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Knowledge State Sensitive Mission Rehearsal

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Abstract

Considerable resources continue to be allocated to the development of visually impressive displays of information for training and decision-making. Literature indicates that the medium and realism of visualizations is inconclusive with respect to human effectiveness. In contrast, research has shown that visualizations for tasks such as mission rehearsal with content sensitive to cognitive factors have a significant impact on human performance. At the same time, many domains, such as first-responders or military operations in urban terrain (MOUT), require diverse and infrequently used knowledge in contexts difficult to anticipate. The current research focused on skill degradation mechanisms that can be leveraged to provide more tailored, relevant, and useful content to mission rehearsal simulations. Known models from skill decay and individual differences are posed along with more recent findings associated with interference retrieving procedural knowledge. It is argued that the integration of such factors will complement more developed mechanisms from learning and decision-making to produce a more complete incorporation of knowledge dynamics and facilitate rapid, reliable, and effective human performance.

1 Introduction

An increasingly common feature of operational domains is the need for fewer individuals to perform a wide range of tasks in situations that are difficult to anticipate. Paramedics, infantry performing military operations in urban terrain (MOUT), and hazardous material accident responders are some examples where particular individuals must recall skills that may not have been reinforced for quite some time in potentially unprecedented contexts. Moreover, the individual is expected to perform objectively, consistently, and effectively. The need exists to improve the tools, information, and resources provided to the individual to meet such expectations.

The current research highlights more specific problems common to the complex domains mentioned which can be more broadly characterized as quick response teams. Traditional approaches to improve human performance in diverse contexts such as mission rehearsal are discussed. In addition, a proposal to incorporate more complete models of cognitive skill is included that could be incorporated into mission rehearsal tools to provide tailored information with respect to specific individuals and their approaching operation.

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2 Domain Constraints for Quick Response Teams

Much effort is typically made to establish and maintain competency in skills through training and exercises. Training hopes to at least provide a baseline understanding of the knowledge that will lead to desired levels of performance. While training is useful there are some bounds that limit the value added. First, one cannot draw a correlation between training and subsequent performance (Reason & Hobbs, 2003). Contextual factors and resources available can disrupt the relationship between training and performance. The variety in potential contexts is difficult to fully incorporate in initial training or operational exercises and can consequently render the relationship between training and performance inconclusive.

Despite the inherent complexity in potential contexts, the individual is expected to succeed. Since all contexts cannot be anticipated well ahead of an initiating event, a significant amount of agility is needed in the following general areas: incorporate whatever preliminary information/intelligence is available, perform some level of planning and coordination, upon arrival perform a situation assessment, and finally take action. Quick response teams and their task demands fit well into the naturalistic decision-making contexts addressed by Klein (1997). Earlier, Klein (1989) observed that recognition primed decision making constituted more effort to gain situation awareness than deliberating over possible courses of action in contrast to research associated with less temporally demanding contexts (Newell & Simon, 1972).

Since situation assessment is an important means of adapting to diverse contexts, there is a period of time necessary to perform the assessment. The problem is that the need to act as quickly as possible limits the duration of situation assessment. Therefore, if resources can be provided to minimize the time necessary to gain situation awareness the response team can take action sooner.

A real and significant example of contextual constraints is associated with the resources available in response to an initiating event. The entire or ideal staff will not always be available. Consequently, the available responders may need to take on different or even new (with respect to a given individual) task or responsibility. Certain pieces of equipment may or may not be available or resources normally available at a particular site will not be available. Such potential and reasonable constraints require agility; however, such agility cannot be relied upon. Quick response teams desire to as prepared as possible to minimize the need for real-time situation assessment, re-assessment, and delays in acting effectively.

While training can provide a somewhat consistent baseline across team members, the level and type of actual experience can further complicate performance. Variations in experience yields varied expectations, biases, and capabilities. Much of the burden to account for this source of variability rests with the human-human team interaction.

Many response teams must travel to the site requiring their skills. Increasingly military forces and emergency response teams must be prepared to travel anywhere in the world to execute their mission. During transit to the site, it is of interest to the current research to exploit this time to rehearse an upcoming mission.

3 Factors in Mission Rehearsal

A well-known means of preparing for a mission is to rehearse the upcoming activity. Practical benefits include a better understanding of roles and responsibilities in the context of squads or teams as well as the timing and sequence of events leading to some objective. While the benefits may be practical and easily understood, the factors that influence the value and effectiveness of mission rehearsal are less straightforward. The medium of visualization for example could come in many forms. Pilots have traditionally rehearsed flights simply using maps and in contrast much research has explored computationally intensive mediums such as immersive virtual environments (Stedmon & Stone, 2001). Ultimately it necessary to more objectively assess the value of various mediums in relation to human effectiveness and this issue will be addressed shortly.

Another significant factor in mission rehearsal is associated with the content of information provided to the individuals tasked with the mission. The level of detail can include very abstract thresholds to highly detailed and exhaustive plans exploring as many contingencies as possible. Designers of mission rehearsal resources may devote less effort to the content in favor of the medium and the cost/benefit may be unclear.

The human factors community has a strong appreciation for the value of conforming a design to the intended user or user population. The user represents the greatest source of system variability but also the greatest area of opportunity. Mission rehearsal effectiveness is greatly influenced by the level of consideration devoted to understanding the user. While there can be many users of mission rehearsal systems, the current research focused on users collaborating on teams responding to some emergency or short-notice mission.

3.1 Perceptual versus Cognitive Fidelity

Significant resources have been invested in visualization technology. Modern visualizations provide stereoscopic and three-dimensional imagery with the stated need of "realism" (Hill et al., 2003). The presentation of such visually compelling displays and multi-modal virtual environments provides an invaluable resource to entertain and garner support for funding.

The pursuit of realistic rehearsal or training mediums has no end, but can be held in check with objective performance measures. Beyond visual, other dimensions are being addressed to facilitate realistic training mediums including auditory and emotions (Gratch & Marsella, 2001). Some research has shown the value of perceptual/motor fidelity for training novices in tasks more perceptual/motor in nature (Corbin, 1967). However, the literature contains significant arguments that guided mental rehearsal of pending tasks facilitates effective execution of predominantly physical skills (Prather, 1973; Nullmeyer & Spiker, 2000). Since physically rehearsing a task that may be primarily physical in nature is not critical, providing visualizations in potentially confined spaces (e.g., in transit to a site as noted earlier) is a reasonable approach to rehearsing missions.

Given the hardware, software, and personnel resources necessary to support modern visualizations, the matter of cost/benefit must be addressed. Ultimately, the investment must generate significantly improved human effectiveness. Suggestions have been made that realistic imagery for training is necessary to facilitate positive transfer to operational settings (Gratch & Marsella, 2001). Outside of subjective experiences shared by users, the reality is empirical research continues to struggle in the effort to prove the value of three-dimensional visualizations or virtual environments (Stedmon & Stone, 2001; Pleban & Salvetti, 2003). Lintern (et al., 1997) even found that less simulator scene detail resulted in better transfer of training than moderate scene detail. Despite the ongoing efforts to research visualization technology, the literature has consistently indicated the superior value of addressing content and cognitive factors in training and rehearsal domains (Salas, Bowers, & Rhodenizer, 1998; Nullmeyer & Spiker, 2000; Kozlowski et al., 2001).

3.1.1 Guidelines on Rehearsal Content

All rehearsal systems fundamentally intend to provide information that is relevant and facilitates positive transfer to the upcoming mission. Practical value is added by rehearsing contexts that may contain unusual circumstances. Consequently, an individual or team can perform some situation assessment prior to the actual mission and explore possible courses of action.

Since research has indicated the value of being sensitive to cognitive factors, it will be pertinent to delineate those factors. Understanding, modeling, and applying cognitive factors is challenging, but the current research contends that the most significant and measurable gains in performance through rehearsal systems can be generated in this focus area.

An initial step is to understand the type of knowledge associated with the mission. Tulving (1972) has noted that different types of knowledge exhibit varying characteristics with respect to learning, retention, and retrieval. For example, the knowledge of riding a bicycle is quite different (Fleishman & Parker, 1962; Hammerton, 1963) in comparison to the knowledge of facts such as phone numbers or spoken languages (Bahrick, 1984). Skills such as riding a bicycle are retained in memory better than phone numbers or even discrete motor skills such as cardiac resuscitation (McKenna & Glendon, 1985). The dynamics of various knowledge types are helpful to understand in education and domains such as the military. Military domains often utilize reserve units and while initial training may establish competency above some threshold, factors including the passage of time may degrade such knowledge beneath that threshold. Understanding the factors that can degrade critical skills has been a concern to the United States Army (Rose, 1989) and parallels potential issues with quick response teams. Many variables can influence the state of knowledge in memory (to be discussed), but just as the passage of time between the application of military skills can degrade that knowledge, much time can pass between the application of an increasing range of skills necessary to perform particular skills in domains such as paramedic or special operations.

A feature distinguishing some approaches to rehearsal is the level of guidance offered by the rehearsal medium. Traditional forms of rehearsal have little to no guidance such as pilots choreographing flights using maps. On the other end of the spectrum there are vivid animations of collaborating humans or avatars that can provide a variety of interactions and guidance (Hill et al., 2003). With regards to the form of guidance offered, research indicates that some form of guidance in rehearsal is preferred over no guidance (Prather, 1973). Furthermore, research with guided training/rehearsal points to cognitive factors as a necessary characteristic to address when designing rehearsal systems (Nullmeyer & Spiker, 2000). Lintern (et al., 1989) determined that the content of instructional simulators should systematically change as proficiency in the skill improves. The current research argues that the system should not only be sensitive to the level of proficiency, but the level of knowledge degradation as well.

Much effort and research has been devoted to education and training programs. As noted earlier, the diversity of skills and contexts renders the value of training limited. If a rehearsal system was sensitive to the state of knowledge necessary to perform an approaching mission, the knowledge stored in memory could be activated to higher levels. Higher levels of activation will facilitate retrieval and corresponding performance.

4 Augmenting Mission Rehearsal Using Models Sensitive to Knowledge Degradation

The pursuit of greater cognitive fidelity can be augmented by models incorporating knowledge degradation mechanisms. Much time can pass between the reinforcement of various skills and many tasks can interfere with the retrieval of necessary skills. At the same time, an upcoming mission may demand effective retrieval of a potentially degraded skill. The current research contends that a rehearsal system that more directly guides an individual through the review of degraded knowledge in relation to likely contextual constraints will provide a substantial means of rapid, consistent, and effective performance.

4.1 Leveraging Knowledge Degradation Mechanisms

Knowledge degradation mechanisms can be divided into two categories. Decay mechanisms offer one means of modeling the reduction in retrieval activation of knowledge in relation to the passage of time. The second category includes interference mechanisms which addresses the interaction of knowledge in memory resulting in retrieval of desired or relevant knowledge being inhibited by less relevant knowledge.

Memory loss has often been attributed to the passage of time and is referred to as decay (Brown, 1958; Conrad, 1957). Wickelgren (1976) provides a helpful summary of decay theories, and a review of interference theories as well. An appealing characteristic of the time-based decay hypothesis is the accuracy of retention functions. Time-based mathematical models of forgetting have used decay for over one hundred years (Rubin & Wenzel, 1996). Rubin and Wenzel (1996) examined 210 data sets that conform to Jost's Second Law, which states that the rate of forgetting continually decreases with increasing time since learning. The most common function, adopted by researchers such as Anderson and Lebiere (1998), is the power function (McBride and Dosher, 1997; Wixted & Ebbesen, 1991, 1997). The power functions, applied by researchers such as Wixted and Ebbesen, typically account for over 95 percent of the variance.

Decay theories have some limitations in that they provide a descriptive rather than a prescriptive explanation for the loss of knowledge (Gazzaniga, Ivry, & Mangun, 1998). Nairne (1996) noted that decay theory is analogous to attributing the rusting of metal to the passage of time. Therefore, just as oxidation provides a more meaningful explanation of rust, interference is a more explanatory mechanism of knowledge degradation.

The fundamental principle of interference theories is that two elements of memory can inhibit the retrieval of one or the other. Anderson and Neely (1996) characterized interference as "the impaired ability to remember an item when it is similar to other items stored in memory." (p. 237) Brannon and Koubek (2001) reviewed much of the research surrounding decay and interference. While most memory research addresses declarative knowledge, less research deals with more procedural knowledge. Since quick response team domains are more reliant upon procedural knowledge than declarative knowledge, it is helpful to understand the similarities of procedural knowledge that render stored knowledge more difficult to retrieve from memory.

Unlike declarative knowledge with stimulus-response associations (e.g., green-go), procedural knowledge has been described as having condition-action associations (Anderson & Lebiere, 1998). Conditions and actions can contain multiple declarative elements (e.g., if light is green and intersection is clear, then press gas and steer right). Given the additional potential dimensions of variation associated with procedural knowledge, what features of procedural knowledge can be similar such that interference is produced?

Brannon, Koubek, and Voss (in press) investigated the use of symbology on a graphical user interface and how interference could be triggered. Participants learned an initial resource management task, then learned a secondary task. The secondary task was similar to the initial task with exception to changes either to the meaning of the graphical symbology or the actions required given the same symbology. Comparable research indicated the meaning behind the visual stimuli had a greater impact on interference than the actions associated with the stimuli (Lovett & Anderson, 1994). Results however indicated the change in actions given the same graphical stimuli generated significant interference and changes to the symbolic meaning were inconclusive.

Many research opportunities exist within the area of procedural knowledge degradation. Advances in this area may have been inhibited by research focusing on the reasonable desire to minimize and/or control factors that produce knowledge degradation. Greater advances in this area can be produced if the intent is to maximize or amplify degradation mechanisms as is normally the case with respect to learning mechanisms. Insights may be produced if degradation mechanisms are combined to determine their effects. For example, Schmidt and Bjork (1992) reviewed research indicating that early success in learning led to poor retention and in contrast diverse, difficult, and error filled learning led to greater retention. With respect to degradation, how might abrupt interference impact retention? The explicit pursuit of maximizing degradation could be valuable to other applications including information operations, but also to improve the understanding and modeling of memory dynamics.

The aforementioned work helps illustrate objective insight available to leverage in designing a rehearsal system sensitive to the dynamics of memory. Given the established findings in the literature, knowledge degradation mechanisms represent an interesting and potentially valuable dimension in the design of mission rehearsal systems.

4.2 Advanced Mission Rehearsal Systems

An attractive feature of future mission rehearsal systems will be functions allocated to a cognitive system. Unlike some methods of computationally modeling notional human information processing, cognitive systems more directly address how the information is being processed. Insight from empirical human subject research is leveraged to instantiate the information processing features in a computational system. In contrast machine learning algorithms and approaches such as expert systems more directly address the functional capability of the system rather than how the information is being processed.

The Sandia Cognitive System is one example (Forsythe & Xavier, 2002; Forsythe et al., 2003). The development of the Sandia system included models that are tailored to particular subject matter experts such as quick response team members. Having an individual model provides the ability to generate tailored displays of information for quick responders traveling to a mission going over the situation. The model can be sensitive to an individual's training, experience, and patterns of decision-making. In addition, empirically evaluated factors with respect to individual differences can be utilized (Kyllonen & Tirre, 1988). A product then of the cognitive system is the ability for an individual to have a form of mentor or coach supporting them in a given task.

While individuals will have their own cognitive system to facilitate information processing, the collaboration across a quick response team can be accounted for by each tailored cognitive system. Therefore, the cognitive system can account for certain individuals not being present for example to fulfill the mission in the development of a mission to rehearse. If multiple individuals can perform the same task, the level of proficiency with the necessary skills can be accounted for by the cognitive system and as a result, recommendations can be made for which individual should fulfill the task.

A cognitive system in a mission rehearsal application can be supported by other existing computational resources. Output from data mining, state machines and multi-sensor fusion algorithms has been in development to support decision-making (Waltz, 1997; Hall & Llinas, 2001). The appropriate level of fusion is an optimization problem (Duggan et al., 2004) and given contextual constraints, the optimal level of fusion can be a moving target. The current research views functions allocated to cognitive systems as a means of compensating for individual and contextual variability to achieve more reliable and effective information to the quick responder rehearsing a mission.

5 Conclusion

Fewer individuals are being tasked with a greater range of responsibilities in dynamic situations. The consequence of error is often significant, yet responders to emergencies are being expected to perform quickly, consistently, and effectively. This research has summarized the circumstances surrounding quick response teams and the opportunities that exist through mission rehearsal to improve the likelihood of successful human performance.

Many factors that make the quick response team domain complex can be addressed through mission rehearsal and the use of the time traveling to a particular site. While much research has been invested in understanding learning mechanisms for training applications, the value of such concepts is limited. A system that is sensitive to the availability of relevant knowledge in an individual's memory can provide rehearsal content that better supports mission planning and situation assessment. The anticipated product is an improved ability for the individual to adjust to the unique circumstances in a given mission and perform more efficiently and effectively.

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