

ABOVE REAL-TIME TRAINING APPLIED TO AIR COMBAT SKILLS

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Abstract

Experimenters tested the training benefits of an instructional strategy in which simulated events in a real-time simulation are made to occur faster than normal. Two experiments were conducted to evaluate applications of above real-time training (ARTT) for training air combat skills and emergency procedures. In the first experiment, experienced, Air Force F-16 pilots practiced emergency procedures and air intercepts using conventional, real-time simulation or ARTT at 1.5 times real time. The pilots trained using ARTT received the same number of training trials but less clock time in the simulator as pilots trained in real time. All pilots were then tested in real time. Pilots trained using ARTT performed emergency procedures and defeated bandit aircraft significantly faster than pilots trained in real time. In the second experiment, student F-16 pilots practiced using air-to-air radar in real time or ARTT. Students trained using ARTT received more training trials in approximately the same amount of clock time as the students trained in real time. ARTT students performed better on a real-time test than students trained in real time. It is concluded that ARTT which does not overload a trainee's working memory is more time efficient than conventional, real-time simulation and can improve performance by allowing more training events to be experienced within a given period of simulator time. ARTT also supported better real-time test performance under some conditions. As an instructional strategy, ARTT was found to be simple, inexpensive, and robust.

About the authors

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In the early 1970s, engineers and test pilots at the National Aeronautics and Space Administration's (NASA) Dryden Flight Research Center increased the effectiveness of flight training simulators by deliberately distorting simulated time. Kolf (1973) and Hoey (1976) briefly document simulator training interventions which were aimed at improving test pilots' ability to keep up with the pace of events in flight. Kolf notes that, "regardless of the type or amount of pre-flight simulator training accomplished by the pilot, the actual flight seems to take place in a much faster time frame than real time," (p. 1). Hoey (1976) reports that in the X-15 program, pilots typically spent ten hours in the simulator for each ten minutes of flight. Even with this preparation, pilots reported that, "It sure seems to happen faster in the real airplane," or, "I had the feeling that I was 'behind the airplane' ", (pp. 2-3). As an experiment, Kolf increased the rate of simulated time in the M2-F3 Lifting Body simulator. In the modified simulator, a mission profile which normally required 10 minutes to complete, took place in only 6 minutes, 40 seconds. Three experienced M2-F3 pilots flew a familiar mission at 1.5 times real time and all agreed with "enthusiastic responses," (p. 2) that the modified simulator felt exactly like the aircraft. A second application of fast-time simulation (Hoey, 1976) was to a flight test program for remotely piloted vehicles (RPV). RPV pilots who used simulation at 1.4 times real time as final preparation before a flight reported being, "Less rushed and more confident," (p.18) than when using real-time training exclusively.

The NASA application of Above Real-Time Training (ARTT) was limited to training expert pilots preparing for specific missions. Manipulating apparent time has been evaluated more recently as an instructional tool for both novices and experienced individuals. Schneider, Vidulich, & Yeh (1982) and Vidulich, Yeh, & Schneider (1983) used time-compression to help train air traffic controllers. The task for these

controllers was to monitor an aircraft's flight path on a radar display and issue turning instructions so that the aircraft would fly through a specific vector. Actual aircraft would traverse 20 nautical miles and require approximately five minutes at 260 knots to complete the turn. These researchers increased the apparent rate of time in the simulator to 20 times real time so that a turn would be complete in approximately 15 seconds. Vidulich, Yeh, & Schneider (1983) trained university students over four hours to perform a turn-point task. A group of students who performed the task in real time experienced approximately 32 trials in four hours of training. A group performing the same task using ARTT at 20 times real time received approximately 260 time-compressed trials followed by only three or four real-time trials in four hours of training. All trainees were tested at real time for two hours. ARTT subjects showed significantly better performance at initiating turns properly. These authors assert that the ARTT improves training effectiveness by allowing many trials and training under a mild speed stress.

Guckenberger, Uliano, & Lane (1992) trained novices, university students, in tank gunnery using several ARTT conditions. In this experiment, students were trained in gunnery tasks which required them to detect, identify, and shoot a moving target using an M1 tank part-task trainer. Students received five familiarization trials in real time followed by 15 training trials in real time or in one of four ARTT conditions. Students were then tested in real time. Subjects in all four ARTT groups showed better performance on test trials than the students trained in real time. Guckenberger, Uliano, Lane, & Stanney (1993) conducted an experiment using 24 experienced F-16C pilots. Pilots trained at real time, 1.5 times real time, 2.0 times real time, or with a random mix of apparent times. Pilots then tested at real time. One task required the pilot to engage a bandit and to perform a complex threat response when a warning was detected. For this

dual-threat task, the 2.0 times real-time and mixed-ARTT groups showed faster threat response than the group trained in real time and all ARTT groups achieved significantly more bandit kills during real-time, test trials.

Schneider (1989) proposes that the primary effect of time compression is to allow more training trials within a given period of clock time. In the air traffic control studies, subjects were given the same amount of training time in the simulator so that the ARTT subjects received more training trials. In contrast, Guckenberger et al. gave all subjects the same number of training trials so that the ARTT subjects received less training time than the students trained in real time. Since the students trained using ARTT performed better on real-time test trials than students trained in real time, Guckenberger et al.'s results indicate that ARTT has a beneficial effect beyond simply increasing the number of training events.

The present research effort has focused on application of ARTT to air radar interpretation/air intercept and emergency procedures. Previous research on ARTT has used university students as trainees and/or low fidelity simulators. This research employed Air Force F-16 pilots and student pilots, high-fidelity simulators, and training problems which emphasize skills required for air combat.

EXPERIMENT 1: ARTT FOR EMERGENCY PROCEDURES TRAINING WITH EXPERIENCED PILOTS

For this experiment, experienced F-16 pilots conducted single-ship, defensive, counterair missions over a ground target using two scenarios. In one scenario, single-emergency, the pilot's aircraft suffered engine failure. The pilot's task was to restart the engine and then to engage an incoming bandit. In the second scenario, multiple-emergencies, the pilot had to respond to several emergencies and engage two bandits in succession. Pilots received initial training in real time followed by additional practice in real time or at 1.5 times real time. All pilots were then tested in real time.

Research Methods

Participants. The participants in this experiment were 12 F-16C pilots from the 347th Fighter Wing, Moody Air Force Base, GA. Pilot experience ranged from 150 to 1600 F-16 hours.

Apparatus. An F-16 trainer developed by the ECC International Corporation, Orlando FL, was selected for this experiment. The ECC F-16 simulator was developed for the Air Force Unit Training Device program and later modified for ARTT research. The ECC simulator incorporates F-16 aerodynamics and avionics capabilities with a three-screen, out-the-window visual display system. The system has the capability to present scenarios in which other aircraft fly in prerecorded flight paths. This system was modified for ARTT by altering the software time integration factor. The amount of assigned simulated time between frame updates was increased by a factor of 1.5. The simulation model produces the same number of frames updates as during real-time operation but more simulated time has passed between updates.

Procedure. Pilots were randomly assigned to either the RTT or ARTT condition. All pilots received familiarization training in the ECC F-16 simulator in real time. Familiarization consisted of flying vertical-S maneuvers, 90° turns, and loops. After familiarization, pilots were trained and tested in one of the two emergency conditions (single or multiple) selected at random. After a break, the pilot was trained and tested in the other condition. For both conditions, pilots received initial training in real time until they could complete the task without failures or restarts. Typically, initial training required three or four trials. Data from these trials were not analyzed. Six additional practice trials were then conducted in real time or above real time. Finally, all pilots received four, real-time, test trials using the same scenarios as used in training. Dependent measures were time required to correct emergencies and time required to kill the bandits.

Single emergency. Pilots were initialized at 2000' AGL and 480 knots inbound toward a power plant which they were tasked to defend against air assault. Shortly after the trial started, the F-16's engine failed and the pilot had to restart using established procedures. Immediately after restart, the pilot engaged a MiG-29. The trial ended when the bandit aircraft was killed. Dependent variables

were time to restart engine and time to kill the bandit.

Multiple emergency. The multiple emergency task was similar to the single emergency except the pilot first had to check an equipment hot indicator light, restart a failed engine, acknowledge another indicator light (hydraulic failure), and then engage a MiG-29 followed by a second MiG-29. Dependent variables were time to respond to the equipment hot light, time to restart the engine, time to respond to the hydraulic failure indicator light, and time to kill both bandits.

Results

Single emergency. Mean time to restart the engine and time required to kill the bandit on test trials are plotted on Figure 1. Test performance on both variables was not affected by training condition. Time required to restart the failed engine, $t(11) = 0.08, ns$, and time required to kill the bandit, $t(11) = 0.4, ns$, were not significantly different between the RTT and ARTT pilots.

Multiple emergency. Mean time on test trials to respond to the equipment hot light, time to restart the failed engine, time to respond to the

hydraulic failure light, and time to kill both bandits are plotted on Figure 2. On real-time test trials, time to clear the equipment hot light was not significantly affected by training condition, $t(11) =$

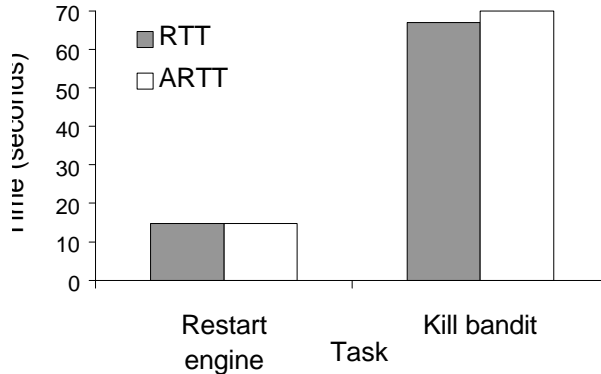


Figure 1. Mean time to restart engine and kill bandit for test trials.

1.65, *ns*. However, times required to restart the failed engine, $t(11) = -4.54, p < .001$, respond to hydraulic failure, $t(11) = -4.93, p < .001$, and kill both bandits, $t(11) = -2.76, p = .018$, were all significantly less for pilots trained using ARTT than for pilots trained using RTT.

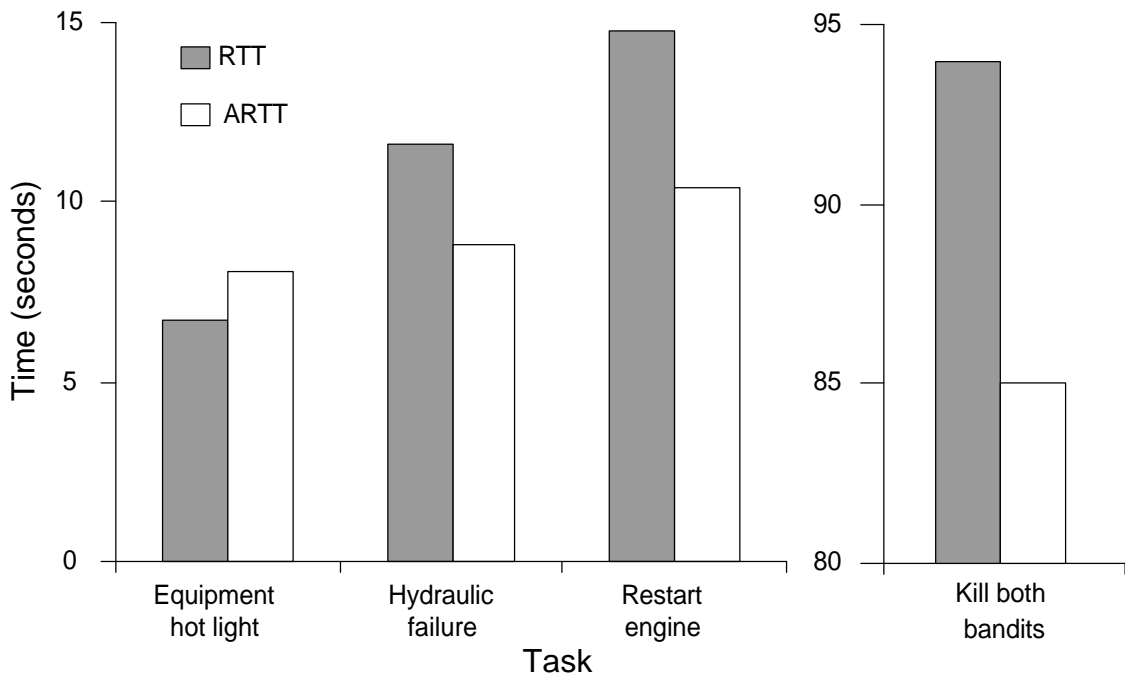


Figure 2. Mean time to respond to equipment hot indicator, hydraulic failure, restart engine, and kill two bandits on test trials.

Discussion

The ARTT pilots in this experiment replicated the training procedures used by NASA in that the pilots experienced initial training in real time followed by additional trials at 1.5 times real time. The RTT pilots received all training trials in real time. The experience of NASA pilots was that ARTT provided better preparation for highly demanding missions than real-time simulation. In this experiment, ARTT was more time efficient than RTT for the single emergency task but provided no additional training benefits. Pilots in the single-emergency task performed engine restarts and defeated a bandit aircraft as quickly as pilots trained in real time but no faster. However, in the more complex multiple-emergency task, pilots who practiced using ARTT were able to perform two of the three required emergency procedures, and killed both bandit aircraft significantly faster than pilots who trained in real time. For these experienced F-16 pilots, the single-emergency task which consisted of restarting the engine and engaging a single bandit was not especially demanding. ARTT provided no training advantage for this task other than reducing the amount of clock time required to complete a given number of practice scenarios. The multiple emergency task was more demanding of the pilot's time and workload management skills. For this task, practice using ARTT after initial training in real time helped the pilot to perform the emergency procedures and to successfully engage both bandits significantly faster than pilots who received all of their training in real time.

Conclusions. These results support the hypothesis that ARTT provides improved training for some tasks compared to conventional, real-time training. Pilots trained using ARTT performed responses in the single-emergency task as well as pilots trained in real time. ARTT was more efficient than real-time training in that pilots trained using ARTT were able to perform on test trials as well as pilots trained in real time but with less training time. For the more demanding multiple-emergency task, pilots trained using ARTT performed emergency responses faster than pilots trained using RTT for three of the four dependent variables. ARTT provided better training than real-time training provided that: (a) the tasks being trained are highly demanding of a pilot's time and workload management skills, and (b) the pilot has received initial training in real time.

EXPERIMENT 2: ARTT RADAR SKILLS TRAINING WITH STUDENT PILOTS

In experiment 1, the trainees were mission-ready fighter pilots who were well trained in the tasks that were simulated but lacked recent experience. For these trainees, ARTT produced equal or better test performance with less training time than real-time simulation. In experiment 2, the training benefits of ARTT were assessed with student pilots in a Formal Training Unit (FTU). In this experiment, a radar-skills task was used as a supplement to an existing training syllabus. Students practiced radar skills within a mission context after they had successfully completed the air-to-air portion of the F-16 FTU syllabus. Further, in experiment 1, all pilots received the same number of training trials with the ARTT pilots receiving less time (clock hours) in the simulator than the pilots trained in real time. In experiment 2, ARTT pilots received more training trials using approximately the same amount of clock time in the simulator than the pilots trained in real time. In this respect, experiment 2 replicated the procedure used by Vidulich, Yeh, and Schneider (1983) who used ARTT to provide more training in a given time period than could be provided using real-time simulation.

Research Methods

Participants. The participants in this study were 24 students in the F-16C training course, 58th Fighter Wing at Luke Air Force Base, AZ. All participants were new to the F-16 with between 40 and 130 F-16 hours. Of the 24 pilots, 19 had no previous Air Force flying experience other than Undergraduate Pilot Training and Lead-in Fighter Training for a total of 260 to 615 flight hours. The remaining pilots had previous assignments in other aircraft which were not equipped with air-to-air radar. These pilots had 1500 to 2100 hours in other aircraft but only 50 to 100 F-16 hours. All pilots had completed the air-to-air portion of training and had successfully completed simulator and aircraft sorties requiring use of the air-to-air radar.

Apparatus. The Armstrong Laboratory Air Intercept Trainer-Plus (AIT+) was selected for this experiment. The AIT+ is an Armstrong Laboratory F-16 Air Intercept Trainer which has been modified by replacing the computing hardware and software with components from the Armstrong Laboratory Multi-Task Trainer (Boyle and

Edwards, 1992). The AIT+ is a high-fidelity F-16C simulator limited to air-to-air operations. The AIT+ incorporates flight, engine, and radar simulations, with hands-on-throttle-and-stick (HOTAS) controls, a radar display, radar control panel, and a color monitor which includes a heads-up display (HUD) and a limited out-the-window display. For this experiment, the AIT+ operated in autopilot mode in that the aircraft's altitude, airspeed, and heading were fixed. The AIT+ was modified for ARTT by changing the time integration factor.

Procedure. Pilots were randomly assigned to the RTT or the ARTT group. The objective of radar skills training was to increase pilot proficiency in using air radar to search and sort multiple, maneuvering targets. For the radar skills task, pilots received the following instructions:

“For the radar skills task, your F-16 will fly on autopilot on a straight-and-level course into a bandit formation. All bandits in the scenario will fly preplanned routes. Your task is to use the radar as effectively and efficiently as possible to provide you with all of the critical information concerning the inbound bandits. When performing the radar skills tasks, your performance and the evaluator's grading will depend on your ability to:

- Search all airspace (surface to 50k) before the closest bandit is within 40nm
- Know the initial picture (number of bandits, formation, aspect, altitude, airspeed)
- Determine bandit actions (maneuvers)
- Know the picture after bandit actions
- Know which bandit is the highest threat.”

The pilot's F-16 was initialized at 15,000 feet, 450 knots airspeed, and heading 360.

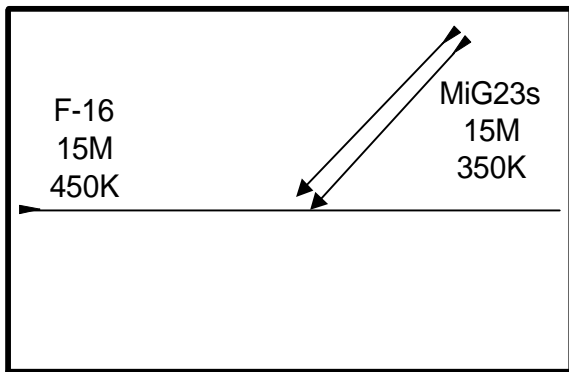


Figure 3. Simple scenario from the radar skills task.

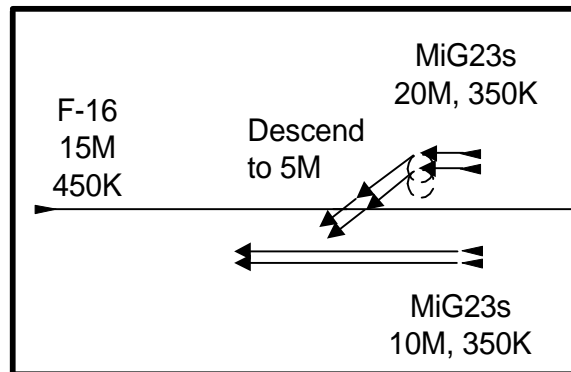


Figure 4. Moderately complex scenario from the radar skills task.

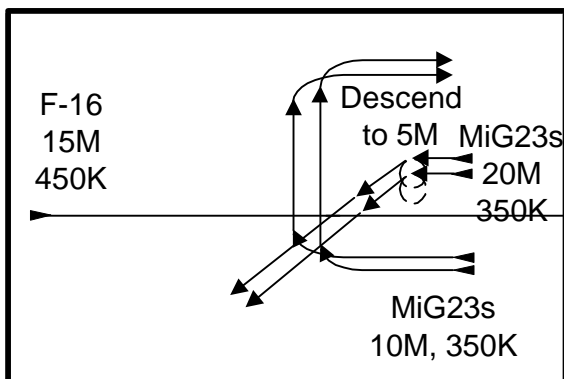


Figure 5. Difficult scenario from the radar skills task.

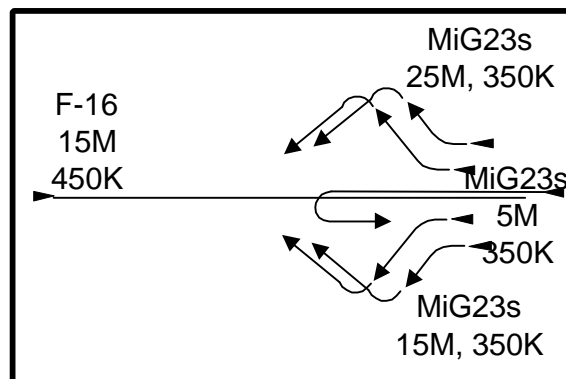


Figure 6. Test scenario (most difficult) from the radar skills task.

The radar skills task began with a relatively simple scenario (see Figure 3 for an example). The pilot was to call out radar contacts and bandit actions as they occurred. The evaluator, a retired F-16 instructor pilot and squadron commander, stood just behind the cockpit and could view the radar screen on a video monitor.

The pilot's radar skills performance was scored on a scale of 0 to 3 for each of four sub-tasks: search the airspace and sample the contacts; sort the formations and monitor actions; describe picture after bandit action; and, target the highest priority threat before coming within 10 nm. The pilot's scores for each of the four subtasks were summed for a composite run-time score. After passing the bandit formation, the simulation stopped and the evaluator asked the pilot to debrief the scenario. Debrief consisted of four subtasks: describe the initial picture, bandit actions, the picture after bandit action and, the factors used to determine the highest threat. Debrief performance was scored using the same scale as for the run-time scores. During training trials, the evaluator provided feedback on the scenario after the pilot had completed his debrief.

Pilots received 10 or 15 training scenarios. Pilots in the RTT condition received two relatively simple scenarios, three moderately complex scenarios (Figure 4), and five complex scenarios (Figure 5). Pilots in the ARTT condition received the same simple, moderate, and complex scenarios plus five additional complex scenarios for a total of 15 training trials. All pilots were tested in

real time on five scenarios which were more complex than any of the training scenarios (Figure 6).

Results

Scores for training and test trials were grouped into blocks depending on scenario difficulty. Trials 1 - 5 were grouped as simple - moderate complexity scenarios, trials 6 - 10 as difficult, and trials 11 - 15 also as difficult, but for the ARTT group only. Trials 16 - 20 were test trials and were designed to be more difficult than any of the training trials. Mean percent scores grouped into blocks are plotted for run-time scores on Figure 7 and for debrief scores on Figure 8. Test performance was not significantly different between the RTT and ARTT groups for run-time scores ($\bar{X}_{RTT} = 77.5$, $\bar{X}_{ARTT} = 81.7$, $t(22) = 1.97$, $p = .062$). For debrief scores, test performance for the ARTT group was significantly higher than for the RTT group ($\bar{X}_{RTT} = 75.8$, $\bar{X}_{ARTT} = 82.5$, $t(22) = 2.38$, $p = .026$).

Comparing scores on training trials and test trials, run-time scores for the ARTT group show significant increase from training to test ($F(1, 11) = 19.64$, $p = .001$) while for the RTT group, there is no significant change in run-time scores from training to test ($F(1, 11) = 1.44$, $p = .256$), see Figure 7. For debrief scores, the ARTT group shows a significant increase from training to test ($F(1, 11) = 10.76$, $p = .007$), while the RTT group shows a significant decrease ($F(1, 11) = 38.71$, $p < .000$), see Figure 8.

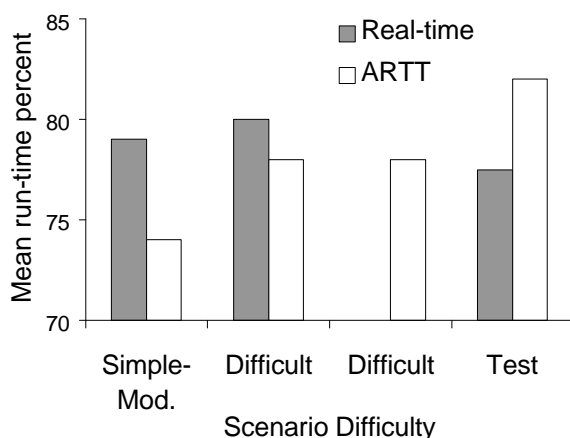


Figure 7. Mean run-time scores by scenario difficulty.

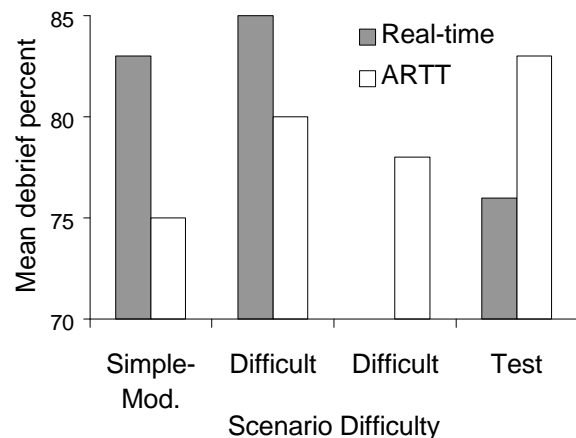


Figure 8. Mean debrief scores by scenario difficulty.

Discussion

In experiment 1, ARTT provided equal or improved training using less time spent in the simulator. In experiment 2, ARTT pilots received more training trials than the RTT pilots while time spent in the simulator was approximately equal for both groups. Student pilot debrief scores on the test trials were significantly higher for the ARTT group than for the RTT group. Further, the ARTT group showed a significant increase in run-time and debrief scores from the difficult training trials to the more complex test trials which were presented in real time. The RTT group showed no change in performance between training and test trials for run-time scores (see Figure 7) and a significant decrease for debrief scores (see Figure 8). Overall, the idea of using ARTT to provide additional training trials within the same amount of clock time as real-time training as suggested by Vidulich et al (1983) was supported.

ARTT will interfere with effective training if the pace of events is so rapid that students cannot keep up. Evidence for this effect would be that students using ARTT would produce lower performance scores than students using RTT and that ARTT student performance would not improve. In this experiment, performance scores of students using ARTT were indeed initially lower than scores of students using RTT, however, ARTT student performance significantly improved from trials 1 - 5 (simple-moderate scenarios) to trials 6-10 (difficult scenarios) for run time but not for debrief scores. Performance scores for students trained in real time did not change significantly from the simple-moderate scenarios to the difficult scenarios. Overall, ARTT at 1.5 times real time was not a problem for advanced student pilots although there was an initial performance deficit.

SUMMARY AND CONCLUSIONS

The concept of above real-time training was developed by engineers and pilots as a practical solution to an immediate problem. There are two proposed advantages to ARTT. The first is simple efficiency. Compared to real-time training, a pilot using ARTT can experience a given number of training events in fewer clock hours of simulator time or, the pilot using ARTT could experience more training events in a fixed amount of training time. The second proposed advantage to ARTT is that ARTT should provide for easier transition to the more demanding environment of actual flight

than normal-time simulation. The experience of NASA test pilots was that actual flight was more demanding than simulation; ARTT felt more like the airplane than a high-fidelity, real-time simulation.

In the first experiment, experienced F-16 pilots performed air-combat tasks while responding to in-flight emergencies. Pilots trained using ARTT performed a single-emergency procedure and engaged a single bandit as well as pilots trained in real time but no better. ARTT was more efficient than real-time training in that pilots trained using ARTT were able to perform on test trials as well as pilots trained in real time but with fewer clock hours of simulator time. However, in a more demanding multiple-emergency task, pilots who received initial training in real time, followed by additional practice using ARTT, performed emergency procedures and engaged two bandits faster than pilots who received all training in real time. This experiment supports the hypothesis that ARTT can provide better transition to a more demanding task environment than real-time training for selected tasks.

In the second experiment, student F-16 pilots performed a radar skills task. Unlike the more experienced pilots in experiment 1, performance of student pilots on this task was initially degraded by ARTT, however, ARTT pilot performance improved with additional training trials. In this experiment, ARTT was used to increase the number of training trials presented within approximately 30 minutes of simulator time. Student pilots trained in real time received 10 training trials while pilots trained using ARTT received 15 trials. Pilots trained using ARTT performed better on real-time, test trials than pilots trained in real time. The combination of ARTT plus additional training trials led to improved performance on the test trials without increasing clock hours in the simulator.

As an instructional strategy, ARTT is inexpensive to implement and can increase time efficiency and training effectiveness for many training tasks. The hypothesis that ARTT is more efficient than real-time simulation was supported. Compared to real-time simulator training, time-compressed training that does not overload the trainee can support equivalent levels of test performance with fewer hours of clock time in a simulator or improved test performance with equal amounts of clock time in a simulator. The hypothesis that transition to a more demanding

task will be increased by ARTT without additional training trials was also supported for some tasks. Pilots who received initial training in real time followed by additional practice using ARTT performed faster than pilots trained in real time for highly demanding tasks.

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