medical Information Visualization Assistant, version two. (Figure 2 depicts the MIVA 1.0 and 2.0 interfaces.) Envisioned as a means to rapidly analyze and interpret trends in EMR data, our goal (in designing the MIVA 2.0 dashboard) was to positively impact patient diagnostic outcomes and ultimately patient safety by reducing the burden of cognitive strain experienced by many ICU clinicians.

Background

The National Research Council, in its 2009 report, emphasized the need to support cognition, visualization, decision-making, and workflow optimization in healthcare by means of an effective computing infrastructure.[22] Early ICU data visualization systems were time-oriented that allowed an analysis of electronic patient records, making it easier for clinicians to quickly assess the overall condition of a patient's history, while also displaying data trends, significant information and events, and spot omissions in treatment at several levels of detail and abstraction.[23-25]

Although critical care decision-support must be facilitated by reliable clinical data,[26] information visualization can also provide valuable assistance to a critical care team for data analysis and patient diagnosis. Notably, effective information visualization can amplify cognitive processes by providing computer-supported visual representations of patient data. The purpose of visualization is for *rapid information assimilation*, pattern recognition, and diagnostic insights derived from examining large amounts of data. Hence, in addition to existing conventional bedside visual displays, critical care teams should be supported by appropriate visualization systems in order to reduce user error and ease cognitive load.

Patient data placed in meaningful contexts become relevant medical information that is usable and sharable,[27] from which clinical knowledge can be derived. Through collaborative knowledge sharing, clinical practice allows distributed intelligence to create a patient-centered community that provides clinical group problem-solving and processes such as "reflection-in-action."[28-29] In other words, ICU information visualization can profoundly impact the predicting of clinical events, planning the courses of action, and diagnosing patient adverse events. Moreover, the human-centered design and usability testing of more effective BMD and EMR interfaces continues to be a priority that should support clinical information processing, patient diagnosis, and long-term patient care.[30] As such, this paper reports on a phase-two design study that compared the usability and effectiveness of a novel visualization application (MIVA 2.0) with a paper charting system, commonly used to support ICU patient data documentation activities.

System Description

MIVA 2.0 is a novel EMR dashboard technology,[31-34] that uses a visualization engine to deliver multivariate biometric data by transforming it into temporal resolutions. The result is a spatial organization of multiple datasets that allow rapid analysis and interpretation of trends. Intended as a mobile technology, MIVA 2.0 was not designed to replicate existing BMD that display patient vital sign data or CDS systems that provide recommendations through rules-based alerts or predictive models. Rather, MIVA 2.0 was designed to optimize diagnosis speed and accuracy by rapid recognition of essential changes in physiological data over a designated time frame, e.g., several minutes, hours, days, or weeks. Using selection menus, ICU clinicians control the necessary data sources and density, time periods, and time resolutions to narrow down their diagnostic target of a patient's condition. Figure 2 illustrates the past two iterations: MIVA 1.0 and 2.0.

The MIVA 2.0 system was designed to maximize the clinician's ability to control and compare what data is visualized during a specific context-related patient episode or general diagnosis, e.g., during daily rounds. Building MIVA 2.0 as an interactive prototype (using Flash ActionScript[35]), findings from Study One[32] (MIVA 1.0) informed the redesign of the visualization system and interface, as illustrated in Figure 2B and Figure 3.

Method

Participants: A convenience sample of 12 clinicians (6 physicians and 6 nurses) of mixed gender from the medical population of the Indiana University, School of Medicine and School of Nursing were recruited. A bulk email invitation to potential participants was sent to a group of 15 clinicians known directly/indirectly by the investigators. The 12 volunteers were evenly split into two groups according to gender and profession (physician/nurse), and in the order that their email arrived confirming their availability for the study. Hence, a control group of six and an experimental group of six was formed. All participants had various experiences in the ICU and/or Emergency Room. Physicians and nurses were evenly split between the two groups according to their professional backgrounds.

Study Design: Following the development phase of MIVA 2.0, a mixed-methods evaluation study, comprising of quantitative and qualitative measures were employed to compare MIVA 2.0 with medical paper records commonly used for patient charting. Quantitative performance measures were comprised of eight usability time-on-task (speed) test and clinical decision-making (accuracy) task questions and 31 structured usability (Likert scale) questions, and seven qualitative open-ended interview questions. The experimental and control groups completed the usability task questions and interview, while only the experimental group completed the structured usability questions. The experimental group was provided a five-minute priming session to familiarize themselves with the functionality of MIVA 2.0 (Figure 2B), while the control group was provided a five-minute priming session to understand the paper medical chart data (Figure 4).

Participants from both groups were provided a written paragraph that outlined a fictitious clinical scenario to establish the context of the medical event. (See box below.) Both the paper charts and the MIVA 2.0 system reflected the same 12 hours of charting data. In the latter case, MIVA's patient data was pre-loaded into the system for purposes of the study. MIVA 2.0 data was streamed from a Microsoft Excel data loop that resided on the laptop computer. (Although MIVA 2.0 was designed for use on a laptop and tablet, the usability study used the former because most clinicians noted this as their primary form of reviewing patient information.) Once the participants reviewed the clinical scenario, they were provided the eight multiple-choice questions. (See the Appendix for all usability task questions.) As such, to ascertain the correct answer to the eight questions, the control group analyzed data from the paper medical charts, while the experimental group clicked through the necessary menus/controls of the interactive MIVA prototype to find and analyze data.

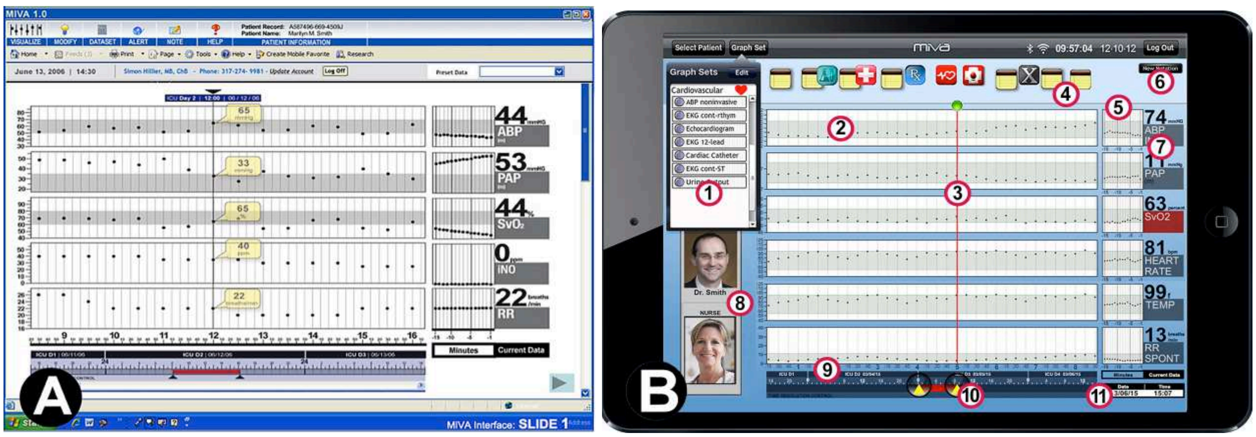

Figure 2. (A) MIVA 1.0 static prototype developed for PC Windows (Study: 2008) and **(B)** MIVA 2.0 interactive prototype developed for tablet and laptop. Core tools/functions include: **1)** Vital sign pool, **2)** Information-visualization timeline, **3)** Data-point scrubber-bar, **4)** Intervention/note icon tray, **5)** 15 min. data-status, **6)** New clinical note generator, **7)** Current data-status, **8)** Attending clinicians, **9)** Time-line indicator, **10)** Time resolution control, and **11)** Current time /date.

Clinical Scenario: *A 6-month old infant has undergone repair of an AV Canal. The post-operative course is complicated by pulmonary hypertension, requiring nitric oxide (iNO) to be started on the second postoperative day. On the third postoperative day you are called to the bedside at 14:15 because of an acute deterioration. The bedside nurse states that the patient's mean arterial pressure (ABP) and mixed venous oxygen saturation (SvO*$_2$*) have declined and the mean pulmonary artery pressure (PAP) has increased over the past 15 minutes.*

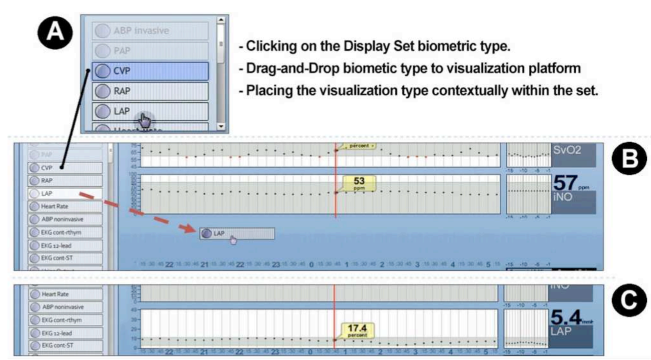

Figure 3. The drag-n-drop process for changing new biometric parameters for information visualization.

Test Measures and Methods for Data Analysis

Usability (Time-on-Task) Speed Test: Participants from the experimental and control groups were tested for execution speed, i.e., time taken to complete each task in minutes and seconds. No time limits were imposed. The Mann-Whitney non-parametric test and independent samples t-test was used to identify any significant differences in task execution speed between the two groups. SPSS v21 was used in all usability statistical analysis.

Usability (Clinical Decision-Making) Accuracy Test: Participants from the experimental and control groups were also tested for the decision-making accuracy of their responses to each of the multiple-choice questions. The response to each question was judged as either correct or incorrect. A Chi-squared test was used to identify the overall significant difference in accuracy between the experimental and control groups.

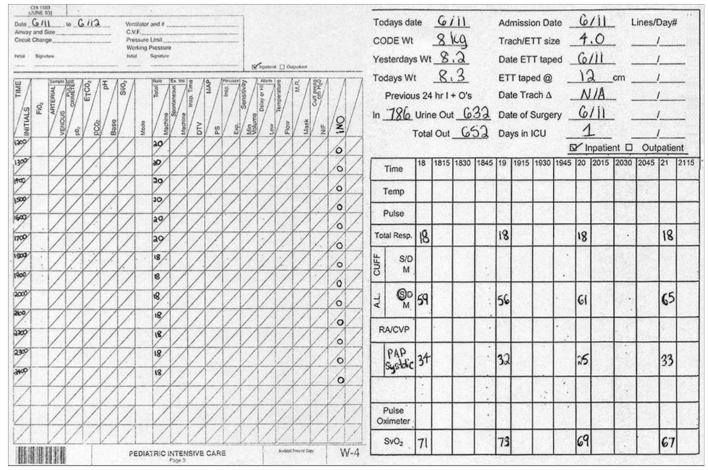

Figure 4. Paper medical charts used by the control group.

Post-Test (Context-of-Use) Questionnaire: Following the usability time-on-task and decision-making test, the control group participants were also allowed a five-minute priming session to experiment with MIVA 2.0. (We anticipated that their valued input as clinicians would provide further information (positively or negatively) regarding the potential of the system.) Hence, participants from the experimental and control groups were provided a post-test questionnaire composed of structured and semi-structured questions that addressed the context-of-use and usability of MIVA 2.0. The semi-structured questions focused more on task execution, medium of execution, learning, cognition, articulation, and long-term outcomes of either paper charts (control) or MIVA 2.0 interfaces (experimental). Participants were provided structured Likert questions (Range 1-5) and semi-structured questions, which yielded mean scores, percentages, and short comments regarding MIVA's interface and interaction design, and overall usability.

Open-Ended (Usability) Interview: Participants from the experimental and control groups were given an interview to comment on the general functionality, usability, utility, and user experience of MIVA 2.0, as well as its potential to support clinical work in the ICU. All 12 participants were interviewed, which were video recorded and transcribed. A content analysis was done of the transcription using ATLAS.ti (v1.0.15).[36] Participants were allowed ample time to discuss the usability, usefulness, and limitations of MIVA 2.0 and its potential use in the context of a real-world ICU environment.

Findings

The usability speed test identified no significant difference in time-on-task between the control group (M=1.30, SD=.78) and the experimental group (M=1.53, SD=.87). However, an independent samples t-test identified that the experimental group (MIVA 2.0) participants performed significantly faster, overall, than the control group in answering two questions: [Q3] $t(10)=3.11$, $p=.011$, $r=.70$; [Q4] $t(10)=3.65$, $p=.004$, $r=.76$. The clinical decision-making accuracy test identified an overall significant difference in accuracy of the eight question test between the experimental (M=.65, SD = .30) and control groups (M=.58, SD = .36): $\chi^2(1,12)=5.04$, $p=.03$, suggesting that the experiment group test score was more accurate than the control group. See Appendix for all eight questions.

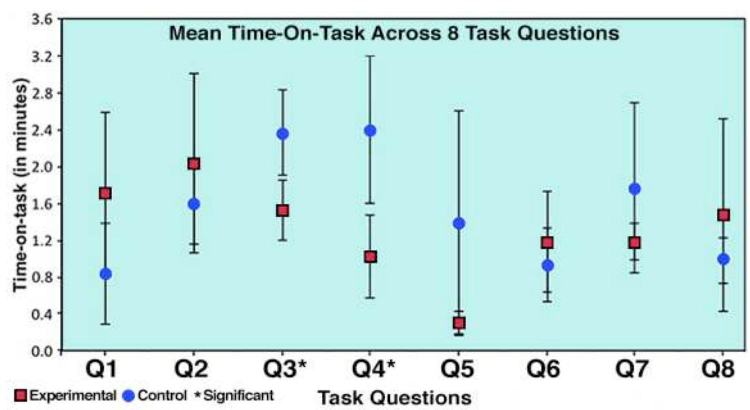

Figure 5. Illustrates significant difference of time-on-task data between the control and experimental groups based on eight scenario questions. See eight task questions in Appendix.

The post-test structured questions yielded a mean response that included 67% of both the control and experimental groups reporting that MIVA 2.0 provided consistent interface and interaction sequencing. This included: clarity of wording, meaningful icons, labels positioned appropriately, requiring a minimal learning curve, and had overall positive feelings towards the interface based on their experience. Also, 83% of all participants reported minimal user action required in using MIVA 2.0. Regarding post-test semi-structured responses, participants noted that MIVA 2.0 provided five interface elements or functions that added to its potential as a clinical information dashboard:

1. MIVA 2.0's information visualization points were easily accessible and without the need to additionally review traditional paper charts,
2. MIVA 2.0's clinical use was consistent with ICU clinical practice,
3. MIVA 2.0 provided easily understandable icons that represented clinical interventions such as lab work, x-rays, meds, etc., which provide external clues about group work, coordination, and communication,
4. MIVA 2.0 provided easy access to externally distributed knowledge (e.g., clinical notes port in through the electronic medical record system), and
5. MIVA 2.0 was a solution to resolve conflicts about interpreting others' activity.

NOTE: Seventy-five percent of all participants agreed that current approaches to collecting and presenting ICU critical care data is not sufficient for supporting accurate diagnoses or management of the critically ill. They also made comparative comments about the importance, limitations, learnability, and long-term consequences of paper chart verses MIVA 2.0. See Table 1.

Content analysis of transcribed interviews yielded in-depth participant perceptions of how MIVA 2.0 might successfully or unsuccessfully integrate into the ecological space of the ICU. Five major themes emerged from our qualitative analysis, which we describe in detail below. (Also see the visual representation of these five themes in Figure 6.)

The themes include: **(1)** MIVA 2.0's potential for providing current information tools and needs, **(2)** Current division of labor in the ICU, **(3)** Implicit and explicit rules, strategies, and checklists currently used in the ICU and MIVA 2.0 complementing them, **(4)** Changes to the clinical practices and outcomes brought about by MIVA 2.0, and **(5)** Drawbacks of the changes caused by MIVA 2.0 to the ICU ecological space.

Table 1. Comparison of conventional paper medical charts and MIVA 2.0.

TOPIC	PAPER CHARTS	MIVA 2.0
Importance to Clinical Work	• Absolutely critical in the ICU. • Have natural affordances that are difficult to replicate.	• Can be very helpful in the ICU.
Learnability	• Require an initial investment in learning. • Work routinely in the ICU environment with no learning needed.	• Is similar to other information displays and thus requires minimal learning. • Is much easier than commercial EMR systems.
Limitations	• Cannot view data efficiently or integrate different pieces of information very well. • Require more mental effort: flipping pages with different data in different places. • Are not computable.	• Lack of familiarity. • May only be able to compare five visual data points simultaneously. • Lack of the undo option. • No emergency exit appears anywhere.
Long-term Consequence	• Provide greater chances for errors. • Give an inefficient interpretation of data leading to inaccurate conclusions.	• May expedite data interpretation / trend analysis. • Provides user-controlled display with info access. • Allows for faster decision-making.

(1) <u>Current information tools and needs</u>. As a preface to their comments on MIVA 2.0, participants reported that paper and electronic tools[37] were the current standard of use in the ICU. They also noted that strips of paper are used owing to ease of data entry, while health information technology, (e.g., bedside devices and EMR systems) are also used to display and store massive patient datasets in addition to clinician orders. Participants stated that although paper offered a natural affordance and was convenient with respect to recording data, data access and interpretation and sorting through complex data was limited. The visualization component of MIVA 2.0 was reported as easier to interpret at a glance and helped sorting through complex datasets.

Participants also agreed that MIVA 2.0 had the capacity of complementing the current information and cognitive needs of ICU clinicians. Overall, participants showed a positive attitude towards the interface look/feel, interaction sequencing, and the learning curve of the MIVA 2.0. Participants reported becoming familiar with MIVA 2.0 with minimal effort. There were, however, minor differences with respect to the cosmetic interface and interaction sequences between the control and experimental participants. Thus, while the overall look and feel was stated as intuitive, clear and easy to understand by the control participants, the experimental participants remarked that the appearance and behavior of the interface still had several issues to overcome. For instance, control group participant P3 (experimental group) and P4 (control group) stated:

"*You need to use color sparingly. I think the use of color is smartly done here. There are not too many different colors. And so the colors are used strategically to facilitate decision-making. The contrast seems appropriate with the colors chosen. The data is easy to manipulate, allowing me to see a different time scale.*"

"*MIVA should be tested with a scenario with many more data points, e.g., more clinical notes. Most ICU patients, if they are there for more than a week, will have more than a 1000 notes. Can you put 1000 icons up there? …Maybe you have to group them.*"

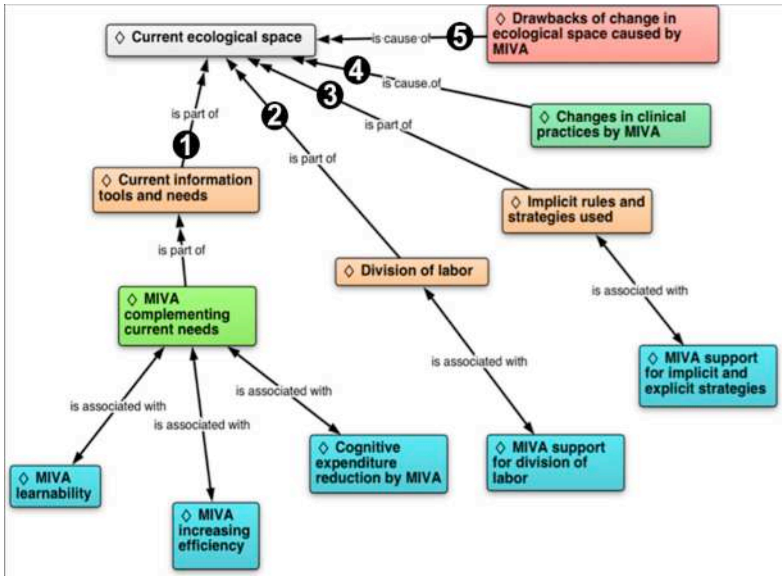

Figure 6. Network of themes from qualitative analysis of interview data.

Participants stated that MIVA 2.0 increased efficiency when compared to current tools with respect to time expenditure and that it contributed to reduction in the cognitive effort, which is needed for data interpretation and decision-making as compared with the current electronic tabular formats and/or paper charts. For example, P6 stated,

"One ends up looking back at each number in a tabular format, similar to paper format. You could do some simple graphing of the data over time, which wasn't terribly intuitive or usable. One is left with using tabular data. The graphical representation to my eye looks much easier to interpret when comparing variables."

(2) Division of labor. Participants reported the potential of MIVA 2.0 to support ICU collaborative working patterns (and workflow overall), where multidisciplinary teams of clinicians coordinate during rounds to understand, discuss, and administer patient care. Participants also perceived MIVA 2.0's potential to support the handing-off process during the change of shifts, commending MIVA 2.0's ability to off-load manual data-entry of patient information by nurses. For example, P1 stated,

"These data points/graphs across the top, in terms of clinical notes or x-rays taken or medications, allows you to see what data is in relation to each other. For example, if a nurse performs a certain task using certain parameters he/she can get better at understanding the patient data after the fact without having to communicate directly with others about the information. So you have the presentation of all the information from all of those different groups all in one simultaneous place that would allow for enhanced deliver of care."

(3) Implicit and explicit rules, strategies, and checklists. Participants stated MIVA 2.0 would be useful in following requirement guidelines and checklists (dictated by hospital administration), specifically to ensure that all patient care follows established protocols in administering medications. For example, P10 explained,

"From a physician's standpoint, it's the overall care that is important; e.g., if they are on a ventilator we have a check list to go through to determine if they have had the daily weaning of their sedation. We look at ventilator settings to see if there is an ability to take them off based on a couple of parameters… It (MIVA 2.0) would be helpful for some of our weaning off of the ventilator, i.e., by having information displayed over time you can compare it to previous day."

(4) Changes in clinical practices and outcomes by MIVA 2.0. Participants reported the shift in clinical practices towards more time being spent on analyzing patient data and making more informed decisions as a result of MIVA 2.0. For example, P6 stated,

"After people get used to MIVA, they will make more educated decisions based on the patient's status. They would be able spot trends sooner or more accurately then compared to the tabular data. Then hopefully in the long run, improve patient outcomes… If you are able to take this with you on your rounds on a tablet, this would allow clinicians to be more informed throughout the rounds, thus allowing you to make more accurate or quicker decisions in terms of care management… That would make sense if you were able to see the data, the trends and the relationships easier, i.e., you would be able to address the problems sooner and more efficiently, thereby, hopefully, improving outcomes."

(5) Drawbacks of changes to the ICU ecological space caused by MIVA 2.0**.** Although overall participants expressed positive attitude towards the inclusion and usage of MIVA 2.0 in the ICU, they were some who expressed concern over the increased interactivity and access to patient information. For example, P2 contradicted P6:

> *"…the tradeoff is the extent by which MIVA distracts the team from engaging with one another. I don't like it when I am working with a distracted team member. I don't like it when I am working with a resident that is looking up the labs in the middle of discussing the case. So, they may not be engaged to the extent to which they should be if they are using these visualizable tools, i.e., a potential trade-off would be their distraction from engaging with one another."*

Discussion and Conclusion

This paper described the testing of MIVA 2.0, an information visualization dashboard tool for the ICU. A mixed methods approach comprised of performance/usability testing, post-test structure and semi-structured questionnaires, and open-ended interviews were conducted. Findings suggest that MIVA 2.0 has the potential to out-perform the use of paper charts (or other electronic one-way data input devices) in retrieving and analyzing patient data. Participants also noted that MIVA 2.0 was designed with a keen awareness of the broader context for the (real-world) ICU experience; and as such, has the potential to support a rich social matrix of clinical activity. Further, there was concurrence that MIVA 2.0 showed promise for significantly impacting clinical decision-support, as well as improving clinical workflow effectiveness. One participant suggested that adhering to internal workflow practices would also help MIVA 2.0 integrate seamlessly into the current ICU EMR system, provided the visualization paradigms used are carefully balanced between being informative and visually distractive.

All the participants agreed that MIVA 2.0 has the potential to change current ICU clinical practice through the emergence of new analyses and reduced time and effort in placing requests for data. They noted that this might also lead to changes in the function of some of the clinical roles in the ICU environment. The participants, however, suggested that integrating predictive clinical rules and providing a mechanism for the clinician to customize the tool (e.g., setting alerts) would lead to better decision support and patient care. In addition, participants noted scalability and programmed spontaneity as potential challenges that might be faced when MIVA 2.0 is implemented. Additional, however, the authors believe initial tool learning may impact cognitive load.

Limitations of the study relate primarily to this early stage of development of the visualization prototype, a relatively small sample size, and the use of a single clinical scenario. As such, our study should be expanded to include more advanced computer prototypes, a larger sample size, and a broader range of problems, ideally from several clinical ICU settings that require collaboration with intensivists across teams and physical locations. Further limitations of the study relate to lack of consideration for communication and collaboration between the critical care team members in the ICU. For example, during the open-ended interview sessions, participants discussed the need for frequent communication between the team members as a critical component of ICU collaborative processes. For instance, if there is the need for frequent communication between the respiratory therapy team, physical therapy team, nursing team and medical team, MIVA 2.0 could provide specific tool functionality that would facilitate greater interaction and access to workflow information.

Underscoring the importance of these latter findings (related to communication and collaboration), the authors have begun a review of significance of integrating communication-information technology (CIT) into the existing MIVA framework. In further support of a revised model, studies have shown that a major source of workflow error and cognitive strain is related to communication and collaboration breakdown.[38] These findings state that 91% of all medical mishaps are due to communication difficulties and inefficient team collaboration and decision-making.[39] Communication among clinicians, including but not limited to face-to-face interaction, is often interrupted and of poor quality. This has lead to inefficiencies and potential error in the ICU, where rapid and accurate communication is essential for delivering safe patient care.[40] Also, inadequate and inefficient collaboration among nurses and doctors increases the average length of stay of patients, leading to severe inconvenience and greater patient mortality. Direct verbal communication is one of the chief sources of trust building among ICU clinicians, which fortifies work relationships and cognizance of others' expertise, leading to increased collaboration.[41] In sum, it has been found that ICU clinicians using CIT improve team relationships, staff satisfaction and patient care.[42] Such technologies can improve communication speed by 92%, communication reliability by 92%, coordination by 88%, reduced staff frustration by 75%, and faster and safer patient care.[43]

In addition to the above discussion and limitations of MIVA 2.0, MIVA 3.0 is currently being designed to include communication functionality. Since nurses and physicians hold different abilities and experiences of clinical decision-making, good communication and collaboration between multidisciplinary teams is essential.[44] Hence, communication among clinical staff should consist of more than face-to-face, but also incorporate the use of synchronous and asynchronous CIT (e.g., smartphone, email, text and video conference) in order to optimize and enable bi-directional, rapid, secure, and non-disruptive transmission of content-rich messages, for purposes of expediting and increasing the accuracy and effectiveness of decision-making.[45]

While the study in this paper focused on usability, user experience, and reducing cognitive load and time spent in analyzing patient data, our assessment only indirectly addressed MIVA's impact on workflow. For this reason, the author's current development of MIVA 3.0 includes the goal of optimizing real-time diagnostic solutions during clinical workflow. The primary aim of this work will firstly uncover evidence from three hospital ICUs to more precisely determine how to model workflow, using methods that include ethnographic observation, shadowing and self-reporting interviews. The Experience Sampling method will also be used to collect data on clinician cognitive load and decision-making. From this data, we will construct workflow models that comply with IOM recommendations for ICU patient safety and clinical effectiveness and efficiency.[46] ICU workflow models will provide the underlying groundwork for the design of the MIVA 3.0 prototype, followed by a series of comparative (clinical scenario) studies to evaluate the impact of the prototypes on team performance.

Acknowledgement

We thank the Indiana University Purdue University Solution Center for providing funding for MIVA (proof-of-concept) funding for research, Phases 1-4, which supported the design, development, and testing of MIVA 1.0 and 2.0.

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APPENDIX

MIVA In-Lab Scenario / Usability Time-on-Task/Speed and Decision-Making/Accuracy Test Questions

For Experimental Group (MIVA) and Control Group (Paper Chart)

1. What is the current ventilator rate (RR)? a) 16, b) 18, c) 24, d) 22, e) 14

2. What was the mixed venous oxygen saturation at noon yesterday? a) 65%, b) 70%, c) 75%, d) 80%, e) 85%

3. When (day / approximate time) did the pulmonary artery pressure begin to increase? a) Post op day 1, early afternoon, b) Post op day 1, late afternoon, c) Post op day 2, early morning, d) Post op day 2, late evening, e) Post op day 3, Noon

4. When was inhaled nitric oxide commenced? a) Post op day 2 - 0100hrs, b) Post op day 2 - 0800hrs, c) Post op day 2 - 1200hrs, d) Post op day 2 - 1400hrs, e) Post op day 2 - 2000hrs

5. What was the starting dose of inhaled nitric oxide? a) 20ppm, b) 25ppm, c) 15ppm, d) 40ppm, e) 30ppm

6. What happened to the mixed venous oxygen saturation after starting nitric oxide? (*Context: Transient is defined (as <30minutes; Sustained is defined as >30minutes.*) a) Sustained decrease, b) Sustained increase, c) No change, d) Transient decrease, e) Transient increase

7. What event precipitated the most recent acute deterioration? a) Withdrawal of iNO b) Ventilator rate weaning, c) Increase of iNO dose, d) Increase of ventilator rate, e) Insufficient data presented

8. How does the current mean PA pressure compare to the mean systemic pressure? a) PA pressure ~1/3 systemic, b) PA pressure is supra-systemic, c) PA and Systemic pressures are equal, d) PA pressure is 2/3 systemic, e) PA pressure is ½ systemic

Post Test - Structured Usability and Context-of-Use - Likert Questionnaire

For Experimental Group (MIVA) [1=SD 2 = D 3 = NA 4 = A 5 = SA]

>> CONSISTENCY <<

1. Was the user feedback consistent?

2. Was the labeling configuration consistent?

3. Was the labeling and/or wording familiar?

4. Was the display consistent with clinical conventions?

5. Were the user actions required consistent?

>> LEARNABILITY <<

6. Did MIVA provide clarity of wording?

7. Was the data grouping reasonable for easy understanding and analysis?

8. Was the grouping of menu options logical?

9. Were the command names meaningful?

10. Were abbreviations, acronyms, and graphic symbols useful and clear?

11. Did MIVA provide meaningful symbols/icons for the verbal labels?

>> MINIMAL ACTION <<

12. Did MIVA require minimal cursor/pointer positioning and action?

13. Did MIVA require minimal steps in sequential menu selection?

14. Did MIVA require minimal user control actions?

15. Did MIVA provide understandable hierarchic menus for sequential selection?

>> PERCEPTUAL LIMITATION <<

16. Were all or most display elements distinctive?

17. Does MIVA provide easily distinguished colors?

18. Does MIVA provide visually distinctive data fields?

19. Are data groups of information demarcated clearly?

20. Is the information density reasonable and easy to read?

>> GENERAL USE <<

21. Did you understand the visualization model MIVA uses?

22. Is MIVA well-suited for the ICU or another clinical environment?

23. Does MIVA have the potential to overcome the limitations of using paper charts?

24. Does MIVA have the potential to be an important part of your patient diagnosis?

25. Could MIVA provide most of the information you need to make health care decisions?

26. Could MIVA help to avoid unnecessary learning and analysis of patient information?

27. Could MIVA provide clues about your own work for others caring for this patient?

28. Is the knowledge of other care-givers easily accessible when necessary?

29. Do you have overall positive feelings about using MIVA?

30. Was all the information needed to answer the test questions available?

>> OVERALL IMPRESSION OF MIVA <<

31. On a scale of 1 to 10, 1 being the WORST, and 10 being the BEST, how would you rate MIVA based on what you have experienced today? (Circle 1) **1 2 3 4 5 6 7 8 9 10**

Post Test - Open-Ended Interview Questions

For Experimental Group (MIVA) and Control Group (Paper Chart)

1. What was your immediate impression of MIVA?

2. Did you enjoy using MIVA?

3. What did you like the most/least about the MIVA?

4. How would you grade MIVA's easy of use? A B C D F

5. What was your first impression about the colors, type, interface layout, and interactive tools of MIVA?

6. Did you understand how to use the menus and buttons right away?

7. What did you think were the biggest problems with MIVA?