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Individual Squad Weapon–Fire Control Testbed Development and Evaluation of Trigger Activation Zone Size and Dwell Time Effects on Shooting Performance

Patrick Wiley, William Harper, Jennifer Swoboda, Sam Ortega,
William Maslin, Richard Diego, and Andrew Tweedell

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| <p>A live-fire evaluation was conducted on trigger-release criteria combinations composed of two target activation zone (TAZ) dwell times and two TAZ sizes for the Individual Squad Weapon–Fire Control Testbed (ISW-FCT) assist mode in comparison with two shooting paradigms for legacy technology (M4 with rifle combat optic [RCO]) for midrange (100–300 m) targets. Results showed that the ISW-FCT with fire control (FC) criteria of a 5-inch radius TAZ size with 0.5-s TAZ dwell time performed equal to baseline (M4 with RCO) with the instructional paradigm “well-aimed shot” for expert shooters. This comes with a time penalty of approximately 1 s. The US Army Combat Capabilities Development Command Analysis Center provided FC technology design guidelines for optimal trigger-release criteria for midrange targets. This system could greatly benefit novice shooters, but the potential time penalty needs to be explored. The system could train shooters how to get on target quicker and stabilize the weapon for optimal accuracy of the first shot.</p> | | | | | |
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Contents

| | |
|--|-----------|
| List of Figures | v |
| List of Tables | v |
| 1. Introduction | 1 |
| 2. Methods | 2 |
| 2.1 Testing Location | 2 |
| 2.2 ISW-FCT Development | 3 |
| 2.3 Target Detection and Shot Location Measurement | 4 |
| 2.4 Trigger Control | 4 |
| 2.5 Trigger-Release Criteria and Overlays | 5 |
| 2.6 Validation of ISW-FCT V1.0 | 6 |
| 2.7 Participants | 6 |
| 2.8 Equipment | 7 |
| 2.9 Range Layout and Scenarios | 8 |
| 2.10 Conditions | 9 |
| 2.11 Procedure | 9 |
| 2.12 Data Analysis | 11 |
| 3. Results | 11 |
| 3.1 Direction of Muzzle Travel Effect on Group Radius and Radial Error | 11 |
| 3.2 Trigger Activation Zone Size | 12 |
| 3.3 Trigger Activation Zone Dwell Time | 14 |
| 3.4 Group Radius for All Six Conditions | 15 |
| 3.5 Radial Error for All Six Conditions | 16 |
| 3.6 Time to Shot (Engagement Time) | 17 |

| | |
|--|-----------|
| 4. Discussion | 19 |
| 4.1 Direction of Muzzle Travel | 19 |
| 4.2 Trigger Activation Zone Size | 19 |
| 4.3 Trigger Activation Zone Dwell Time | 19 |
| 4.4 Time to Shot (Engagement Time) | 20 |
| 4.5 Recommendations for Future Augmented Trigger Development | 20 |
| 5. Conclusion | 21 |
| 6. References | 22 |
| List of Symbols, Abbreviations, and Acronyms | 23 |

List of Figures

| | | |
|---------|--|----|
| Fig. 1 | DAC M-Range at Aberdeen Proving Ground, MD | 3 |
| Fig. 2 | ISW-FCT version 1.0..... | 3 |
| Fig. 3 | ArUco code mounted to target with a grid for shot location | 4 |
| Fig. 4 | ISW-FCT v1.0 trigger control system | 4 |
| Fig. 5 | ISW-FCT v1.0 auxiliary display of what the shooter sees | 5 |
| Fig. 6 | ISW-FCT v1.0 mounted to XY position table | 6 |
| Fig. 7 | Groups produced by various velocities of disturbed reticle fire | 6 |
| Fig. 8 | M4A1 carbine with M150 RCO | 7 |
| Fig. 9 | M150 RCO by Trijicon..... | 7 |
| Fig. 10 | Range layout for evaluation | 8 |
| Fig. 11 | Screenshot of shooter getting on target from the left hold aim point ... | 9 |
| Fig. 12 | Example shot registration from ArUco posters | 11 |
| Fig. 13 | Group radius and radial error for direction of muzzle travel from hold (values are not statistically different)..... | 12 |
| Fig. 14 | Group radius and radial error for TAZ size | 13 |
| Fig. 15 | Group radius and radial error for TAZ dwell time | 14 |
| Fig. 16 | Group radius error for all six fire conditions | 16 |
| Fig. 17 | Radial error for all six fire conditions..... | 17 |
| Fig. 18 | Time to shot for all six fire conditions..... | 18 |

List of Tables

| | | |
|---------|---|----|
| Table 1 | Sample for trial 1 right (hold right then get on target and fire at tone) | 10 |
| Table 2 | Sample for trial 2 left (hold left then get on target and fire at tone) | 10 |

1. Introduction

Legacy small arms fire control (FC) systems comprise optics integrated with aim-point assistance such as the red dot in the close combat optic and the bullet drop compensator in the rifle combat optic (RCO). Add-on components afford additional capabilities like ranging targets, producing thermal images, and illuminating targets during nighttime operations. The Army has identified a need to bring advanced FC technologies to the dismounted Soldier for increased lethality. Advances in technology have enabled FC technologies and systems to be developed to a size and weight suitable for small arms platforms like the M4 carbine (e.g., Smart Shooter).¹ These systems offer potential advantages in Soldier lethality by automating tasks, subtasks, or combinations of tasks in the Soldier's FC procedures. Systems can provide various levels of target detection, identification (ID), locking, and ranging with the capability to provide a firing solution in the form of an adjusted aim point via a disturbed reticle for optimal shot placement on the target lock. Adding capability to lock out the trigger until the disturbed reticle coincides with optimal shot placement may increase first shot hit percentage and accuracy. Many features are software driven and can allow for reconfiguration by the user as a system input. Further advancements could provide the capability to track, prioritize, and share multiple targets simultaneously.

Previous investigations by the US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) have found significant performance differences when using commercially developed augmented trigger systems. These commercial technologies focus on the algorithmic and mechanical solutions to the FC space but allow for little exploration of human-machine integration application to understand FC implications on operational performance. Technology-only solutions to small arms FC will continue to lag behind unautomated solutions and only provide trade-offs between speed, accuracy, and usability. Understanding how Soldiers interact with augmented trigger systems requires specific development and parameterization through experimentation.

The purpose of this effort was to compare the shooter in-the-loop performance for live-fire scenarios to characterize and evaluate various combinations of FC technologies and target management. The goal was to provide design guidelines for small arms FC technologies, tactics, techniques, and procedures for superior lethality by optimizing individual shooting performance and providing networked situational awareness for target prioritization and handoff for fire teams and squads.

A live-fire software and hardware rifle platform was developed to demonstrate and evaluate FC criteria for optimal trigger release that provides lethality equivalent or

greater than an expert shooter with legacy technology (M4 with RCO) at midrange (100–300 m) targets. Several iterations of design and pilot testing led to the development of the Individual Squad Weapon–Fire Control Testbed (ISW-FCT) version 1.0. The ISW-FCT version 1.0 included a fixed-magnification camera mounted to the M4 aligned to view ArUco code targets mounted to determine target ID, center of mass (CoM), and range as a form of simulated automated target recognition (ATR). This information was input into a software program to conduct ballistics calculations and provide visual overlays (including a disturbed reticle for elevation) to the shooter’s display. The program was also used to generate criteria for trigger control. The trigger control system consisted of wire linkage from the side-mounted servomotor to the safety. This provided a trigger interrupt function by rotating the safety out of the way of the trigger and allowed for trigger assist by rotating the safety with a connection to the trigger to fire the weapon.

This evaluation compared trigger-release criteria combinations composed of two target activation zone (TAZ) dwell times and two TAZ sizes for the ISW-FCT assist mode with two shooting paradigms for legacy technology (M4 with RCO) for midrange (100–300 m) targets. Note that in trigger-assist mode, the weapon would automatically fire once the shooter entered the TAZ and the dwell requirements were met. Measurements included grouping radius, radial error, and time to shot for all six conditions (see Section 2.10).

2. Methods

2.1 Testing Location

This development effort and evaluations were conducted at the DEVCOM Analysis Center (DAC) M-Range live-fire facility at Aberdeen Proving Ground, Maryland (Fig. 1).



Fig. 1 DAC M-Range at Aberdeen Proving Ground, Maryland

2.2 ISW-FCT Development

DAC created the ISW-FCT to evaluate FC technologies. The first version of an ISW-FCT was developed to demonstrate and evaluate FC criteria for optimal trigger release to deliver an accurate and timely shot. The development of ISW-FCT version (v) 1.0 included an M4 with a fixed-lens camera, a scope-mounted display, a trigger control system, and a PC to manage FC (Fig. 2). The PC serves to collate data, generate ballistic solutions, generate overlays for FC, and manage FC criteria for trigger control.

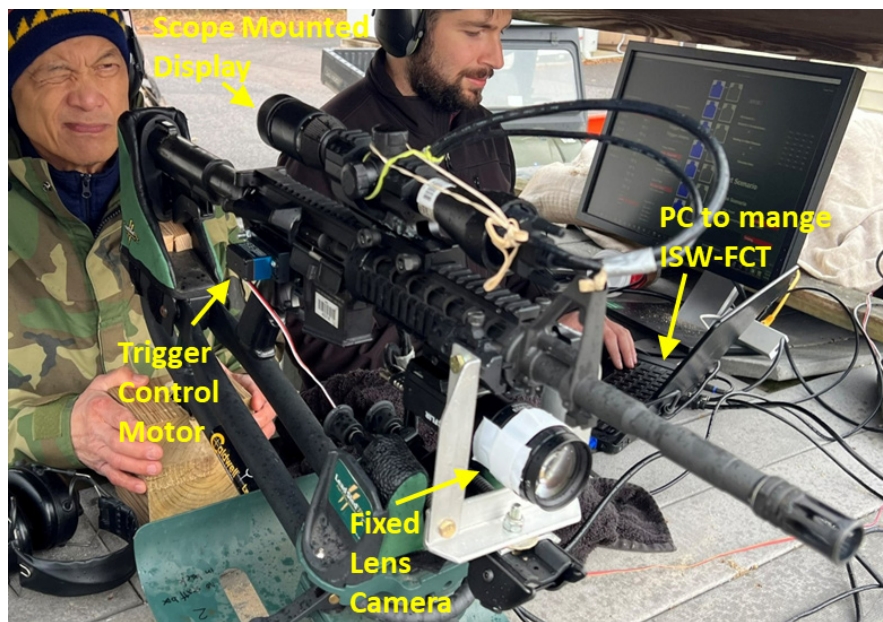


Fig. 2 ISW-FCT v1.0

2.3 Target Detection and Shot Location Measurement

ATR information was simulated by mounting an ArUco code onto the target (Fig. 3). When the ArUco is in the camera view, the custom software program determines target ID, CoM, and range as a form of simulated ATR. The software then performs ballistics calculations to provide visual overlays (including a disturbed reticle for elevation) to the shooter via a 1-inch-diagonal display configured as a scope.

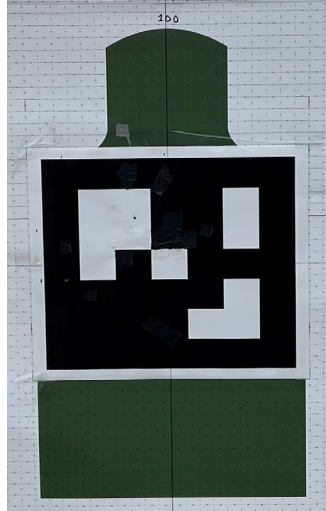


Fig. 3 ArUco code mounted to target with a grid for shot location

2.4 Trigger Control

The program was also used to generate criteria for trigger control. The trigger control system consisted of wire linkage from the side-mounted servomotor to the safety (Fig. 4). This provided a trigger interrupt function from the safety and allowed for trigger assist by rotating the safety out of the way of the trigger.



Fig. 4 ISW-FCT v1.0 trigger control system

2.5 Trigger-Release Criteria and Overlays

The trigger-release criteria are customizable in shape, size, and dwell time. In our evaluation, the shooter sees a disturbed reticle (i.e., red crosshair) that is corrected for range and a trigger-release criteria representation displayed as a yellow circle presented at the CoM of the E-type silhouette (Esil). During engagement, the shooter need only deliver the disturbed reticle to the yellow circle to enable the weapon to fire once all trigger-release criteria are met. For this evaluation, DAC chose criteria met when the crosshair enters the perimeter of a circle or entering the circle plus a dwell time within the circle. Figure 5 shows an auxiliary view of what the shooter sees for the ISW-FCT in trigger-assist mode: a disturbed reticle that is corrected for range and a trigger-release criteria shown as a 5-inch yellow circle. For evaluation purposes, two circle sizes (5- and 10-inch radius) centered about the Esil CoM were chosen, with two dwell times (0 and 0.5 s). Circles were chosen to present a symmetrical trigger release regardless of the muzzle travel direction, providing an equidistant crossing of the disturbed reticle relative to target CoM. Dwell times were also selected based on a live-fire pilot test that demonstrated a settling of muzzle velocity within the circle.

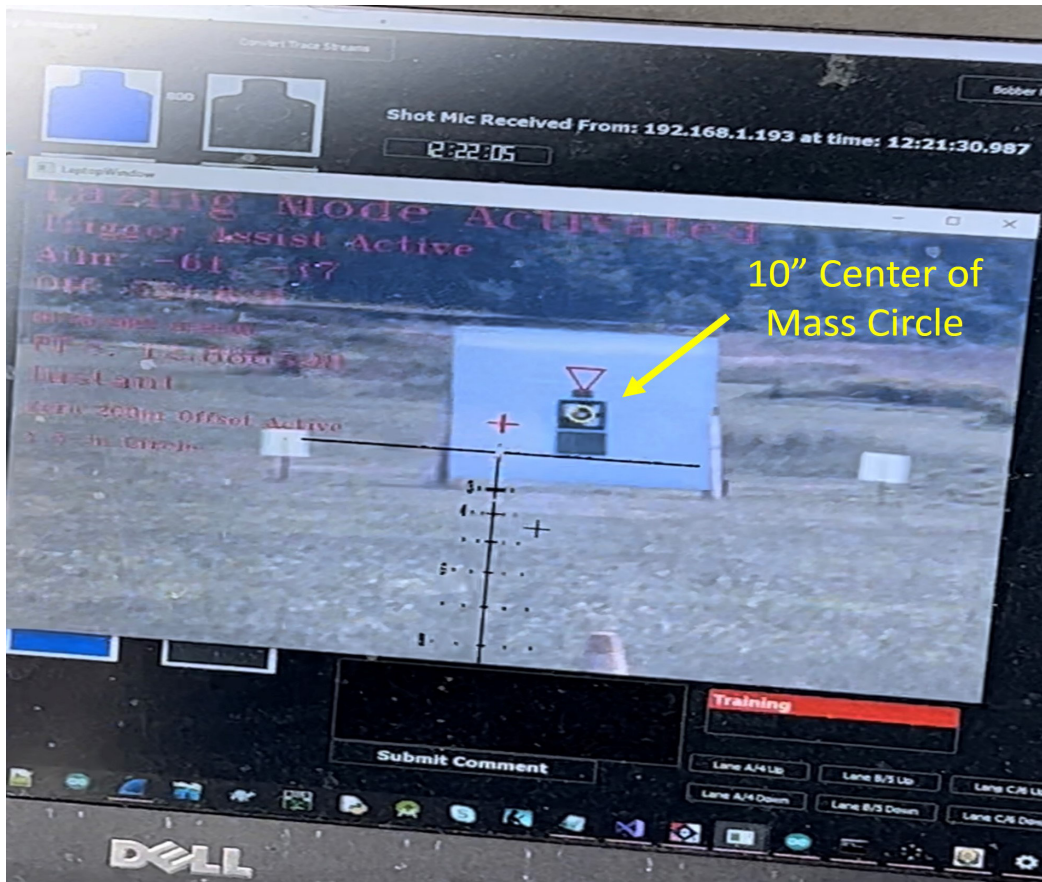


Fig. 5 ISW-FCT v1.0 auxiliary display of what the shooter sees

2.6 Validation of ISW-FCT V1.0

The capability of the system was verified through a live-fire pilot test using an XY positioning table (Fig. 6). Figure 7 shows groups produced by drifting through the TAZs. A zero was established by bumping the crosshairs across the zero TAZ to set scope settings for accurate shots, and then four trials were run for four steady-state velocities ($V_4 > V_3 > V_2 > V_1$).



Fig. 6 ISW-FCT v1.0 mounted to XY position table

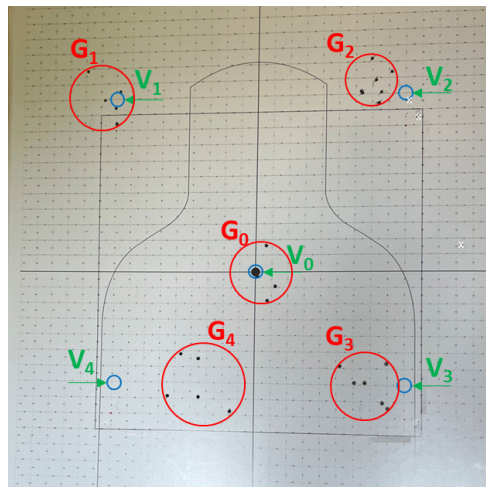


Fig. 7 Groups produced by various velocities of disturbed reticle fire

2.7 Participants

Five expert-level shooters participated in this evaluation. The protocol was approved by the ARL Institutional Review Board as nonhuman subject research. Each participant trained on the use of the ISW-FCT in assist mode and practiced on each of the six conditions. Live-fire target engagements were conducted to measure group radius, radial error, and engagement time for static Esil targets at 100, 200, and 300 m. The test was of minimal risk to participants (i.e., bug bites, ticks, sore hands and wrists). There was a risk of hearing damage if the participant did not properly wear the provided hearing protection. Test participants were provided a range safety briefing prior to firing on the range and the DAC

M-Range standard operating procedure was followed to ensure all test participants' safety. Test participants were told to wear hearing and eye protection whenever firing a weapon, and all personnel within 30 m of firing also were required to wear hearing protection. Lane safeties were responsible for ensuring that hearing and eye protection were used whenever firing occurred.

2.8 Equipment

The M4A1 carbine (Fig. 8) is a shorter and lighter variant of the M16A2 assault rifle. The M4A1 is a 5.56- × 45-mm NATO, air-cooled, direct impingement gas-operated, magazine-fed carbine. It has a 14.5-inch (370-mm) barrel and a telescoping stock.



Fig. 8 M4A1 carbine with M150 RCO

The M150 RCO is a 4 × 32 scope developed by Trijicon (Fig. 9). The RCO is designed for the M4, M16A2, M16A4, and M249 SAW machine gun in an automatic rifle role. It provides the shooter with quick target acquisition at close combat ranges (i.e., out to 150 m) while providing enhanced target ID and hit probability out to 800 m using 4× magnification and an etched-in bullet drop compensator.



Fig. 9 M150 RCO by Trijicon

The final ISW-FCT included an M4 with a fixed-lens camera, a scope-mounted display, a trigger control system, and a PC to manage FC. An XY positioning table was developed and used for vertical and horizontal steady-state movements of the

ISW-FCT system. Controlled movement of the disturbed reticle into the TAZ was established using a joystick or preprogrammed movements set in motion by a button push.

2.9 Range Layout and Scenarios

The DAC M-Range was set up to collect shooting performance from five expert shooters for each of the six conditions of FC systems (Fig. 10). Two trials of 18 target scenarios were run for each condition (6 targets at each range of 100, 200, and 300 m).

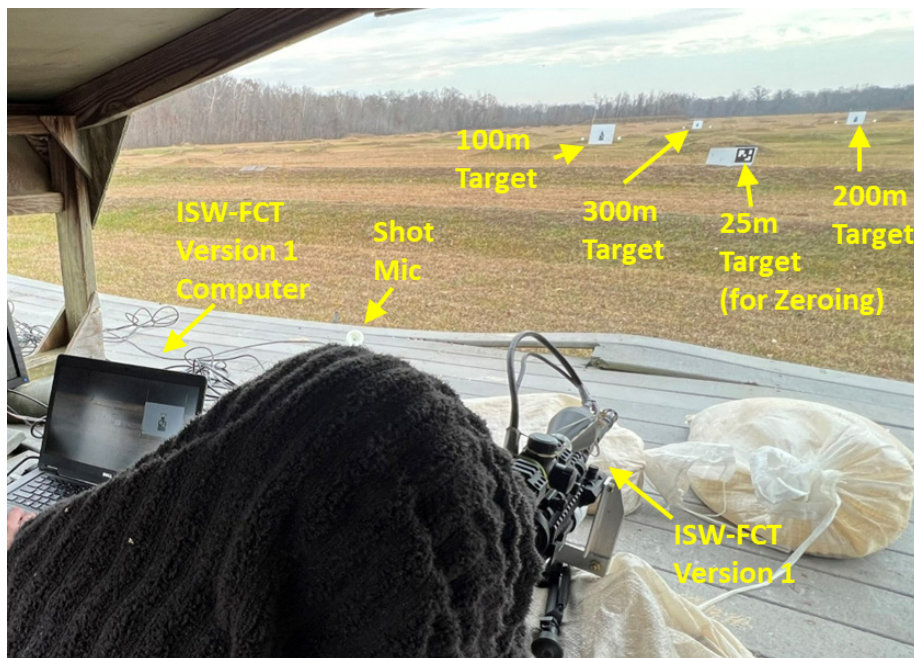


Fig. 10 Range layout for evaluation

Trial 1 was run with the starting hold aim point to the right of the targets, and trial two was run with the starting hold aim point to the left of the targets (Fig. 11). A tone was used to indicate when the shooter should transition from hold point to target. Fatigue was not an issue for shooters; the pace was slow and shooters were allowed to take a break whenever they wanted.

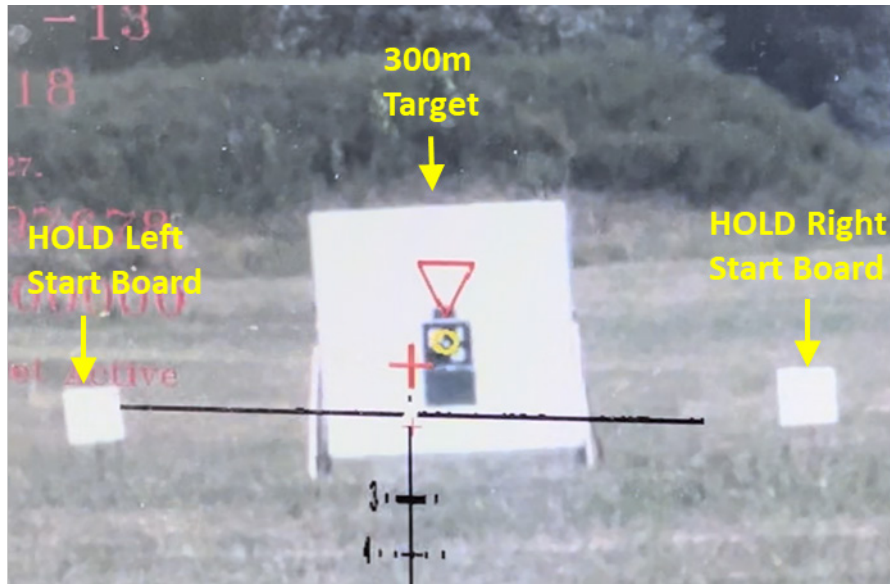


Fig. 11 Screenshot of shooter getting on target from the left hold aim point

2.10 Conditions

Conditions were as follows:

- 1) ISW-FCT in trigger-assist mode with 5-inch radius TAZ coupled with 0.0-s TAZ dwell time,
- 2) ISW-FCT in trigger-assist mode with 5-inch radius TAZ coupled with 0.5-s TAZ dwell time,
- 3) ISW-FCT in trigger-assist mode with 10-inch radius TAZ coupled with 0.0-s TAZ dwell time,
- 4) ISW-FCT in trigger-assist mode with 10-inch radius TAZ coupled with 0.5-s TAZ dwell time,
- 5) Baseline (M4 with RCO) with the instructional paradigm of “fast as you accurately can” (FAYAC), and
- 6) Baseline (M4 with RCO) with the instructional paradigm of “well-aimed shot” (WAS).

2.11 Procedure

The order of conditions was randomized for each participant. Right and left starting hold trials were run for each condition with a small break in between. Note that if a right trial was run the shooter would hold on to the Hold Right Start Board (Fig. 11) and wait for a tone before directing fire to the target directly left of the

hold board. Left trials were conducted similarly, but with opposite travel direction. Each trial provided six presentations for each of three ranges (100, 200, and 300 m) totaling 18 target opportunities. Tables 1 and 2 provide samples of what was run in condition 3 with the FAYAC paradigm. Between trials the weapon would be cleared, the shooter would take a break, and observers would identify and mark each shot as originating from the right or left.

Table 1 Sample for trial 1 right (hold right then get on target and fire at tone)

| Target | Notes | Target | Notes |
|--------|-------|--------|-------|
| 200R | | 300R | |
| 200R | | 100R | |
| 300R | | 100R | |
| 100R | | 200R | |
| 300R | | 300R | |
| 200R | | 100R | |
| 100R | | 100R | |
| 300R | | 300R | |
| 200R | | 200R | |

Table 2 Sample for trial 2 left (hold left then get on target and fire at tone)

| Target | Notes | Target | Notes |
|--------|-------|--------|-------|
| 100L | | 100L | |
| 200L | | 200L | |
| 100L | | 100L | |
| 300L | | 200L | |
| 200L | | 300L | |
| 200L | | 300L | |
| 100L | | 200L | |
| 300L | | 300L | |
| 300L | | 100L | |

Time-to-shot data were recorded from tone to shot registration by shot mic. Shot registration posters were collected after all six conditions were completed and replaced with fresh shot registration posters (Fig. 12). The shot location data were then manually transferred to a database.

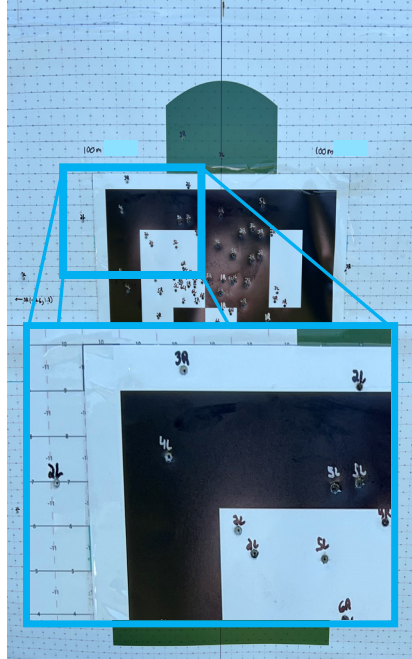


Fig. 12 Example shot registration from ArUco posters

2.12 Data Analysis

Shot location data was used to generate group radius for six shots taken from each muzzle travel direction, at each range, for every condition. The same shot location data was used to generate the radial error (shot location from CoM) for each shot taken from each direction, at each range, for every condition.² As this work is exploratory in nature, different within-subjects analyses of variance (ANOVAs) were utilized depending on the comparisons to determine the effectiveness of these parameters to capture differences in weapon firing for alternative trigger systems at each distance range separately. Firing performance was assessed for each range distance separately because the focus of this work is on the assistance technologies themselves and range distance naturally has a degrading impact on accuracy and precision.

3. Results

3.1 Direction of Muzzle Travel Effect on Group Radius and Radial Error

For group radius, three separate one-way ANOVAs yielded no significant difference between shots fired from muzzle travel direction of left compared with right at 100 m ($F [1, 4] = 0.110, p = 0.762$), 200 m ($F [1, 4] = 7.069, p = 0.076$), and 300 m ($F [1, 4] = 0.454, p = 0.549$) (Fig. 13). For radial error, an ANOVA

yielded no significant difference between shots fired from muzzle travel direction of left compared with right at 100 m ($F [1, 4] = 1.945, p = 0.257$), 200 m ($F [1, 4] = 0.832, p = 0.429$), and 300 m ($F [1, 4] = 0.326, p = 0.608$) (Fig. 13). There was no significant difference ($p > 0.05$) in group radius and radial error for muzzle travel direction for all ranges and conditions.

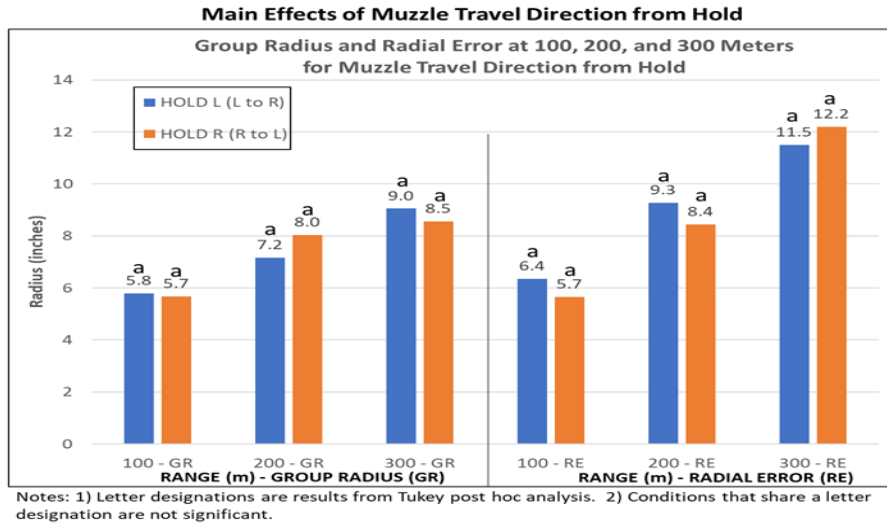


Fig. 13 Group radius and radial error for direction of muzzle travel from hold (values are not statistically different)

3.2 Trigger Activation Zone Size

Three separate within-subjects one-way ANOVAs determined if significant differences existed for group radius between conditions at 100 m ($F [3, 9] = 23.508, p < 0.001$), 200 m ($F [3, 9] = 11.449, p = 0.002$), and 300 m ($F [3, 9] = 3.917, p = 0.048$). A similar ANOVA determined if significant differences existed for radial error between conditions at 100 m ($F [3, 9] = 32.744, p < 0.001$), 200 m ($F [3, 9] = 3.541, p = 0.061$), and 300 m ($F [3, 9] = 2.984, p = 0.089$). For each range resulting in $\alpha < 0.05$, a Tukey post hoc test was performed to identify differences between conditions for group radius (Fig. 14).

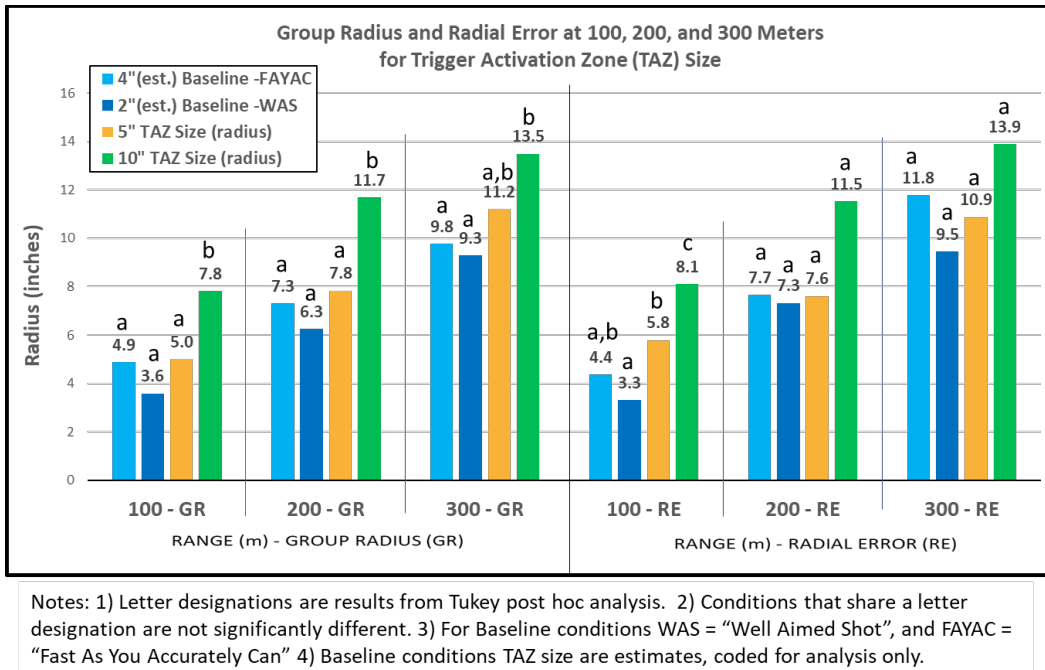


Fig. 14 Group radius and radial error for TAZ size

There was no difference in group radius at all three ranges when comparing any baseline condition to 5-inch radius TAZ. However, when the TAZ increased to 10 inches, the group radius was significantly greater than all other conditions at all three ranges. Combining the means of baseline FAYAC, baseline WAS, and 5-inch radius TAZ yielded a mean group radius of approximately 4.5 inches for 100-m targets, approximately 7.1 inches for 200-m targets, and approximately 10.1 inches for 300-m targets. Comparatively, the 10-inch radius TAZ yielded a larger group radius of approximately 7.8 inches for 100-m targets (~74% increase), approximately 11.7 inches for 200-m targets (~64% increase), and approximately 13.5 inches for 300-m targets (~34% increase).

A significant difference in radial error was found for 100-m targets. Baseline WAS had a best radial error at 3.3 inches and was statistically the same as baseline FAYAC with a group radius of 4.4 inches. The 5-inch radius TAZ yielded a radial error of 5.8 inches and was statistically different with approximately a 75% increase from baseline WAS but was not statistically different from baseline FAYAC. When the TAZ increased to 10 inches, the radial error was significantly greater at 8.1 inches. There was no significant difference between the 4 conditions (i.e., baseline WAS, baseline FAYAC, 5-inch radius TAZ, and 10-inch radius TAZ) for 200- and 300-m targets.

With respect to precision (represented by group radius), firing a weapon with an electronic trigger release with trigger-release criteria for a 5-inch radius TAZ is no

different than an expert shooter firing supported with a baseline weapon system (i.e., M4 with ACOG), regardless of engagement paradigm (WAS compared with FAYAC) for all three ranges.

With respect to accuracy (represented by radial error), firing a weapon with an electronic trigger release with a 5-inch radius TAZ is on par with an expert shooter firing supported with a baseline weapon system (i.e., M4 with ACOG) under the engagement paradigm of FAYAC at 100 m whereas increasing the TAZ to 10 inches yields poor accuracy. This effect was not observed for 200- and 300-m targets in the evaluation.

3.3 Trigger Activation Zone Dwell Time

Three separate within-subjects one-way ANOVAs determined if significant differences existed for group radius between conditions at 100 m ($F [3, 9] = 25.293$, $p < 0.001$), 200 m ($F [3, 9] = 22.708$, $p < 0.001$), and 300 m ($F [3, 9] = 8.554$, $p = 0.005$). A similar ANOVA also was performed to determine if significant differences existed for radial error between conditions at 100 m ($F [3, 9] = 25.356$, $p < 0.001$) and 200 m ($F [3, 9] = 5.203$, $p = 0.023$). For each range resulting in $\alpha < 0.05$, a Tukey post hoc test was performed to identify differences between conditions for group radius (Fig. 15).

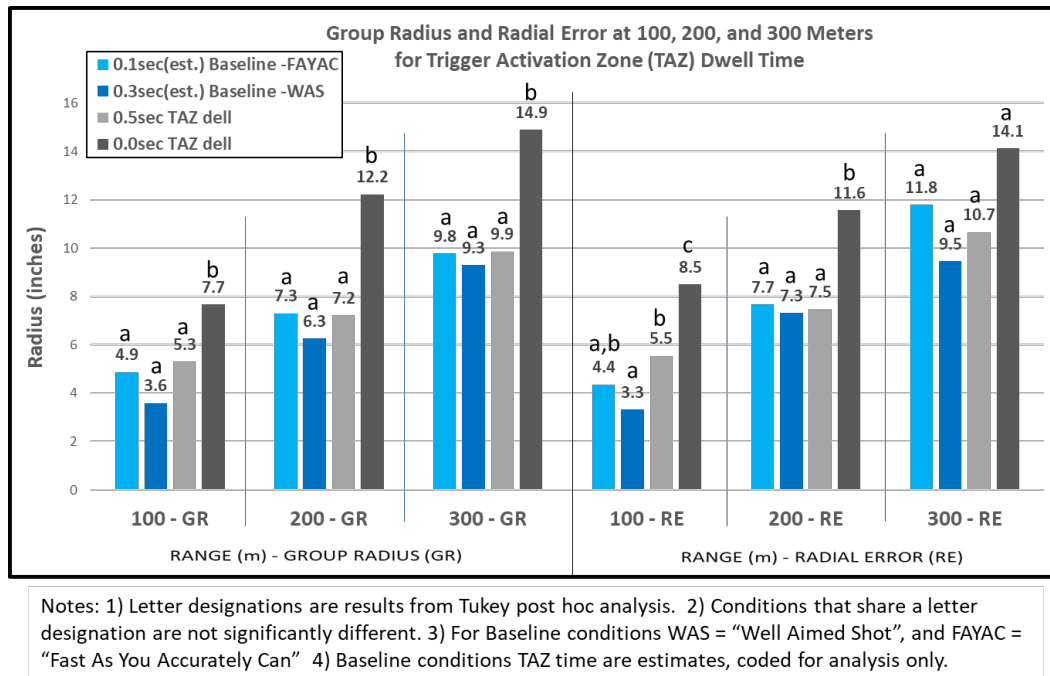


Fig. 15 Group radius and radial error for TAZ dwell time

There was no difference in group radius at all three ranges when comparing any baseline condition to a 0.5-s TAZ dwell time. However, when the TAZ dwell time

is 0.0 s, the group radius is significantly greater for all three ranges. Combining the means of baseline FAYAC, baseline WAS, and 5-inch radius TAZ yielded a mean group radius of approximately 4.6 inches for 100-m targets, approximately 6.9 inches for 200-m targets, and approximately 9.3 inches for 300-m targets. Comparatively, the 10-inch radius TAZ yielded a larger group radius of 7.7 inches for 100-m targets (~67% increase), approximately 12.2 inches for 200-m targets (~77% increase), and approximately 14.9 inches for 300-m targets (~55% increase).

A significant difference in radial error was found for 100-m targets. Baseline WAS had a best radial error at 3.3 inches and was statistically the same as baseline FAYAC with a radial error of 4.4 inches. A 0.5-s dwell time yielded a radial error of 5.5 inches and was statistically different (~77% increased) from baseline WAS but not statistically different from baseline FAYAC. At 200 m, a 0.0-s dwell time yielded a radial of 11.6 inches and was statistically different (~55% increased) from the means of baseline FAYAC, baseline WAS, and a 0.5-s dwell time, with a mean radial error of 7.5 inches. There was no significant difference in radial error between the four conditions (i.e., baseline WAS, baseline FAYAC, 0.5-s TAZ dwell time, and 0.0-s TAZ dwell time) for 300-m targets.

With respect to precision (represented by group radius), firing a weapon with an electronic trigger release with trigger-release criteria of a 0.5-s TAZ dwell time is no different than an expert shooter firing supported with a baseline weapon system (i.e., M4 with ACOG) for all three ranges. A 0.0-s TAZ dwell time makes for poor precision for all three ranges.

With respect to accuracy (represented by radial error), firing a weapon with an electronic trigger release with trigger-release criteria of a 0.5-s TAZ dwell time is on par with an expert shooter firing supported with a baseline weapon system (i.e., M4 with ACOG) under the engagement paradigm of FAYAC for 100 m whereas using a 0.0-s TAZ dwell time of yields poor accuracy. This effect was not observed for 200- and 300-m targets in the evaluation.

3.4 Group Radius for All Six Conditions

Three separate within-subjects one-way ANOVAs determined if significant differences existed for group radius between conditions at 100 m ($F [5, 15] = 14.493, p = 0.001$), 200 m ($F [5, 15] = 14.406, p = 0.001$), and 300 m ($F [5, 15] = 6.665, p = 0.002$). For each range resulting in $\alpha < 0.05$, a Tukey post hoc test was performed to identify differences between conditions for group radius (Fig. 16).

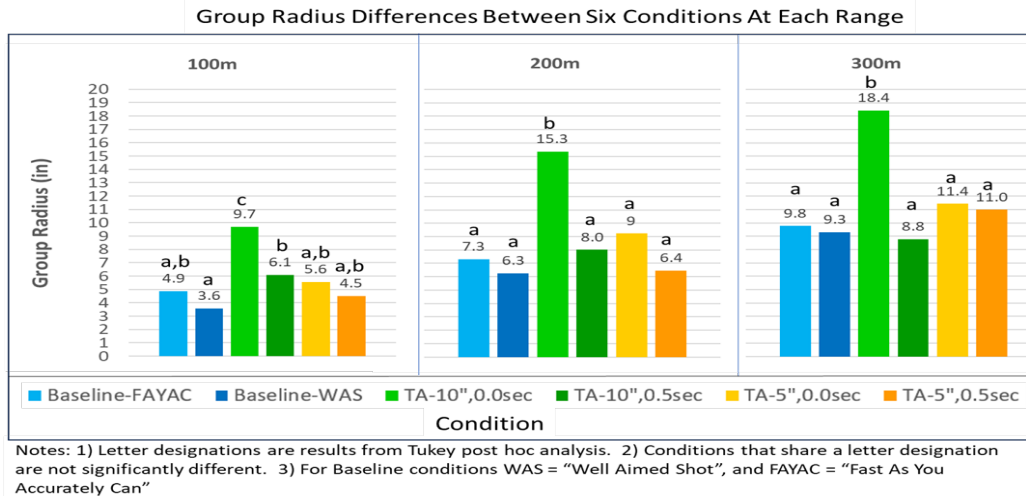


Fig. 16 Group radius error for all six fire conditions

There was a significant difference ($p < 0.05$) between all 6 FC conditions for group radius for each range (100, 200, and 300 m). For targets at 100 m, the best group radius was achieved by both baseline conditions and both trigger-assist mode with a TAZ size 5-inch radius, with an average group radius of 4.63 inches that is significantly different when compared with trigger-assist modes with a TAZ size 10-inch radius (with no dwell time and with a dwell time of 0.5 s) increasing the group radius to an average of 7.89 inches.

For targets at 200 m, the group radius was statistically the same for five of the six conditions with an average group radius of 7.45 inches, while one condition (trigger-assist mode with a TAZ size 10-inch radius coupled to a dwell time of 0.0 s) is statistically greater with a group radius of 15.35 inches.

For targets at 300 m, the group radius was statistically the same for five of the six conditions with an average group radius of 10.05 inches, while one condition (trigger-assist mode with a TAZ size 10-inch radius coupled to a dwell time of 0.0 s) is statistically greater with a group radius of 18.43 inches.

3.5 Radial Error for All Six Conditions

Three separate within-subjects one-way ANOVAs determined if significant differences existed for radial error between conditions at 100 m ($F [5, 15] = 17.225$, $p = 0.001$), 200 m ($F [5, 15] = 5.812$, $p = 0.004$), and 300 m ($F [5, 15] = 2.661$, $p = 0.065$). For each range resulting in $\alpha < 0.05$, a Tukey post hoc test was performed to identify differences between conditions for group radius (Fig. 17).

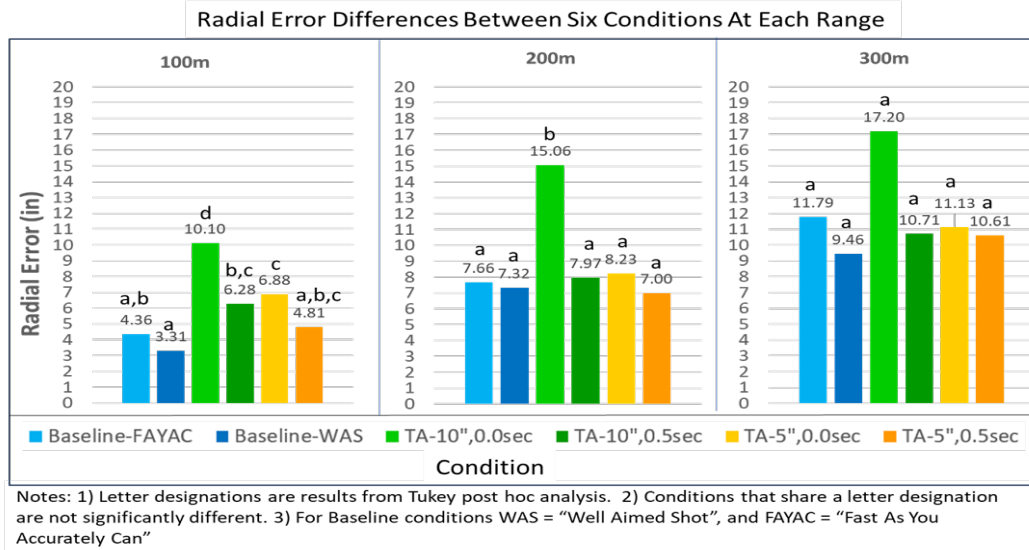


Fig. 17 Radial error for all six fire conditions

There was a significant difference between all six FC conditions for radial error for 100- and 200-m targets. The trend was the same but without significance for 300-m targets. For targets at 100 m, the best radial error was achieved by both baseline conditions and trigger-assist mode with a 5-inch radius TAZ coupled with a 0.5-s dwell time with a mean radial error of 4.83 inches. The next level of acceptable radial error was achieved through trigger-assist mode with a 10-inch radius TAZ coupled with a 0.5-s dwell time with a radial error of 6.28 inches, followed by trigger-assist mode with a 5-inch radius TAZ coupled with a 0.0-s dwell time with a radial error of 6.88 inches. The largest radial error is produced by trigger-assist mode with a 10-inch radius TAZ coupled with a 0.0-s dwell time increasing the radial error to 10.1 inches.

For targets at 200 m, the radial error was statistically the same for 5 of the 6 conditions with a mean group radius of 7.64 inches, while 1 condition (i.e., trigger-assist mode with a 10-inch radius TAZ coupled with a 0.0-s dwell time), is statistically greater with a group radius of 15.06 inches. For targets at 300 m, all 6 conditions were statistically the same ($p = 0.065$).

3.6 Time to Shot (Engagement Time)

Three separate within-subjects one-way ANOVAs determined if significant differences existed between conditions at 100 m ($F [5, 15] = 15.196, p = 0.001$), 200 m ($F [5, 15] = 15.196, p = 0.001$), and 300 m ($F [5, 15] = 15.196, p = 0.001$). For each range resulting in $\alpha < 0.05$, a Tukey post hoc test was performed to identify differences between conditions for time to shot (Fig. 18).

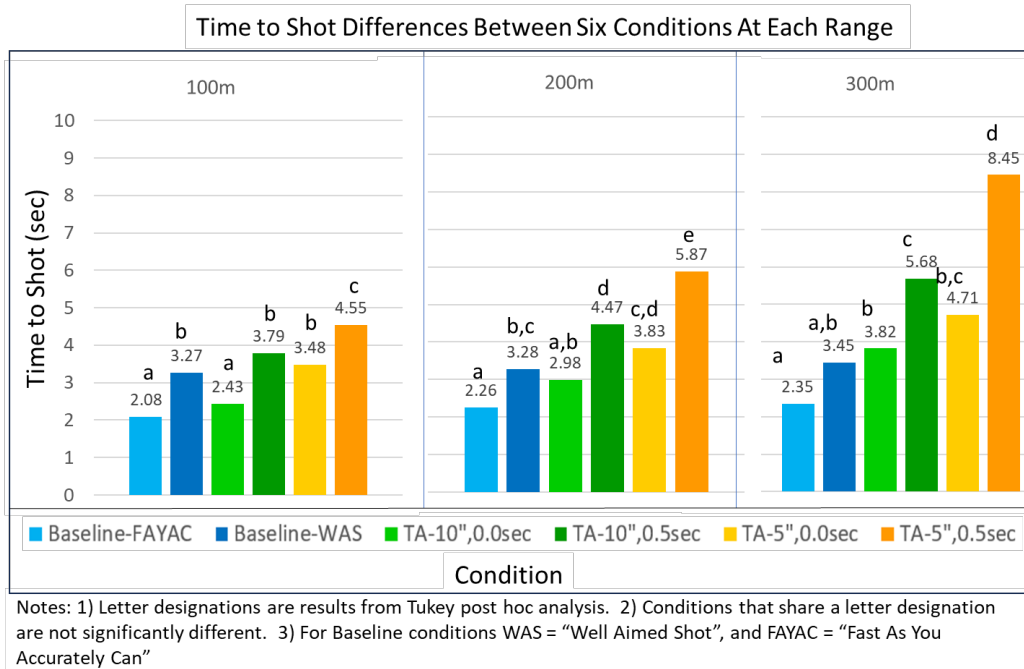


Fig. 18 Time to shot for all six fire conditions

There was a significant difference ($p < 0.05$) between all six FC conditions for time to shot for all three ranges. For targets at 100 m, the best time to shot was achieved by baseline FAYAC and trigger-assist mode with a 10-inch radius TAZ coupled with a 0.0-s dwell time with a mean of 2.25 s. Baseline WAS, trigger-assist mode with a 5-inch radius TAZ coupled with a 0.0-s dwell time, and trigger-assist mode with a 10-inch radius TAZ coupled with a 0.5-s dwell time had a mean time to shot of 3.51 s (a 1.26 s increase) at 100 m. Also at 100 m, trigger-assist mode with a 5-inch radius TAZ coupled with a 0.5-s dwell time had a time to shot of 4.55 s (an additional 1.03 s increase or 2.29 s over the best time-to-shot performer).

For targets at 200 m, the best time to shot was achieved by baseline FAYAC at 2.26 s. Trigger-assist mode with a 10-inch radius TAZ coupled with a 0.0-s dwell time was at 2.98 s, closely followed by baseline WAS at 3.28 s, trigger-assist mode with a 5-inch radius TAZ coupled with a 0.0-s dwell time at 3.83 s, and trigger-assist mode with a 10-inch radius TAZ coupled with a 0.5-s dwell time at a mean time to shot of 4.47 s. Coming in last for the 200-m target was trigger-assist mode with a 5-inch radius TAZ coupled with a 0.5-s dwell time with a time to shot of 5.87 s.

For targets at 300 m, the best time to shot was achieved by baseline FAYAC at 2.35 s. Next were baseline WAS at 3.45 s, trigger-assist mode with a 10-inch radius TAZ coupled with a 0.0-s dwell time at 3.82 s, trigger-assist mode with a 5-inch radius TAZ coupled with a 0.5-s dwell time at 4.71 s, and trigger-assist mode with

a 10-inch radius TAZ coupled with a 0.5-s dwell time at 5.68 s. Coming in last for the 300-m target was trigger-assist mode with a 5-inch radius TAZ coupled with a 0.5-s dwell time with a time to shot of 8.45 s.

4. Discussion

4.1 Direction of Muzzle Travel

Data was collected and analyzed to compare starting points from the right and left sides of the target in the manner described in Section 2.11. There was no significant difference in group radius and radial error for muzzle travel direction for all ranges and conditions. Future evaluations can avoid the need to consider direction of muzzle travel with respect to shot location at target plane for supported firing postures. However, firing unsupported would still need to be considered for evaluations.

4.2 Trigger Activation Zone Size

There is no difference in group radius or radial error when comparing baseline condition with trigger-assist mode with a 5-inch radius TAZ at all three ranges. Regardless of dwell time, using trigger-assist mode with a 5-inch radius TAZ produces the same results for precision and accuracy as an expert shooter while taking their time for a WAS and firing an M4 carbine with an ACOG sight in a supported posture.

However, when the TAZ radius increases to 10 inches, the group radius is significantly greater than any baseline condition for all three ranges. This effect increases with range; for trigger-assist mode set with a TAZ 0.0-s dwell time it yields a group radius of 11.7 inches at 200 m and 13.5 inches at 300 m. For radial error, this effect is the same for 100-m targets and has a similar trend for 200- and 300-m targets. Considering that the width of an Esil target is approximately 20 inches wide, using a trigger-assist mode with a 10-inch radius TAZ results in poor precision and accuracy for ranges of 100, 200, and 300 m.

4.3 Trigger Activation Zone Dwell Time

There is no difference in group radius when comparing any baseline condition with trigger-assist mode with a TAZ 0.5-s dwell time for all three ranges. Regardless of TAZ size, using trigger-assist mode with a TAZ 0.5-s dwell time produces the same results for precision as an expert shooter while taking their time for a WAS and firing an M4 carbine with an ACOG sight in a supported posture.

For radial error, the trend was the same when comparing any baseline condition with trigger-assist mode with a 0.5-s dwell time for all three ranges, but not significant. Inclusion of a lower-level shooting group would probably induce the same effect for radial error that is seen in group radius.

However, the group radius is significantly higher than any baseline condition for all ranges when the dwell time is 0.0 s. This effect increases with range and the group radius for trigger-assist mode set with a 0.0-s dwell time yields 12.2 inches at 200 m and 14.9 inches at 300 m. For radial error, this effect is the same for 100- and 200-m targets and has a similar trend for 300-m targets. Considering that the width of an Esil target is approximately 20 inches wide, using a trigger-assist mode set with a 0.0-s dwell time results in poor precision and accuracy for ranges of 100, 200, and 300 m.

4.4 Time to Shot (Engagement Time)

Regardless of distance, smaller TAZ sizes and longer dwell times increased the time to shot. While this resulted in only 1 to 2 s increases for 100 and 200 m, a 4-s increase was observed for the 300-m condition. It is anticipated this trend would continue for further distances unless variable zoom optics were integrated into the system.

4.5 Recommendations for Future Augmented Trigger Development

A suggestion for future research is to evaluate effects on precision as defined by group radial standard deviation. The methods for collecting this data (using paper at range to accrue bullet holes) results in highly accurate data at the cost of time to collect and then process it. Alternative methods, including acoustics systems for bullets that are in supersonic flight, should be considered. Also, the digital display for the ISW-FCT could be upgraded to work well in daylight conditions. Upgrades should consider a pivot from a camera-based system to the use of a variable-zoom optic to increase shooter performance and allow engagements beyond 300 m. An upgraded weapon with a better minute of angle than the M4 should also be considered.

Near-term research should focus on the tradeoff space between TAZ size and dwell time and include unsupported shooting postures. Perhaps consider inclusion of several TAZ sizes in and around 5 inches. Consider using dynamic TAZ size (above 2 inches and well under 10 inches) that increases with range. Concurrent research could focus on the addition of display or auditory aids to assist shooters with expedient and smooth transitions to target. Future research should focus on

gathering real-time data from the aim point path to govern dynamic TAZ criteria for superior precision and accuracy in a timely manner.

Finally, a higher number of participants would likely enhance the effects of this evaluation, and the inclusion of a lower-level shooting group would allow for generalization to the Army populace and help identify gaps or methods for enhanced training.

5. Conclusion

The testbed successfully demonstrated the ability to control and parameterize various FC criteria for investigating the effectiveness of alternative trigger systems. The results suggest that technology-only trigger solutions for small arms FC, where software and hardware are developed without regard to their specific interaction with the operator, can lead to ineffective platforms. Furthermore, context must also be considered. Currently, an interrupted trigger system does not understand and adapt to the differences between longer range shots where time may not be a factor and closer range scenarios where speed is likely more critical than accuracy. As can be seen from our results, the increased lethality (accuracy and precision) had diminishing returns as targets got closer and shot priorities (speed compared with accuracy) changed. It is recommended that hardware and software for advanced small arms FC be developed in parallel with specific experimentation to understand human and contextual effects on performance, beyond just a human factors approach.

The issues and recommendations above will become even more critical for small unit federated FC environments within networked battlefields. This specific scenario was beyond the scope of the current experimentation, but it does highlight the cascade of effects ineffective FC technologies could have on higher echelon operations.

6. References

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2. Johnson RF. Statistical measures of marksmanship. Army Research Institute of Environmental Medicine (US); 2001 Feb. Report No.: TN-01/2. <https://apps.dtic.mil/sti/tr/pdf/ADA387108.pdf>

List of Symbols, Abbreviations, and Acronyms

| | |
|---------|---|
| ANOVA | analysis of variance |
| ARL | Army Research Laboratory |
| ATR | automated target recognition |
| CoM | center of mass |
| DAC | DEVCOM Analysis Center |
| DEVCOM | US Army Combat Capabilities Development Command |
| Esil | E-type silhouette target |
| FAYAC | fast as you accurately can |
| FC | fire control |
| ID | identification |
| ISW-FCT | Individual Squad Weapon–Fire Control Testbed |
| NATO | North Atlantic Treaty Organization |
| PC | personal computer |
| RCO | rifle combat optic |
| SA | situational awareness |
| TAZ | trigger activation zone |
| WAS | well-aimed shot |