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The Effects of Physical Impairment on Shooting Performance

by Jennifer C. Swoboda, William Harper, Frank Morelli, and Patrick Wiley

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Jennifer C. Swoboda, William Harper, Frank Morelli, and Patrick Wiley
Human Research and Engineering Directorate, ARL

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14. ABSTRACT

This study was conducted to support improvements to the models used to support the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) program. The goal of this research study was to provide data to support verification and validation (V&V) of human performance modeling for task-based impairment within the Operational Requirement-Based Casualty Assessment (ORCA) model. Using human factors methods, we generated data to artificially simulate elemental capability degradation (e.g., vision, hand use) and measured task performance ability. For the aimed portion (50–300-m, foxhole supported firing position), hit percentage data showed significant differences for range to target only. While expected for the closest (50 m) and furthest (300 m) ranges, no significant differences appeared in the reflexive portion (10- and 25-m, standing unsupported with the weapon in low ready position) nor were there any other significant differences for hit percentage data. As expected, target radial error for the aimed and reflexive positions increased as range increased. Physical impairment of the shooters' dominant side significantly affected target engagement time. It took longer to engage the target when the dominant side was impaired, forcing shooters to fire from their non-dominant side. For the aimed position, range to target and impairment condition showed an interaction, i.e., at shorter ranges, impairment affected the target engagement time significantly, while at longer ranges, where performance is already decremented (due to range), impairment had less of an effect.

15. SUBJECT TERMS

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1. Project Background

The U.S. Army has funded a large-scale program, Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC). JTAPIC is a partnership whose purpose is to collect, integrate, and analyze operational and injury data. The main mission of the JTAPIC program is to conduct rapid, scientifically and medically based analyses of injuries sustained in combat; evaluate the effectiveness of personal protective equipment and vehicle crew protection systems; and translate the findings into guidance for system developers to guide improvements that alter the performance envelopes of protection systems. Its goal is to improve our understanding of vulnerabilities to threats and enable the development of improved tactics, techniques, and procedures (TTPs) and materiel solutions to prevent or mitigate traumatic injuries.

This study was conducted to support improvements to the models used to support the JTAPIC program. The goal of this effort was to improve human performance modeling for task-based impairment and provide data to support verification and validation (V&V). Specifically, information gathered from this experiment will be used to guide improvements to the operational capability requirements within the Operational Requirement-Based Casualty Assessment (ORCA). Data were generated using human factors methods to artificially simulate elemental capability degradation (e.g., vision, hand use) and measure the ability to perform tasks. These volunteers were asked to perform a shooting task, which under normal circumstances requires the use of hands and eyes, and were evaluated on their performance. These data will serve to verify and validate the elemental capability requirements for shooting tasks and the effect of visual and hand impairment.

Little research has been conducted examining the effects of physical impairment on shooting performance. In fact, after an extensive literature review, there was no literature that investigated impairment of a hand or arm and the effect it would have on shooting performance. Similarly, there has been little research examining visual impairment and shooting performance. Hatch, Hilber, Elledge et al.[1] investigated the effects of visual acuity on target discrimination and marksmanship. Specifically of interest was what visual acuity level is needed for a military member to shoot effectively during combat. Results indicated that vision readiness standards of 20/40 or better corrected or uncorrected is the transition point for performance in target discrimination and marksmanship ability.

The goal of this study was to characterize shooting performance during simulated impaired hand and impaired vision conditions. The results of this study will contribute to the adjustment of task

[1] Hatch, B. C.; Hilber, D. J.; Elledge, J. B.; Stout, J. W.; Lee, R. B. The Effects of Visual Acuity on Target Discrimination and Shooting Performance. *Optometry and Vision Science* **2009**, *86*, 1359–1367.

descriptions or adjustment of the capability scales used in human performance modeling for task-based impairment.

2. Synopsis

The physical impairment of a Soldier during a mission will likely change the Soldier's ability to aim and fire a weapon. This study examined the effects of an artificially impaired hand and eye on shooting performance. These physical impairments simulated scenarios where a Soldier injured in combat is still required to complete the mission. The ability to aim and shoot, with artificially restricted hand use and artificially impaired vision, was evaluated. Two shooting tasks were completed: aimed shooting, in which targets are presented at 50, 100, 200, and 300 m and shooters are in a foxhole supported position; and reflexive shooting, in which targets are presented at 10 and 25 m and shooters are in a standing, unsupported position with weapon at the low ready. The shooting tasks encompassed firing at targets under time-pressure, with and without physical impairment. The main goal of this study was to determine how an artificially impaired hand and artificially impaired vision affects shooting performance under a time stress. The results of this study will be used to verify and validate capability requirements used in human performance modeling for shooting and the effect of impairment.

3. Participants

Fifteen members of the Department of Defense (DoD) Special Response Team (SRT) stationed at Aberdeen Proving Ground, MD, participated in this study. Participants were not required to have any specific Military Occupational Specialty (MOS), though for the purposes of this study, they were required to be experienced shooters that have successfully qualified with an M4 within the past year. Most of these personnel are prior-service military and train in shooting frequently.

3.1 Pretest Orientation and Volunteer Agreement

Test participants were given an orientation on the study's purpose and the details of their participation. They were briefed on the experimental objectives and procedures, told how results would be used, and told what benefits the military can expect from this investigation. Any questions the participants had regarding the study were answered. The test participants were then asked to complete an Informed Consent Form. Its contents were explained verbally, and participants were asked to read and sign the form if they decided to participate. Test participants were informed that they could withdraw from participation at any time without prejudice, though no participants decided to withdraw over the course of this study. Participants were also asked for permission to photograph or videotape their experimental sessions.

3.2 Demographics and Visual Acuity

Demographic and visual acuity data were taken on each participant. Participants provided their personal demographic information using the Demographic Data Form (appendix A). Participants ranged in age from 28 to 46 years. Visual acuity was measured for each participant using a Titmus vision testing apparatus. Corrected monocular visual acuities for both far and near distances were measured and recorded. Each participant had minimum correctable vision of 20/20 in one eye and 20/100 in the other eye, which is the current visual requirement for infantry. Five participants were aided by corrective contact lenses. Ocular dominance was determined using the sighting method. Participants were also asked their normal shooting eye and shooting handedness.

All experimental participants were experienced tactical police officers. They have held this position ranging from 3 to 12 years. All participants were male, and all had qualified within the last year using the M4 carbine (all 15 at the *expert* level [score of 170–200 on the standard weapons qualification course]). Though experimental trials only occurred during daylight hours, no participants reported any difficulty seeing objects during the day or night. Ten of the 15 participants reported prior experience using a wide range of rifle optics, to include the M68 close combat optic (CCO) employed in this study, as well as the Trijicon advanced combat optical gunsight (ACOG), an alternate and common weapon optic used within the armed services. Two of the 15 participants were left-handed, two reported being ambidextrous, and two expressed left-eye dominance.

3.3 Anthropometry

Anthropometric data were collected from each participant. Summary anthropometric statistics are shown in table 1.

Table 1. Summary anthropometric statistics collapsed across experimental participants.

	N	Minimum	Maximum	Mean	Standard Deviation
Height (cm)	15	162.2	188.0	174.7	7.7
Weight (kg)	15	74.0	113.2	91.4	12.7
Interpupillary breadth (mm)	15	57.5	71.0	63.5	3.8
Hand length (cm)	15	17.5	20.4	18.9	0.9
Wrist-center grip length (cm)	15	6.3	9.1	7.3	0.8
Wrist-wall length (cm)	15	59.6	75.1	65.9	3.6
Wrist-wall length, extended (cm)	15	68.6	86.3	79.0	4.7
Grip diameter, inside (cm)	15	13.7	18.0	16.3	1.3
Grip strength – left (kg)	15	42.0	81.3	64.7	9.8
Grip strength – right (kg)	15	48.7	80.0	68.5	8.8

4. Objectives

The following were the objectives of this study:

- To quantify the effect that a simulated impaired hand (dominant and non-dominant) has on a shooter's ability to hit targets at various ranges in both the reflexive and aimed firing scenarios.
- To quantify the effect that simulated impaired vision (dominant eye and non-dominant eye) has on a shooter's ability to hit targets at various ranges in both the reflexive and aimed firing scenarios.
- To quantify the effect that simulated, simultaneous dominant hand and vision impairment has on a shooter's ability to hit targets at various ranges in both the reflexive and aimed firing scenarios.
- To quantify the effect that accommodation time has on a shooter's ability to hit targets after being impaired at various ranges in both the reflexive and aimed firing scenarios.

5. Apparatus

5.1 M-Range

M-Range (figure 1) is a computerized state-of-the-art facility for examining Soldier-weapon performance. It consists of multiple stationary pop-up targets, controlled from a computer-equipped command and control center. This experimental facility permits the engagement of targets at a wide variety of distances, target exposure times, and angles. It features four firing lanes with targets from 10 to 550 m on the two left lanes and targets from 10 to 1000 m on the two right lanes. Targets (figure 2) at the 10 and 25 m are for firing personal defense weapons or reflexive firing and targets at 50, 75, 100, 150, 200, 250, 300, 400, 500, and 550 m are for rifle firing. Targets out to 1000 m can be used for sniper rifles and machineguns. A shot microphone is also used at each firing position. The shot microphone is sensitive to the muzzle blast of every round fired and sends a signal to record the time that a shot was fired, whether firing in semi-automatic or full automatic mode. An array of microphones located beneath each target can determine the location of bullet impact on the target accurate to within 5 mm. The array of microphones can also determine the bullet miss location within about 30 cm around the "E"-type silhouette target. The computerized command and control center can present programmed arrays of targets at any distance, time interval, target exposure time, and target sequence. The computer system has a software package that records and reduces range events such as targets presented, target exposure time, target hits, shot location, shots fired, and time of each shot fired.

Figure 1. Human Research and Engineering Directorate's (HRED) M-range shooting performance research facility.

Figure 2. Olive Drab (OD) "E"-type silhouette pop-up targets at M-range.

5.2 Weapons

The M4/M4A1 5.56-mm carbine (figure 3) is a lightweight, gas-operated, air-cooled, magazine-fed, selective-rate, shoulder-fired weapon with a collapsible polymer butt stock. A shortened variant of the M16A2 rifle, the M4 is equipped with a shorter barrel, collapsible stock, and optional accessory rails. The M4 provides shooters operating in close-quarters with improved handling and the capability to rapidly and accurately engage targets at extended ranges, day or night, with accurate, lethal fire.

Figure 3. M4 carbine.

5.3 Sighting System

Only one sighting system, the M68 reflex sight (figure 4), also known as the CCO, was used in this study. It is a battery powered non-magnifying red dot type of reflex sight for the M16 series of rifle. The CCO is the standard sight used by the U.S. Army.

Figure 4. The M68 CCO reflex sight.

6. Experimental Design

6.1 Experimental Conditions

There were seven conditions in this study. Five of these conditions involved some degree of simulated physical impairment. Two baseline conditions were included to examine the effects of practice, exposure time, and condition order on shooter performance. The following conditions were used in this study:

- Initial Baseline – No simulated impairment
- Simulated dominant hand impairment
- Simulated non-dominant hand impairment
- Simulated dominant eye impairment
- Simulated non-dominant eye impairment
- Simulated dominant hand impairment and dominant eye impairment, simultaneously
- Final Baseline – No simulated impairment

Independent variables included impairment condition, range to target, and accommodation time. Target ranges for reflexive firing trials were 10 and 25 m, while target ranges for the aimed fire portion of the study were 50, 100, 200, and 300 m. Accommodation time was included at the request of the U.S. Army Research Laboratory's (ARL) Survivability and Lethality Analysis Directorate (SLAD) in order to provide data needed for their models. The initial trial commenced immediately after impairment. The following trial began after a 5-min interval. This interval allowed investigators to see the effect of performance after some time to accommodate to the injury. No shooting occurred during this 5-min interval. Exposure time (i.e., the time the target was exposed for sighting acquisition) was set at 4.0 s for reflexive firing conditions and 5.0 s for aimed firing conditions.

6.2 Range Familiarization

Once the participants met the basic criteria to serve in this study, were briefed on the experimental procedure, and signed an informed consent form, they proceeded with range familiarization. They were thoroughly briefed on the conduct of the study, all standard operating procedures (SOPs), and safety requirements relative to the facility. The participants wore interceptor body armor (IBA) and the advanced combat helmet (ACH) for all firing trials. Protective plates were not worn.

Shooters were shown a visual example of the aim point prior to initiating the trial. The aim point was a center of mass location on the target. Shooters were told to aim at the center of mass location of the target. They were scored on how close the round hit relative to that point and they were timed on how long it took them to fire each round.

6.3 Training

Following range familiarization, shooters were issued the weapon they would be firing. Shooters then zeroed the M68 sight that was mounted on the weapon according to zeroing procedures for the weapon. Shooters completed one familiarization trial in the baseline condition for both reflexive and aimed fire.

6.4 Testing Sequence

Shooters fired in all experimental conditions over the course of one day. To account for practice and order effects, the shooter order for conditions 1–5 was counterbalanced (see appendix B). Following the five counterbalanced conditions, a sixth condition was run to discern the combined effects of impairment to both eye and hand simultaneously. Dominant hand and dominant eye were simultaneously impaired for both the reflexive and aimed fire tasks. A seventh condition was conducted as a final baseline condition where the shooter was not impaired and the data from this final condition were used for determining if the shooter proficiency increased as a result of the time on the range.

After the brief familiarization period, the Soldier was artificially impaired based on the experimental condition counterbalancing scheme shown in appendix B. Hand impairment was accomplished by having either the Soldier's dominant or non-dominant hand wrapped and immobilized in a fist position so that fingers and thumbs could not be used for weapon manipulation. This prevented the Soldier from using his hand in any of the shooting tasks. Visual impairment was accomplished by securing a headband-type opaque eye patch over the dominant or non-dominant eye (figure 5).

Figure 5. Experimental participant in hand impairment condition (right) and eye impairment condition (right).

The first eight shooters began with the reflexive firing task and then completed the aimed firing task. The remaining seven shooters began with aimed firing and followed with reflexive firing. Shooters proceeded to either the reflexive or aimed firing task as directed by the principal investigator. Each Soldier performed two experimental trials for each condition, separated by approximately 5 min. The first experimental trial was conducted immediately after impairment was established. The second experimental trial began approximately 5 min later in order to examine the effect of the shooters' accommodation to induced impairment. This procedure was followed for all five conditions for both the aimed and reflexive firing conditions. After completion of five of the reflexive or aimed firing conditions, they proceeded to the other firing task (aimed or reflexive) that they had not yet completed. Exact time intervals were recorded for all trials and conditions.

During the reflexive firing trials, targets appeared at ranges of 10 and 25 m with an exposure time of 4.0 s. Fifteen targets were presented at each range in a random order for each trial. Shooters were in the standing unsupported firing position and started with the weapon in the low ready position. When the target was exposed, the Soldier engaged the target with a single shot. During the aimed fire task, participants fired from the foxhole supported firing position at targets at ranges of 50, 100, 200, and 300 m with seven targets appearing at each range for each trial. Targets had an exposure time of 5.0 s. When the target was exposed, the Soldier engaged the target with a single aimed shot. For all of these trials, the aim point was a marked center of mass location on the target. Shooters were told to aim at the marked center of mass location of the target and they were scored on how close the round hit relative to that point and that they would be timed on how long it took them to fire each round.

After completion of the first five counterbalanced conditions for both the reflexive and aimed position, the shooter returned back to the first of their firing positions, reflexive or aimed, and completed the last two conditions. Subsequently, the last two conditions were also completed in the other firing position (aimed or reflexive). After each Soldier completed the reflexive firing and aimed firing for a condition, they completed a post-firing questionnaire (appendix C).

The shooters followed the order presented in appendix B for each of the reflexive and aimed tasks separately. Shooters were given an ~5-min rest period between experimental conditions. Shooters had an ~30-min rest period between reflexive and aimed shooting positions. This was repeated until the participant completed all the conditions. Shooters participated in the study during daylight hours from approximately 0800 to 1630. Data collection took place over a four-week period, as participants were available, with each Soldier actively shooting for one day, assuming one active firing lane. Two shooters reported to the research site each day and participated in the experiment for one day only.

To ensure optimal safety for the shooters and range personnel, a safety rig was developed to ensure that if the shooter lost control of the weapon, it couldn't swing or fall in such a manner as to be pointed at the shooters, experimenters, or range personnel (figure 6). This device was only required during the reflexive firing task. For the aimed fire task, the weapon was supported and there was no need to guard against loss of weapon control. The support device was built so that if the Soldier lost control of the weapon with his forward hand, the weapon was caught by the support system and would not point at the Soldier's feet and would keep the weapon pointed in a safe direction. The support system was constructed as to minimize any interference with the shooter and the shooting task. ARL Safety Office personnel inspected the device prior to experimentation to ensure optimal safety.

Shooters in this evaluation were asked permission to be photographed and/or videotaped. Their decision to allow photographic capture or video of their image was also voluntary and explicit permission was obtained from the shooter before any photographs or video were taken. All images were used solely to illustrate different impairment conditions and human performance data for the purposes of this evaluation.

Figure 6. Safety rig used during reflexive firing task.

7. Independent Variables

The independent variables for this study were the following:

- Simulated Impairment – baseline, dominant hand, non-dominant hand, dominant eye, non-dominant eye, dominant hand and eye, and final baseline
- Accommodation Time – immediately after impairment and after 5-min accommodation
- Range to target – 10 and 25 m (reflexive fire) and 50, 100, 200, and 300 m (aimed fire)

8. Dependent Variables

The dependent variables for this study were the following:

- Target hit percentage
- Radial error from the center of the target
- Target engagement time

9. Data Analysis

The data for the reflexive firing and aimed firing portions of the study were analyzed separately. These shooting tasks were markedly different and the target exposure time and firing methods used were different between these scenarios.

The data from both the reflexive fire and aimed fire tasks were analyzed in the same manner. The reflexive fire task had two levels: 10 and 25 m. The aimed fire task had four levels: 50, 100, 200, and 300 m. First, descriptive statistics on the dependent measures of hit percentage, radial error, and time to first-shot were calculated for each condition in both the reflexive fire and aimed fire portions of the study. Next, separate independent three-factor [7 (physical impairment) X 2 (range to target - reflexive) X 2 (accommodation time)] and [7 (physical impairment) X 4 (range to target – aimed) X 2 (accommodation time)], within-subjects, analyses of variance (ANOVA) were conducted on the dependent measures of hit percentage, radial error, and target engagement time. If significant main effects were observed, Tukey Honestly Significant Difference (HSD) post-hoc tests were employed to determine which conditions were significantly different from each other.

10. Results

10.1 Objective Shooting Performance Data

10.1.1 The Effect of Range, Physical Impairment and Accommodation Time on Aimed Shooting Performance

For the target hit percentage data, range to target ($F(3, 42) = 190.95$, $p = 0.000$) was found to have a significant effect. As would be expected, there was a significant difference in hit percentage for the various ranges to target, with the farther distance resulting in lower hit percentages (figure 7). Tukey HSD post-hoc analyses showed that there was a significant difference in hit percentage between each range except for the 50- and 100-m ranges. Letters denote the significant difference between each range distance; like letters indicate that there are no significant differences between the range distances.

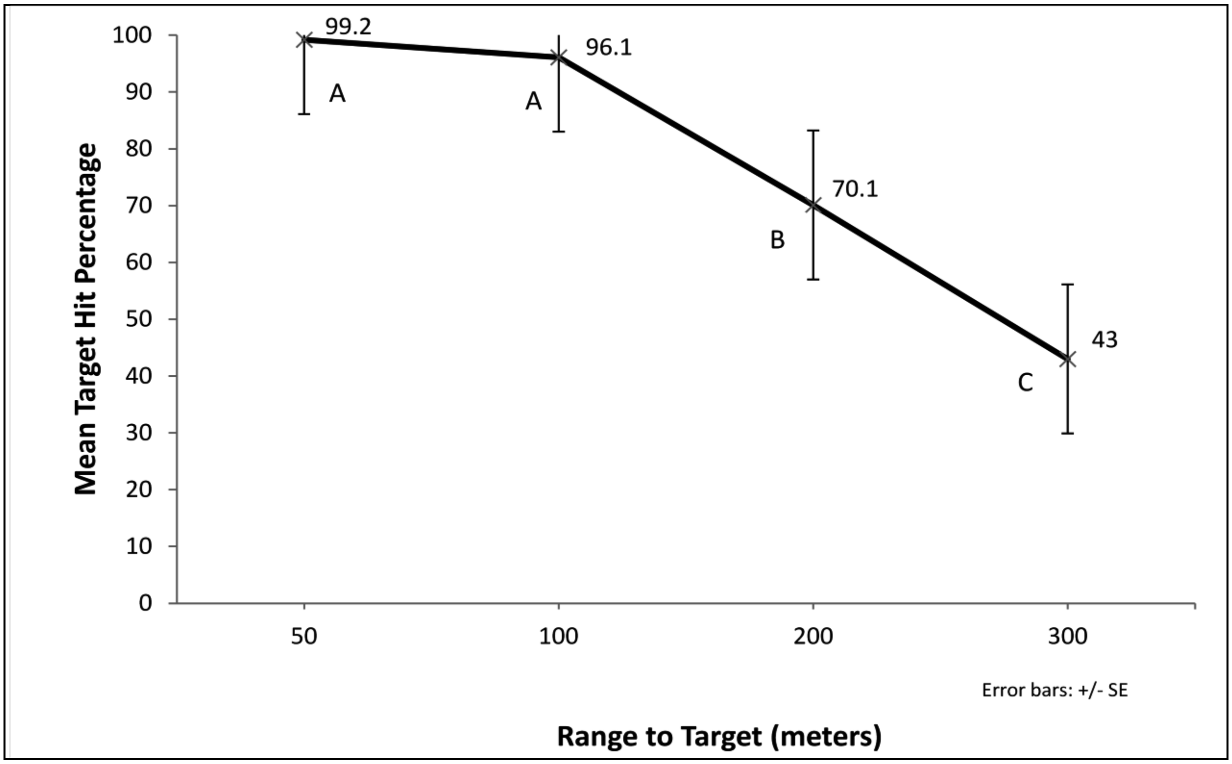

Figure 7. The effect of range to target on mean target hit percentage for the aimed fire shooting task.

There were no significant effects of physical impairment condition or accommodation time on target hit percentage.

For the target radial error data, a main effect of range to target ($F(3, 42) = 161.67$, $p = 0.000$) was found. Tukey HSD post-hoc analyses showed that for aimed fire, each range was significantly different from each other. Letters denote the significant difference between each range distance; like letters indicate that there are no significant differences between the range distances. As shown in figure 8, radial error increased significantly from one range to the next as range increased. Because all of the shots outside the detection envelope were not factored into the radial error means, the radial error is somewhat underestimated for certain conditions. Shots outside the detection area were counted as those shots that were off the center of the target by 22 in or more, or hit the berm in front of the target. The shots outside the detection area percentage was 8.3% for baseline, 15.3% for dominant eye, 13.1% for non-dominant eye, 12% for dominant hand, 11.7% for non-dominant hand, 10.3% for dominant hand and eye, and 10% for the final baseline condition.

There were no significant effects of physical impairment condition or accommodation time on target radial error.

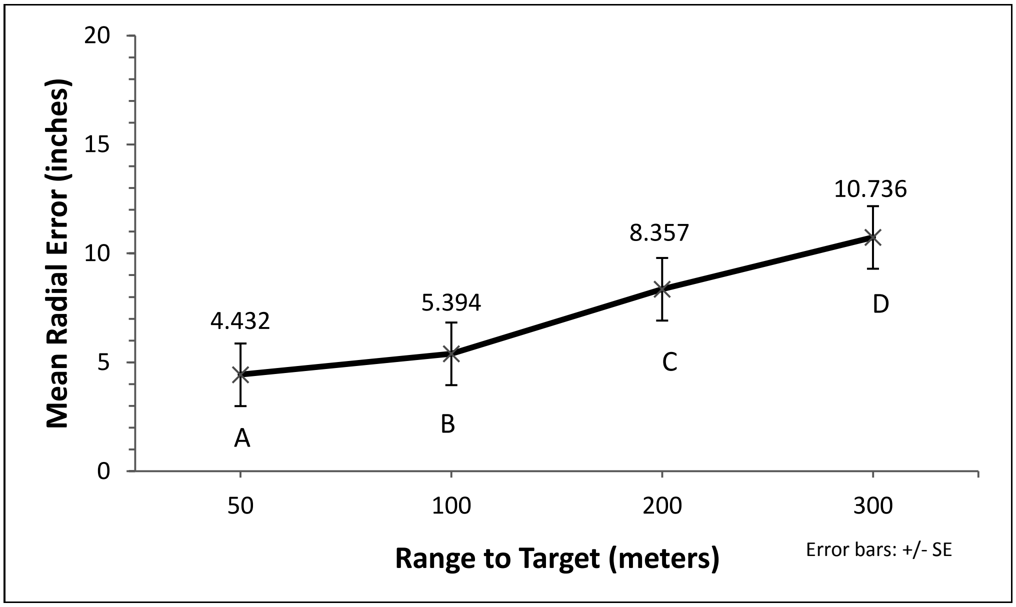

Figure 8. Effect of range to target on the mean radial error of the shot for the aimed fire shooting task.

Main effects of physical impairment condition (F(6, 81) = 7.11, p = 0.000) and range to target (F(3, 42) = 149.76, p = 0.000) were found relative to target engagement time. Post hoc Tukey HSD analyses revealed significant differences between some of the physical impairment conditions (figure 9). Letters denote the significant difference between each impairment condition; like letters indicate that there are no significant differences between the impairment conditions. The dominant hand, dominant eye, and dominant hand/eye conditions were statistically similar. These conditions all had significantly longer target engagement times than the initial and final baseline conditions. The dominant hand and dominant eye condition also had significantly longer target engagement times than the non-dominant hand and non-dominant eye conditions. This indicates that when shooters were forced to switch to their non-dominant shooting side, engagement times significantly increased. Furthermore, there were no significant differences in engagement time between the initial and final baseline conditions. Although the target engagement time for the non-dominant eye condition was significantly shorter than for the dominant eye and dominant hand conditions, the target engagement time for the non-dominant eye was also significantly longer than the non-dominant hand, as well as the initial and final baseline conditions. The non-dominant hand condition showed significantly shorter target engagement times than all other impairment conditions, except for the initial and final baseline. The lack of a significant difference with the initial and final baseline conditions and the non-dominant hand condition is likely due to this condition being so similar to the baseline conditions where there is no impairment. The dominant hand/eye condition showed a significantly longer target engagement time than the non-dominant hand condition and the initial and final baseline conditions. The dominant hand/eye condition was statistically similar in target engagement time with the dominant eye, dominant hand, and non-dominant eye conditions.

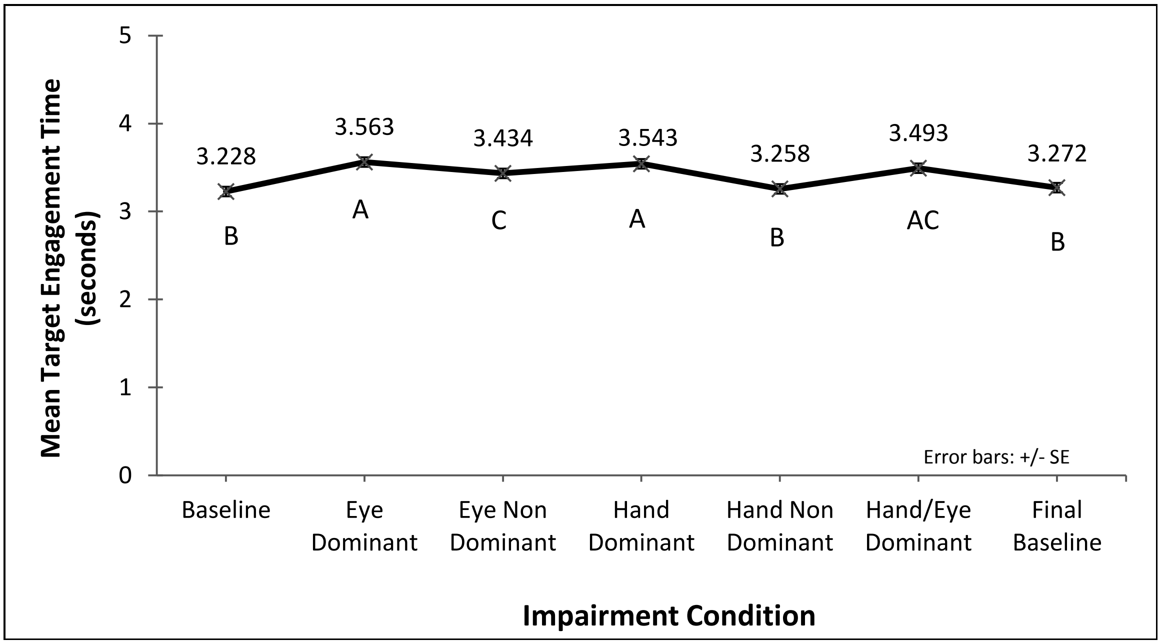

Figure 9. Effects of impairment condition on the mean target engagement time for the aimed fire shooting task.

The range to target showed significant differences in engagement time between all range distances (figure 10). As range to target increased, engagement time increased as well. Letters denote the significant difference between each range distance; like letters indicate that there are no significant differences between the range distances.

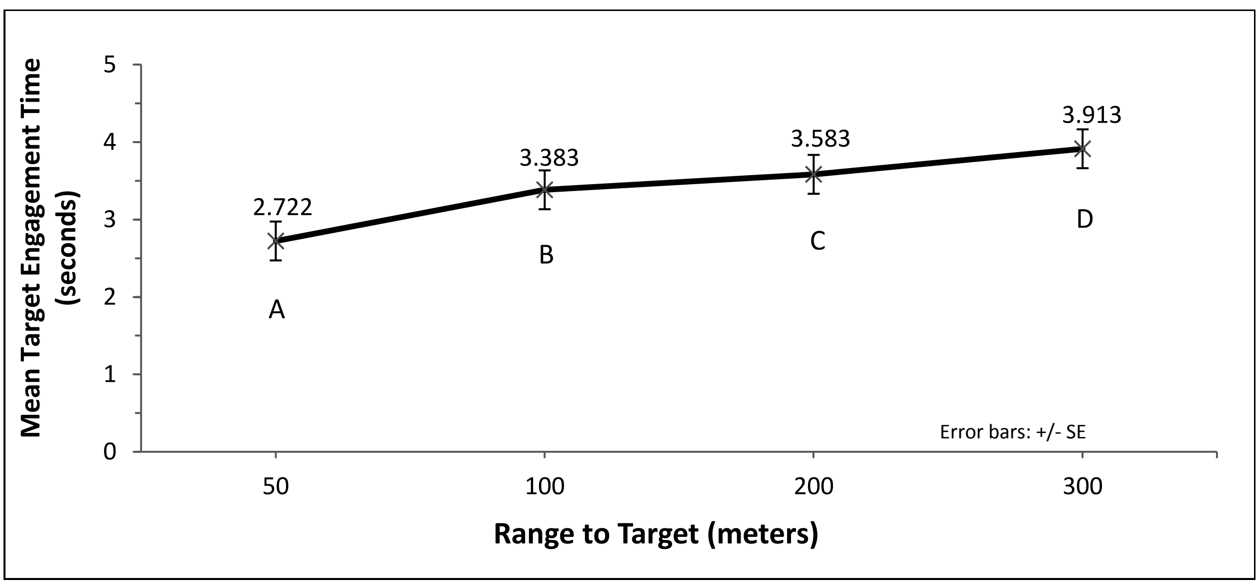

Figure 10. The significant effect of range to target on the mean target engagement time for the aimed fire shooting task.

A significant interaction of impairment condition x range to target was also found, F(18, 243) = 2.04, p = 0.008, relative to target engagement time (figure 11). Separate post-hoc Tukey HSD analyses examining the effect of the impairment condition at each range were conducted. Although it appears that the three shortest distances follow a similar pattern, and that they differ from the farthest distance of 300 m, enough differences exist between the various conditions to examine each range independently. At the 50-m range, the dominant hand and dominant eye impairment conditions target engagement time was significantly slower than the non-dominant hand and non-dominant eye conditions. Furthermore, the dominant hand/eye condition was statistically similar to the other dominant conditions, but also similar to the non-dominant eye condition. When the non-dominant hand or non-dominant eye was impaired, target engagement time was statistically similar between the two and also similar to the final baseline condition. In addition, the non-dominant hand condition was also statistically similar to the initial baseline condition. It was apparent that when the shooter was forced to switch to the non-dominant shooting side because of dominant physical impairment, target engagement time increased. Alternatively, when the non-dominant side was impaired, target engagement time trended towards the baseline.

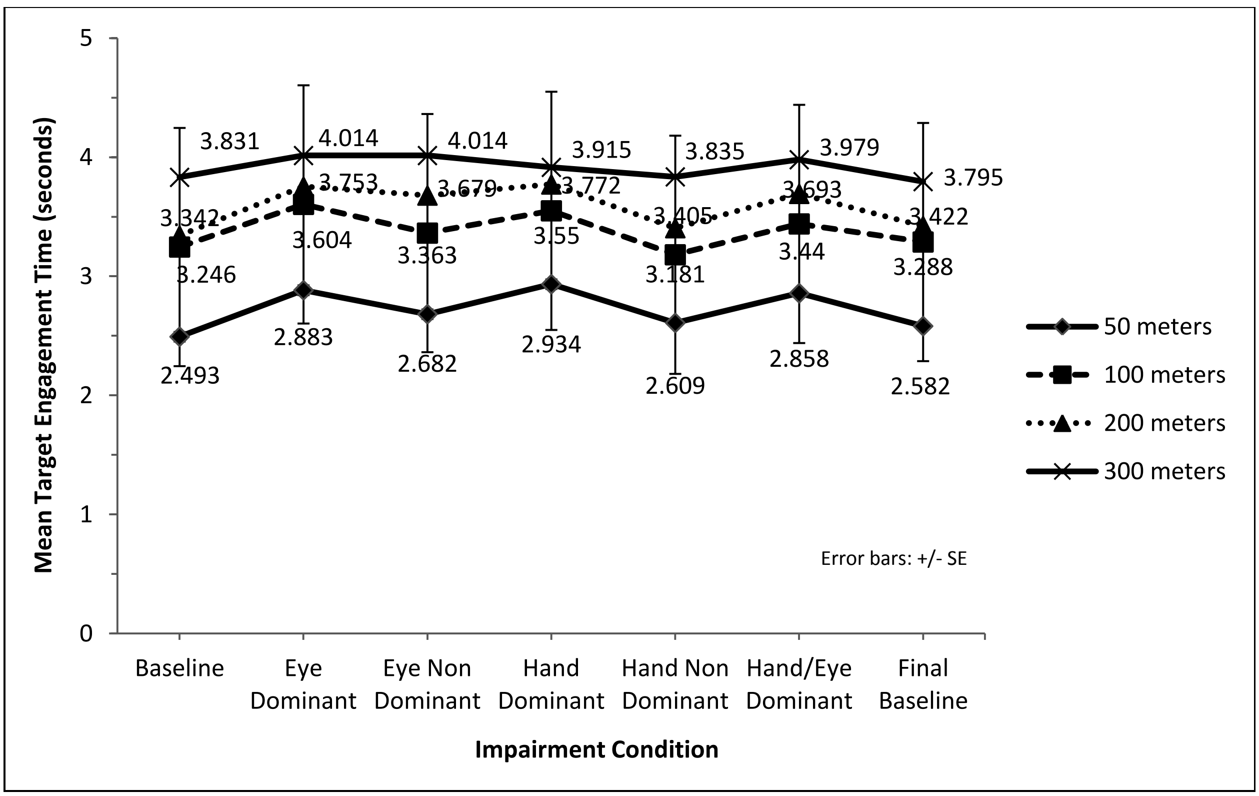

Figure 11. The significant interaction of impairment condition x range to target on the mean target engagement time for the aimed fire shooting task.

At the 100-m range, the dominant eye and the dominant hand conditions exhibited statistically slower target engagement times than the non-dominant eye and non-dominant hand conditions. Also, the dominant hand and dominant eye conditions were statistically similar to one another. Similarly, the non-dominant hand and non-dominant eye conditions were also similar to one another. The dominant hand/eye condition was similar to the dominant hand condition, but had faster target engagement times compared to the dominant eye condition. At this range, it took significantly more time to engage the target in the dominant eye condition than in the dominant hand/eye condition. The non-dominant eye condition had a significantly slower target engagement time compared to the non-dominant hand. Nevertheless, both of these non-dominant conditions were statistically similar to both the initial and final baseline conditions.

At 200 m, the dominant conditions (hand, eye, hand/eye), as well as the non-dominant eye condition, revealed the slowest target engagement times. These four conditions were statistically similar and significantly different from the non-dominant hand condition and the initial and final baseline conditions. Not only did this illustrate the difficulty in switching to the non-dominant shooting side during dominant impairment, but it also indicated that the effect of the non-dominant eye condition became similar to those in dominant impairment conditions. The non-dominant hand condition revealed a significantly faster target engagement time than all of the dominant impairment conditions and the non-dominant eye condition. This condition at this range was similar to shooting in the baseline conditions.

Lastly, at 300 m, the number of significant differences between conditions markedly decreased. The dominant hand, non-dominant hand, and dominant hand/eye conditions were similar and not significantly different from the initial and final baseline. Also at this range, the dominant hand and dominant hand/eye conditions exhibited no significant differences relative to any other impairment condition. The dominant eye and non-dominant eye conditions exhibited the only significant differences. They were statistically slower than both baseline conditions, as well as the non-dominant hand condition. It is apparent from these findings that at closer ranges, the effect of impairment on target engagement time was most evident. At longer ranges, where performance was already decremented (due to range), additional decrement caused by impairment was less evident.

Across experimental conditions, there was no significant effect found between accommodation time and engagement time.

10.1.2 The Effect of Range, Physical Impairment and Accommodation Time on Reflexive Shooting Performance

For the target hit percentage data, no significant main effects or interaction effects were found.

For the target radial error data, a main effect of range to target ($F(1, 14) = 22.53$, $p = 0.000$) was found (figure 12). As would be expected, as range to target increased so did radial error. There were no significant interactions. As in the aimed fire data, shots that were outside the shot detection envelope were not factored into the means for radial error. Consequently, the radial error is slightly underestimated. There were a very low number of shots outside the detection envelope for reflexive fire. The percentage of shots outside the detection area was 0.0% for baseline, 0.8% for dominant eye, 0.6% for non-dominant eye, 1.0% for dominant hand, 0.2% for non-dominant hand, 0.4% for dominant hand and eye, and 1.3% for final baseline condition.

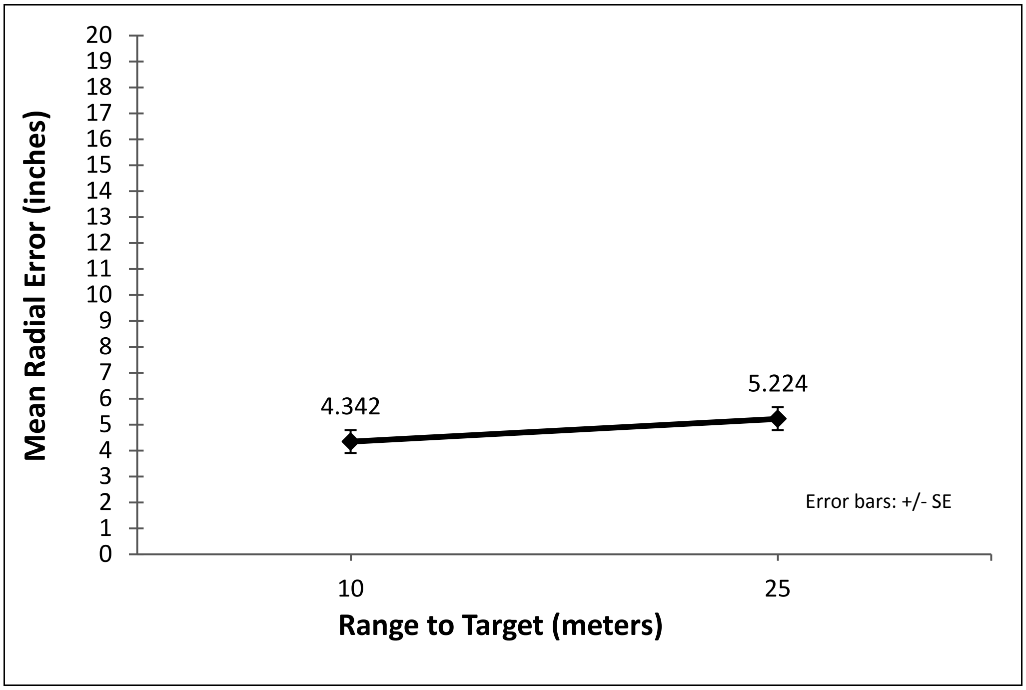

Figure 12. The significant effect of range to target on the mean radial error of the shot for the reflexive firing shooting task.

For target engagement time data, a significant main effect of impairment condition (F(6, 84) = 15.61, p = 0.000) was observed for the reflexive firing task. Figure 13 shows the effect of impairment condition on target engagement time. Tukey post-hoc analyses showed a pattern of significant differences similar to that seen in the aimed firing tasks. Letters denote the significant difference between each impairment condition; like letters indicate that there are no significant differences between the impairment conditions. The initial baseline condition was significantly different from all other impairment conditions, except for the final baseline. The dominant eye, dominant hand, and dominant hand/eye condition were significantly longer than all other impairment conditions. The non-dominant eye and the non-dominant hand conditions were significantly different from all other impairment conditions. Furthermore, these two conditions were statistically similar. The non-dominant conditions were significantly shorter than all the dominant conditions, but significantly longer than the baseline conditions. There were no significant differences in engagement time between the initial and final baseline conditions. It was evident from these results that impairment of the dominant shooting side had a significant impact on target engagement time.

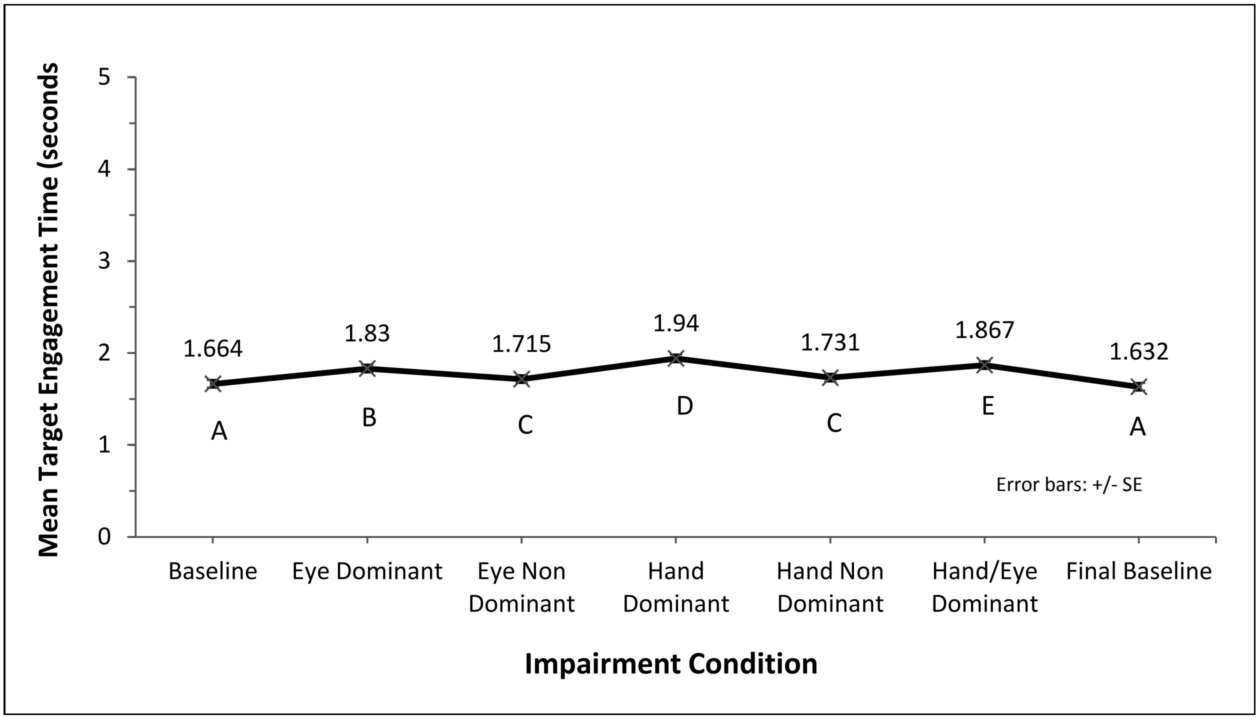

Figure 13. The significant effect of impairment condition to target engagement time for the reflexive firing shooting task.

Also for target engagement time, a significant main effect of range to target ($F(1, 14) = 92.12$, $p = 0.000$) was observed. As shown in figure 14, target engagement time significantly increased from the 10- to 25-m range.

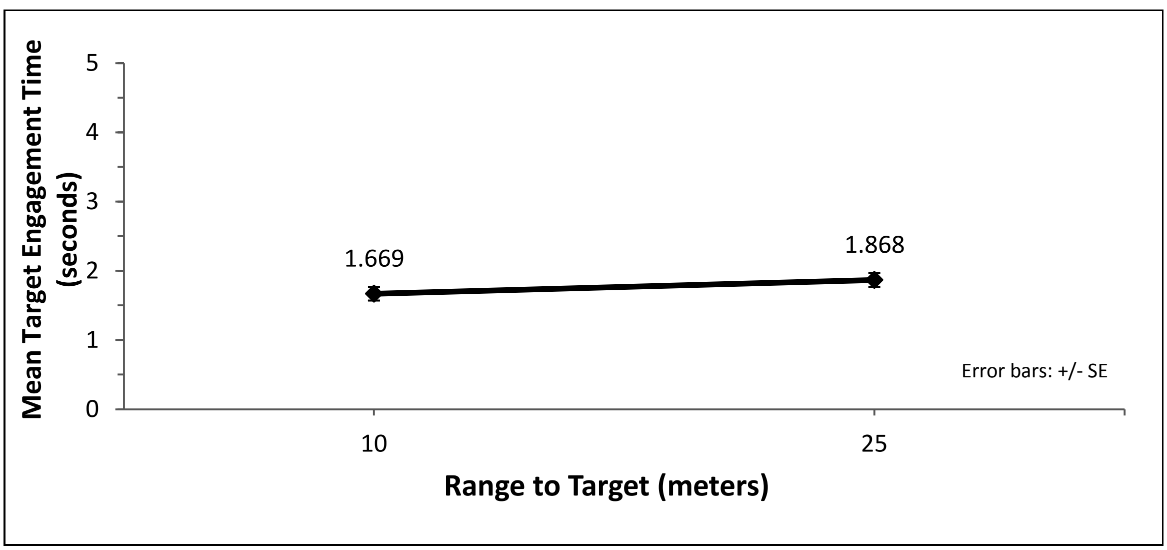

Figure 14. The significant effect of range to target on target engagement time for the reflexive firing shooting task.

In addition, a significant main effect of accommodation time ($F(1, 14) = 5.61$, $p = 0.033$) for target engagement time was revealed. Figure 15 shows a significant decrease in target engagement time from initial impairment (trial 1) to 5 min later (trial 2).

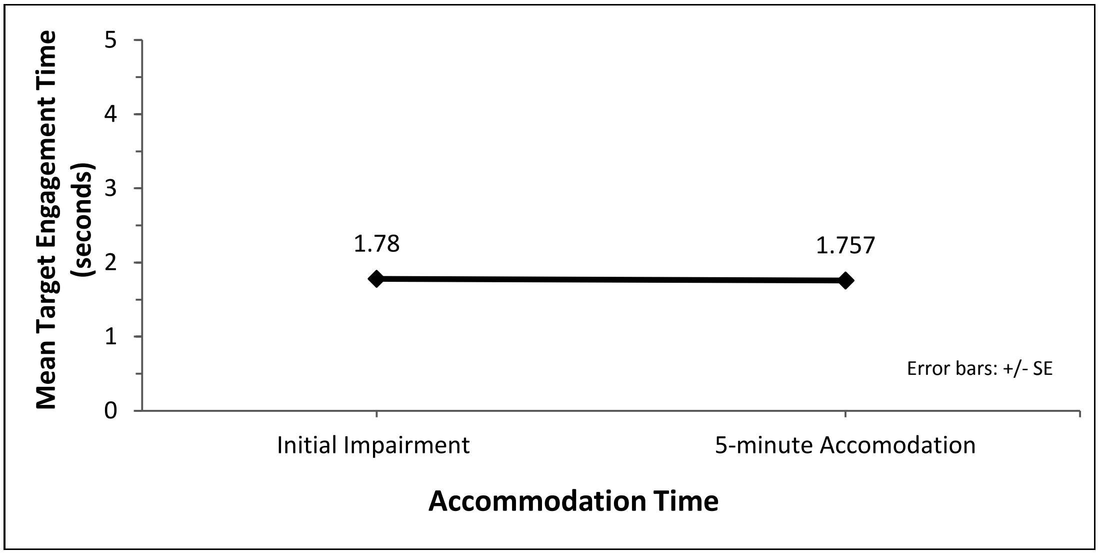

Figure 15. The significant effect of trial on target engagement time for the reflexive firing shooting task.

10.2 Subjective Data

After completing each of the aimed fire and reflexive fire sequences for each experimental condition, participants completed a post-firing questionnaire. The questionnaire prompted test participants to rate their ability to (1) control the weapon, (2) acquire a normal sight picture, (3) acquire a good sight picture, (4) acquire a consistent sight picture, (5) maintain buttstock stability while firing, (6) attain a comfortable firing position, and (7) pull the trigger.

In the aimed shooting position, 46.7% of test participants reported the dominant eye impairment condition as being the most difficult to obtain a good sight picture in the aimed shooting position (figure 16). On the other hand, in the reflexive shooting position, 40% of test participants reported difficulty in obtaining a good sight picture for the dominant eye, dominant hand, and dominant hand/eye impairment conditions (figure 17). It is possible that firing from the unsupported firing position led to this more widespread reported difficulty in the reflexive position.

Test participants in the aimed fire position reported that 80% attempted to make adjustments during the non-dominant hand condition in order to improve their shooting performance (figure 18). In addition, 73.3% of the participants reported making attempted adjustments for the dominant eye and dominant hand conditions. Interestingly, in the reflexive shooting position, the majority of participants (80%) reported making adjustments to improve shooting performance when in the dominant hand condition (figure 19). The next most reported was during the non-dominant hand condition where 73.3% reported making adjustments.

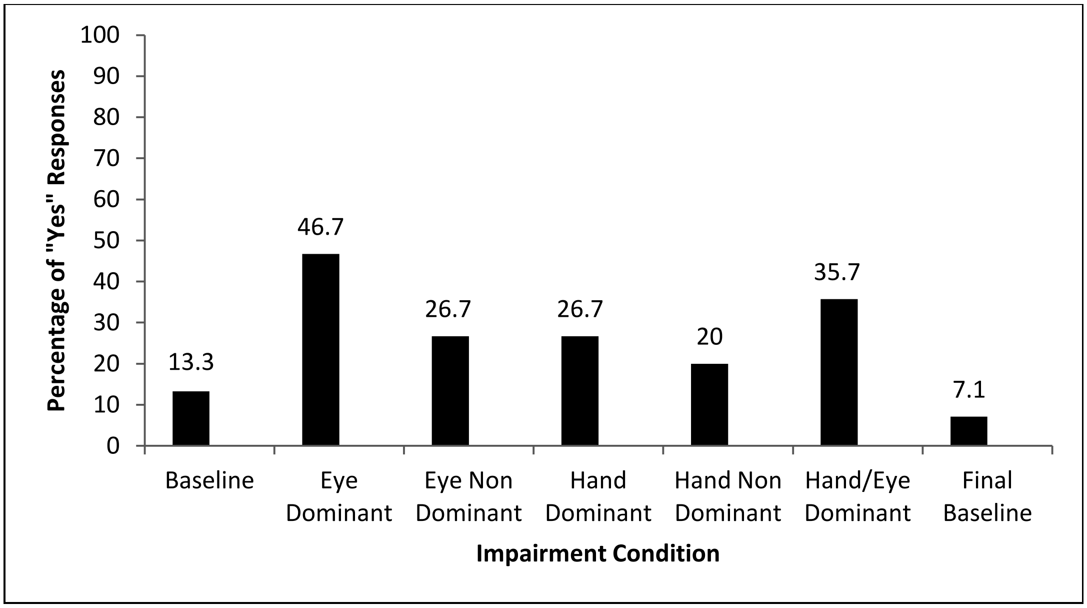

Figure 16. Percent of test participants reporting that it was difficult to obtain a good sight picture in aimed shooting position.

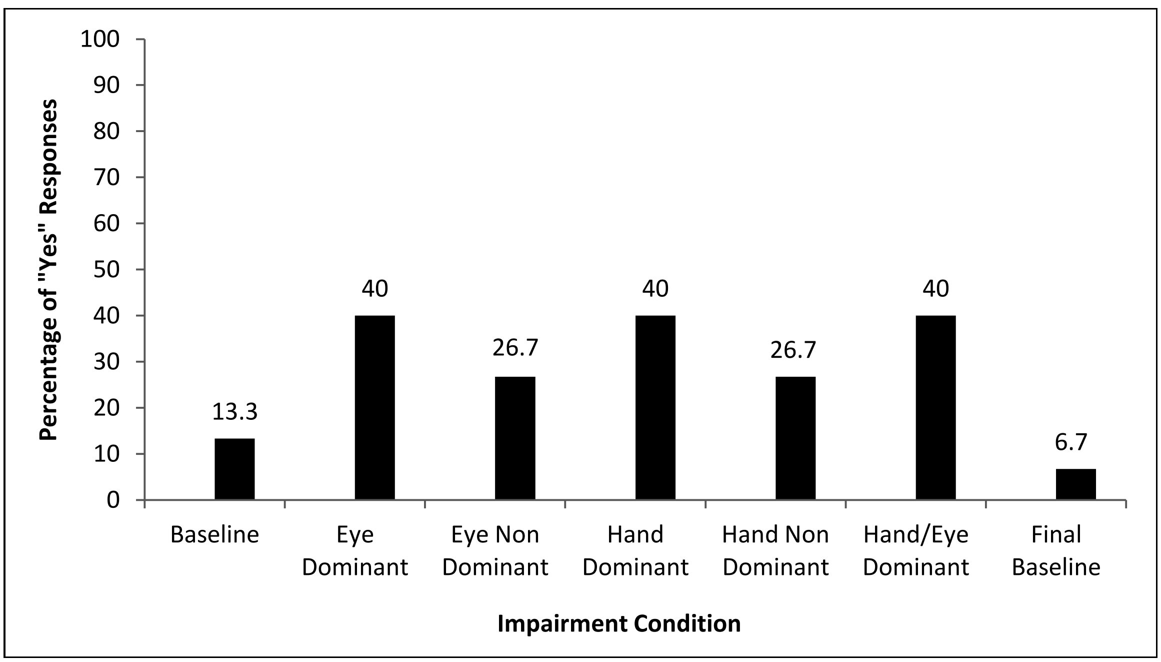

Figure 17. Percent of test participants reporting that it was difficult to obtain a good sight picture in reflexive shooting position.

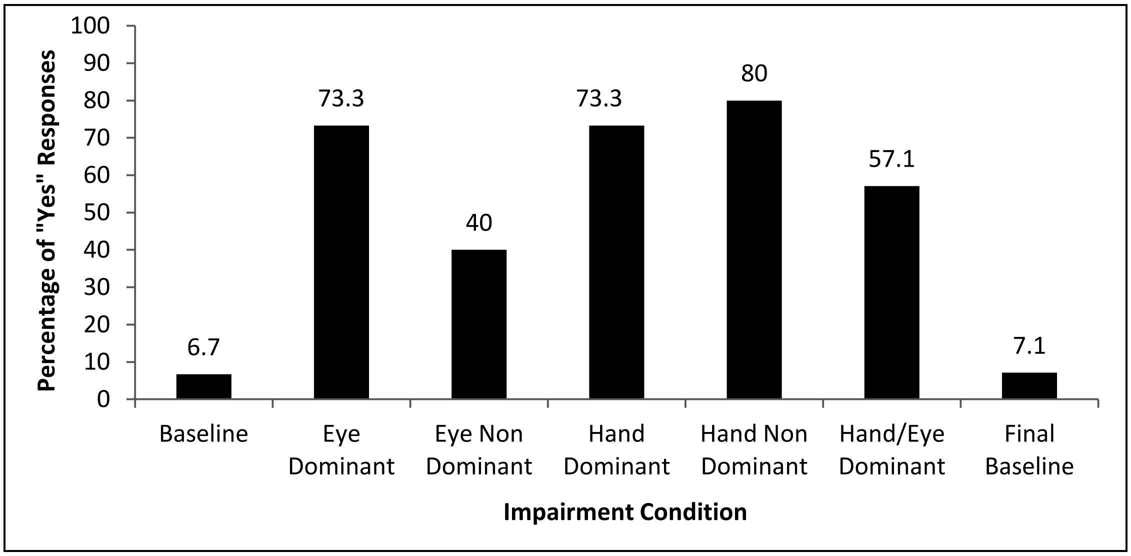

Figure 18. Percent of test participants reporting that they attempted to make adjustments to improve shooting performance in aimed shooting position.

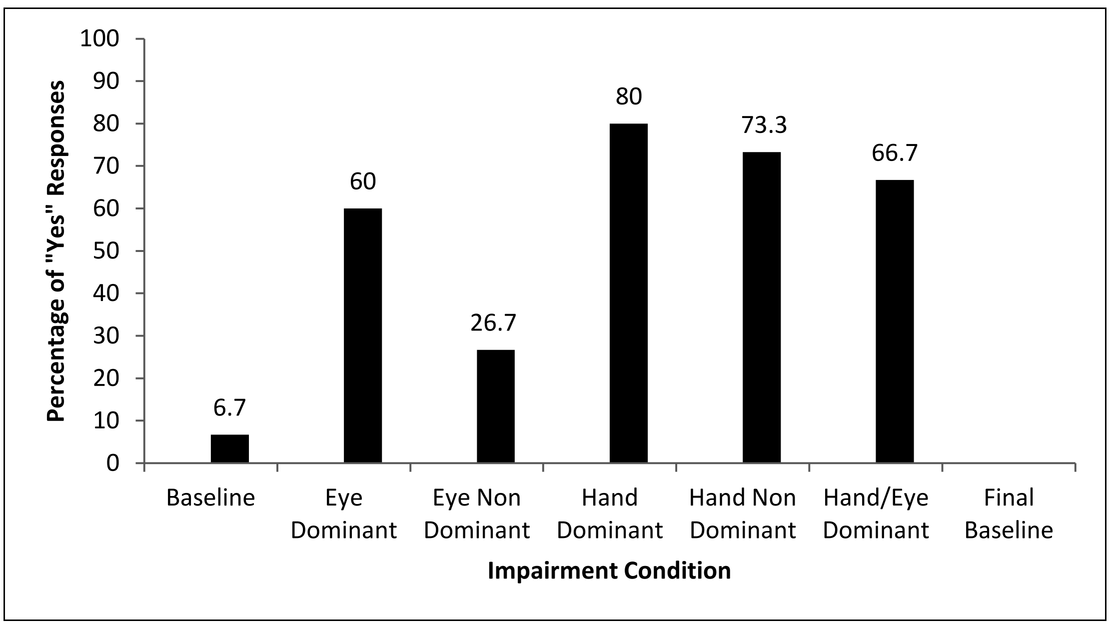

Figure 19. Percent of test participants reporting that they attempted to make adjustments to improve shooting performance in reflexive shooting position.

The ability of participants to control the weapon in the aimed firing position was reported lowest for the dominant hand, non-dominant hand and hand/eye dominant conditions with a rating of slightly good (figure 20). Similarly, the ratings in the reflexive firing position were reported lowest with a rating of slightly good for those same dominant impairment conditions (figure 21).

1	2	3	4	5	6	7
Very Bad	Moderately Bad	Slightly Bad	Neutral	Slightly Good	Moderately Good	Very Good

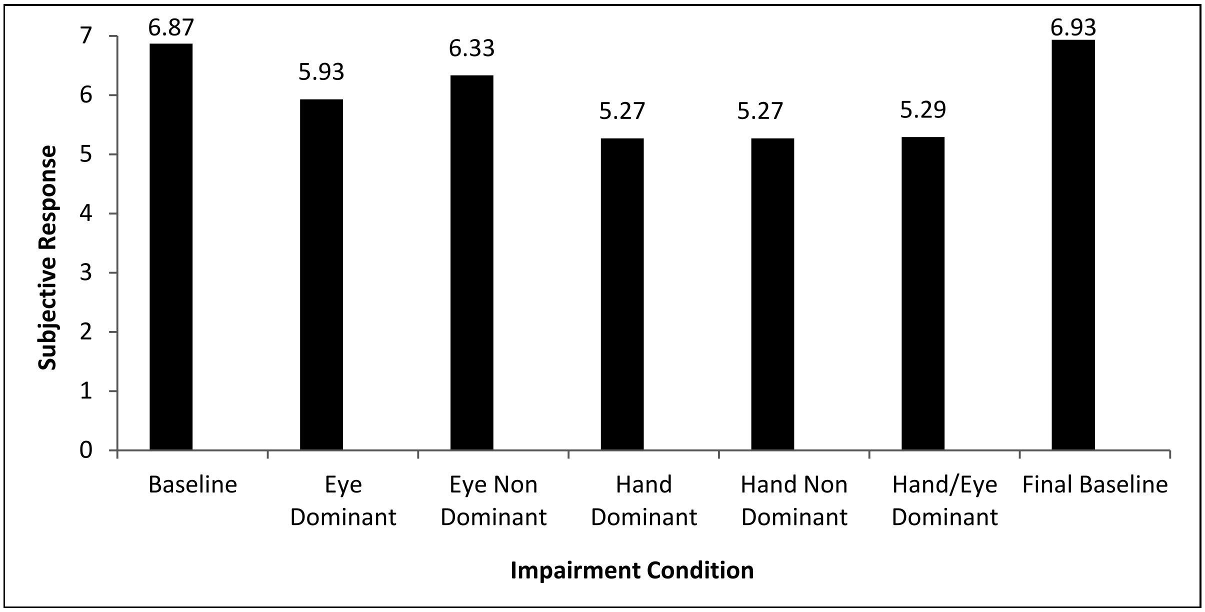

Figure 20. Rating of ability to control the weapon by impairment condition in aimed firing position.

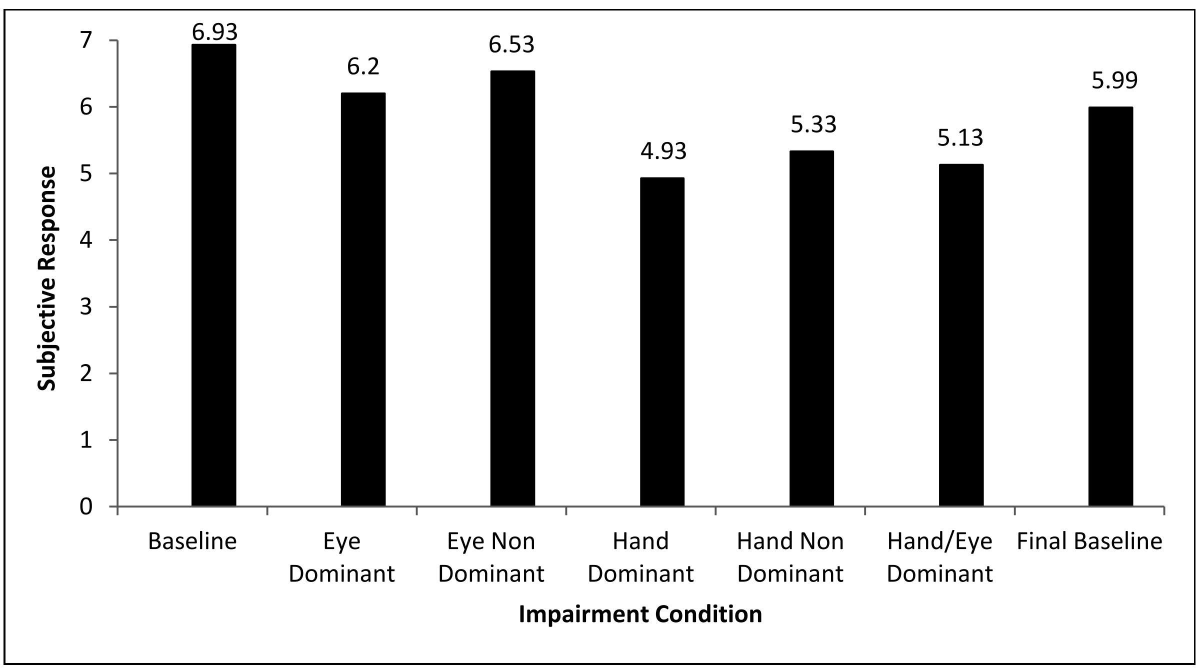

Figure 21. Rating of ability to control the weapon by impairment condition in reflexive firing position.

The ability to get a normal sight picture was rated lowest for the dominant eye, non-dominant eye, dominant hand, and dominant hand/eye conditions with a rating of slightly good for the aimed shooting position (figure 22). Participants in the reflexive shooting position reported a rating of slightly good for dominant hand and dominant hand/eye conditions (figure 23).

Participants rated the ability to obtain a good sight picture in the aimed shooting position was most difficult in the eye dominant condition with a rating of neutral (figure 24). The most difficult in the reflexive shooting position was the dominant hand, non-dominant hand, and dominant hand/eye conditions with a rating of slightly good (figure 25).

The stability of the butt stock while firing in the aimed position was rated slightly good for the dominant eye, dominant hand, non-dominant hand, and dominant hand/eye positions (figure 26). For the reflexive shooting position, the ratings were even lower, with a rating of neutral for the dominant hand, non-dominant hand, and dominant hand/eye conditions (figure 27).

Participant's ability to get a consistent sight picture in the aimed shooting position was lowest at slightly good for the dominant eye, non-dominant eye, dominant hand, and hand/eye dominant conditions (figure 28). The reflexive shooting position revealed similar ratings with the lowest at slightly good for the dominant hand, non-dominant hand, and dominant hand/eye conditions (figure 29).

The ability to attain a comfortable firing position in the aimed position was rated the lowest at slightly good for the dominant eye, dominant hand, and dominant hand/eye conditions (figure 30). The reflexive firing position revealed similar ratings with the dominant hand condition rated slightly lower with a neutral rating (figure 31). The non-dominant hand and dominant hand/eye conditions were rated next highest at slightly good.

Lastly, the participants rating of the ability to pull the trigger was very similar across both the aimed and reflexive firing position (figures 32 and 33). All of the participants rated this task moderately good across all impairment conditions.

Results are summarized graphically, across experimental participants, in figures 16–33.

1	2	3	4	5	6	7
Very Bad	Moderately Bad	Slightly Bad	Neutral	Slightly Good	Moderately Good	Very Good

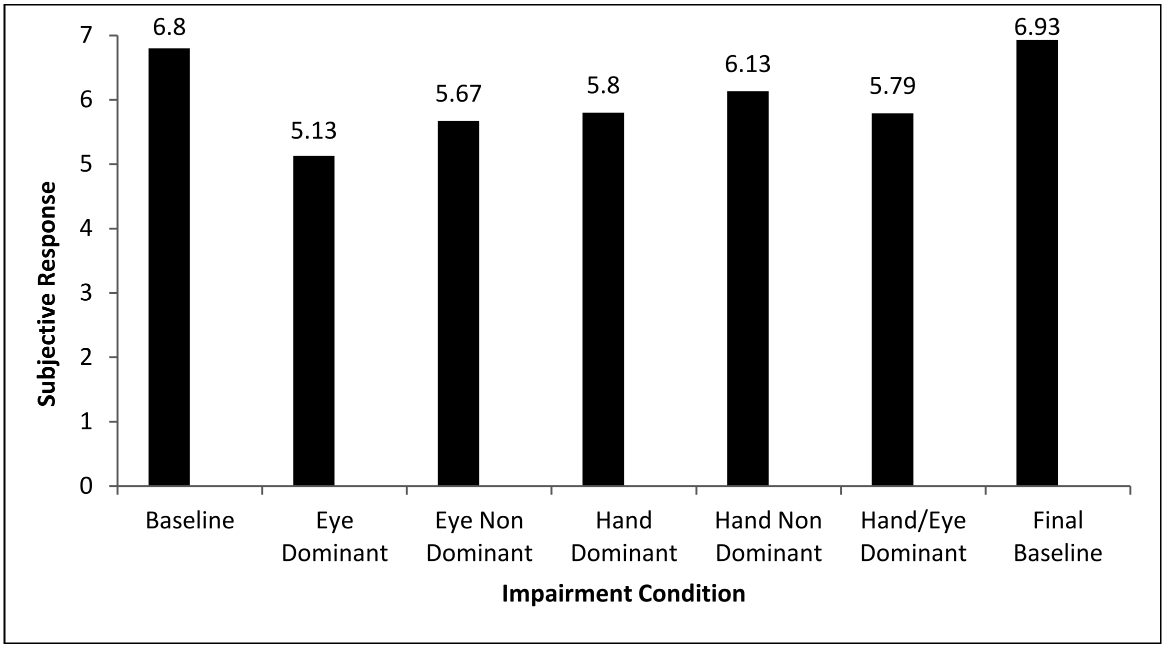

Figure 22. Rating of ability to get a normal sight picture by impairment condition in aimed shooting position.

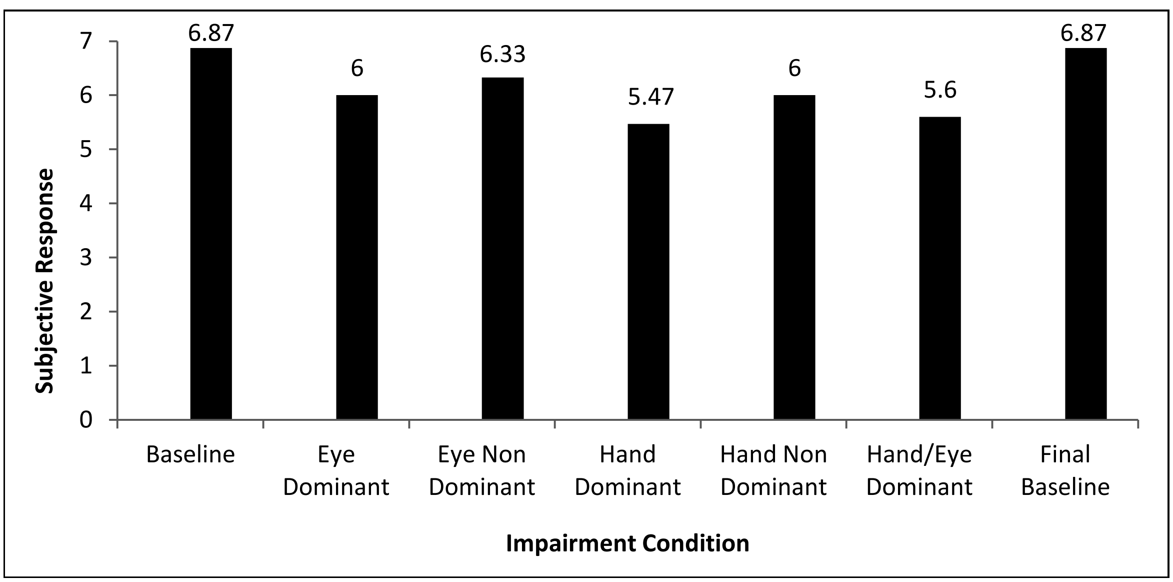

Figure 23. Rating of ability to get a normal sight picture by impairment condition in reflexive shooting position.

1	2	3	4	5	6	7
Very Bad	Moderately Bad	Slightly Bad	Neutral	Slightly Good	Moderately Good	Very Good

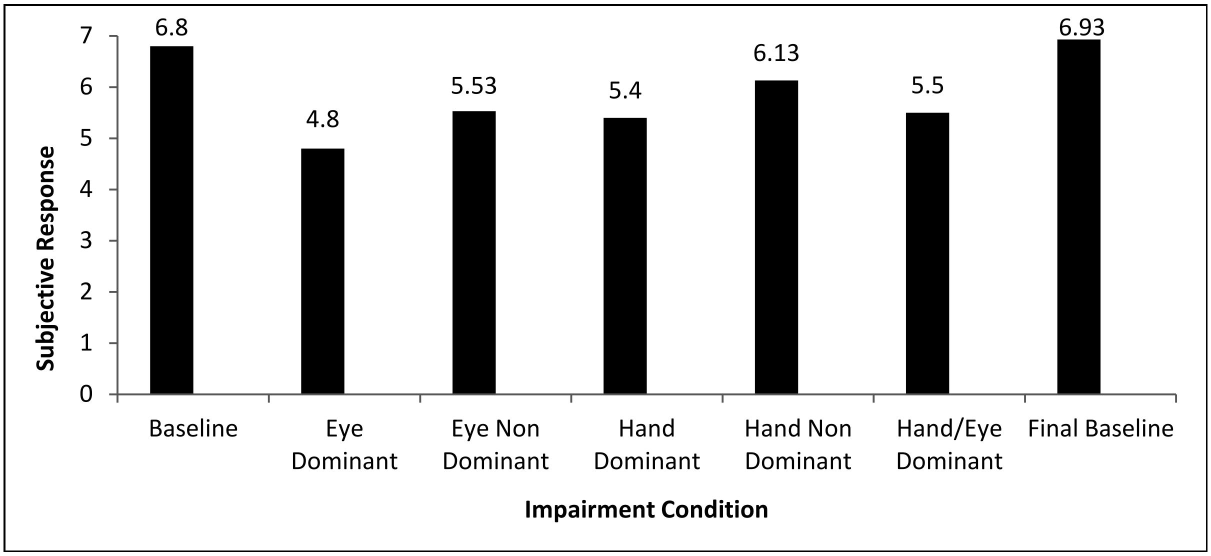

Figure 24. Rating of ability to obtain good sight picture by impairment condition in aimed shooting position.

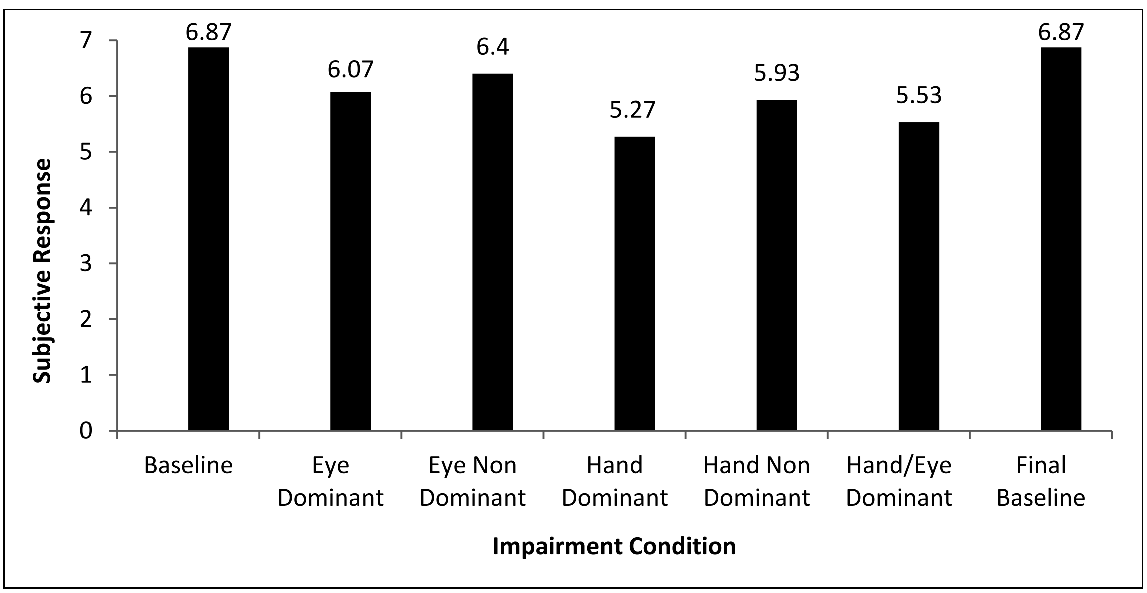

Figure 25. Rating of ability to obtain good sight picture by impairment condition in reflexive shooting position.

1	2	3	4	5	6	7
Very Bad	Moderately Bad	Slightly Bad	Neutral	Slightly Good	Moderately Good	Very Good

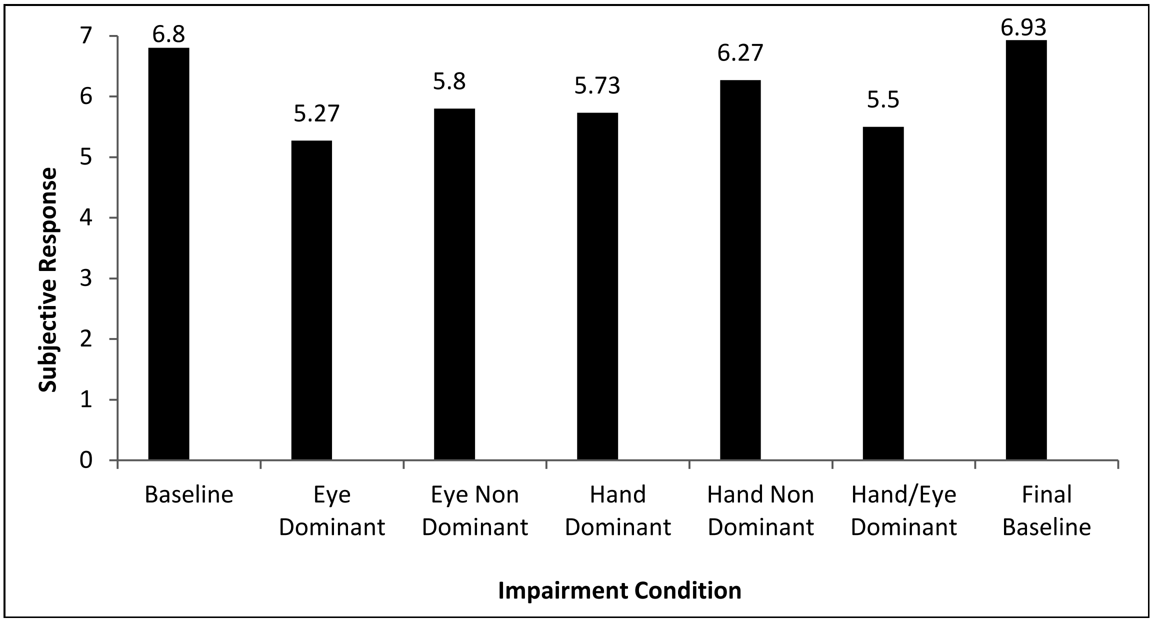

Figure 26. Rating of ability to get a consistent sight picture by impairment condition in aimed shooting position.

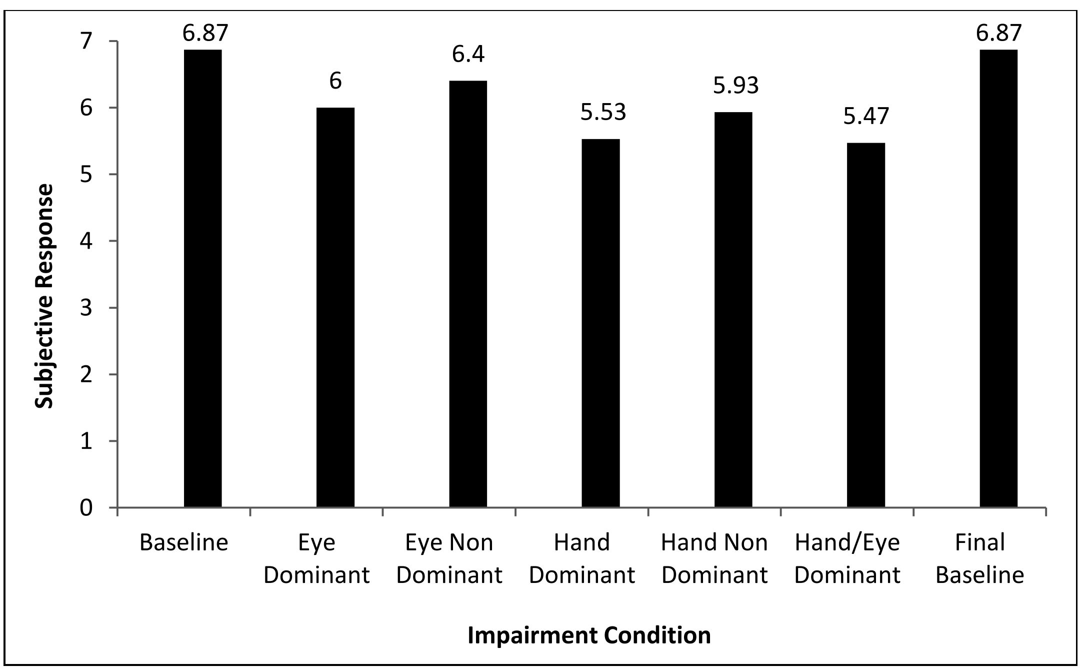

Figure 27. Rating of ability to get a consistent sight picture by impairment condition in reflexive shooting position.

1	2	3	4	5	6	7
Very Bad	Moderately Bad	Slightly Bad	Neutral	Slightly Good	Moderately Good	Very Good

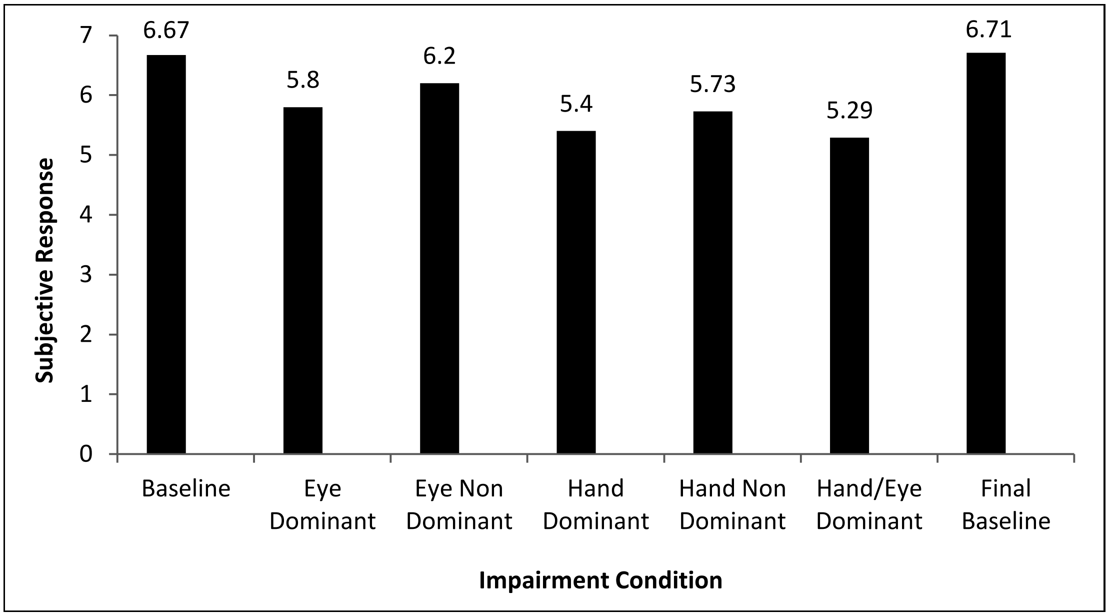

Figure 28. Rating of stability of butt stock while firing by impairment condition in aimed shooting position.

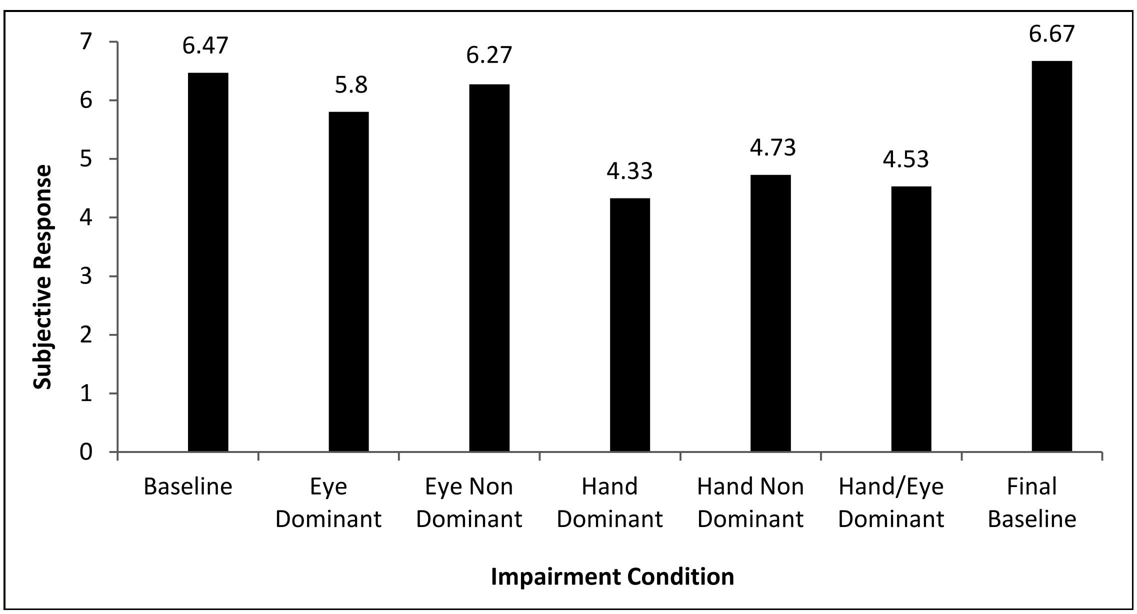

Figure 29. Rating of stability of butt stock while firing by impairment condition in reflexive shooting position.

1	2	3	4	5	6	7
Very Bad	Moderately Bad	Slightly Bad	Neutral	Slightly Good	Moderately Good	Very Good

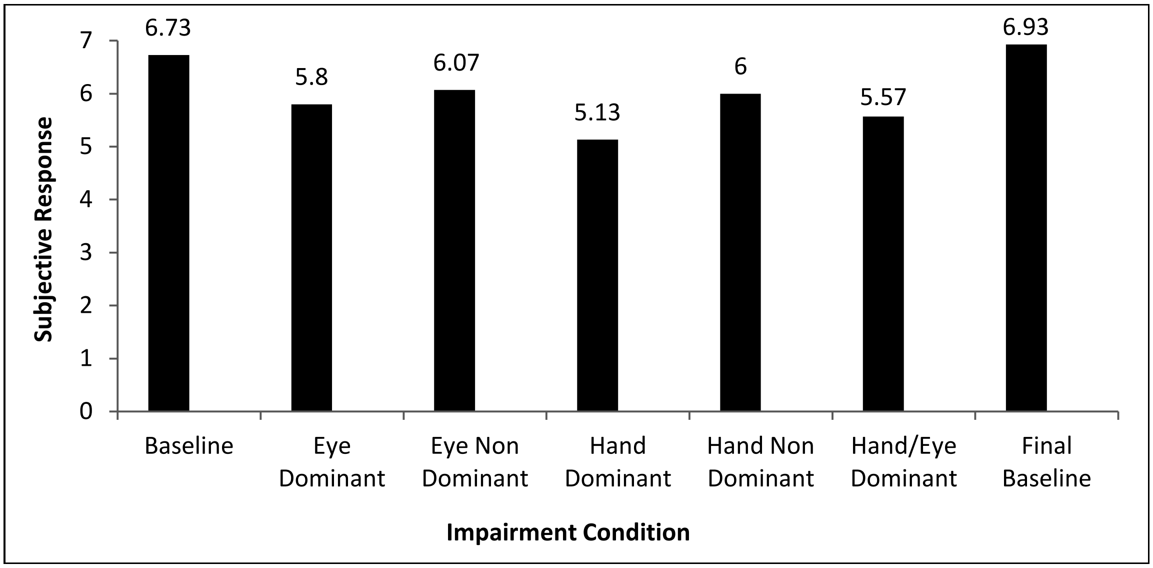

Figure 30. Rating of ability to attain a comfortable firing position by impairment condition in aimed firing position.

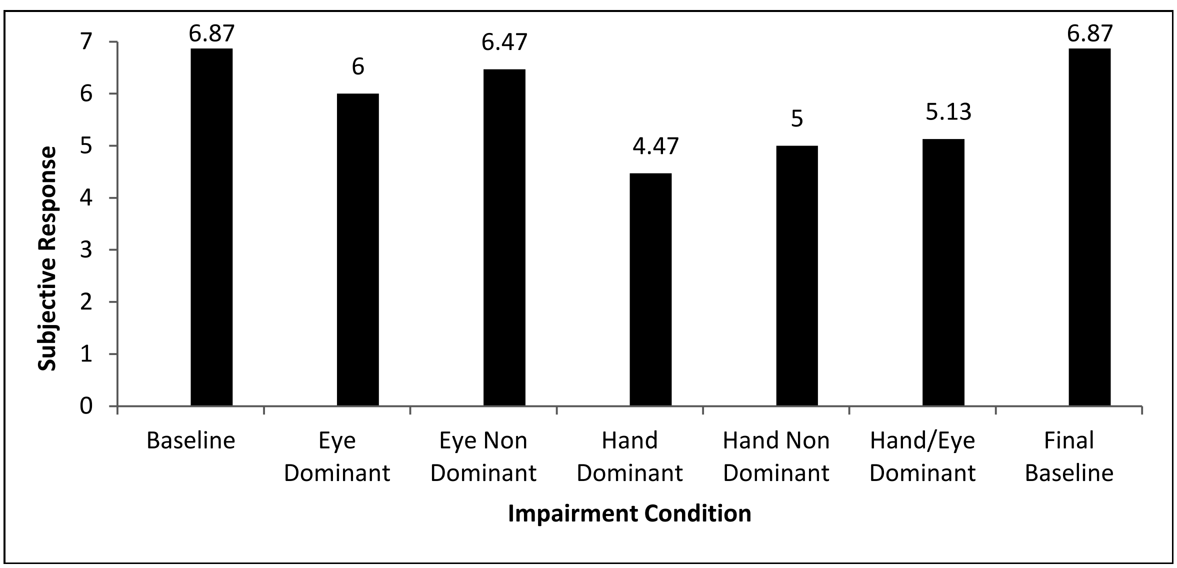

Figure 31. Rating of ability to attain a comfortable firing position by impairment condition in reflexive firing position.

1	2	3	4	5	6	7
Very Bad	Moderately Bad	Slightly Bad	Neutral	Slightly Good	Moderately Good	Very Good

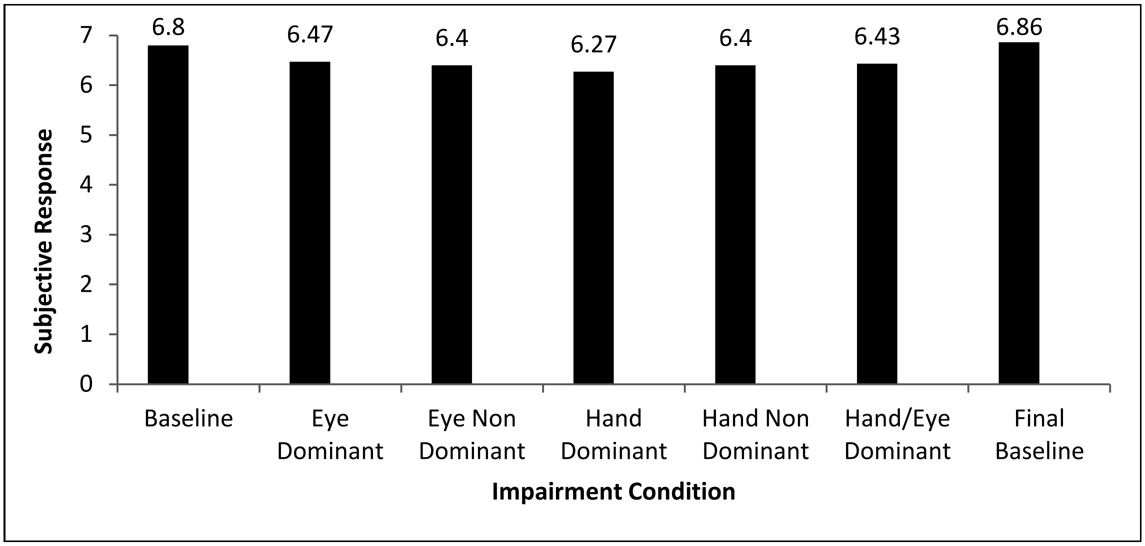

Figure 32. Rating of ability to pull the trigger by impairment condition in aimed firing position.

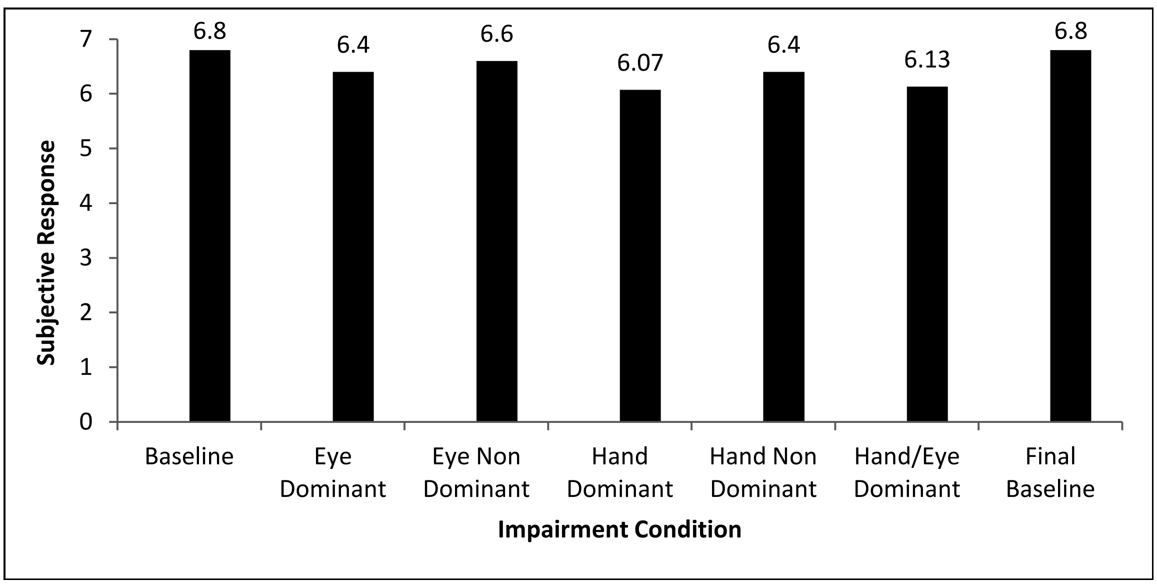

Figure 33. Rating of ability to pull the trigger by impairment condition in reflexive firing position.

11. Discussion

The effects of impairment condition and accommodation time on shooting performance were not as pronounced as expected. The hit percentage data for aimed fire (50-, 100-, 200-, and 300-m targets) from a foxhole supported firing position showed no effect of impairment condition or accommodation time. The only significant effect on hit percentage data at the aimed firing position was for range to target, which is to be expected, given that marksmanship difficulty increases, generally speaking, as range to target increases. There was no significant difference in hit percentage between the closer ranges (50 and 100 m). However, there was a significant degradation in hit percentage between the 200- and 300-m ranges. The 200- and 300-m ranges also had significantly lower hit percentages than the closer ranges (50 and 100 m). The target radial error data for the aimed fire task showed a similar trend as the hit percentage data in that the only significant effect occurred for range to target. As would be expected, as range to target increased, so did mean radial error. There was a significant difference in mean radial error between each of the distances.

The target engagement time data for aimed fire showed significant differences between most of the different impairment conditions. The dominant hand and dominant eye impairment conditions had longer target engagement times than the non-dominant hand and non-dominant eye conditions. In these conditions, shooters switched the weapon to the non-dominant side, resulting in increased engagement times. However, the non-dominant hand impairment condition revealed a significantly shorter target engagement time than all other impairment conditions, with the exception of the initial and final baseline conditions. This impairment condition is similar to the baseline conditions with no impairment at all. The dominant hand/eye condition was significantly longer that the non-dominant hand condition, but similar to the dominant eye, dominant hand, and non-dominant eye condition. In addition, there was no difference between the initial and final baseline conditions.

Similar to target radial error, target engagement time data showed a significant increase as range to target increased. This was expected, because more precise aiming was required to hit targets at greater distances. The precise aiming took more time. No significant effects were found between accommodation time and target engagement time.

The interaction between impairment condition and range showed effects on target engagement time. Analysis of the individual range distances allowed the effects of impairment condition to be more adequately understood. At the closer ranges (50 and 100 m), the dominant hand and dominant eye conditions exhibited much longer target engagement times compared to the non-dominant hand and non-dominant eye conditions. The dominant hand/eye condition target engagement times were similar to the other dominant conditions as well as the non-dominant eye condition. This clearly shows that when the switch from the dominant shooting side to the non-dominant shooting side is required, a marked effect is seen in target engagement timing. At the 100-m range the dominant hand/eye condition was similar to the dominant hand condition, yet exhibited shorter target engagement times compared to the dominant eye condition. Also, both non-dominant conditions were similar to the baseline conditions. As the range increased to 200 m, the effects of range and condition on target engagement time began to reach asymptote. At this distance, all of the dominant conditions, as well as the non-dominant eye condition, exhibited similar target engagement times. Also of interest is also that the non-dominant hand condition is similar to both baseline conditions. This is evident that impairment of the non-dominant hand had little effect on shooting performance. Finally, at the 300-m range, the differences between conditions continued to lessen. The target engagement times of the dominant hand, non-dominant hand, dominant hand/eye, and initial and final baseline were all similar. The only significant differences occurred with the dominant and non-dominant eye conditions. One possible reason that the differences in time of engagement increased as range increased was the precision aiming required at extended distances.

The reflexive firing task showed no significant effects or interactions for the target hit percentage data. The mean radial shot error data followed the same pattern of significance as in the aimed fired task. As would be expected, as range increased, mean radial shot error significantly increased.

The reflexive fire target engagement time data showed that the initial and final baseline were similar and did not exhibit a significant difference. All the impairment conditions exhibited a significantly longer target engagement time from the two baseline conditions. Also, the non-dominant hand impairment and non-dominant eye impairment showed no significant difference in target engagement time. These two conditions were significantly shorter in comparison to the dominant eye condition and the dominant hand condition. This was the same pattern of significance found in the aimed fired task. Impairment of the dominant shooting side caused the shooters to switch to their non-dominant shooting hand. This, in turn, increased the time needed to engage the target.

As would be expected and similar to the aimed fire task, target engagement time significantly increased as a range to target increased. The reflexive fire task was the only task that exhibited any effect of accommodation time between trials. The reflexive fire condition did show a significant effect of trial on target engagement time. After a 5-min accommodation period, target engagement time significantly decreased. The mean difference between the initial trial and the 5-min accommodation trial was 0.023 s.

The subjective data also showed that there was difficulty in obtaining a good sight picture during the dominant eye condition, dominant hand position (specifically for reflexive fire), and dominant hand/eye condition. The majority of the subjects reported that they attempted to make adjustments to improve shooting performance for the eye dominant, hand dominant, hand non-dominant, and hand and eye dominant conditions, regardless of firing task. The subjective results revealed the subjects did not think they had any problem controlling the weapon. The most difficult condition to control the weapon was reported to be the dominant hand in the reflexive fire condition. Ratings for the ability to get a normal sight picture ranged from "slightly good" to "very good" across the impairment conditions. The subjective rating of ability to obtain a good sight picture only was lower for the dominant eye position during the aimed fire task. Furthermore, ratings for being able to get a consistent sight picture were very good, with even the dominant eye position maintaining a consistent picture, although not necessarily a good one. Ratings for the stability of butt stock while firing were lowest for the reflexive fire task for dominant hand, non-dominant hand, and dominant hand and eye conditions. It is apparent that even with the impairment of the hand, either dominant or non-dominant, there is the ability to stabilize the butt stock of the weapon during reflexive fire. The subjective results showed a lower rating for the ability to attain a comfortable firing position when the dominant hand was impaired during the reflexive fire task. Subjective ratings of ability to pull the trigger were exceptionally high, between "moderately good" and "very good."

In summary, the target hit percentage, radial error data, and target engagement time had degraded performance as a function of range to target for the aimed fire task. As indicated by the interaction, as the range increased, the effect of physical impairment on target engagement time was reduced. Physical impairment did have a significant effect on the target engagement time for both the aimed fire and reflexive fire tasks, although not to the degree expected. The mean radial error data and target engagement time for the reflexive fire task also displayed degradation in performance as a function of range. Also, target engagement time decreased in the reflexive condition as a result of a 5-min accommodation period between trials.

12. Conclusions

The results of this study show that the effects of physical impairment, although not as obvious as expected, were most pronounced when the dominant shooting side was impaired. The only measure showing significant differences due to impairment condition was target engagement time. This occurred in both the aimed and reflexive shooting positions. Overall, it was apparent that physical impairment of the shooter's dominant side had a significant effect on target engagement time. In general, it took a longer time to engage the target when the dominant side was impaired and shooters were forced to switch to their non-dominant side. Also, for the aimed position, range to target and impairment condition showed an interaction. As range to target increased, the effect of impairment condition on target engagement time decreased. It was clear from the results that an impairment of the dominant side, either eye or hand, caused significant effects in the ability of a shooter to engage targets in a timely manner. For the aimed portion of the study, hit percentage data only showed significant differences for range to target. For hit percentage, there was no effect due to impairment. With the closest range of 50 m and the farthest range of 300 m, it was expected that significant differences would occur. This significant difference of range to target was not present in the reflexive portion of the study, nor were there any other significant differences for hit percentage data. The target radial error for both the aimed and reflexive firing positions only showed significant differences for range to target. Again, this was expected; as the range increased, the target radial error increased.

It is important to note that the population of shooters used for this study were expert-qualified shooters with tactical experience and training that exceeds that of the average U.S. Army Soldier. These shooters participate in a regular training regime that enables them to maintain expert shooting performance. The shooters are also trained in shooting with their non-dominant hand, which most likely contributed their successful accommodation to impairment. The results of this study may therefore have been a conservative representation of marksmanship performance relative to shooters with less live-fire training. Shooters with less training may be affected more due to impairment condition than was shown in this study.

Further research may include recruiting participants that while expert-qualified, may not practice the switching dominant and non-dominant shooting hands on a regular basis. Also of interest would be the impairment of not only the firing hand but the entire arm, thereby eliminating the use of the forearm as a stabilizing point. An anecdotal observation as well as discussion with shooters also revealed that there may be a benefit to impairment. That is, shooting with simulated impairment followed by subsequent shooting without impairment, may actually improve shooting performance. This suggested effect may be worth further investigation. Further research will be guided by the needs of ARL SLAD and the data needed to support improvements to their modeling efforts, thereby supporting the overarching JTAPIC program.

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Appendix A. Demographic Data Form

This appendix appears in its original form, without editorial change.

APPENDIX A
DEMOGRAPHIC QUESTIONNAIRE

Participant Number ________

Age_____ Gender ____ Rank______ Year and Month entered Military Service _____ / ____

Height ___ ft. ___ in. Weight _____lbs. Primary MOS______ Secondary MOS______

Job Title/Description: __________________Time in current job ________________

1. When was the last time you qualified with the M4 Carbine/M16 Rifle?

   Month ______ Year _____

2. What is your current level of qualification as rifleman?

   Marksman____ Sharpshooter ____ Expert ____

3. What was your level of qualification as rifleman prior to qualification listed in item 2?

   Marksman____ Sharpshooter ____ Expert ____

4. Are you left-handed ____, right-handed ____ or ambidextrous____? (Check one)

5. Are you a left-handed ____or right-handed ____rifle shooter? (Check one)

6. Do you use your ____left eye or ____right eye to aim a weapon? (Check one)

7. Do you wear prescription glasses or contact lenses when you shoot? Yes ___ No ___

8. Do you have any unusual difficulties seeing objects during daytime? Yes ___ No ___
   If yes, what difficulties do you experience?

9. Do you have any unusual difficulties seeing objects during night? Yes ___ No ___
   If yes, what difficulties do you experience?

10. Do you have experience using optical devices or thermal sights? Yes ___ No ___
    If yes, list the type of device(s) you have used in the space below:

Appendix B. Counterbalanced Order of Impairment

Table B-1 shows the counterbalanced order of impairment for each test participant.

Table B-1. Counterbalanced order of impairment for each test participant. Note: conditions in trials 6 and 7 are not counterbalanced.

Shooter	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6	Condition 7
1	A	B	E	C	D	F	G
2	B	C	A	D	E	F	G
3	C	D	B	E	A	F	G
4	D	E	C	A	B	F	G
5	E	A	D	C	B	F	G
6	D	C	E	B	A	F	G
7	E	D	A	C	B	F	G
8	A	E	B	D	C	F	G
9	A	B	E	C	D	F	G
10	B	C	A	D	E	F	G
11	C	D	B	E	A	F	G
12	D	E	C	A	B	F	G
13	E	A	D	C	B	F	G
14	D	C	E	B	A	F	G
15	E	D	A	C	B	F	G
16	A	E	B	D	C	F	G

Note: A = baseline; B = hand-dominant; C = eye – dominant; D = eye – non-dominant; E = hand – non-dominant; F = hand and eye – dominant; G = final baseline.

Appendix C. Post-Firing Questionnaire

This appendix appears in its original form, without editorial change.

POST-FIRING QUESTIONNAIRE

Test Participant number ______ Condition:________ Date:______

During the following questions, the term "normal cheek weld" is defined as: Your personal position and pressure (trained established and used) on the standard weapon every time you shoulder the weapon to acquire your sight picture.

1. Were you able to cheek the weapon as you normally do and still get a good sight picture?

Yes No If no, explain below

2. Compared to my normal cheek weld, my cheek pressure against the stock was:

1	2	3	4	5	6	7
Much more pressure	Moderately more pressure	Slightly more pressure	Same pressure as your normal cheek weld	Slightly less pressure	Moderately less pressure	Much less pressure

Comments:

3. Compared to my normal cheek weld, my head tilt over the stock was:

1	2	3	4	5	6	7
Much more tilt	Moderately more tilt	Slightly More tilt	Same tilt as usual	Slightly less tilt	Moderately less tilt	Much less tilt

Comments:

4. Compared to my normal cheek weld, the weapon cant (tilt) was:

1	2	3	4	5	6	7
Much more cant	Moderately more cant	Slightly More cant	Same cant as usual	Slightly less cant	Moderately less cant	Much less cant

Comments:

Please rate the following as it pertains to your experience with the weapon condition you just fired using the 7-point scale as shown below.

1	2	3	4	5	6	7	**N**
Very Bad	Moderately Bad	Slightly Bad	Neutral	Slightly Good	Moderately Good	Very Good	Could not Evaluate

	1	2	3	4	5	6	7	**N**
5. Ability to zero the weapon								
6. Ability to get a normal sight picture								
7. Ability to obtain a good sight picture given combat time constraints								
8. Ability to get a consistent sight picture								
9. Stability of the buttstock while firing (Good stability would be if the buttstock did not slip out of position, bad stability would be if the butt stock did slip out of position)								
10. Ability to attain a comfortable firing position								

Please provide any additional comments on the condition you just fired:

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List of Symbols, Abbreviations, and Acronyms

ACH	advanced combat helmet
ACOG	advanced combat optical gunsight
ANOVA	analyses of variance
ARL	U.S. Army Research Laboratory
CCO	close combat optic
DoD	Department of Defense
HRED	Human Research and Engineering Directorate
HSD	Honestly Significant Difference
IBA	interceptor body armor
JTAPIC	Joint Trauma Analysis and Prevention of Injury in Combat
MOS	Military Occupational Specialty
OD	Olive Drab
ORCA	Operational Requirement-Based Casualty Assessment
SLAD	Survivability and Lethality Analysis Directorate
SOP	standard operating procedure
SRT	Special Response Team
TTPs	tactics, techniques, and procedures
V&V	verification and validation

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