Training Effectiveness Evaluation of Real-time Metacognitive Feedback

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ABSTRACT

Given the limited application of adaptive training to military tactical training in a scenario-based context, there is little guidance from empirical research on which variables to adapt, how and when to adapt training feedback, and the types of training effectiveness benefits that may be realized. This effort leveraged and extended extant guidance to judiciously select and evaluate adaptive, metacognitive, real-time feedback approaches to improve tactical decision making (Jonassen & Tessmer, 1996). Feedback was incorporated into a tactical scenario, prompting students to think about allocating tactical resources based on capabilities and limitations and to manage scenario events. Findings indicate that there are increases in tactical knowledge about a scenario when Surface Warfare Officer (SWO) trainees receive metacognitive real-time adaptive feedback versus post scenario debrief on scenario events.

ABOUT THE AUTHORS

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INTRODUCTION

Scenario-based training (SBT) has been used extensively within the military and has been a widely accepted approach to training (Cannon-Bowers & Salas, 1998). It has been utilized as an effective method for training the integration of multiple complex skills and exercising naturalistic decision making (Cannon-Bowers & Salas, 1998; Martin, Schatz, Bowers, Hughes, Fowlkes, & Nicholson, 2009). A major challenge, however, is that SBT often requires a cadre of instructors to manage an exercise, monitor performance, and provide feedback to trainees on their use of assets to resolve tactical problems. An approach to mitigating the negative impact of SBT on instructor resources is to utilize adaptive training capabilities as they relate to real-time feedback. Adaptive training environments can serve as a means to assess trainee knowledge and/or skill and provide tailored feedback or remedial actions (e.g., providing feedback messages when performance deviates, changes to scenario entities, such as ambiguity or difficulty, etc.) thereby reducing the impact on instructor workload while preserving training value.

Tailoring feedback effectively requires careful consideration of both pedagogical components of a training objective (i.e., how to best increase learning on a skill) and tactical consideration of when to incorporate feedback into a training event without disrupting the exercise. This study focused primarily on feedback introduced real-time during scenario performance. Guidance on feedback timing and related issues was provided by Smith-Jentsch, Cannon-Bowers, and Salas (1997). For example, feedback provided immediately (i.e., after an error has occurred within a training event) may indicate that the trainee has taken the incorrect action, but can interfere with the trainee's skill development if they are unable to link their error with a future consequence. On the other hand, feedback that is provided *after* the training event may provide a detailed analysis of why the behavior was problematic and alternate courses of action. However, there may not be a chance for trainees to correct errors. In complex, expensive, live/simulated military training environments, follow up opportunities are not common.

Ideally, a blended approach that leverages the strengths of the above methods would be utilized, allowing trainees to analyze their errors in real time, determine alternate courses of action, while providing additional chances to improve performance within a single training event. As described next, metacognitive feedback may provide an effective approach to framing feedback content to improve complex skills (e.g., decision making) by guiding trainees to monitor and analyze their performance during problem events within SBT (Fiore & Vogel-Walcutt, 2010).

Metacognitive Feedback

Metacognition is a learning strategy that focuses on increasing the learner's monitoring of self and/or others' performance. Metacognitive individuals and teams engage in situation assessment for detecting gaps or ambiguities in the environment, self/team monitoring that supports the adjustment of activities to achieve optimal performance, and effective task sequencing and time management to meet goals (Zsambok, Klein, Kyne, & Klinger, 2003; Smith-Jentsch, Zeisig, Acton, & McPherson, 1998). In addition, highly metacognitive individuals have been found to be more adaptive to dynamic scenarios (Haynie, 2005; Pressley, Snyder & Cariglia-Bull, 1987) and have enhanced ability to assess and act in situations characterized by complexity, ambiguity, high stakes, and time pressure

(Freeman & Cohen, 1996). Due to these benefits, this construct can be viewed as a higher order training objective that facilitates *how* to think versus *what* to think.

Research suggests several methods for increasing metacognition in individuals. Prompts are a method that uses questions to provide students with an opportunity to think about a specific situation (e.g., "Did you understand the material in the last paragraph?") or that provides hints about the meaning of a situation (Berthold, Nuckles, Renkl, 2007). Metacognitive prompts encourage students to carry out self-explanation and self-evaluation activities that can focus learners' attention on their mental activities (Durlach & Ray, 2011; Lane, 2007). Reflective questioning is another method that is effective for teaching reading and math (Palincsar and Brown, 1984; Morrison & Fletcher, 2002). This approach encourages students to periodically stop activity and ask themselves what they understand or do not understand about a problem. Reigeluth and Stein (1983) suggest that prompts can be used to activate previously learned knowledge and strategies. In SBT, this may be especially useful, as a scenario may provide the first opportunity to consolidate knowledge and skills recently learned in a classroom setting and apply them in a tactical context. However, the use of external prompts can be intrusive. In tactical scenarios, the pace can be fast and trainees may be highly immersed. Stopping trainees to provide metacognitive prompts may halt activity and pull the students out of the problem. Feedback that is provided from an entity outside of the training event can pull attention from the in-world entities and redirect it to the real-world environment (e.g., the classroom) thus decreasing immersion in the scenario and reducing training effectiveness.

While a controlled laboratory study would allow for the manipulation of feedback timing and the presence or absence of metacognitive prompts, the primary goal of this field investigation was to extend the pedagogical benefit of metacognitive strategies to a highly dynamic realistic training situation with current trainees in the schoolhouse. Metacognitive prompts were developed as embedded communications between scenario entities, (i.e., from virtual team members), in order to maintain trainee immersion in the scenario. When performance deviated from expected parameters, these natural prompts were used to inform the trainee that a problem situation had occurred (e.g., "Radar coverage has been lost.") or that a resource was not being effectively utilized. This provided trainees with an opportunity to reassess a situation that required action. Afterwards, the trainee had an opportunity to take action to effectively deal with the situation. However, if performance still did not improve, a second set of metacognitive prompts provided information about the capabilities and limitations of various assets. For example, in the test scenario used for this investigation, trainees who had not ordered the visual identification (VID) of a threatening scenario entity were initially prompted that a Vertical Takeoff Unmanned Aerial Vehicle (VTUAV) was available for tasking. If the hint that that particular asset was available did not produce a VID order it was followed by another prompt stating, "VTUAV available for VID tasking if required." The inclusion of the term VID should have provided another hint to the trainee that that asset had a camera capable of providing a view of the threatening craft. The goal of this approach was to facilitate a mental simulation of whether the selected asset was the most efficient use of resources, by using a hint that a resource has capabilities that are/are not best suited for a select problem.

The objective of this effort was to determine if real-time, adaptive, metacognitive feedback could improve an individual's decision making knowledge more than experiential learning that occurs through SBT with post-scenario debrief on scenario events. Future analyses will examine trainee performance data collected during scenario runs and still being extracted from the simulation environment.

Hypothesis

Tactical knowledge related to enabling training objectives targeted for remediation was expected to be greater for trainees receiving adaptive metacognitive feedback than for trainees receiving post scenario (i.e., non adaptive) debrief on scenario events. To assess this, trainees were asked on a post-scenario questionnaire to identify the most effective courses of action within the tactical scenario and describe reasoning behind their choices.

METHOD

A between-subjects design was employed in which trainees received SBT with or without real-time adaptive metacognitive feedback and were evaluated on their tactical decision making knowledge and skills. Trainees were assigned to one of the following conditions:

> Non adaptive Post-Scenario Debrief on Scenario Events: Trainees received a debrief of scenario events after scenario training.
>
> Adaptive Real-time Metacognitive Feedback: Trainees received real-time metacognitive prompts when performance was outside expected parameters. Prompts were designed to encourage trainees to assess the situation and determine the best course of action.

To determine the differences in tactical decision making knowledge between the Non adaptive Post-Scenario Debrief and the Adaptive Real-time Metacognitive Feedback group, the plan for analysis was to statistically compare groups on the number of correct responses to questions on a Tactical Decision Making Questionnaire about events that had occurred during a SBT exercise and the appropriate actions that should have been taken. The appropriate actions had been predetermined by in-house subject matter experts who had developed the test scenario.

Participants

This experiment was conducted at Surface Warfare Officers School (SWOS), with 36 Department Head students as participants. Students had an average of 10.5 years experience in the military, and none of the students had previous experience with the simulation software that was used as the experimental testbed. As these students are the targeted population and intended users of the training system under development, they are in the best position and have the necessary qualifications to perform the training tasks involved.

Measures

Demographic Questionnaire

Participants were administered a demographic questionnaire to determine if students had previous experience with the simulation software.

Tactical Decision Making Knowledge Tests

Participants completed a nine item test developed by subject matter experts that asked them to answer questions regarding the most effective tactical approach to the problem presented in the scenario and the reasoning for selecting the approach. Comparisons were made between Adaptive Real-time Metacognitive Feedback and Non adaptive Post-Scenario Debrief groups on each of the individual questions as well as the percentage of correct responses associated with the Enabling Objectives that were targeted with feedback (e.g., efficient and effective allocation of resources for the scenario events).

Training Simulation

Adaptive Training Prototype

The individual-level adaptive training prototype developed for this study was based on a training tool for prospective Tactical Action Officers (TAOs) to practice mission-planning skills. This application, known as the TAO Sandbox, had been previously developed by University of Southern California (USC) Center for Cognitive Technology (CCT) for authoring tactical decision making scenarios and for practicing tactical planning. Trainees solve problems by running scenarios, ordinarily at some multiple of real-time, utilizing resources to try to avoid or to detect and defend against hostile units. Under Adaptive Training for Combat Information Centers (ATCIC) sponsorship, the TAO Sandbox was enhanced to provide a testbed for investigating adaptive training techniques to support problem solving by detecting the conditions for adaptations (i.e., deviations in expected performance) and delivering adaptive feedback. Within the training portion of the scenario, events created an opportunity to exercise actions related to the Enabling Objectives of: utilizing knowledge of the capabilities and limitations of enemy and friendly assets, establishing priorities of action, determining the correct employment of friendly assets, and maintaining situational awareness. The degree to which the learning objective was met was evaluated by performance assessment criteria assessed in real-time. For the real-time metacognitive feedback condition, when the criteria were not met, a metacognitive prompt was provided (see Figure 1).

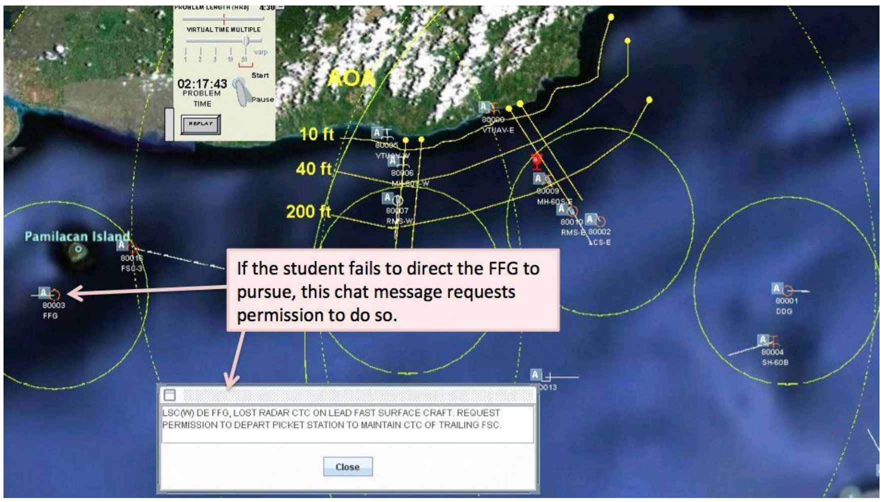

Figure 1. Example of Real-time Metacognitive Prompt

Procedure

Upon arrival, participants reviewed and signed an informed consent form, completed a demographic questionnaire, received orientation on the simulation system and symbology, and were assigned to one of the two conditions; Non adaptive Post-Scenario Debrief on Scenario Events or Adaptive Real-time Metacognitive Feedback.

For both conditions, the participants engaged in SBT tasks within the context of performing the role of TAO within an exercise in which ownship was designated Commander Mine Warfare / Surface Action Group under a potential threat (e.g., Unknown Assumed Enemy Fast Attack Craft [FAC]) on a heading toward ownship. The trainee worked to best utilize available assets to gain and maintain situational awareness. During the scenario, this involved establishing and maintaining radar contact, gaining VID, and achieving intimidating weapons coverage before reaching the weapons release range for the threat. Next, the trainee determined courses of action in response to the potential threat. In the scenario, one such course of action was a “Stand or Scramble” decision between staying in place and preparing for potential surface action or moving to another location to establish a safe distance from the threat. Either choice required establishing priorities and achieving the right balance between maintaining safety of ship, achieving mission effectiveness, protecting organic assets, following Rules of Engagement, and meeting Commander’s Intent.

Feedback

In the Adaptive Real-time Metacognitive Feedback condition, trainees were assessed to determine whether their performance was within acceptable parameters of expected time and accuracy (e.g., correct asset assigned on time). If performance dropped below these levels, trainees received a metacognitive prompt through a chat window (see Figure 1). The predefined metacognitive prompts appeared in the trainee's display, and were manually dismissed. Based on the trainee's performance, they could potentially receive between zero and eleven feedback messages.

For the Non adaptive Post-Scenario Debrief condition, trainees performed the scenario without any feedback related to their performance. At the end of the scenario training and test, they received a summary of the scenario events before completing post scenario evaluations.

After the training session, trainees completed the Tactical Decision Making Knowledge Test, were debriefed, and dismissed.

RESULTS

Overall scores on the Tactical Decision Making Knowledge Test did not reach significance. ($t[34] = 1.66$, $p = 0.052$). There was no statistically significant difference between adaptive and non adaptive conditions. However, on average, for those questions that were directly related to the adaptive training remediations, students in the adaptive condition performed significantly better (5.61 correct answers) than students in the non adaptive condition (4.33 correct answers), $t(34) = 1.84$, $p <.05$.

Analysis of individual questionnaire items revealed some statistically significant differences between the two groups related to certain scenario adaptations. First, on average, the adaptive training group provided more correct answers when asked to provide reasons for the use of assets within the scenario (1.27 versus 0.72, $t[34] = 2.49$, $p < 0.01$). Second, the adaptive training group provided more correct answers to questions related to the Enabling Objectives of utilizing knowledge of the capabilities and limitations of enemy and friendly assets, establishing priorities of action, and determining the correct employment of friendly assets. The friendly asset in this case was an SH-60 helicopter to be utilized in achieving the mission priorities of maintaining continuous radar coverage and intimidating weapons coverage on unknown and potentially hostile FACs closing on the high value unit (LCS West). If the SH-60 had not been correctly assigned to tasks beforehand, the following remedial communications were embedded in the scenario:

> LCS(W) DE DDG, SH-60 AVAILABLE FOR YOUR TASKING IF REQUIRED.
> LCS(W) DE DDG, SH-60 AVAILABLE TO PROVIDE EXTENDED RADAR AND WEAPONS COVERAGE OF INBOUND SURFACE CRAFT

The adaptive training group had a significantly higher percentage of correctly identifying intimidating weapons coverage as a priority than the non adaptive group (72.2% versus 44.4 %, $t[34] = 1.71$, $p < .05$). They also provided significantly more correct answers identifying the SH-60 as the best asset to achieve intimidating weapons coverage (44.4% versus 16.6%, $t[34] = 1.84$, $p < 0.05$). Finally, more participants in the adaptive training group correctly identified the reason that the SH-60 was the best choice for achieving intimidating weapons coverage (88.8% versus 55.5%, $p < .05$).

Third, during the scenario, one event was tied to the training objectives of maintaining situational awareness and establishing priorities based on capabilities and limitations of friendly assets for an impending surface action. The event involved a helicopter with an in-flight emergency (i.e., a chip light) that required immediate landing. Given the impending surface action on the closest ship, the best choice was to land on another ship. Of the students who experienced that in-flight emergency during the scenario, eight students (all from the adaptive condition) landed the helo on the correct ship based on a remediation in the form of a communication from the ship Helo Control Officer, stating, "CIC, HELO CONTROL. In view of pending surface action, recommend reassign MH-60 to FFG."

DISCUSSION

The results of this investigation provide clear support for the utility of using adaptive metacognitive feedback for increasing targeted tactical knowledge over receiving no adaptive feedback during SBT. More specifically, the remediations resulted in direct improvements in tactical decision making knowledge related to task prioritization and for utilizing the capabilities and limitations of assets to effectively support those priorities. An example of how the adaptive training feature supported this is evident in how the students described utilizing the helicopter to effectively support priorities for maintaining radar coverage and providing intimidating weapons coverage on fast approaching threats. Given its pervasive use in fleet operations, it can be assumed that most, if not all, of the targeted participants would be aware of the capabilities and limitations of the SH-60 helicopter. The metacognitive prompts were designed to provide cues that would bolster the ability of trainees to reflect upon their own decision process based on scenario context and effective asset employment. However, while this evidence is indeed encouraging, it should be noted that it does not, by any means, provide conclusive proof of the value of adaptive training in a scenario-based context. As mentioned previously, this was designed as a field study to investigate the utility of real-time adaptive metacognitive prompts versus no adaptive prompts in a tactical decision making SBT with a limited number of trainees available. As such, we did not attempt to experimentally manipulate the presence or absence of metacognitive content or the timing (i.e., real-time versus after action) of the prompts. While our training effectiveness results supported our hypotheses and were consistent with the adaptive training literature, future studies must focus on the direct manipulation of these independent variables.

The success or failure of applying adaptive training concepts to dynamic, multi-mission SBT will ultimately lie in how well the research evidence supports the effectiveness of the training pedagogy *and* how easy or difficult it will be for instructors to implement. Therefore, as the ATCIC program develops new adaptive training concepts, evaluations of training strategies continue to be a key component in providing evidence of training effectiveness. In addition, a focus on instructor centered design will support the goal of facilitating implementation by instructors. As such, these issues are being tackled, with an eye toward design and test, to determine how to provide adaptive training capabilities in a generalizable way that allows instructors to efficiently and effectively utilize adaptive training strategies.

Finally, it should be noted that the results reported herein were questionnaire-based and, as such, primarily focused on the acquisition of tactical knowledge. A major potential advantage of applying adaptive training principles to SBT certainly lies in its ability to support the acquisition or improvement of tactical skills. Human performance data on the timeliness and accuracy of the execution of tactical tasks (e.g., assignment of assets, tasking orders) were also captured as part of this study. These data are currently being extracted from the simulation environment and analyzed, which will allow us to better evaluate the impact of the presence or absence of individual remediation strategies on real-time performance of tactical skills.

CONCLUSION

The ATCIC program is continuing to develop and refine adaptive training concepts utilizing the design reference scenario that was used for this study. As we continue this process, our goal is to expand our adaptive capability to team level interaction in a more complex multi-mission environment. Moreover, the goal of this effort is to transition these adaptive training features into the Navy training infrastructure and to extend the capability to additional training domains and decision making contexts.

This effort is currently being conducted under the Office of Naval Research Capable Manpower Future Naval Capability program. The views expressed herein are those of the authors and do not necessarily reflect the views of the Department of Defense, the Department of the Navy, or the Naval Air Warfare Center Training Systems Division.

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