EFFECTS OF INFORMATION PRESENTATION MODALITIES ON ANTIBIOTIC REASSESSMENT DECISION-MAKING IN PICU: A COMPARISON STUDY

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Abstract

Antibiotic resistance due to unnecessarily prolonged treatment course in the pediatric intensive care unit (PICU) remains a major healthcare challenge worldwide. Yet, appropriate clinical decision to stop the empiric treatment is susceptible to subjective judgment and often affected by the availability, accessibility, and modality of clinical information. This mix of factors for success has given rise to the challenge of effectively translating data to clinical decision-making. Visually presented clinical information is generally favored by physicians. However, there has been limited work to identify the appropriate clinical context and information presentation modality for a given decision support tool. Moreover, physician's cognitive processes of changing belief when interacting with visually presented clinical information remain unexplored.

This comparison study sought to assess the impact of information-presentation modality in a simulated environment using 4 case-vignettes and employed a factorial design with the following factors: 2 (decision correctness) × 2 (information presentation modality) × 4 (complexity-decision pairs). We hypothesized that compared to text narration, an interactive visualization would increase the correctness in decision outcome and change in belief of ongoing bacterial infection.

22 physicians completed the study. Overall, the interactive visualization led to small, but statistically nonsignificant, improvements in decision accuracy over text narration (χ^2 (16) = 17.92, p = 0.33; LR (16) = 20.33, p = 0.21). However, when patient's medical history was complex and required stopping of antibiotics, visualization significantly outperformed text narration in supporting making the accurate decision (p = 0.03). This result suggests that a

complex patient's clinical information presented with an interactive trend graph may provide better basis for clinical decision-making than a traditional clinical note.

We conclude that interactive visualization may be helpful for physicians assessing their antibiotic strategy for patients with a complex medical history. Future studies should conduct clinical trials investigating the use of interactive visualization to appropriately stop treatments given a complex patient medical history.

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Introduction

Infections are among the leading causes of death in pediatric patients[1]. Due to their immature and compromised immune systems, pediatric patients are at high risk for bacterial infection and sepsis in hospitals. The use of broad-spectrum antibiotics to reduce the risk of bacterial infection and sepsis in the pediatric intensive care unit (PICU) marked a crucial milestone against infectious disease[2]. However, morbidity and mortality from sepsis remain significant. As antibiotics are generally effective in inhibiting the growth of sensitive bacteria, certain bacteria survive and become resistant to antibiotics over time[3]. Antibiotic resistance is associated with high morbidity, mortality, and healthcare utilization worldwide[4,5]. As evidence has shown, one of the major contributing factors to this prevalent issue is the misuse of antibiotics, often the result of unnecessarily prolonged treatment courses[6,7]. Like other medical practices, the use of antibiotics in young children is a decision tradeoff between risk and benefit. In practice, clinical decisions are affected by the availability, accessibility, and modality of clinical information[8,9].

It is routine practice for physicians to start broad-spectrum antibiotic treatment when the true state of the bacterial infection is uncertain[10]. A reassessment to determine whether to discontinue the empiric treatment is generally done 48 to 72 hours after initiation of treatment; in the ICU, this assessment is often performed by a clinician other than the one who started the medication. Though the initiation of antibiotics is regulated by antimicrobial oversight programs, such as prospective audit and feedback (PAF) and preauthorization, a change in the treatment course is at the discretion of individual physician[11]. Such decisions are made primarily based on patient's medical history and updated laboratory data. Confusing this decision making, clinical

definitions and guidelines for bacterial infections, such as sepsis or septic shock, remain debated among physicians[12]. Decisions to discontinue treatment are susceptible to subjective judgments in lieu of evidence-based practice, creating variability across physicians defined as *Noise* by Kahneman in his recent work[13].

Various clinical decision support tools, including visualizations and other modalities, have been investigated to improve physicians' compacity to make decisions intelligently in the targeted clinical context[14–18]. It was shown that physicians preferred graphical information display, such as tables and interactive visualizations, compared to the traditional narrative format. Because the graphical modality was associated with reduced cognitive effort and improved memory retrieval when reviewing complex clinical information[14,17,18]. A recent case vignette study investigating the use of interactive visual display for interpretating the result of clinical trials specifically suggested that it is important to further investigating how display modalities affect the correctness of decision-making probability estimation and of decision outcomes in care settings[14]. Additionally, another study also investigated how visually presented data are interpreted that is relevant to favored prior beliefs. Prior beliefs can distort the perception of new evidence, as is seen in widespread evidence of confirmation bias[19].

The purpose of the current comparison study was to investigate whether the use of interactive visualization would have an impact on decision-making in discontinuing antibiotic treatment in the PICU. We hypothesized that an interactive visualization would increase the correctness in decision outcome and change in belief of ongoing bacterial infection. The interactive visualization employed was designed to help clinicians rapidly view and synthesize complex patient-level clinical information.

Deidentified data of the cases were queried and integrated using the Precision Medicine Analytics Platform (PMAP) at the Johns Hopkins University Technology Innovation Center. The terminology *information presentation modality* was adopted in this paper because it captures the connotation of activation of a different underlying cognitive process compares to the term *information presentation format*[17].

Methods

Study design

This comparison study sought the impact of information-presentation modality in a simulated environment and employed a within-subject factorial design. The primary factor was information presentation modality. The second factor, case complexity (complex and simple), provided an opportunity to assess confounding by case severity and, if no confounding were found, then replicability of the primary comparison. The third factor was correctness of the decision: stop antibiotics (patient did not have a bacterial infection) or continue (patient did).

Each participant received a set of vignettes defined by combinations of these factors. Two clinical experts (JF, JB) constructed the vignettes based on four real cases from the PICU at Johns Hopkins Hospital, where the ground truth of whether to continue antibiotics was known. The complexity of each case was determined by the clinicians, based on their assessment of the presence of complex baseline procedures or medical history prior to the PICU admission, such as chemotherapy or surgical operation. Therefore, the four cases comprised 4 complexity-ground-truth pairs: 1) complex-stop 2) simple-stop 3) complex-continue and 4) simple-continue.

The "stimulus" to each participant was a pair of cases, the first being one modality, the second, the other. The number of pairs is the number of permutations of 2 cases out of 4, without

replacement, for a total of 12 for text first, visualization second (T_iV_j), and another 12 for the second order (V_iT_j), for a total of 24 pairs. To eliminate biases due to carryover effect, where a previous treatment alters the effect of a subsequent treatment on the same participant, and to order effect, where the order of treatments modifies the effect of treatments, designed a complete counterbalancing Latin Square[20]. (Table 1).

Table 1: Complete counterbalancing design combinations

T_1V_2	T_2V_1	T_3V_1	T_4V_1	V_1T_2	V_2T_1	V_3T_1	V_4T_1
T_1V_3	T_2V_3	T_3V_2	T_4V_2	V_1T_3	V_2T_3	V_3T_2	V_4T_2
T_1V_4	T_2V_4	T_3V_4	T_4V_3	V_1T_4	V_2T_4	V_3T_4	V_4T_3

Participants and Recruitment

The inclusion criteria were that participants must be current pediatric intensive care unit (PICU) physicians working at Johns Hopkins Hospital. About 130 PICU physicians at Johns Hopkins Hospital qualified for the inclusion criteria and were invited to join the study through e-mail and fliers. A total of 24 physicians signed up using *Microsoft Forms* in 1 month. In reality, some participants did not complete the study, we shifted the design to partial counterbalancing[21]. 6 attendings were known to members of the study team, however, all participants have never been exposed to the study materials.

Presentations Modalities

Text
Display for text narration followed SOAP Note Format (Subjective, Objective, Assessment/Problem List, Plan) as a common note writing schema – HPI, OR Details, Interval Events, Exams, Labs, A/P which is familiar to the study participants[22]. Text narration describes clinical information using complete sentences and phrases with words, abbreviations, and numerical expressions.

Visualization

Developed by Matthew Chapman at the Applied Physics Lab (APL) under the guidance of two clinical experts, J.B and J.F, the web-based visualization displays clinical information with an interactive trend graph. It comprises change of physical location, pSOFA score[23], ventilation, vasoactive-inotropic score (VIS), sedation, vital signs, antibiotics uses, and lab results. It was built according to the principle proposed by Schneiderman that the tested visualization first provide an information overview, with the ability to zoom and filter to retrieve details on demand[24]. So, the display allows users to hover over a single data point to view details such as value, status, results, and timestamp; it also displays a cross-sectional view of all data points when hovering over the time axis on the top row. Depending on the clinical need, users have the option to zoom-in or zoom-out on the time axis to view trend data in various scales and have the freedom to hide any datapoint to rearrange the display. Standard shape and color codes were
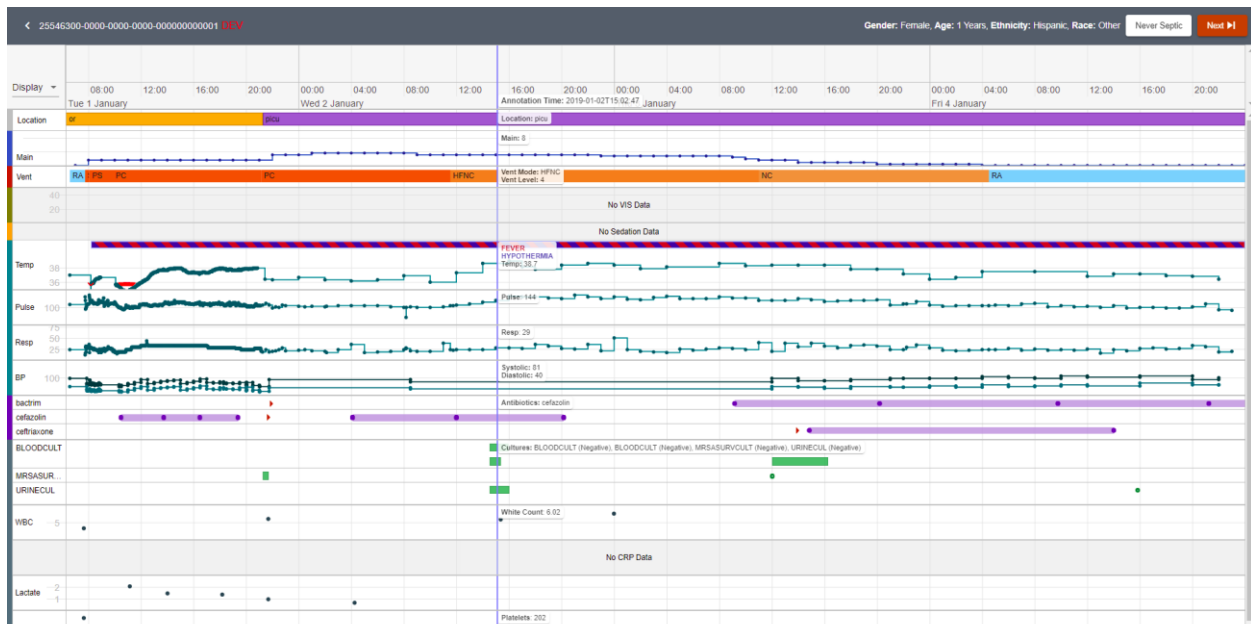

Figure 1:A screenshot of the interactive visualization displaying case 1, showing the cross-sectional data at 15:02, Jan 02, 2019.

used throughout the graph to reduce the learning curve and elicit an intuitive user experience. (Figure 1)

Study procedure

Recruitment letters were sent to all eligible participants via e-mail and fliers, containing a link and a QR code to the *Microsoft Forms™* sign-up page where demographics/baseline information, including name, contact, professional level, and preferred time for the study, were collected. The study coordinator then followed up with a *Microsoft Outlook™* calendar invitation along with a *Zoom™* link. Participants were informed about the study context, but they were blinded to the study goals and hypotheses. Each participant was randomly assigned to receive 1 of the 24 sets of cases, shown in Table 1, using a random shuffling sequence generated by the np.random.shuffle( ) function of *Python3*. Prior to each interview, the designated text narration and interactive visualization were loaded in the SAFE Desktop with *Microsoft Word™* and *Google Chrome™* respectively. We followed the same structured script while conducting interviews using the *Qualtrics™* survey on the interviewer's end. The survey questions were not visible to the participants. It was the interviewer who input the answers to the survey so that the participants could focus on the cognitive tasks. During each Zoom interview, the interviewer displayed two case vignettes, one at a time, on an extension monitor and shared that screen with the participant. There was no washout period between the two cases. To observe the naturalistic decision-making process[25], participants were authorized to control the interviewer's extension screen remotely using their own devices and to explore the case vignettes without interference from the interviewer. Questions were asked after participants were done viewing each case. Video and audio from the interviews were recorded and transcribed as qualitative data. A $50 Amazon gift card was sent to each participant who completed the study via e-mail within 24 hours.

The study was approved by the Institutional Review Board at Johns Hopkins Medicine (JHM). The JHM IRB has determined the study application, IRB00255463, qualifies as exempt research under the DHHS regulations.

Measures

We developed process measurement to assess physicians' belief change as follows, using their perceived probability of bacterial infection (0-100%) within each case: Participants were given limited access to clinical information in the case vignette up until the point when antibiotics were initiated. The first belief of bacterial infection was reported along with their agreement with the decision to start administering any antibiotics. The interviewer then gave participants access to the rest of the case and recorded the second belief of any ongoing bacterial infection by the end of each case. To assess the outcome of decision-making, participants were asked whether to keep the current antibiotics treatment course or terminate the treatment using a binary item: Continue or Stop; this assessment was the core dependent outcome variable. Participants were also given the option to explain their cognitive process along with each measured item. General qualitative questions regarding their accustomed practice on antibiotics reassessment, acquisition of clinical information, and feedbacks to the visualization were asked at the end of each interview session.

Data and Analysis

Raw response data were exported as .csv file from Qualtrics.com. Each value in the response was separated by a comma and each response was separated by a newline character. Fields that were auto-generated by the Qualtrics survey were dropped. Belief reported as a range of probabilities were taken as midpoint. Case number, complexity level, and ground truth were added to the data frame as new columns. A Boolean outcome variable was generated for whether the physician's

decision matches the predefined ground truth (0=No, 1=Yes). Change between belief of ongoing infection was computed as a vector to assess the effect of presentation modality on changing physician's belief in the right direction.

Descriptive statistics generated frequency tables. Decision agreement among physicians were calculated by Cohen's kappa[26]. Four statistical tests were performed. In Test 1, we compared overall decision correctness by presentation modality using a 2×2×4 contingency table: Log Likelihood Ratio Chi-square test[27]. Sensitivity analyses for case-level decision accuracy were conducted as 2×2 tables using Fisher Exact test[21]. Belief of ongoing infection and its relationship with decision outcome were examined in Test 2, 3, and 4. P values were used entirely heuristically due to the small sample size in each cell and the exploratory nature of the test. The original dataset was in wide-format, it was transformed to a long-format to fit the models for the repeated measures within participants. Coding was done in *JupyterLab* using *Python3*.

Results

Participants

Of the 24 PICU physicians who signed up, 22 completed the study. Participants were residents (50.0%), fellows (23.0%), and attendings (27.0%). 2 residents did not show up to the interview session and were lost to follow up. Due to the missingness of the 2 participants, the study design shifted to a partial counterbalancing, omitting cases T_1V_2 and T_1V_3.

Statistics

[Test 1] *Decisions:*
Overall, more decisions of continuing antibiotics treatment (68.18%) than stopping (31.82%) were observed (Figure 2). Of the 44 cases tested, there were more correct decisions (61.36%)

than false decisions (38.64%) when calibrated to the ground truth. There was a fair agreement of 61.36% among physicians (kappa = 0.21, SE = 0.14, 95% CI = [-0.060, 0.489]). Of the decisions that were made correctly, there were more decisions to continue (66.66%) than to stop (33.34%) the presented antibiotic treatment when displayed with visualization (Figure 3).
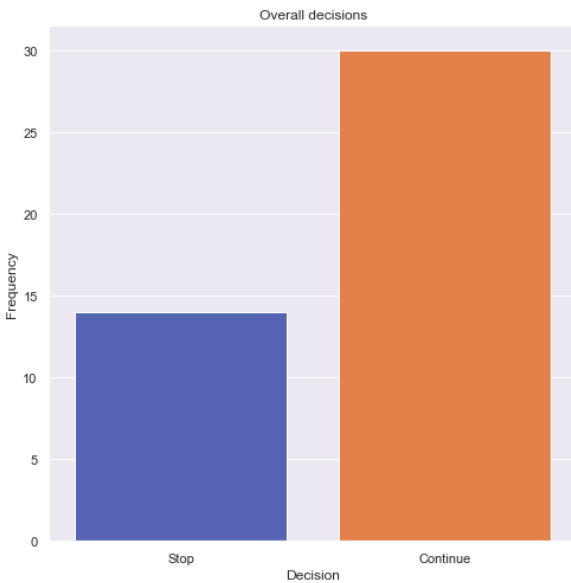

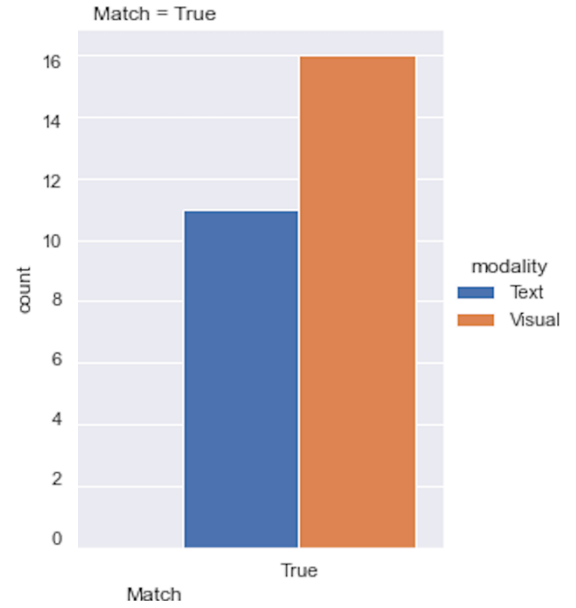Figure 3: Overall decisions to continue vs. stop antibiotics

Figure 2: Frequency of correct decisions by modality

A three-way contingency table, involving the three categorical variables, was generated to assess the global effect of modality on decision accuracy by case. On the contingency table of the 3 categorical variables, no statistically significant difference was found between the text narration and interactive visualization across 4 cases (χ^2 (16) = 17.92, p = 0.33; LR (16) = 20.33, p = 0.21), taking the 2 confounders (case severity and ground-truth decision into account).

Table 1: Three-way contingency table

Case	1		2		3		4		Total
Modality	Text	Visual	Text	Visual	Text	Visual	Text	Visual	
Match									
False	3	0	5	4	1	1	2	1	17
True	1	6	1	1	5	4	4	5	27
Total	4	6	6	5	6	5	6	6	44

To further explore the difference between the two modalities, we conducted Fisher's exact tests on the 4 partial tables from the three-way contingency table to compare the effect of modality on decision match in each case. Given the small sample size in each table, Fisher's exact test is preferred over Chi-square test. Case 1 was constructed with complex medical history and ground
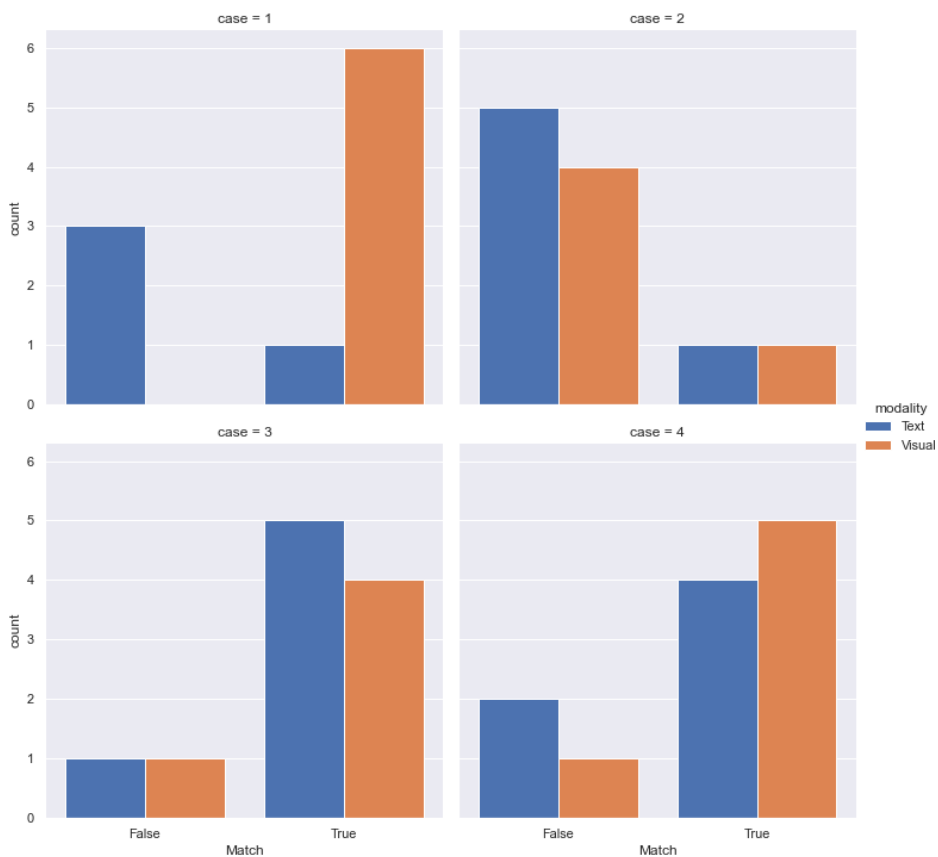

Figure 4: Frequency of correct decisions by modality and case

truth of stop using antibiotics. Visualization group significantly outperformed text group in making the accurate decision in case 1 ($p = 0.03$). However, there were no differences between text and visual in other 3 cases: case 2 ($OR = 1.25$, $p = 1.00$), case 3 ($OR = 1.25$, $p = 1.00$), and case 4 ($OR = 1.25$, $p = 1.00$).

[Test 2] *Belief*:

Of the total 44 cases measured, there were marginally more change in belief towards the ground truth (54.50%). Visualization accounted for more than half of total correct belief updates (62.50%). And there were less incorrect belief updates (35.0%) in visual group compared to the text group.
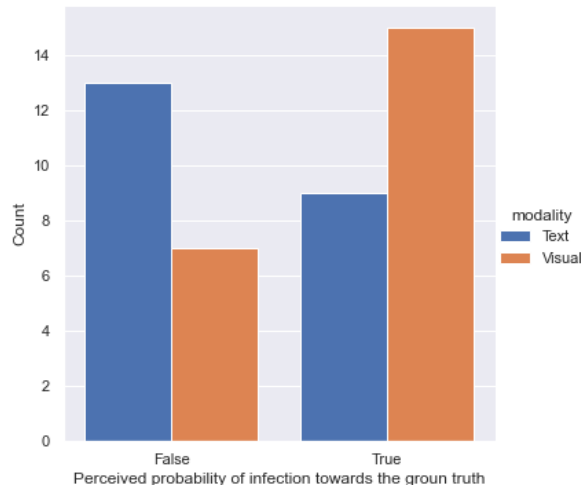

Figure 5: Frequency of belief update by modality

The same statistical tests were employed to assess the global effect of modality on change of perceived probability by case. No statistically significant difference was found between the text narration and interactive visualization, taking case complexity and ground-truth decision into account, across 4 cases (χ^2 (16) = 15.90, P = 0.46; LR (16) = 19.67, p = 0.24).

There was no statistically significant difference between the text narration and interactive visualization in each case: case 1 (OR = inf, p = 0.47), case 2 (OR = 20.00, p = 0.08), case 3 (OR = inf, p = 0.45), case 4 (OR = 1.00, p = 1.00).

[Test 3] *Belief-decision consistency*:

Overall, correct changes of perceived probability did not necessarily correspond to correct decision-making (50.0%). However, of the 22 consistent perception and decision pairs, there were more consistent pairs from the visual group (63.64%) compared to the text group.
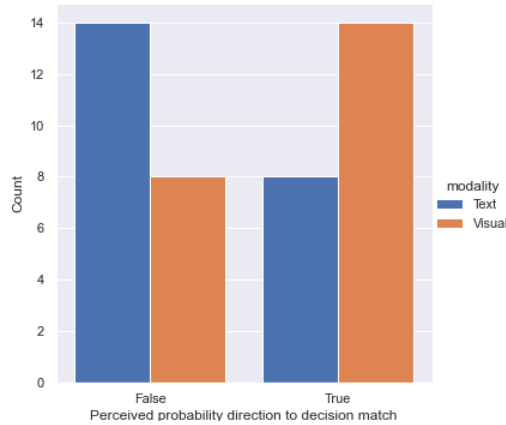
Figure 6: Frequency of belief update toward the ground truth by modality

The same tests were employed to assess the global effect of modality on consistent change pf perceived probability to decision by case. No significant difference between the text narration and interactive visualization across 4 cases (χ^2 (16) = 10.33, P = 0.85; LR (16) = 12.85, p = 0.68). There were no significant differences between text and visual on belief-decision consistency in each case: case 1 (OR = 6.00, p = 0.52), case 2 (p = 0.06), case 3 (OR = 4.00, p = 0.55), case 4 (OR = 0.50, p = 1.00).

[Test 4] *Belief update and decision:*
Belief update of ongoing infection was taken an absolute value to measure the magnitude regardless of direction. We defined major update of belief when the change in the magnitude was above the median (median=13.75%) and minor update of belief as below the median. Of the 22
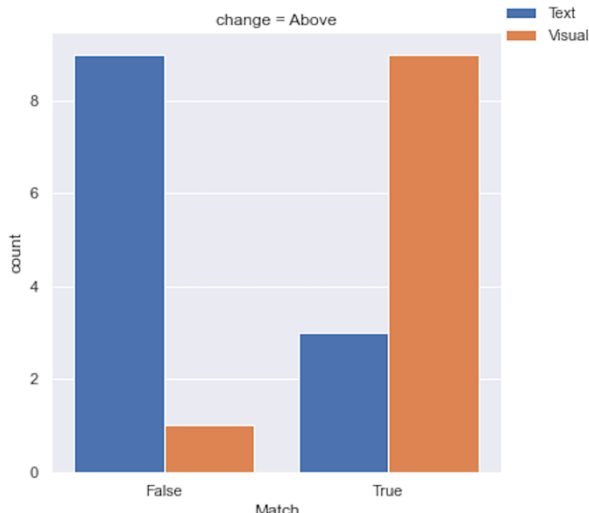

Figure 7: Frequency of major belief update by modality

major change observations, there were similar number of correct decisions (12) and false

decisions (10). Of the correct decisions, more correct decisions from the visualization group

(75%) than the text group (25%): OR = 27.0, P = 0.004.

Discussion

Summary/Main finding

To investigate how information presentation modality might affect clinical decision to stepdown

antibiotics treatment course at 48 to 72 hours in the PICU, we conducted this comparison study

with a within subject factorial design. Overall, the interactive visualization led to small, but

consistent, improvements in decision accuracy over text narration. Especially, when patient's

medical history was complex and required stopping of antibiotics, visualization significantly

outperformed text narration in making the accurate decision. This result suggests that a complex

patient's clinical information presented with an interactive trend graph may provide better basis

for clinical decision-making than a traditional clinical note.

Limitation of previous research/ my major innovation

Visualization technologies offer promising features to improve decision making by clinicians in

the intensive care setting[28]. While tabletop simulations have a long history in the literature on

clinical decision making[29], this study is among the first to assess the effect of information

presentation modality on antibiotic reassessment decision using case vignettes. To the best of our

knowledge, this study is the first to compare interactive visualization against traditional text

narration exclusively with physicians from PICU. The current study adds to this limited literature

and expands the work of 4 studies that demonstrated the usability of interactive visualization in

presenting complex clinical information[14–16,18]. However, these studies were limited to only process outcomes, such as physicians' preference, usability ratings, and open-ended decisions, rather than patient outcomes, as we have done.

There are several innovations in our study compared to the previous studies. First, our vignettes and visualization were constructed based on deidentified retrospective patient data that had clear clinical outcomes. The ground truth on whether to continue or stop the antibiotics was predetermined based on the actual clinical outcomes. Second, we employed outcome measure (Continue or Stop) along with two repeated process measures (belief of ongoing infection) to assess decision accuracy of a specific clinical task when calibrated against the ground truth. We were able to assess the changes of belief and their relationship with decision outcomes quantitatively. Third, the study data were collected passively by the interviewer while participants focused on the vignettes, allowing us to capture naturalistic decision-making.

Secondary findings

Consistent with the current clinical practice, our results indicated that physicians tend to continue using antibiotics even when the opposing clinical evidence was clear. As an attempt to improve antibiotic decision-making in the PICU, our results revealed a few other novel phenomena when decisions were moderated by information presentation modality. When the change of belief is greater than 14%, visualization significantly improve decision accuracy compared to text narrative [test 4]. This finding was echoed by the other two results from the study. Overall, belief updates were more likely to be accurate when information was presented in visualization than text [test 2]. And belief updates were more likely to be consistent with decision outcomes when presented with visualization [test 3]. Our results suggest that visualization potentially encourages physicians to make decisions towards truth when there is a significant update on their belief.

While the cognitive mechanism for our finding is still unclear, two prominent school of thoughts may help explain this phenomenon. The first is that stopping antibiotics for a patient with a complex medical history involves higher risks and demands a more complicated decision-making from physicians. Visualization reduces physician's cognitive workload by consolidating multiple data sources into a single display[30,31]. Alternatively, the yield of decision error in complex-stop context could be also due to an enhanced dual-process cognitive reasoning encouraged by the data-rich visualization[32] .As the task complexity increases, the demand for more types of information and data sources also increases[33]. And therefore, visualization consisted with comprehensive clinical data sources satisfies the high demand of detailed information for an accurate decision-making.

Limitations

It is plausible that a number of limitations might have influenced the results obtained. To begin with, the loss of two participants in case T_1V_2 and T_1V_3 resulted in missing data. The study design shifted from complete counterbalancing to partial counterbalancing, potentially compromising the significant result identified in case 1. If both decisions were made correctly in the text group, the significant difference between text and visualization in complex-stop case would go away. Thus, our primary finding is not robust. An additional source of error in our statistical analysis is discounting the heterogeneity of repeated measures in the contingency table. When data are repeatedly measured on the same participant, decision outcomes collected on the same participant are positively correlated with each other. However, this issue may pose only small-scale effect on our analysis since the cell size in the contingency table was small. During the study, participants often had a challenging time to report their beliefs of ongoing infection as percentages. Future studies could implement a formal belief assessment to obtain

more accurate percentage. Lastly, this study is also limited due to testing a prototype version of the interactive visualization. Our visualization was only assessable in the test environment. The display was shared through Zoom, lagged computer response and internet quality might affect the usability of the tool and indirectly affect the decision outcomes.

Future work

This study shows that there is a need for a thorough randomized clinical trial to investigate the causal relationship between decision accuracy and information presentation modality. Our results demonstrated a specific clinical use case of visualization in the PICU. Future works should focus on implementing the interactive visualization for patients who presented with complex medical history and require stepping down from antibiotics.

Conclusion

In this tabletop simulation study using specially crafted vignettes, our results suggest that interactive visualization may be helpful for physicians assessing their antibiotic strategy for patients with a complex medical history. Our findings suggest a specific clinical use case of interactive visualization. Future studies should conduct clinical trials investigating the use of interactive visualization to appropriately stop treatments given a complex patient medical history.

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