FIXATION AND ATTENTION ALLOCATION IN ANESTHESIOLOGY CRISIS MANAGEMENT: AN ABSTRACTION HIERARCHY PERSPECTIVE

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ABSTRACT. The abstraction hierarchy analysis tool developed by Vicente and Rasmussen (1992) for Ecological Interface Design (EID) provides an in depth understanding of work domain constraints and information requirements. EID and work domain analysis (WDA) have been successfully applied in several fields. However, application in the medical domain has proven to be much more difficult. This study examines the relationships between three components within the OR: the surgical team, medical equipment, and the patient. It is hypothesized that crisis management failure in the OR is due to attentional mis-allocation and can be undone by re-directing team members' attention to the appropriate level of information structure. We propose a novel structure, based on existing work domain models for the operating room, to analyze the behavior of OR teams and map their attention allocation within the abstraction hierarchy to explain fixation during medical problem solving and crisis management.

INTRODUCTION

The theoretical tools used for work domain analysis (WDA) and ecological interface design (EID) can help provide a more in depth understanding of system constraints and information requirements in complex sociotechnical environments (Burns and Hajdukiewicz, 2004). EID was borne by the application of Rasmussen’s skills, rules, and knowledge (SRK) theory of cognitive control to the design of user interfaces and controls. The SRK framework is generally accepted throughout industry as appropriately descriptive for the way workers interact with complex human-machine systems (see Figure 1). Knowledge elicitation from the workers in these environments can help to identify hierarchal functional links within the system which can then be used in the design of interfaces and development of operating procedures to improve performance, diagnosis, and problem solving.

Similarly, WDA allows for the generation of a work domain model that captures the goals, constraints, and variables inherent in the system. The system is modeled along two dimensions, abstraction and decomposition. Decomposition modeling is a traditional breakdown of the system into subsystems and components. Development of an abstraction hierarchy (AH) reveals the functional relationships between system components. The AH represents means-ends links between higher level goals and lower level physical constraints and properties. Five levels of abstraction have generally been described for most complex systems (Figure 2).

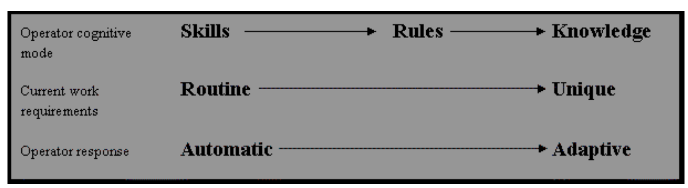

Figure 1. Operator behavior and problem solving continuum in SRK model (Vicente and Rasmussen, 1992)

EID and work domain analysis have seen success in several different fields, including military command and control, process control, and information retrieval. However, EID and WDA application in the medical domain has proven to be much more problematic. The operating room, in particular, offers several challenges not yet met. A new perspective on the problem is necessary in order to overcome the difficulties inherent in this domain, and to accurately model the surgical environment as a whole.

Hospital operating rooms (ORs) are complex socio-technical systems in which OR staff must integrate massive amounts of information from multiple sources to make decisions throughout the surgical procedure. In such a system, the numerous layers and components present countless opportunities for conflict. Considering the many different ways in which people, equipment, and the environment can interact; it is not surprising that operators in these systems must be highly skilled, professional problem-solvers. We propose that with appropriate modifications to the generic AH, we are able to map the behavior, actions, and decisions of people operating in a complex socio-technical system onto a work domain model to understand and interpret the decision-making process. Furthermore, we propose to use this model to examine the notion of fixation in decision-making during crisis management for the anesthesiologist.

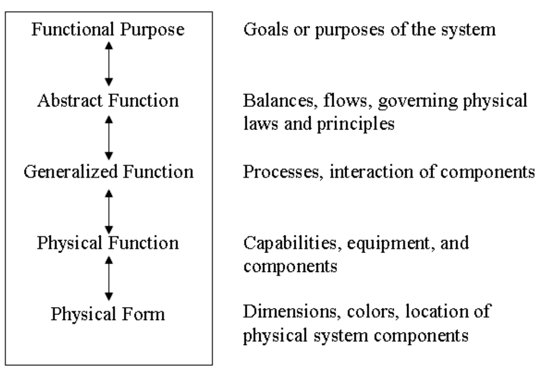

Figure 2. Abstraction hierarchy

Fixation errors are often the result of several contributing factors, many of which can be described using the AH framework (De Keyser & Woods, 1990). In a system as complex as the OR, the staff must carefully choose where to direct their limited cognitive resources. Information is available at several levels of abstraction. However, the mismatches critical to problem-solving described by De Keyser may not be apparent at the current level of focus. Is the anesthesiologist focusing attention on the physical operation of the ventilator, or on the flow of properly oxygenated blood throughout the body? By identifying the distribution of attention within the abstraction hierarchy, we aim to more fully describe the nature of fixation and how to prevent it in real-time problem solving. This paper presents results from modeling the work domain, and behavior and decision mapping within the AH framework.

METHODS

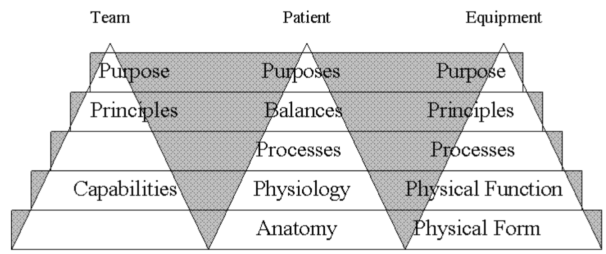

Figure 3. The operating room work domain

Subjects

We used data that were previously collected for another study (Rudolph, 2003). Thirty-nine anesthesiology residents from local hospitals were observed and videotaped during a basic anesthesiology crisis management training course at the Center for Medical Simulation (Cambridge, Massachusetts). The training course was conducted in a high-fidelity simulator of the operating room. There were five first year residents, twenty second year residents, ten third-year residents, and five fourth year residents.

Crisis Management Scenario

In the observed scenario, the subject anesthesiologist was called to take over anesthesia for a 29 year-old female patient about to undergo an appendectomy. The departing attending anesthesiologist briefed the subject upon arrival and turned over the patient while she was still conscious. With the exception of the subject, all people in the operating room were either simulation centre staff or outside confederates enlisted to play a role. Shortly after anesthetizing the patient, the patient's condition began to deteriorate, and the subject (anesthesia resident) was forced to diagnose and treat symptoms of a ventilation problem. Unbeknownst to the subject, the ventilation problem was from a hardened mucous plug blocking the base of the breathing tube.

Attempts[tjh1] to treat any diagnoses other than the blocked breathing tube would not resolve the ventilation problem. If the situation was not resolved in an appropriate and timely manner, the patient's condition could worsen and result in cardiac arrest. The subject typically called for assistance at some point in the scenario, and another participant was called in to help.

Data Analysis

In this study, we considered three key components in the work domain analysis: the surgical team, the medical equipment in the room, and the patient. Different AH labels were adopted to more accurately represent the medical domain (see Figure 3). The videotapes and transcripts of verbalization during the scenarios were coded. Each action, statement and interaction of the subject anesthesiologist was assigned a numerical code from one to five, depending on where attention was focused within the abstraction hierarchy. Level 5 corresponded to the Purposes or Functional Purpose level, and 1 corresponded to the Anatomy or Physical Form level.

RESULTS & DISCUSSION

A simple work domain analysis conducted on the operating room environment revealed the possibility of different interactions between the three components of the work domain. The three subsystems shared a common purpose of improving the health of the patient. We proposed that these three components converge on several levels of the AH (see Figure 4).

Using this model, we mapped the events from the crisis management scenarios to examine the phenomenon of fixation. Fixation occurs when the subject continues to exploit a known strategy or treatment algorithm despite the presence of contradictory evidence (De Keyser & Woods, 1990; Rudolph, 2003). Our analysis also incorporated the notion of attention switching to help explain "fixation".

Rudolph (2003) describes "experimental" problem-solvers as continuously switching back and forth between exploration of new diagnoses, and exploitation of existing knowledge within a given diagnosis. This switching requires a division of attention within the abstraction hierarchy resembling the Insightful performers described by Janzen and Vicente (1998). It is reasonable to expect the shifts between levels of abstraction to coincide with the shift of focus from determining the validity of a particular diagnosis to the consideration of other diagnoses. Therefore, if the diagnosis appears to be incorrect, the physician will re-evaluate the symptoms at the functional purpose and abstract function levels, before descending through the hierarchy to identify another hypothetical root cause for the problem.

Those physicians categorized as fixated in the exploration-exploitation analysis may outwardly appear similar to experimental problem-solvers in the abstraction hierarchy. A similar attention allocation strategy would be utilized, with the physician narrowing focus while exploiting a particular routine, and expanding the focus to determine whether or not it is working. However, the fixated problem solver will be trapped in a linear exchange between the upper and lower levels of abstraction.

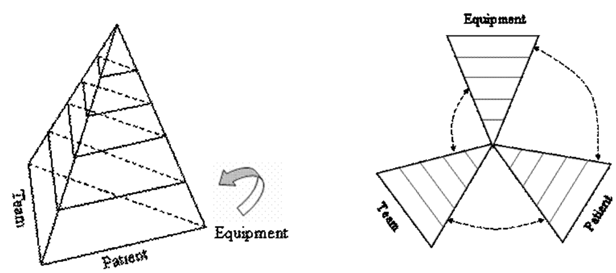

Figure 4. Pyramid and spoke-shaped work domain models.

To test our proposed model using, we plotted the attention switching between the levels of abstraction over time for each case observed (Figure 5). The plot starts at the ninth minute of the scenario, as the anesthesiologist's behavior was not coded prior to the recognition of the existence of a problem.

Figure 5 shows initial rapid oscillations between higher and lower levels of abstraction indicating that the anesthesiologist was shifting focus between the discrepancy at the Functional Purpose level (i.e. the patient is not doing well) to Physical Function, Physiology and Process variables (i.e. elevated heart rate, reduced oxygen saturation, etc.). Although the subject modeled in Figure 5 was classified by Rudolph (2003) as a fixated problem solver, attention allocation matching our predicted profile for an experimental problem solver is seen in the second half of the plot. A negative slope or step pattern appears around the fifteenth minute of the scenario. This type of behavior resembles traditional troubleshooting, as the anesthesiologist identified the chain of discrepancies from the abstract level (poor patient condition) down through the hierarchy (high carbon dioxide and low oxygen in the blood; difficulty in expanding the patient's lungs) to a specific physical cause (blocked endotracheal tube). Further in the plot, the reverse pattern in seen, which represents hypothesis testing. The anesthesiologist attempted treatment, then mentally climbed the hierarchy to determine if the desired effect was achieved at each level of abstraction.

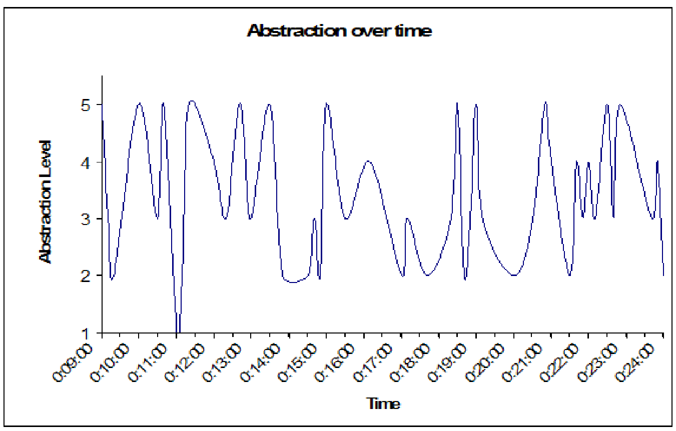

Figure 5. Anesthesiologist's attention allocation within the AH

Future planned studies will further clarify whether the lower levels of abstraction converge and align as in the pyramid model, or whether there are loose associations between different levels and nodes, as shown by the dotted lines in the spoke model. By mapping the decision-making process of these physicians onto the work domain, we can demonstrate differences in attention allocation within the abstraction hierarchy for various problem solving strategies (Figure 6). This will help our understanding of problem-solving in critical medical incidents, as well as the interaction of the key components of the operating room. Methods for interrupting stalled or erroneous decision-making cycles can be developed from the resulting critical incident behavior maps.

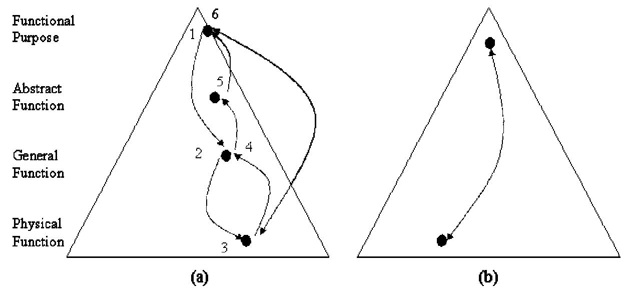

Figure 6. Comparison of experimental (a) and fixated (b) problem solving strategies. The experimental problem solver shifts attention through the AH as necessary to understand the cause and solution to the problem, while the fixated person cycles back and forth between goals ("the system isn't working properly") and variables ("reading B appears abnormal").

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