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Vlad Zotov, Jerzy Jarmasz, Ken Ueno
Defence Research and Development Canada – Toronto

Eric Kramkowski
QTAC Inc.

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Vlad Zotov[1], Jerzy Jarmasz[1], Ken Ueno[1], & Eric Kramkowski[2]

[1]Defence Research & Development Canada; [2]QTAC Inc.

The development of embedded trainers and intelligent tutoring systems (ITS) may allow modern militaries to maintain high proficiency in marksmanship skills despite limitations on training personnel and resources. A system embedding an ITS in a future rifle concept was developed to examine the potential of such technologies. This system was based on two main concepts: 1) instance-based learning and practice that uses a Smart Sight System to present a perceptual cue adjusted for the target's properties and environmental variables and 2) rule-based learning that relies on artificial intelligence algorithm that delivers training tips and feedback to participants.

The experimental task involved engaging moving targets on a virtual shooting range. Three types of training were compared: a control group that received no additional training, a standard Canadian Armed Forces (CAF) training group, and an advanced training group that received ITS training. The results showed that additional training—both CAF and ITS—improved shooting accuracy. The performance in the ITS condition was consistently better than in the Control group or in the CAF training group on selected measures of performance.

INTRODUCTION

The Canadian Armed Forces are in the process of modernizing their small arms capability. To support this program, S&T is being tasked to identify technologies and methods that will enhance the effectiveness of CAF soldiers. The emphasis is on using new technologies to enhance soldiers' effectiveness but also on training applications and methods to apply these technologies to improve basic marksmanship skills. With help of these new technologies the proposed training systems could alleviate limitations in training resources and personnel for marksmanship training, which are not uncommon in modern militaries. In particular, Intelligent Tutoring Systems (ITS) embedded in future "smart" rifle systems promise to deliver autonomous, portable and on-demand marksmanship training to troops.

Intelligent, autonomous training systems have been successfully used in multiple academic and military applications (for reviews, Kulik & Fletcher, 2016; VanLehn, 2011), but a recognized gap still exists in the training paradigm where tasks involve the interplay between cognitive and psychomotor tasks. A prior work did some investigation in the field. Rickel and Johnson (1999) have tested the application of ITSs for training procedural mechanical tasks within virtual reality scenarios guided by pedagogical agents. Lieberman & Breazeal (2007) investigate a vibro-tactile feedback approach to learning new motor skills. The findings across these and other studies are promising; however, their approaches impose some limitations on the training systems, such as confinements to its strict lab settings, or limited portability.

The Moving Targets Intelligent Tutoring System (MT-ITS) presented in this paper is an attempt to develop a portable embedded training system using new technologies and methods developed within the S&T small weapon modernization program. The system is designed to improve one of the more challenging skills in the field of marksmanship training: engaging moving targets. The MT-ITS architecture includes typical ITS components (Freedman, 2005): a domain module, which is built on eliciting expert knowledge; an instructor module, which is represented in the form of tips and corrections aimed to improve performance, and a student module, which is obtained by collecting performance data.

The moving target tutor incorporates two main components: (a) a digital sight concept incorporating visualization technologies developed in support of the CAF's small arms modernization effort, and (b) a modelling-based component that relies on a previously developed cognitive tutoring system.

The digital sight component of the MT-ITS uses a Smart Sight System, which provides users with a calculated perceptual cue indicating where the weapon should be aimed to hit a target at its current distance and speed.

The modelling-based component relies on artificial intelligence algorithms that deliver training tips and feedback to participants. The algorithm is based on the work of Yeh and Ritter (2012), who developed the "Declarative to Procedural Moving Target Tutor" (D2P/MTT) that teaches trainees how to adjust their point-of-aim (POA) depending on speed, distance, and angle of movement of the target. The D2P/MTT gradually introduces each component of the task, providing plenty of practice to allow the transfer of knowledge from declarative to procedural memory. While this ITS showed a benefit in increasing trainees' theoretical knowledge, it is a knowledge-based tutor, and as such it does not allow trainees to put this knowledge into practice. The MT-ITS builds on the D2P/MTT concept by also incorporating features designed to allow trainees to develop practical marksmanship skills.

The MT-ITS was implemented in the Virtual Battlespace 2 (VBS2) military simulation software platform, which is based on a commercial first-person shooter game. The hardware used was the Virtual Immersive Soldier Simulator (VISS) – a CAVE-like environment that allows a user to aim a mock weapon across projected background screens and engage virtual targets. The weapon is equipped with an OLED micro-display in place of an optical sight, and is motion-tracked by a NaturalPoint OptiTrack infrared tracking system which allows the sight picture in the micro-display to be updated in real time as the user moves the weapon. VBS2 generates the imagery for both the background screens and the micro-display.

The MT-ITS leverages the target visualization capabilities of the digital sight to instantiate an instance-based learning strategy, relying on sequential presentations of the same target with and without cues, teaching participants to associate a target at a given range and speed with the corresponding POA required to hit that target. The un-cued presentations then allow participants to apply the learned POA. The rule-based training works by gradual introduction of the basic skills involved in shooting moving targets, increasing difficulty and providing participants with the opportunity to practice while guided by corrective feedback.

METHOD

Participants

Thirty-eight CAF members, all males between the ages of 18 and 60 years (standard service age range in the CAF), with normal or corrected to normal vision participated in the study. The visual restriction was put in place due to the visual nature of the experiment.

Apparatus and stimuli

Participants performed the experimental task in the simulator as described above. They performed the shooting task in the seated position, with the weapon resting on the magazine, and the magazine resting on a sandbag (Figure 2). The height of the sandbag was adjusted for comfort by adding or removing layers of foam underneath.

There were two types of stimuli: an approximation of the standard NATO E-type training target and an animated hostile figure (as shown in Figure 1). The targets appeared briefly and moved across the scene perpendicular to the participant.

Procedure

Prior to the experimental session, participants were instructed to watch a training video showing different techniques for range estimation and engaging moving targets, derived from the Canadian Forces Operational Shooting Program. The video for participants in the ITS training condition contained a short supplement explaining the POA cue. The duration of the video was approximately 5 minutes.

Upon watching the video, participants started a warm-up session, consisting of engaging 20 different targets varying in speed and distance. During the warm-up session participants received training on how to handle the mock weapon and learned how to interpret the features of the digital sight. The warmup session was followed by Pre-training and Post-training test sessions, each lasting approximately 30 min. In between these sessions there was either a break or a training session, both lasting approximately 20 min, depending on the condition to which participants were assigned.

In the Pre- and Post-training test sessions, participants were presented with an outdoor scene consisting of two gaps in a long wall perpendicular to the participant. After a brief countdown, a virtual human target would run across one of the two gaps, providing a brief (4-8 seconds depending on target speed) opportunity for participants to engage it. Participants were instructed to engage the target as quickly and accurately as possible, but were limited to 8 rounds in their virtual weapon for each target presentation to discourage them from firing indiscriminately. The intention was for them to take deliberate aimed shots, otherwise the POA training would be largely irrelevant. The first round to hit the target ended the presentation and any additional hits were ignored. The Pre-training and Post-training sessions were identical for all three conditions.

Variables and Conditions

Within-subject variables There were 12 types of moving targets varying in speed (slow and fast), direction of movement (from left to right and vice versa), and distance to target (near, mid-range, and distant).

Between-subject condition Participants were randomly assigned to one of three groups: one experimental condition (using the MT-ITS trainer) or one of two control groups, namely standard CAF training, or a no-training, test-only condition. All three groups were shown an instructional video showing the basics of shooting moving targets.

No-training condition. For the “No-training” condition, participants received no training between the pre- and post-test sessions, taking a 20-minute break instead.

CAF training condition. The “CAF training” control condition consisted of practicing at engaging moving targets in a virtual shooting range scenario. Similar to the test scenario, participants were presented with a single target moving perpendicularly and were instructed to engage it as quickly and accurately as possible. Unlike the test scenario or the ITS training condition, the parameters for this condition were designed to represent basic moving target training that is possible with existing tools and techniques only. The targets approximated a standard NATO E-type silhouette target and the only feedback provided after each target presentation was the location of hits and the overall size of the hit grouping, reflecting the limited amount of information available from a physical range target. Participants were allowed to keep firing all 8 rounds in their weapon for each target presentation (i.e. the target did not fall after the first hit) to maximize learning opportunities. Each participant completed four repetitions with each type of target outlined above (12 targets varying in distance, speed, and direction of movement), gradually increasing in difficulty, followed by a block of 16 targets that appeared at pseudo-random distances, speeds, and directions. Target distances were randomly adjusted by ±20% of the standard values to provide more varied practice. The total time to complete the CAF training session was approximately 20 minutes.

ITS training. This training condition used the full MT-ITSto provide more detailed feedback to the participants in a virtual shooting range scenario. This scenario was similar to the CAF training scenario, except the target was a fully-animated virtual human, and all of the features of the ITS system were enabled (on-screen POA cue, target range and speed readouts, real-time hit feedback indicator, enhanced feedback screen). As shown in Figure 1, the enhanced feedback screen provides the locations of participant POA at each shot release relative to the correct system-calculated POA in addition to hit locations, grouping size, rate of fire, and some corrective verbal coaching based on their performance. All of the shot (point-of-aim) and hit (point-of-impact) data is individually labeled and numbered, unlike the CAF training feedback, which only shows unlabeled hits. Importantly, shots that missed the target are also captured in the feedback. The total time to complete the ITS training session was approximately 20 min.

Experimental hypotheses

The general hypothesis considered in this experiment was that training of any kind would improve marksmanship performance with moving targets relative to the No-training condition. We also hypothesized that the embedded MT-ITS would improve marksmanship with moving targets more than the CAF training condition, given its more systematic presentation of aiming cues and feedback.

RESULTS

Overall marksmanship performance

Throughout this section, the results will be reported using three dependent measures of performance: accuracy and efficiency of shooting as well as response time. Accuracy of shooting is a percentage of hits for each target. Considering that each target was presented 8 times, accuracy is calculated as (number of hits)/(number of targets presented)x100. Efficiency of shooting is defined as a mean number of shots to hit a target (from the first shot to the shot that hit the target included). This measure is related to accuracy, but sometimes it provides additional information that accuracy might obscure. For example, for easy-to-hit targets, the accuracy was often at 100%, but the number of shots would vary as participants often used more than one shot engaging these easy targets. Thus, the efficiency of shooting provides fine-grained details of performance in cases when accuracy fails to differentiate. The last variable collected was response time: the time lapsed from the onset of target appearance to the moment the target was shot. This measure was the noisiest due to internal variance in VBS2 timing; specifically, the onset of target appearance varied randomly (up to 2 sec), adding variance to the measure. When all three measures were consistent among each other, only accuracy was reported. The independent variables were: distance to target, speed of target, test session (i.e., the tests before and after the training period, or the rest period for the control group), and direction of target movement (left-to-right vs right-to-left).

Considering that the size of each group was relatively small, it is possible that participants' age, experience, education etc. might affect their marksmanship performance. While there were some differences among the three groups, no single demographic characteristic in any group was significantly different.

Distance and Speed. Our results showed that shooting performance was inversely related to distance to target and speed of target, consistent with marksmanship performance of soldiers at live shooting ranges (as observed by CAF marksmanship instructors). The results were analyzed in a mixed-measures ANOVA with four within-subjects factors (direction left-to-right and right-to-left--, distance x 3, speed x 2, test session x 2), and one between-subjects factor (training x 3; note that the effects of training condition are discussed separately below). All target-related effects were significant for all three dependent measures, except for direction of movement. Figure 3 shows how shooting accuracy decreases with distance and how target speed affects performance (Left Panel versus Right Panel of the figure). With regard to specific dependent measures, there was a steep drop in accuracy for shooting fast targets at distant targets, suggesting an interaction between speed and distance, which was confirmed by the ANOVA ($F(2, 36) = 77.52$, $p < .001$), showing that fast targets at distant targets were especially hard to hit. In terms of efficiency, mean number of shots to hit the target increased from 1.46 to 4.46 for slow targets and from 2.57 to 11.15 for fast targets.

Direction. Prior to this study, the anecdotal evidence provided by CAF shooting range instructors suggested that shooting moving targets from left to right is easier and more accurate than shooting from right to left due to less convenient motion (toward the body versus away from body for right-handed shooters). However, in our results, there was no effect of direction of movement on accuracy of shooting, efficiency of fire or response time to hit the target. Even when individual participants' data was reviewed, only two participants performed significantly better shooting left-to-right targets and one participant was better shooting right-to-left.

Performance according to training condition

There was no main effect of training condition in the ANOVAs reported above. However, there was an interaction between training condition, speed and testing session on accuracy, $F(2,36) = 4.49$, $p < .05$. To better understanding this interaction, we represent it in Figure 4 in terms of the training gain (i.e., difference score between the post- and pre-training test sessions) for each speed and training condition. As is shown in Figure 4, the ITS training condition showed consistent training gains for accuracy at both slow and fast target speeds, whereas the No-training (i.e., practice-only) condition exhibited a training gain mainly for fast targets, and the CAF training condition exhibited a gain mainly for slow targets only. Thus, our results suggest that different training interventions we examined might produce benefits only for specific target types, and that the MT-ITS might produce the most consistent improvements across target types.

DISCUSSION

The participants performed well shooting slow targets from near- and mid-distances. Performance was significantly worse for shooting fast targets at longer ranges: not only did average performance drop significantly, participants needed more time and used more shots (around 3.45 rounds on average up from 1.81 on average) to hit a single target. The study confirmed the pattern one would expect intuitively, and that is often reported by CAF marksmanship instructors: accuracy of shooting is often inversely related to the distance and speed of the moving target. However, the direction of target movement had no effect on performance, contrary to anecdotal reports. The experiment demonstrated that practicing shooting moving target in and of itself can have a beneficial effect on marksmanship performance, regardless of training received or the shooting experience of the participants. This result in itself is to be expected, but it is a good reminder of the various options that are available to maintaining marksmanship proficiency. Furthermore, this result allows us to better assess the gains observed with CAF and ITS training.

The study also showed that the MT-ITS improved performance over and above practice alone, and sometimes outperformed CAF training in this regard. However, MT-ITS advantage was not consistent across all target conditions, occurring primarily for the slower targets. Thus, while these results suggest that the MT-ITS may be an effective training tool under certain conditions, more work is required to understand how and to what extent it can be improved, and what role it could ultimately play in the CAF's small arms training programs. There are a number of specific questions that should be addressed by future research on the MT-ITS. For instance, it would be important to determine the relative contributions of its components (i.e., the target cueing technologies, the performance-based feedback function, or the instance-based training approach) to its effects on marksmanship performance, and which of these would result in the most performance gains if improved. Also, it would be important to determine why the MT-ITS was less effective at improving performance with distant and fast targets. Is it because of the inherent difficulty of shooting such targets? Is it because more training with the MT-ITS is required (i.e., because the training time in this study was suboptimal)? Or is it because the MT-ITS itself needs to be improved before more gains are observed? Finally, it remains to be determined whether the improvements observed with the MT-ITS transfer to the live firing range and more effective operational firepower.

Despite the questions that remain to be resolved about the ultimate worthiness of the MT-ITS as a training tool for marksmanship skills, the results of the study presented here show that the concept embodied by the MT-ITS is viable. Considering the advances in mobile, portable computing power that are expected to enable reliable assisted target cueing and ITS onboard "smart" rifles in the near future, the MT-ITS concept has good potential for supporting improved maintenance of marksmanship skills in the future in a relatively practical and inexpensive way, even in the face of possible limitations in training resources and personnel.

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FIGURES

Figure 1: Feedback provided by MT-ITS through weapon sight.

Figure 2: Virtual Immersive Soldier Simulator.

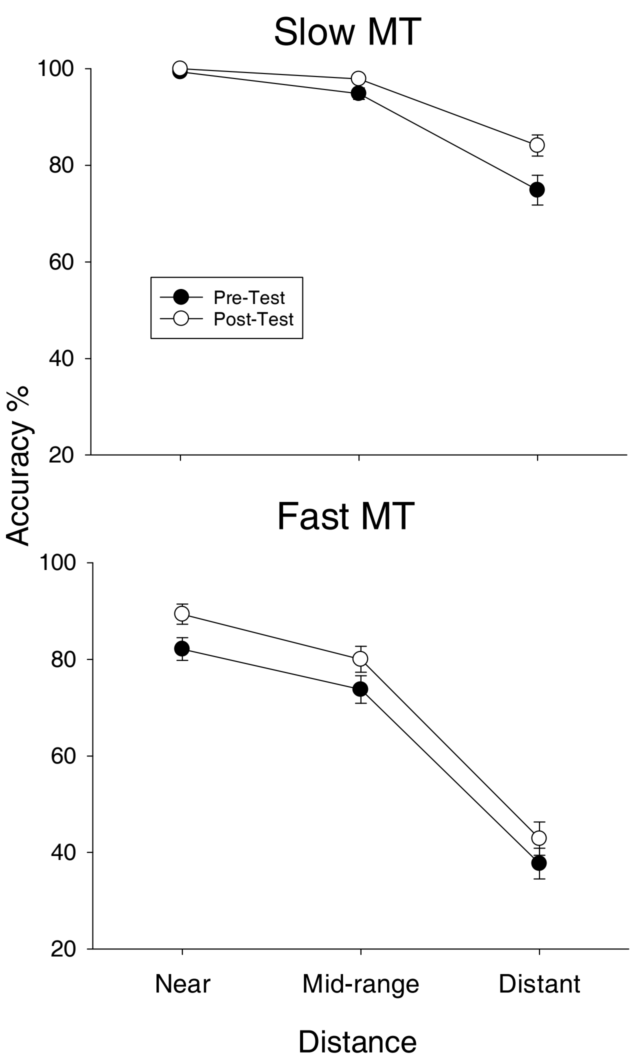

Figure 3. Shooting accuracy for slow moving targets (Top Panel) and fast moving targets (Bottom Panel) as a function of distance to the target, before and after training. Note. Error bars represent SEM.

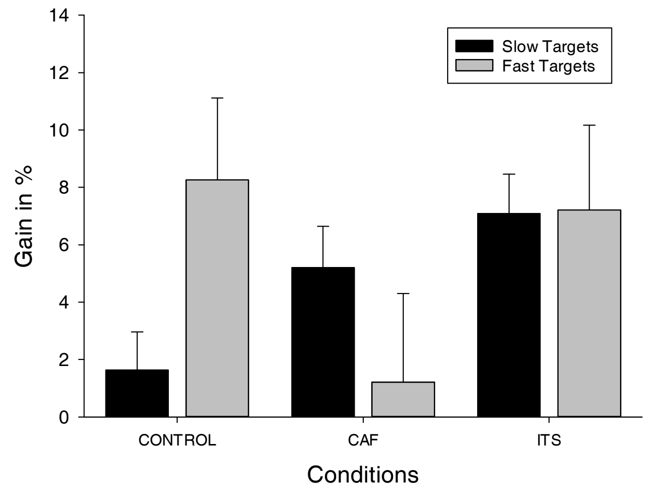

Figure 4. Shooting accuracy boosts for training conditions as a difference between Pre- and Post-sessions. Note. Error bars represent SEM.

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Intelligent Tutoring System, Moving Target, AI, Virtual Reality