Communication and Team Situation Awareness in the OR: Implications for Augmentative Information Display

Avi Parush[1], Chelsea Kramer[1], Tara Foster-Hunt[1], Kathryn Momtahan[2], Aren Hunter[1], and Benjamin Sohmer[3]

[1]Department of Psychology, Carleton University, Ottawa

[2]The Ottawa Hospital

[3]The University of Ottawa Heart Institute

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Abstract

Team Situation Awareness (TSA) is one of the critical factors in effective Operating Room (OR) teamwork and can impact patient safety and quality of care. While previous research showed a relationship between situation awareness, as measured by communication events, and team performance, the implications for developing technology to augment and facilitate TSA were not examined. This research aims to further study situation-related communications in the cardiac OR in order to uncover potential degradation in TSA which may lead to adverse events. The communication loop construct – the full cycle of information flow between the participants in the sequence – was used to assess susceptibility to breakdown. Previous research and the findings here suggest that communication loops that are open, non-directed, or with delayed closure, can be susceptible to information loss. These were quantitatively related to communication indicators of TSA such as questions, replies, and announcements. Taken together, both qualitative and quantitative analyses suggest that a high proportion of TSA-related communication (63%) can be characterized as susceptible to information loss. The findings were then used to derive requirements and design a TSA augmentative display. The design principles and potential benefits of such a display are outlined and discussed.

1. Introduction

Patient safety and medical errors are internationally recognized as a critical problem [1, 2]. While many factors have been associated with medical errors and adverse events, this paper addresses information sharing and team situation awareness as critical factors in effective Operating Room (OR) teamwork and patient safety. The research approach was to focus on communication as an essential process in building and maintaining situation awareness, and in view of its susceptibility to breakdown, explore a possible solution to augment and facilitate these processes.

Teamwork is characteristic to many healthcare contexts and to the OR in particular [3, 4]. The OR is a critical and complex work environment consisting of people, devices and tools, actions and events. Effective teamwork in the OR is critical to patient safety because healthcare workers interact with each other in order to achieve successfully and safely a common goal [5, 6, 7, 8]. To accomplish the common goal, all members of the surgery team must perform their roles and tasks with full and continuous comprehension and awareness of the dynamic situation. To do this they rely on continuous coordination, communication, and information sharing with their team mates [9, 10, 11, 12, 13, 7]. Accurate information sharing among people and technology is essential to effectively coordinate the interdependent activities as part of the teamwork process [14, 13, 15, 16]. The process by which people acquire information (whether from devices and displays or shared with other people), understand it, and utilize it to comprehend and be aware of the dynamic situation is often referred to as Situation Awareness (SA).

1.1 Team Situation Awareness

When considering SA in multiple individuals, a further layer of complexity is added with teams [17]. People need to act reciprocally and interdependently with other team members and the shared environment [18]. Team Situation Awareness (TSA) is the task- and team-oriented knowledge held by everyone in the team and the collective understanding of the unfolding situation [e.g., 11, 15]. For example, TSA in the cardiac operating room prior to going on the by-pass pump may consist of the surgeon knowing that the perfusionist (team-oriented awareness) is ready with the by-pass pump (task-oriented) and that the anesthetist has administered Heparin (team and task oriented awareness). Thus, TSA is more than just adding up each operator's awareness and is facilitated by the interaction within the team [19]. Effective TSA does not depend on all operators being individually aware, nor does it make sense for everybody to be aware of the same thing at the same time [19]. Rather, the right information needs to get to the right person at right time, and this involves team coordination [20]. TSA is facilitated by team processes or behaviors that allow shared knowledge to be constructed and maintained among team members. Information sharing based on communication is essential to building and maintaining TSA [21, 22, 23].

1.2 Team Situation Awareness and Communication

Team communication has been shown to reflect team cognition [e.g., 24] situation awareness in the OR context [e.g., 12], team situation awareness [e.g., 19], team errors [e.g., 25], teamwork and situation awareness in control centers [e.g., 26], to cite a few. Taken together, all these studies stress the strong link between team communication and TSA.

Accurate information sharing among people and technology is essential to effectively coordinate the interdependent activities as part of the teamwork process towards a common goal [15, 16, 27]. Effective communication involves both physical and cognitive processes. It can mitigate interruptions and act as a buffer against failures by facilitating a common awareness of intentions and actions of others, which in turn enables collaboration of coordinated actions [28]. The way information is communicated and distributed within teams affects their performance [29, 30, 31]. A team's pattern of communication serves as a coordination device because it "enables… the sequencing of actions to accomplish tasks required by the work" [12]. Finally, the effectiveness of the team is often reflected by the degree to which members engage in processes for sharing information (e.g., questioning, cross-checking, setting up coordination and priorities, and contingency planning; 32).

Shu and Furuta [29] propose that both verbal and non-verbal communications are the means to achieving the underlying mechanism of TSA. TSA can be understood through the communicative and coordinative practices used within teams [12, 19]. Hazelhurst, McMullen and Gorman [12] study focused on cardioplegia (i.e., induced paralysis of the heart muscle), a time-dependent task based on the interaction of two people, and found that different patterns in communication were associated with team situation awareness and enabled various teamwork processes. Taken together, adequate information sharing via communication is critical to TSA, and is essential to effective teamwork in the OR. In addition, the research suggests that communication patterns can reflect processes of constructing and maintaining TSA.

1.3 Team Situation Awareness and Communication Breakdowns

There are many documented communication breakdowns within healthcare teams that were associated with increased error rates and adverse events [33, 34, 35, 36, 37]. A retrospective review of 16,000 in-hospital deaths [38] found that communication errors were twice as frequent as errors due to inadequate clinical skill. A similar study [39] of primary care physicians suggested that approximately 50 percent of all detected adverse events were associated with communication difficulties. In another study, communication was a causal factor in 43% of errors made in surgery [40]. Taken together, team communication breakdowns were associated with degraded team performance.

Communication breakdown can result in information loss and degraded information sharing within the OR team. Because of the key role of communication in TSA, breakdowns can have in turn a degrading impact on TSA. In aviation, Thornton [41] discovered that the number of situational awareness (i.e., view of positioning in relation to the field) statements made by aircraft crew members was positively correlated with the incidence of committed errors. Helmreich and Davies [42] observed breakdowns in communication that resulted in loss of awareness of the patient's condition, distractions that resulted in failure to note adverse changes in patient status, and disputes between members of anesthesia and surgical teams. In another study of OR observations, Lingard et al. [36] classified roughly 30% of the overall 421 communication events as failures. Failures were defined as communication events flawed in at least one of the following dimensions: content, audience, purpose, or occasion of communication exchange. Communication failures exhibited a common set of problems: timing is too late to be

effective, content is not consistently complete and accurate, key individuals are excluded, and issues are left unresolved until the point of urgency.

1.4 Summary and Objectives

In summary, there is widespread recognition and evidence of the association between OR adverse events and human communication breakdowns. In addition, there is evidence supporting the importance of communication and information flow for TSA and effective teamwork. Unfortunately, there are few conclusive findings and practical approaches to address the potential degradation of TSA in the OR and the possible impact on patient safety. The arising need is to further study the potential for TSA degradation and explore solutions that can mitigate the consequences of such degradation. Specifically, there is a need for a solution that can bring together information from various sources, provide the critical situation information to all OR team members in a continuous manner, and thus minimize the harmful outcomes of communication breakdown and information loss.

The objectives of this study were to address the problem of potential TSA degradation, assess its scope, and then derive recommendations and requirements for technological solutions to augment and facilitate TSA and teamwork. To achieve these objectives, the general rationale of the study consisted of four main phases: 1. Observe and capture OR team communications; 2. Identify and analyze communications reflecting processes of constructing and maintaining TSA; 3. Identify the sub-set of situation-related communications that were susceptible to breakdown and information loss. The identification of TSA communications susceptible to degradation justified the need for developing a TSA display; and finally 4. Based on the identified shared information that

is relevant and critical to being aware of the situation, design a team-oriented display to augment information sharing and facilitate TSA in the OR.

2. Methods

2.1 General Approach

This research was qualitative in nature, where it was impossible to "completely control the what, when, where, and how of participants and their activities" [43, p. 335]. Variability (e.g., case complexity, duration, and number of team members involved) within and across cases was influenced by the needs of the patient and OR scheduling, and not by experimental design. The researchers observed and captured as much information as possible from the participants and allowed patterns to emerge from the data [44, p. 347].

2.2 Observations

Ten open-heart surgeries, all including a heart-lung machine by-pass (i.e., pump by-pass), were observed in a medium-size hospital specializing in cardiology and cardiac surgery, in Ontario, Canada. Each of the observed procedures included a team composed of at least seven healthcare workers from the following healthcare disciplines: Surgery (a surgeon and a resident), anesthesia (an anesthetists and respiratory therapist), perfusion, and nursing (a scrub nurse and circulating nurses). Overall, the sample of observed healthcare workers included 4 different surgeons, 4 different surgery residents, 5 different perfusionists and respiration therapists, 5 different anesthetists, and 15 different nurses.

Each observation was conducted by two observers with a background in the behavioral sciences. Both observers were informed with the basics of cardiac surgery and the typical sequence of events and actions practiced in open heart surgeries. The

observations were initiated with expert-narrated observations, one with each of the observers. Two experienced healthcare workers, an anesthetist and a perfusionist, observed alongside each of the behavioral sciences persons and narrated in detail what was happening during the operation. The observer took notes based on what they perceived and the explanation given by the experienced healthcare worker. The narrated observations were used for three objectives: 1. ensure that the observers understand correctly the sequence of events and medical actions that take place during the surgery; 2. ensure understanding of the "language" used by the healthcare workers when communicating with each other; and 3. the notes taken during the narrated observation used to validate the subsequent notes taken independently by the observers.

Each of the two observers noted the following independently:

- The participants in a given communication episode (e.g., surgeon talking to the scrub nurse).
- Time stamp.
- The information conveyed (e.g., surgeon asking the perfusionist if the ACT (laboratory test) was done).

Each observation yielded two sets of observation notes taken independently by the two observers. These two sets of notes were amalgamated in the following fashion: 1. comparison of the noted surgery phases (e.g., patient prep, going on pump, etc.); 2. comparison of key events and actions within each of the noted surgery phases (e.g., first Heparin administration, placement of the cross-clamps, etc.); 3. comparison of the noted communications within the OR team; 4. resolution of any discrepancies using the notes from the narrated observations; and 5. filling in "missing data" in either of the notes sets

if that data was noted by one of the observers. This process resulted in a single set of observation notes which was more complete and valid.

2.3 Communication Analysis Approach

There are various approaches reported in the literature to analyzing human communication within teams in healthcare, such as the rhetorical framework [26], modified grounded theory [45], or activity framework [12] for uncovering distributed cognition and SA in the cardiac OR. In other domains, the analysis of human communication within teams was based on uncovering utterance types and patterns [e.g., 10, 28, 32]. The common aspects of most of these approaches contain elements from the Conversation Analysis approach [46, 47] which has also been used to analyze team communication in other command and control contexts [e.g., 26]. Following the key elements in Conversation analysis, the full protocols of human verbal communication in the OR were segmented into meaningful sequences, with each sequence made of utterances produced by at least two participants taking turns in the verbal interaction. The following is an example of such a sequence:

Surgeon to Perfusionist: “clamp is on”

Perfusionist to Surgeon: “the pressure is the same-it is not up”

Surgeon to Perfusionist: “is your vent still on?”

Perfusionist to Surgeon: “yes”

Surgeon to Perfusionist: “turn it off”

Perfusionist to Surgeon: “pressure is still the same”

Surgeon to Perfusionist: “OK”.

The iterative nature of qualitative data coding included the identification of meaningful sequences, and coding of communication patterns by two criteria: the speech act and the surgery-specific content. The objective of this coding approach was to identify communications that can reflect processes of building and maintaining TSA. Communication codes and categories were also counted in order to provide an indication of the scope and magnitude of the patterns. However, the numerical data could not undergo a statistical analysis. Small sample sizes and the inability to assign participants to surgeries either randomly or in a counter-balanced fashion meant that some observed participants produced verbal data over repeated procedures, thus violating independence of cases assumption. Therefore, most of the reported results are descriptive and exploratory.

3. Results

3.1 Overview

The objective of the data analysis was to identify situation-related communications that were susceptible to breakdown. To achieve this objective, the analytic approach progressed in two steps: 1. identifying situation-related communications; 2. within the sub-set of situation-related communications, identifying those that were susceptible to breakdown and information loss. Identification of such communications would imply the potential for TSA degradation and justify the need for a TSA display. Once that need was empirically demonstrated, the communication data was subsequently used to derive the information requirements for a TSA display.

3.2 Situation-related Communication Analysis

Following the approach of Conversation Analysis, a total of 461 human face-to-face meaningful sequences were counted across the 10 observed surgeries. Of the 461 communication sequences, 292 (63%) were simple communication sequences involving just a sender and a receiver (e.g. surgeon talking with the perfusionist), and 169 (37%) were extended sequences involving more than two participants in the communication sequence (e.g., the surgeon talks with the perfusionist and the anesthetist). The extended communication sequences in which information was conveyed and shared by several team members have particular importance when considering team situation awareness.

In order to identify and quantify situation-related communication, the analysis focused on utterances in which information about the situation was shared among the participants. These were categorized by two criteria: the speech act and the surgery-specific content. Speech acts which are verbal communication behaviors are defined here

simply as utterances that serve a function in communication. Table 1 shows the speech acts that were defined as situation-related along with an example.

Table 1

Situation-related speech acts categories along with their explanation and an example

Speech Act	Definition	Example
Request	Directing, instructing, or requesting someone to do or report something	"Up on vent"
Announcement	Informing on a value, state, action taken	"Cardioplegia is in now"
Question	Asking about a value, state, action	"Are we ready to go on pump now?"
Reply	Providing information about a value, state, or action as a response to a question	*"What is the ACT now?"* "ACT is 485 now"
Confirmation	Assuring that a request was acted upon	*"Can you go on one more minute?"* "Yes"
Read-back	Repeat of a request, announcement, reply, or confirmation	*"Down on vent now"* "Down on vent"

As can be seen in table 1, the speech acts serve various functions in the communication, and all enable sharing situation-related information among the OR personnel. Overall, there were 231 situation-related sequences. The situation-related sequences and utterances were also categorized by their surgery-specific content. Table 2 shows the various categories of the communication contents that were related to the actual surgery. In addition, the content categories were cross-tabulated with the speech acts. The distribution is shown in Figure 1.

Table 2

Surgery-specific content categories along with their explanation and an example

Category	Explanation	Example
Drug Administration	Medication request, administration, administration confirmation	“Heparin is in”
Patient Status	Patient status such as vitals, flow, pressure, echo and ACT levels	“ACT level is 485 now”
Medical Action	Requested or announced action pertaining to medical process or procedure	“Up on vent”
Equipment	Request or confirmation on equipment adjustment, retrieval or validation	“Bring Onyx25 valve”
Transition	Requesting, announcing, or confirming information related to the transition between surgery phases	“Are we ready to go on pump now?”
Time	Elapsed time since an action, or drug administration, or time to wait to administer or take an action	“1.5 hours since cross-clamp is on”

Requests dealing with medical actions and equipment had the highest relative proportion (9% and 8%, respectively) of situation-related speech acts. In addition, it is important to note that speech acts such as announcements, questions, and replies, dealing with information on patient status, transitions, and medical actions, had a proportion of 1% to 5%. These data further amplified the implication that situation-related communication dealt with important surgery-specific issues such as patient status or transitions within the procedure.

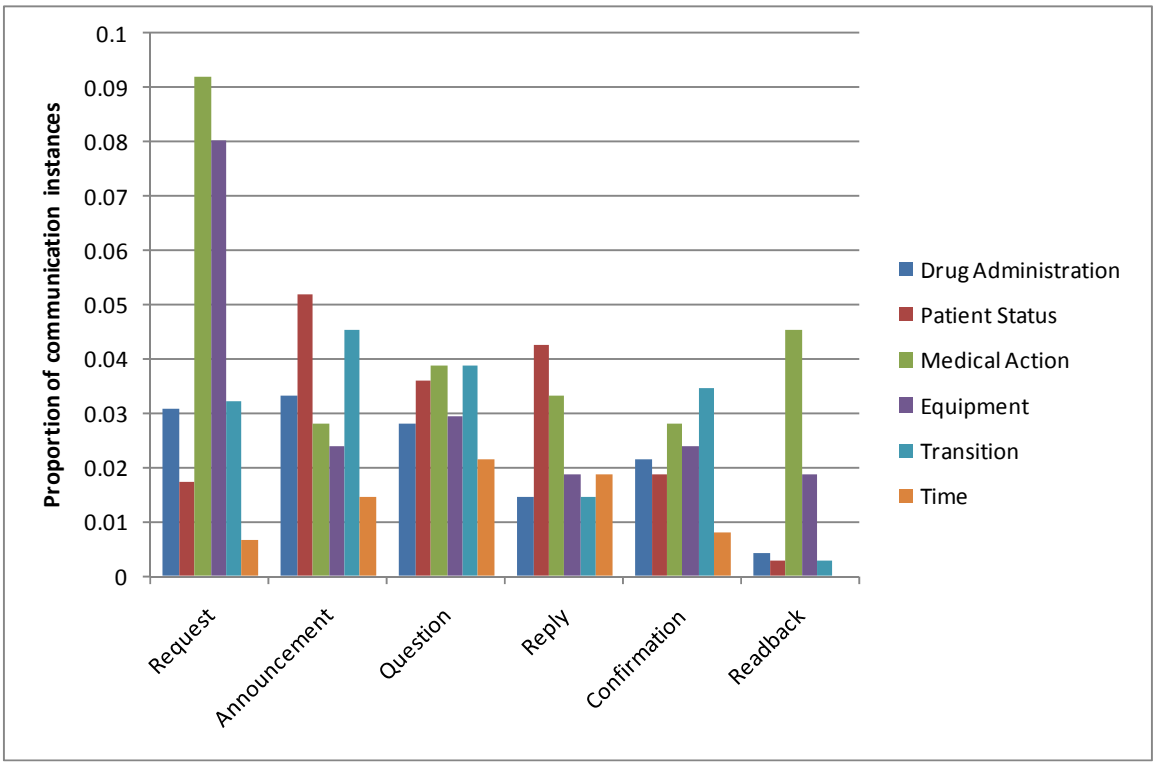

Figure 1: Proportion of susceptible information flow sequences categorized by speech acts and surgery-specific content, relative to the total number of susceptible communications.

3.3 Situation-related Communications Susceptible to Information Loss

In order to assess susceptibility to breakdown and information loss in situation-related communications, we used the communication loop construct – the full cycle of information flow between the participants in the sequence based on Schramm's model of communication, [48], and the work of Cannon-Bowers et al., [49]. Effective human communication involves more than the ability to simply converse with others, and that clear and concise communication is critical [50, 51, 52]. Closed-loop communication involves the following sequence of actions: (1) sender initiates message; (2) receiver accepts message and provides feedback that it was received; and (3) sender double

checks to ensure that message was received as intended. This type of communication has a built-in check to ensure that not only does the communication get to the required person, but that the intended message sent was the same one received. When multiple sources of information as well as multiple recipients are present, such as in the OR, closed-loop communication can differentiate between effective and ineffective teams [see 32, 53]. Communication difficulties can result, among other factors, in defective encoding or decoding, or in the transmission process itself.

In view of this, the following analysis explored the various characteristics of the communication loops with the aim of identifying those that are susceptible to information loss. The following characteristics were typical of most communication sequences:

Loop Closure: In the closed loop, there was always a sender and a receiver responding in a relevant manner to the conveyed information (e.g., a question and an answer to the question; or a command and a confirmation of the command or execution of it). In the open loop, there was no explicitly observed relevant response to the sent communication (e.g., someone asked a question and there was no answer). Open loops can be considered more susceptible to information loss since effective information flow consists of the complete transfer of information from one team member to another [49].

Direction: In the directed loop, the originator of the communication indicated explicitly - either verbally or non-verbally - who they were talking to. In the non-directed loop, the originator did not indicate to whom the communication was directed. Communications not directed at anyone in particular also provide the opportunity for information loss.

Closure timing: The timing of the closure can be significant. In some communication loops, the loop was closed immediately. However, there were communication loops in which there was an observed delay (not immediate) in the closure. Loop closure timing and direction were then combined to further explore the susceptible communications. The combined frequencies of delayed loop closures and directedness are presented in Figure 2.

Figure 2. The relative frequencies of situation-related communications as a function of loop closure, closure timing, and direction.

The findings show that there were situation-related communications directed towards a specific healthcare worker in the OR but that worker did not close the loop (e.g., surgeon asked the perfusionist about the recent value of the ATC, but the perfusionist did not respond). Open loops were observed more often with directed communications as compared to non-directed (e.g., the perfusionist announced the recent ATC level but no one in the OR responded or acknowledged receiving this information). In addition, 33% of the situation-related communications that were directed to a specific

healthcare worker in the OR were closed only after a delay. Overall, 49% of the situation-related communications were identified as susceptible to information loss.

The analysis of susceptible situation-related communication examined also extended communication sequences that included more than two participants. Overall, 41% of the situation-related communications included multiple participants. The proportion of adequate communications (e.g., directed closed loops) compared to susceptible communications was examined for simple vs. extended sequences. The count is summarized and presented in figure 3.

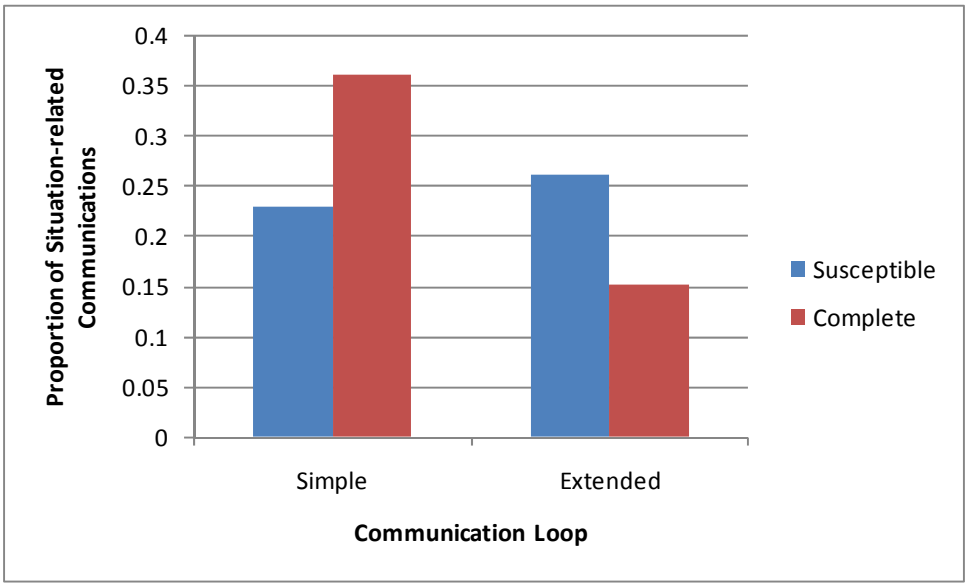

Figure 3. The relative frequencies of situation-related communications as a function of number of participants in the communication loop and susceptibility to information loss.

It can be seen in figure 3 that with simple loops, involving only two participants, there were more complete communications (directed and closed). However, in extended loops which included multiple participants, the proportion of susceptible communications was higher than complete ones. The higher susceptibility to information loss in multi-

participant communication sequences is particularly significant with respect to TSA since the construction and maintenance of TSA is often dependent upon several team members sharing information at the right time.

3.4 The Participants in Susceptible Situation-related Communications

The criticality of the susceptible situation-related communication was further assessed by examining the specific disciplines of OR healthcare workers involved in these sequences. The proportion of sequences is presented in Figure 4 for some of the OR team members that were involved in them. It can be seen that the surgeon, perfusionist, and the anesthetist were involved in the highest proportion of communication sequences. There is also a clear trend indicating that proportion of involvement in susceptible sequences was directly related to the overall involvement in communication. It is interesting to note that both the surgeon and the perfusionist were involved in a high proportion of susceptible communication instances (31% and 26%, respectively). It makes sense because it is the surgeon – whose attention is directed primarily to the surgical site - who relies almost exclusively on human communication to receive situation-related information, with much of it – especially while the patient is on the bypass pump – coming from the perfusionist. Part of this finding is in line with previous research indicating that the surgeon is involved in the highest proportion of communication sequences [54]. As was indicated in the introduction, accurate information sharing among people is essential to effectively coordinate the interdependent activities as part of the teamwork process [15, 16]. The surgeon is a critical component in the construction and maintenance of TSA and the finding here

stresses the susceptibility of the surgeon to information loss and subsequently degradation in TSA.

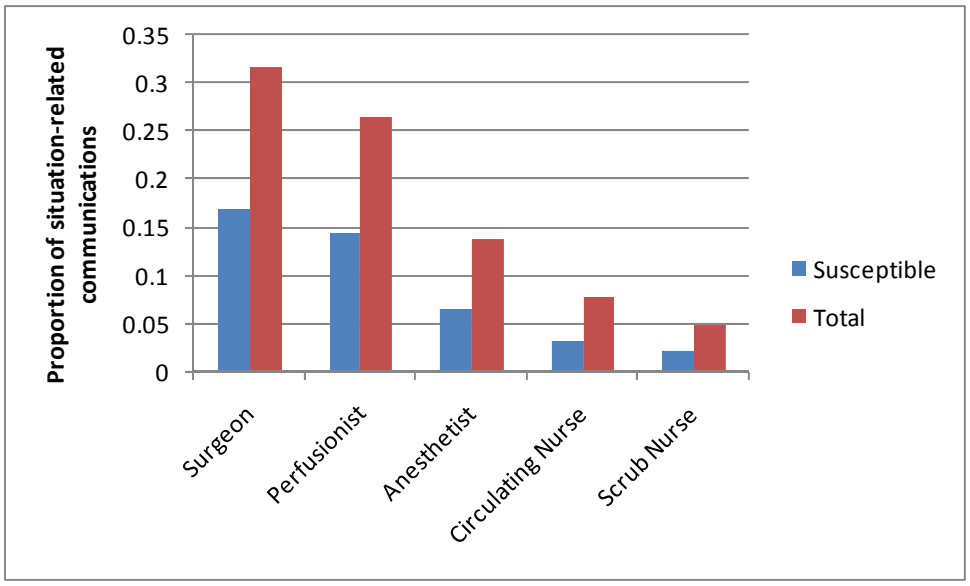

Figure 4: Proportion of susceptible and total situation-related communications that each of the indicated OR team members was involved with, relative to the total number of situation-related communications.

In summary, the analysis of situation-related communication showed a high proportion of susceptibility to information loss. In addition, these susceptible communication sequences deal with critical surgery-specific information such as patient status, medical actions, and transitions. Finally, key OR personnel such as the surgeon, perfusionist, and anesthetist are involved in many of those susceptible communications. Taken together, the findings imply that TSA can potentially be degraded due to information loss. The findings further stress the need to look for means and devices that can mitigate the potential detrimental impact of such degradation by augmenting TSA in the OR. The approach adopted here to address this need was to use the identified shared information within the OR team to develop a TSA augmentative display.

4. Conceptualization of a TSA Augmentative Display

4.1 Determining the Display Requirements

Previous research indicates that it does not make sense for everybody to be aware of everything at all times. The key to constructing and maintaining effective situation awareness is to know what one needs to know at the right time. Consequently, the corpus of the 231 identified shared situation-related communications was used to find a subset of information that is critical to effective and safe teamwork. All sequences of shared situation-related information were aggregated into unique (non-overlapping, non-repeating) items. For example, all instances where the shared information dealt with various aspects of Heparin (e.g., request, administration, amount, etc.) were aggregated into unique information items such as: Heparin Requested, Heparin Administered, etc. This analysis step resulted in a total of 52 unique situation-related information items. All the unique information items were then mapped unto the relevant phase in the procedure (e.g., Heparin is administered before and during the pump bypass, whereas Protamine is administered when weaning the patient off the bypass pump).

The criticality for OR healthcare workers to be aware of the unique information items at the given surgical phase were then rated (on scales from 1 to 7) by 2 surgeons, 2 anesthetists, and 2 perfusionists. There was a high agreement (intra-class correlation = .7) between all raters. The final outcome of this analysis was a prioritized list of shared information items divided into three priority groups within each of the surgery phases. The highest priority group included items with a very high and consistent consensus on the criticality of sharing them among all team members. The medium priority included all items with a mean of 2-4 on the scales. Finally, the third priority included items with a

consistent consensus that it need not be shared within the team. Given the rationale of this study, the list of the highest priority items constituted the requirements of what needs to be displayed to the team. The full process of prioritizing and narrowing down the scope of information items that need to be displayed is also described elsewhere [55].

4.2 Display Design Process and Principles

The primary challenge of conceptualizing the cardiac OR TSA display was to determine how to group and visually present the high priority critical information items. Several alternative grouping criteria and their tradeoffs were considered. Grouping static information items (e.g. patient information) vs. dynamic parameters (e.g., ACT level) provided a strong visual location cue for information searching but lacked the indicated causal relations between parameters (e.g., impact of drugs on ACT level) with respect to the surgical phase. Grouping information items into functional groups (e.g., drug administration parameters) provided a strong visual association between parameters serving similar functions in the procedure but lacked to context sensitivity of the surgical phase and the link to physical and anatomical components (e.g., the pump, lungs, etc.). Grouping information items according to process flow (e.g., Patient prep parameters, and then going on pump, etc.) provided strong time-related information but had the potential of being a display that is too dynamic thus imposing a greater challenge to visual search. And finally, grouping the information items according to physical and/or anatomical grouping (e.g., heart, lungs, drugs, machine, etc.) provided a strong visual association between various critical components of the surgery but lacked the sensitivity to the surgical phase and link to functional groups such as drugs or patient status.

Based on preliminary feedback and after considerations of the various tradeoffs introduced by each of the alternatives, we decided to follow a hybrid grouping approach by combining process with physical and functional groupings in an integrated fashion. In addition, two main human factors engineering design principles were used: 1. Proximity – elements and items that have any close relationships between them, according to a given grouping criterion, should be displayed with a physical proximity to clearly convey their relationship; 2. Redundancy – critical elements and items can be displayed in more than one fashion or in more than one place to ensure that the information is conveyed to the medical and nursing staff in one way or another.

The concept consisted of dividing the display into several visual areas: 1. Patient information (static information); 2. Selected vital signs (dynamic information); 3. Time line of the main critical events that take place throughout the surgery (e.g., administration of drugs or events related to the heart-lung machine). Such a time line was designed to behave dynamically and get updated whenever the selected events took place; and 4. A primary central area depicting the current main event with the associated parameters. The display concept is presented in Figure 5. The design of the central area is a visual mimic of the process and physical relationships between important elements in cardiac surgery. Representation of the patient (lungs and heart) and the heart-lung machine were visually placed separately, similar to how they are arranged in the OR. A representation of the cannulas (tubes) when connected to the patient and the machine were used to create a process flow representation (e.g., on or off pump). Finally, the drugs and the ACT levels which are parameters that help manage the human-machine flow were placed in between these two elements.

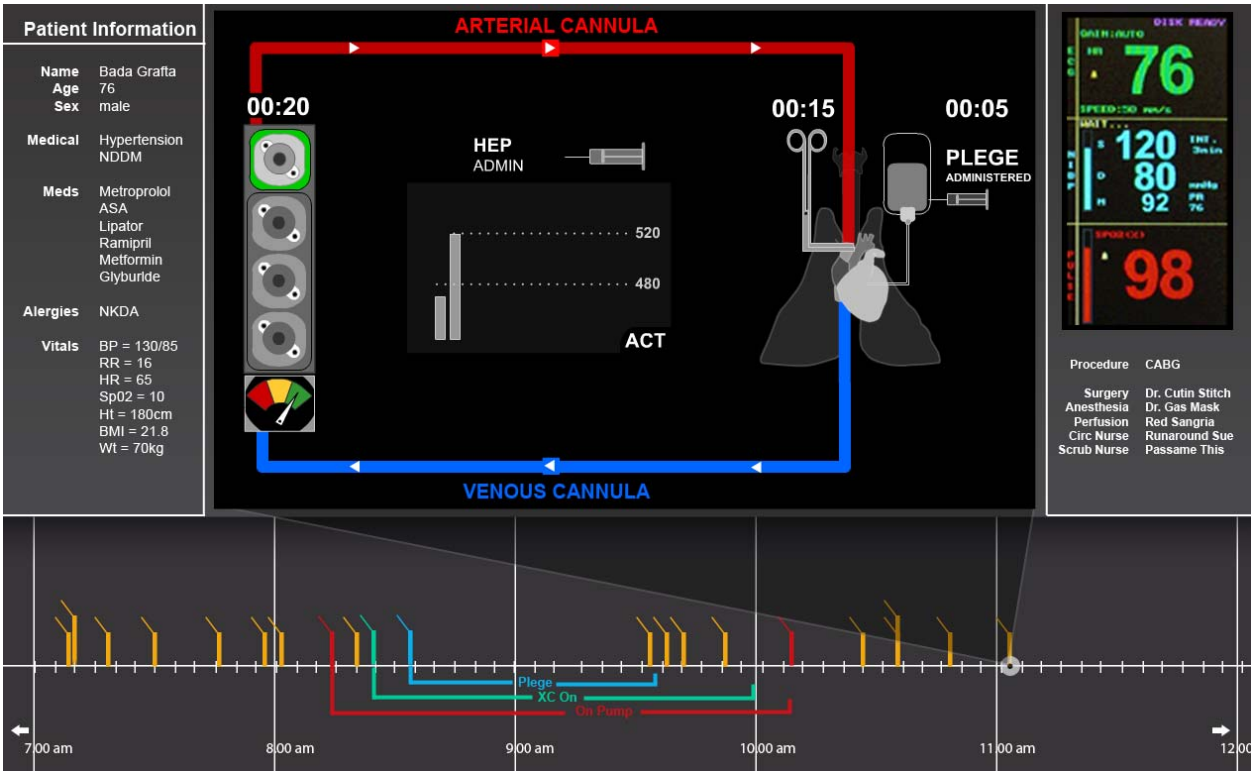

Figure 5: Full conceptual design of the Integrated Cardiac OR Display (iCORD^{TM})

In summary, the proposed concept of a cardiac OR TSA augmentative display is based on the following key principles: 1. The requirements for the display were derived from the communication analysis of all situation-related communications captured during cardiac OR observations; 2. Situation-related information that is critical for at least three OR healthcare workers is displayed in an integrated, context-sensitive, dynamic, and continuous manner; 3. The display design criteria include a mimic of the most critical phase of the surgery (patient being on a pump bypass), along with patient, procedure, and OR team information, vital signs, and an overall time line of the surgery phases and key events and actions.

5. Discussion:

5.1 The display benefits in improving TSA

The purpose of this final section is to discuss the potential benefits of the proposed display concept in improving TSA. The first part of this discussion addresses the current state-of-the-art with respect to similar team-oriented displays. With that context as a background, we proceed to discuss the specific potential impact of the proposed TSA display in this work.

Moss and Xiao [37] suggested that technological applications can be used to change system processes to improve communication and information access, thereby augment information exchange, decrease the dependency on only human communication, and diminish the possibility of adverse events in the clinical setting. Most contemporary OR devices are not designed to optimally allow all team members to receive and effectively assimilate and utilize all critical information. Moreover, most current displays are not designed to facilitate information sharing and team coordination processes.

However, few technologies and display devices supporting information sharing and TSA have been developed and evaluated in various domains. [11, 56, 57, 58]. There are also few reports on the design and development of such applications to support TSA in the medical OR. An integrated SA display for the OR was developed and reported by Lai, Spitz, and Brzezinski [59] and Levine, et al., [60]. Their work emphasizes the integration of all critical information into a single large display to enhance situation awareness. Moreover, the intent with their displays is to facilitate team orientation during the procedure and also during staff changes. Other attempts to develop devices for information sharing are the use of White Boards. Xiao, Lasome, Moss, Mackenzie, and

Faraj [61] developed and assessed a non-electronic large display board in a Level I trauma centre operating room unit, to be used primarily for coordination purposes (e.g., scheduling, staffing, etc.) within the trauma center. France et al. [62] studied an electronic white board in an emergency department. The board displayed patient data, chief complaint, wait time, length of stay, managing physician, # of patients in waiting room, ED occupancy, bed status for providers and cleaning staff. Their evaluation showed more efficient workflow and fewer interruptions to physicians. A similar development was reported by Aronsky, Jones, Lanaghan, and Slovis [63].

The rationale adopted in this project was that the successful design of information sharing applications should be based on an understanding of communication patterns among healthcare workers and the nature and timing of sharing situation-related information. Such understanding uncovered the critical information that was shared and then applied directly to the design of a context-sensitive display for information sharing. In this manner, the proposed display ensures that information can always be retrieved and consequently improve TSA in the following typical information loss circumstances: 1. communication breakdowns – whenever any of the OR healthcare workers missed any critical situation-related information due to any type of distraction, interruption, or communication breakdown, that worker can retrieve the missed information from the display without interrupting or distracting anyone else; 2. missing the pre-operative briefing – whenever any of the OR healthcare workers missed for any reason the pre-operative briefing and joins the procedure after it has already begun, that worker can get the information from the display and construct an updated situation awareness; 3. Intra-operative handoffs – healthcare workers who go on a break or any other errand or

replace others, can get all from the display the required information about all that has taken place when they were not present and what the current situation is and thus re-orient themselves; 4. Failures, errors, and emergencies – when any failures, errors, or an unexpected emergency or complication happen and there is a need to know what was done or not done, the display can provide accurate information about the past and present situation of that procedure thus supporting the OR team in handling the emergency or recovering from the failure. It should be noted that preliminary evaluations with several anesthetists indicated that the display's clear and intuitive design allows them to answer critical questions about the situation thereby mitigating communication breakdown and its potentially-resulting medical errors.

5.2 Future development and research agenda

Our findings demonstrate the potential for TSA degradation in the OR and stress the need to mitigate such possibility. Our proposed display solution to augment TSA in the OR provides design requirements and criteria that were derived from OR team communications. A dynamic simulator of the display has been developed to be used in empirical evaluations of the impact and benefits of the display. The simulator allows for the test facilitator to control various parameters (e.g., administration of drugs, patient satus, etc.) and thus drive the dynamic display according to a given scenario (similar to how typical patient simulators work). The simulation is currently employed in an online survey to cardiac OR professionals to receive their feedback and evaluations. The online survey also includes situation awareness questions that the respondents are asked to answer. In addition, the simulator will be used in a full scale cardiac OR simulation that will include a patient simulator.

The study introduces new questions and a challenging development and research agenda. There is still a need to assess the immediate and long term impact of such an augmentative display on TSA, teamwork, and patient safety in the OR. The methods and design principles proposed here need to be further developed and fine-tuned to become clear and objective guidelines. Finally, there is a need to assess the generalizability of the methods and design principles to other surgical procedures, and other healthcare contexts.

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