Training with Virtual Reality: Lessons Learned

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ABSTRACT

Vertex Solutions, under contract with the Combating Terrorism Technical Support Office (CTTSO), recently delivered an immersive AC-130 virtual reality part task trainer (vrPTT) for use by the Air Force Special Operations Command (AFSOC). The vrPTT provides checklist instruction and practice to AC-130U copilots through the use of an immersive 3D virtual reality (VR) cockpit combined with an intelligent tutor to guide students through 16 copilot checklists and track performance. Key to its delivery, the research team facilitated a verification, validation, and accreditation (VV&A) to confirm that the system met the training requirements for inclusion in the AFSOC 19th SOS Syllabus of Instruction for the AC-130U Mission Qualification Course. Additionally, we conducted a formative evaluation to measure training effectiveness and to inform final refinements to the system. The evaluation participants were AC-130U instructor subject matter experts, current squadron copilots, and current copilot students. The evaluation data included observation of participants using the system, written usability and confidence self-assessment surveys, and individual performance data collected by the intelligent tutor. The results of the evaluation can inform the design and development of future VR training systems. Participants found the system easy to use and 100% believed that the vrPTT would positively supplement existing training to increase confidence and proficiency prior to entering the full motion simulator. Data also indicate the importance of scaffolding within the VR environment to assist with task completion. While the evaluation confirmed many benefits of VR training, it also identified a number of limitations, with most centered on the relative lack of VR hardware/software maturity. Given that technology matures quickly and the identified limitations did not surround the design or implementation of a VR system, we are confident that VR training systems can be a viable time- and cost-saving training option for the military.

ABOUT THE AUTHORS

Ms. Amanda Palla, PMP, is currently the Director of Government Operations at Vertex Solutions, where she manages the teams that design and develop virtual reality (VR) training, web-based training (WBT), instructor-led training (ILT), immersive simulations, and mobile solutions. Amanda has more than 13 years' experience in the training field and has worked with numerous Government clients to deliver training on such topics as weapons familiarization, emergency preparedness response, cross-cultural competence, cross-cultural negotiations, career development, and leadership. She holds an Ed.M. in Secondary Science Education from the University of Illinois and an A.B. in Biological Sciences from the University of Chicago.

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INTRODUCTION

As VR technology is comparatively new to the training community, relatively few studies have been conducted to assess its value to training. Its utility has been discussed as it applies to aviation and the military community at large (Chaoran et. al., 2014; Lele, 2013), but the purpose of this evaluation was to assess the training effectiveness of the AC-130U Virtual Reality Part Task Trainer (vrPTT) to support skill development for AC-130U checklist training in particular. The vrPTT was developed through a project with the Combating Terrorism Technical Support Office (CTTSO) and in partnership with the Air Force Special Operations Command (AFSOC). It established a portable and immersive 3D virtual reality (VR) environment complemented with an automated instructional tutor capable of conducting automated performance analysis, evaluation, training remediation, and records keeping. This technology is intended to allow students to exercise checklist and cockpit knowledge to build mental models and muscle memory necessary for efficiently managing aircraft systems to safely operate the aircraft. It enables students to conduct repetitive checklist task practice to build cognitive and psychomotor skills. Students wear a head-mounted VR display and interact with the vrPTT system using their bare hands (Sikorski et al., 2017). For each of the 16 checklists, the system provides an "instructional" and a "practice" mode. The instructional mode provides audio and text to guide students through the checklist, and is not evaluated. The practice mode removes the guided audio and text and instead provides hints only when students require them to successfully move to the next step. Additionally, the practice mode is evaluated and students must complete a checklist without seeing hints on more than 30% of the steps to pass that checklist. The evaluation of the system included an assessment of both the capabilities of the trainer itself and its effectiveness in providing training support to students as a supplement to the current training system.

The evaluation approach was consistent with the verification and validation portion of the Validation, Verification & Accreditation (VV&A) process as established in the DoD Modeling & Simulation guidance (DoDI 5000.61. December 9, 2009). The evaluation specifically assessed whether the vrPTT's accuracy, correctness, and usability were sufficient to support AC-130U Master Training Task List (MTTL) checklist training contained in the AFSOC 19th SOS Syllabus of Instruction (SOI) for the AC-130U Mission Qualification Course (30 May 2015).

The evaluation posed the following questions:

- Are the operational capabilities of the vrPTT consistent with actual performance requirements?
- Does the vrPTT provide practice on copilot checklist procedures consistent with the requirements in the actual aircraft?
- Does the use of the vrPTT in both the instructional mode and the practice mode improve the learner's performance?
- Does the use of the vrPTT improve the learner's confidence in performing the required tasks?

The formative evaluation was designed to assess, first, the feasibility of using the vrPTT to support the requirements for mission qualification, and second, the degree to which the vrPTT could support the development of muscle memory prior to mission qualification flights in the full-mission simulator or aircraft. The vrPTT has also been considered as an option to support currency by providing opportunities for ongoing practice in a flexible, lower-cost environment than traditional simulator training. The evaluation was performed as a field evaluation, using instructors and recent graduates to validate and verify the system, and actual students who are in the current AC-130U Mission Qualification course to assess the vrPTT's value during the training process.

METHODOLOGY

The evaluation was conducted in two phases: validation/verification and student evaluation of system performance. In the first, a validation and verification of the system, the vrPTT was validated relative to normal aircraft cockpit indications (e.g., instrument locations, functions, and readings), correct sequencing of checklist steps, and virtual tutor programming (e.g., on-screen text displays and audio cues to assist in task sequence). During this validation, discrepancies were identified and changes to the system were made accordingly. Once changes were made to the system based on this initial validation, the subject matter experts (SMEs) conducted another validation of the system. This process continued until all discrepancies were corrected.

Also, as part of the validation and verification phase, squadron-level copilots performed an evaluation of the total system. This phase of the evaluation used both quantitative and qualitative methods. The quantitative assessment measured performance on the checklist procedures using the vrPTT's built-in performance-tracking system. For qualitative assessment, the squadron copilots first completed one checklist in the system's instructional mode, then completed a short qualitative usability survey focused on the instructional mode. Next, the copilots completed the same checklist in practice mode. Copilots then completed two additional checklists in both instructional and practice modes. Following the conclusion of the third checklist in practice mode, the copilots completed two surveys: a qualitative usability survey focused on the practice mode, and a training self-assessment survey. Figure 1 depicts this first phase of the evaluation, the validation and verification of the system.

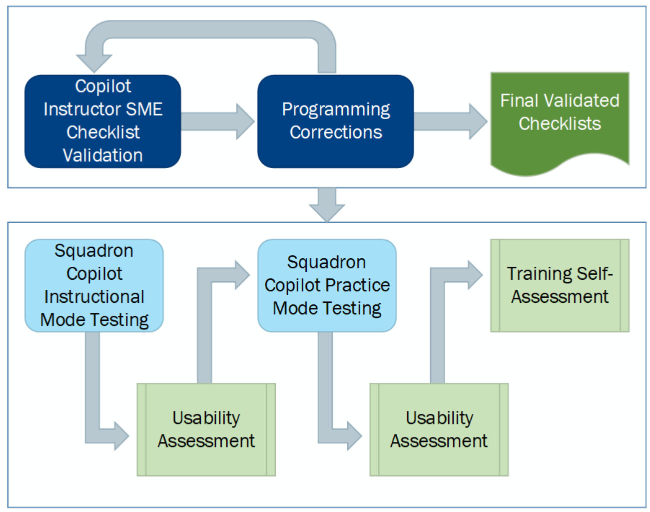

Figure 1. Evaluation Phase 1: Validation/Verification of System Operation

The second phase of the evaluation assessed the system's performance using a control group and an experimental group of students currently enrolled in the AC-130U Mission Qualification Course. Figure 2 depicts this phase of the evaluation. The approach was for one student to go through the established class without using the vrPTT (the control group), while the second student was afforded opportunities to practice with the vrPTT in addition to the classroom sessions (the experimental group). The student using the vrPTT completed both the instructional and practice modes for three checklists.

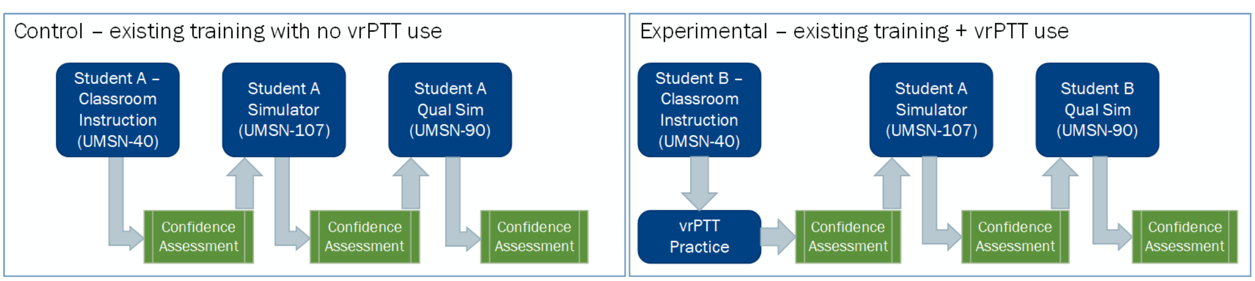

Figure 2. Evaluation Phase 2: vrPTT Student Evaluation of System Performance

Participants

The Phase 1 participants in this study included four graduates of the AC-130U Mission Qualification Course. The two copilot SMEs engaged in the validation and verification of the system were experienced pilots/copilots, with more than 2,000 flying hours each.

During Phase 2, two current students participated in the study. The low number of participants is due to the timing of the class schedules and the low number of copilots (one) going through each course. The student in the first scheduled class, operating as the control group, went through the course (Class 1) without the benefit of the vrPTT. The second student (Class 2) used the vrPTT as a supplement to his instruction. The two students were similar in age, rank, and experience. The researchers treated each subject consistently and the process and procedures were standardized across participants.

Evaluation Method and Procedures

All data collection was based on the AC-130U MTTL. The task steps associated with each checklist were programmed into the vrPTT to mimic the checklist steps as indicated in the 1C-130(A)U-1 Flight Manual and AC-130U copilot checklist. These programmed checklist steps were evaluated and validated as accurate in the virtual environment of the vrPTT and in accordance with the flight manual and checklist.

To assess the learning of each task, the tasks were assigned a skill learning level from (L1) to (L7). Each level corresponded to the action verb associated to the task performance. Level determinations were guided by categories described in the Department of Defense Handbook (MIL-HDBK-29612-2A, 2012) and from copilot instructor interviews. Each task was also assigned a knowledge learning level from (L1), indicating a simple task, to (L5), indicating a complex task. The assignment, evaluation, and revision process mirrored the process for assigning skill-learning levels. Additionally, each checklist was assigned timed performance criteria retrieved from discussions with AC-130U copilot instructors.

Task data collection associated with skill or knowledge provided researchers with data to evaluate particular task learning difficulties. Collecting participant performance measurements based on time performance parameters allowed researchers to analyze muscle memory improvement during vrPTT training evolutions. Both predictive and summative self-assessment surveys were used to collect data for the current state of training and potential training benefits if the vrPTT were incorporated.

Data Collection for Phase 1 – Validation/Verification Testing

The normal MTTL checklist task step procedures associated with the AFSOC SOI Checklist A (UMSN-40), Checklist B (UMSN-107), and Qualification Simulation (UMSN-90) lessons were programmed into the vrPTT to be performed in accordance with task sequences as identified in the 1C-130(A)U-1 Flight Manual (10 August 2015) and copilot checklists.

As stated in the test plan, copilot instructor SMEs were used for validation of training content and verification of planned system functionality. The SMEs were selected based on their position as squadron instructor pilots and their experience in the cockpit. Additionally, copilot evaluators from the squadron were used to evaluate performance in checklist procedures, as well as the vrPTT system's ability to improve learning. The squadron copilot evaluators also evaluated the vrPTT system for ease of operation by answering usability surveys after using the vrPTT. Finally, the squadron copilots were asked to complete reflective self-assessments on AC-130U copilot training they received (current state) and what the benefits gained would be if they had the vrPTT incorporated into the same training. Squadron copilots were selected based on the recency of their graduation from the AC-130U Mission Qualification Course. They also had limited time and experience in an operational squadron. This parameter was significant because the self-assessment surveys required recent memory of 19th SOS AC-130U Mission Qualification Course SOI.

Data Collection Tools

For the validation and verification testing, a test plan was developed for each of the checklists. For each step in each checklist test plan, the following were specified:

- Step functionality (how the step loads and exits)
- Step description (what action is happening during the step)
- Expected result (e.g., instructor audio, condition for moving to the next step)
- A red/yellow/green pass indication for the step
- Comments area for participants to add comments

For the squadron pilots participating in this phase, participant biographical data were collected. To evaluate the vrPTT's instructional and practice modes, participants answered questions on two system-usability surveys. Each of these surveys consisted of sixteen 7-point Likert-scale questions and five or six open-ended questions. The questions measured the participants' agreement with statements regarding the system's usability, and collected data on the participants' general thoughts about the system and its use.

To collect performance and learning data on each checklist training attempt, checklist session data capture sheets were used. Additionally, reflective self-assessment surveys were administered to collect self-confidence data as it relates to the AFSOC 19th SOS AC-130U Mission Qualification Course checklist training.

Data Collection Procedures for Squadron Pilots

Copilot instructor SMEs were briefed on the purpose of the vrPTT Instructional Mode validation/verification plan and the tools to be used for data collection. SME copilots were assisted by vrPTT contract personnel to monitor and annotate any programmed anomalies in the virtual environment. In this process, the copilot instructor SMEs performed each checklist to validate the attributes of the virtual environment. The SMEs were asked to perform the steps listed in the test plan tables. A traffic-light rating system (red, yellow, and green) was used to record expected results. If the expected result occurred, the step was marked as green. If the expected result did not occur, the step was marked as red and what did occur was noted in the Comments column. If the step was completed as designed, but changes were required, the step was highlighted in yellow and requested changes were listed in the Comments column.

The squadron copilot participants were asked to provide biographical/administrative data prior to starting the evaluation. They then conducted checklist training with the vrPTT in the Instructional Mode to become familiar with system operation and the checklist lesson's instructional format. Next, they conducted checklist training in the Practice Mode to capture performance and learning for evaluation. These participants were asked to perform checklist training on three checklists (Taxi, Before Landing, Engine Shutdown) using the vrPTT.

Upon completion of the vrPTT checklist training, the squadron copilots were asked to complete the Instructional and Practice Mode usability survey forms, as well as the reflective self-assessment survey forms to examine whether self-confidence levels would change with vrPTT use.

Data Collection for Phase 2 – Student Evaluation of System Performance

Consistent with Phase 1, the normal MTTL checklist procedures associated with the AFSOC SOI Checklist A (UMSN-40), Checklist B (UMSN-107), and Qualification Simulation (UMSN-90) lessons were used and programmed into the vrPTT to be performed in accordance with task sequences as identified in the 1C-130(A)U-1 Flight Manual and copilot checklists.

In Phase 2 of this evaluation, AFSOC 19th SOS copilot students were used in a control group and experimental group plan. The control group student (N=1) proceeded through current copilot training in its current state. The experimental group student (N=1) proceeded through current training supplemented with the use of the vrPTT. This approach allowed for data collection on simulator performance both with and without the use of the vrPTT. The data collection tools for the student pilots were the same as were used for the squadron pilots who evaluated the system.

Data Collection Procedures for Student Pilots

The control group (Student Copilot Participant A) received AFSOC SOI Checklist A (UMSN-40), Checklist B (UMSN-107), and Qualification Simulation (UMSN-90) lesson training in the current state, which is classroom instruction and simulator instruction. Upon completion of each UMSN, the student was asked to complete a training self-assessment survey to assess the student's confidence in learning and performing checklist tasks with current training methods.

The experimental group (Student Copilot Participant B) received current AFSOC SOI Checklist A (UMSN-40), Checklist B (UMSN-107), and Qualification Simulation (UMSN-90) lessons supplemented with the use of the vrPTT between Checklist A and Checklist B lessons. After the completion of each lesson, and before moving to the simulator, the student used the vrPTT to complete several checklists, then completed both the Instructional and Practice Mode usability survey forms. Upon completion of each UMSN checklist simulator session, the student's performance was annotated and the student was asked to respond to the self-assessment survey questions. This approach provided data on whether simulator self-confidence levels changed with vrPTT use.

Data Collection Limitations

The data collection and analysis sample size for this effort was small owing to class size and schedule during the evaluation period. There were only two classes scheduled, with one copilot student each, during the data collection period. Additionally, time available for vrPTT use was limited to two hours, meaning Student Copilot Participant B could complete only two checklists (and associated surveys).

RESULTS

MTTL Checklists Validation/Verification

Results of checklist validations/verifications are shown in Table 1 and Table 2. These tables provide a summary of the anomalies encountered from the SME review, based on the test plan. An anomaly is defined as a required change to the checklist functionality test plan, regardless of the cause of the anomaly (e.g., programming error, incorrect checklist sequence, 3D model issue). Each anomaly was annotated.

- Step Anomalies. SME requests a change to a step itself (e.g., requests a step to be deleted from the checklist or moved to another location within the checklist, or the wrong step name was annotated).
- Functionality Anomalies. A step loads with incorrect behavior. If a male voice is supposed to narrate a step, for instance, it would be reported as an anomaly if a female voice was heard.
- Description Anomalies. The system uses different nomenclature than the correct nomenclature specified by the SME.
- Expected Result Anomalies. The result of a step is not what is expected. For example, a normal indication may be that a gauge moves from 0 to 100 when a switch is flipped. An anomaly would be that the gauge did not move when the switch was flipped.

As these results show, the number of anomalies decreased significantly following the initial round of review and fixes.

Table 1. First Round Checklist Instructional Mode Validation/Verification Analysis

Total Task Steps	Step Anomalies	Step Anomaly %	Functionality Anomalies	Functionality Anomaly %	Description Anomalies	Description Anomaly %	Expected Result Anomalies	Expected Result Anomaly %
2,096	141	6.7%	310	14.8%	208	9.9%	502	24.0%

Table 2. Second Round Checklist Instructional Mode Validation/Verification Analysis

Total Task Steps	Step Anomalies	Step Anomaly %	Functionality Anomalies	Functionality Anomaly %	Description Anomalies	Description Anomaly %	Expected Result Anomalies	Expected Result Anomaly %
2,096	60	2.9%	60	2.9%	60	2.9%	130	6.2%

This process, used for validation and verification, resulted in changes to the system based on instructor SME input. These results were used to identify system improvement, adjustments for accuracy to aircraft functions, and usability of the system for purposes of instruction. This testing was completed and all anomalies were corrected in the system prior to testing by students, as it was important to present current copilot students with a correctly functioning system.

Usability/Satisfaction

Figure 3 summarizes responses from the Likert-scale usability/satisfaction surveys.

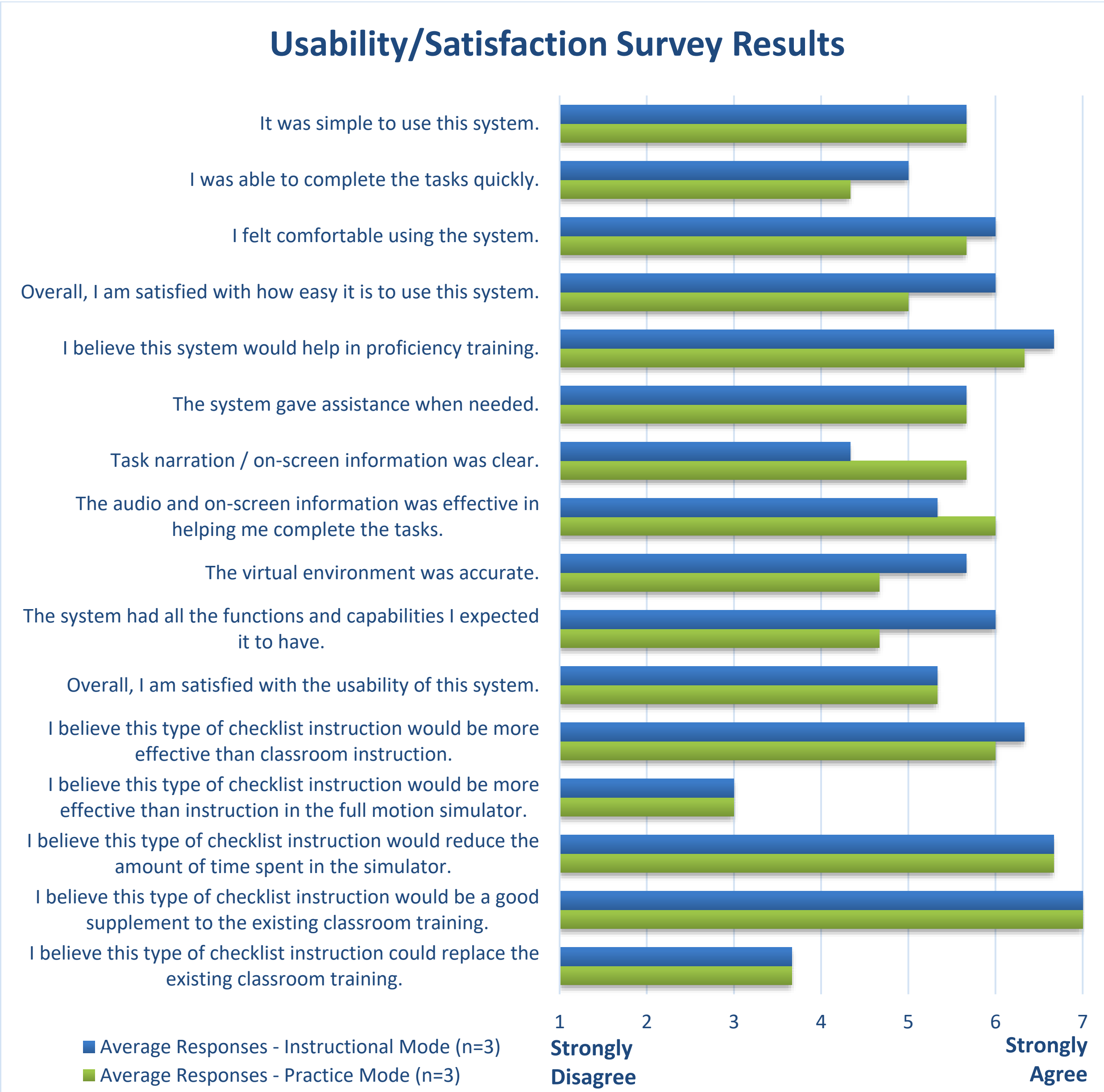

Figure 3. Usability/Satisfaction Survey Results

A majority of the scoring marks were average and above average; very few were below average. Responses indicated that participants thought the system was easy to use and they felt comfortable using it. Using the vrPTT as a supplemental training device in existing checklist training was seen to be beneficial and more effective than classroom checklist instruction. Participants also indicated that the use of the vrPTT may reduce total training time. Participants did not, however, think that the vrPTT could entirely replace classroom instruction, as the classroom instruction provides a lot of the "hows" and "whys" that are not covered by the vrPTT.

Below average responses noted on the table relate to programming parameters affecting the virtual tutor audio and visual aids and cues that could be adjusted to provide better quality. Several additional programming anomalies were noted that could lead to negative training (e.g., switches, knobs, levers moving when hand or arm passes in close proximity). These visual cues, however, were not part of the associated checklist tasks.

During data collection, participants were asked questions relating to the vrPTT system's operation and virtual environment. These open-ended questions were aimed at finding the participants' likes and dislikes regarding the vrPTT system, as well as identifying any usability enhancements. Participants' suggestions, and the resulting changes to the system, are listed in Table 3.

Table 3. Squadron Participant Usability Suggestions & System Changes

Participant	Usability Suggestions	System Change
1	Add a progress bar to the loading screen.	A progress bar was added to the loading screen.
1	Ensure there is audio to go along with moving switches and levers.	Audio feedback was added.
1, B	Improve contrast of the on-screen text so that it is easier to read.	Text contrast was improved.
1	Add a note about rolling up sleeves and removing watches to the "How to use the vrPTT system" checklist.	Additional instructions were added to the system.
1, B	The text-to-speech voice is sometimes hard to understand. Find some better voices.	Select voices were adjusted.
1, 2, B	Remove the physical yoke, as it blocks a number of switches and gauges.	The yoke was removed from the system.
1, 2, B	Have switches lock into the correct position once moved so that it is difficult to accidentally undo an action.	Added programming to disable switches once they are moved into the correct position.
B	Improve technology to read switches and gauges better.	Updates were made to the shaders in the game engine that improved this significantly.
B	Incorporate glove technology to improve hand dexterity.	Out of scope on the current project.

Checklist Performance

Evaluation participants were evaluated relative to their performance in Practice Mode. Checklist performance passing criteria were established within the vrPTT so that a student was required to see hints on less than 30% of the checklist steps (i.e., a 70% score) to pass and progress to the next checklist. The vrPTT was programmed to collect data on each individual who logs in with a user name and password. The data points collected were:

- User Identifier
- Checklist Name
- Pass/Fail
- Score
- Total Checklist Time
- Step Name
- Step Hint Count

These data points, in conjunction with data capture sheets, were used to collect data for analysis. Three additional columns—Common Hints, Knowledge, and Skill—were then added to capture the steps participants had difficulty with (receiving multiple hints) across all checklists and to capture the knowledge and skill learning levels of each task for which a participant received a hint. As an example of the performance data collected, Table 4 summarizes the squadron and student copilot participants' performance on the engine shutdown checklist.

Table 4. Engine Shutdown Checklist Performance

	Attempt Number	Total Time (minutes)	Score	Passed?	Number of Steps That Needed Hints	Total Hints Seen
Squadron Participant 1						
	1	4.38	41.7%	No	14	30
	2	3.15	58.3%	No	10	24
	3	3.11	75.0%	Yes	6	16

	Attempt Number	Total Time (minutes)	Score	Passed?	Number of Steps That Needed Hints	Total Hints Seen
Squadron Participant 2						
	1	3.51	54.2%	No	11	23
	2	3.70	70.8%	Yes	7	13
Student Copilot Participant B						
	1	5.32	29.17%	No	17	48
	2	4.37	45.83%	No	13	38
	3	3.60	54.15%	No	11	29
	4	3.19	66.67%	No	8	20
	5	2.83	66.67%	No	8	14
	6	2.87	70.83%	Yes	7	17

Analyzing the performance data from the vrPTT data extract for the squadron participants revealed low, non-passing scores in the first checklist attempts, which, by observation, resulted from lack of system familiarity. This lack of familiarity led to increased task time completion and multiple hints. Note that hints were programmed to appear whenever learners took longer than a SME-prescribed time to complete a step, regardless of whether the learner made a mistake.

The review of the vrPTT data extract indicates that with each attempt the participants' overall time decreased, but not necessarily the time to complete each previously hinted task. We also noted that each participant's graded score increased with each checklist attempt.

Analysis of the vrPTT performance and learning data extract revealed hint commonalities between participants. These "common hints," in each case, were reduced in the subsequent checklist attempts but were not reduced to zero. For the most part, the hints received involved interactions with switches that were difficult for the participants to manipulate because of the placement in the cockpit combined with the limitations of the Leap Motion hand-tracking device. Only a few of the hints indicated a copilot's lack of knowledge or understanding. As the vrPTT is designed to teach the "textbook" approach to checklist completion, it is likely that the seasoned squadron copilots had developed their own tactics, techniques, and procedures (TTPs) that differed slightly from the checklist sequence being evaluated in the vrPTT. It is interesting to note that, although the student copilot participant received a larger number of step hints than the squadron copilot participants while executing the same two checklists, both sets of participants saw almost identical repeated hints. This lends support to the observations that these hints were due to system usability issues rather than lack of knowledge.

Self-Confidence Assessment

Student copilot participants A & B were asked to complete self-confidence self-assessments. In these assessments, the student copilots reflected on the aspects of current training received while attending the AFSOC 19th SOS Mission Qualification Course. Student A did not use the vrPTT and therefore provided responses to current training methods only. Student B provided responses on current training methods and current training methods supplemented with the use of the vrPTT. This approach provided insight into how the student's self-confidence changed with the introduction of the vrPTT into the current training.

Students rated their confidence on a scale of 1 (low) to 5 (high). In Checklist A (UMSN-40), which is classroom instruction, Student A revealed a one-point self-confidence increase after receiving training. In Checklist B (UMSN-107), which is training conducted in the crew simulator, Student A revealed no change in self-confidence upon completion of the training. There was, however, a two-point increase in self-confidence upon completion of the Qualification Simulation (UMSN-90), which is also training conducted in the crew simulator.

Student B revealed a one-point increase in self-confidence in all three current checklist training events. After conducting current checklist training supplemented with the vrPTT, however, student B revealed a two-point increase in self-confidence for each training event. This increase, though, is the result of responses received for only two of the 16 checklists within Checklist A (UMSN-40), Checklist B (UMSN-107), and Qualification Simulation (UMSN-90) lessons.

As previously identified, Participant B provided responses on current training methods and current training methods supplemented with the use of the vrPTT. These results are also summarized in Table 5.

Table 5. Student Copilots' Average Overall Training Confidence Scores

	Average between UMSN-40, UMSN-107, and UMSN-90 on a Scale of 1 (Low) to 5 (High)		
Question	**Student A**	**Student B**	**Average**
Are you confident that you were prepared to conduct AC-130U checklist procedures?	2.67	3.33	3.00
Are you confident that you are familiar with AC-130U checklist procedures?	3.33	3.33	3.33
Are you confident checklist procedural instruction by a live instructor has prepared you for conducting checklist procedures?	3.33	2.33	2.83
Are you confident that checklist procedures taught by a "hands-on" training method alone would have prepared you for conducting checklist procedures?	4.33	4.00	4.17
Are you confident that classroom instruction improved your cognitive skills (think, learn, remember, reason) associated with performing checklist procedures?	3.67	2.33	3.00
Are you confident that classroom instruction improved your psychomotor skills (hand-eye coordination) associated with checklist procedures?	2.33	2.33	2.33
Given the opportunity to use the virtual reality Part Task Trainer (vrPTT), did it increase your confidence level in performing checklist procedures?		4.33	4.33
Given the opportunity to use the virtual reality Part Task Trainer (vrPTT), what is your level of confidence that it improved your cognitive skills (think, learn, remember, reason) associated with performing checklist procedures?		4.33	4.33
Given the opportunity to use the virtual reality Part Task Trainer (vrPTT) what is your level of confidence that it improved your psychomotor skills (hand-eye coordination) associated with checklist procedures?		4.00	4.00

For each of the confidence questions, students were asked to use their own words to describe what would have increased their confidence. Top answers included access to videos of checklists being performed, more time in the simulator, and more vrPTT time. Specifically related to the vrPTT (last three questions), Student B stated that working out software glitches and using gloves or some other method to fine tune motor skills in the VR environment would improve his confidence beyond the already high 4-point confidence score.

DISCUSSION AND CONCLUSION

Benefits of the vrPTT System

Based on the findings of this evaluation, the use of the vrPTT may be able to provide the following key benefits:

1. Cost savings
2. Instructor time savings
3. Increased checklist proficiency
4. Increased copilot confidence prior to the simulator

Quantifiable time savings could not be measured during this evaluation, as time currently spent in the simulator includes the entire cockpit crew. If the crew finishes their simulator tasks ahead of schedule, additional tasks are added to use the entire simulator time, meaning that time saved for the copilot position specifically could not be measured. Our limited results, however, suggest that use of the vrPTT would increase cockpit and checklist familiarity and therefore reduce the amount of time spent in the simulator.

The vrPTT users found that the intelligent tutor provided instruction and assistance when needed, allowing them to practice checklists to proficiency without the help of a live instructor. The overall vrPTT benefits were summarized well by the copilot student who evaluated the system:

"This system makes learning incredibly easy. It would reduce time fumbling through checklists or displays and takes away pressure of an instructor's constant evaluating over the shoulder. Instead of spending time learning in the valuable sim time, sim time could be performance time. Would increase confidence going into a sim tenfold."

VR Cockpit Trainer Limitations

Three main limitations were identified through the evaluation of the vrPTT system. The first identified limitation was the VR headset resolution. Owing to the detailed nature of the AC-130U cockpit, the 1,080 pixel resolution of current VR headsets does not provide enough pixels to clearly display small text on dials and gauges when the user has a wide field of view. If a user leans in close to an instrument it is readable, but the VR environment does not replicate what a human eye would see from the same distance in the real environment.

The second identified limitation was related to hand tracking and hand interactions with the VR environment. The vrPTT system uses a Leap Motion infrared (IR) sensor mounted to the front of the Oculus Rift head-mounted display (HMD) to allow bare-handed tracking within the vrPTT environment. Bare-handed tracking was a specific requirement of this project to enable users to build muscle memory and to prevent "negative training" that may come from using a controller to interact with the virtual environment. There are inherent limitations, however, to a single-point IR sensor solution. Namely, if line of sight from the IR sensor to the user's fingers is blocked by an arm or hand, the system has no way to accurately resolve the precise position of the fingers. Without precise finger positions, a user has no ability to effectively interact with the cockpit controls. Additionally, interactions with the virtual switches and dials lacked a tactile feel, and users relied on visual cues to know when a switch had moved. This often led to switches being inadvertently moved back into their original position, or past the desired position in the case of three-way switches or levers. This limitation is inherent in any VR system.

The third identified limitation was the lack of ability to track a user's gaze. The front-end analysis showed that 309 of the 654 (47%) copilot checklist tasks are visual tasks, stressing the importance of being able to measure where a user is looking. The solution that was implemented for the vrPTT involved placing a dot in the center of the user's field of view and requiring the user to center that dot over the instrument he or she is required to look at for a defined length of time. During the evaluation, users were often confused by this type of interaction, and it took them some time to get used to performing the gaze verification steps. Ideally, current technology would evolve enough to incorporate gaze tracking in any future vrPTT systems.

Recommendations

Participants indicated that the vrPTT system was easy to use and provided complete and accurate learning objective instruction. Data analysis indicated that once the participants are familiar with the vrPTT system operation their confidence in performing checklist functions in the virtual environment increased. This confidence, coupled with multiple repetitions, increased performance and proficiency. Incorporating participant-recommended usability changes should reduce unnecessary stresses and improve concentration in task accomplishment, performance, and learning.

Incorporate New Technology

The vrPTT system was designed to be hardware agnostic, and some of the main limitations identified centered on the maturity of current VR HMDs and tracking devices (e.g., gloves). As better technology becomes available, it should be integrated into the vrPTT system to improve usability and training effectiveness. Specific technology to incorporate includes higher resolution HMDs, gaze-tracking devices, and VR gloves or other enhanced means to track users' hand positions.

Collect Additional Use Data

Owing to the limited data points collected for analysis, it is recommended that performance and learning data continue to be collected for further analysis. Further analysis with a larger number of data points can be conducted as each AFSOC 19th SOS Mission Qualification Course convenes in order to collect data on copilot students new to the AC-

130U aircraft. Additionally, the vrPTT could be distributed to the operational squadrons to collect performance and learning data from seasoned squadron copilots. This would ensure that data points are collected from personnel with varying levels of flying experience, as well as varying experiences with virtual environment training. The additional data will help identify any further deficiencies in the system or inaccuracies in any of the checklists. Finally, data should be collected on average time spent in the full-motion simulator after supplementing the classroom training with the vrPTT to quantifiably measure whether simulator time decreases as a result of the vrPTT training.

Conclusion

The vrPTT validation and verification process produced meaningful insight into the usability and capability of the vrPTT system. During this process, system performance and accuracy of checklist training were found to be adequate, with few anomalies noted. Any suggested adjustments to the checklist training, however, depended on the depth, breadth, and attention of those SMEs validating and verifying the system. This evaluation identified hardware limitations in accurate hand tracking and adequate visual resolution as the top usability items that need to be addressed to improve the system's effectiveness. Despite the current hardware limitations, preliminary data analysis revealed that repetitive use of the vrPTT in both the instructional mode and the practice mode improved performance and built confidence for the learner.

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