Army Research Laboratory

The Effect of Modified Eye Position on Shooting Performance

by William Harper, Frank Morelli, Samson Ortega, and Patrick Wiley

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14. ABSTRACT

This study was conducted as part of an Army Technology Objective (ATO) called "Helmet Electronics and Display System – Upgradeable Protection" (HEADS-UP) which is a program to leverage science and technology efforts to design a modular-integrated headgear system. This is one of several programs aimed at improving personal protection systems, many of which include adding facial protection from blast and ballistic threats. The addition of facial protection to helmet systems will likely cause a change in the way Soldiers "cheek" a weapon, directly causing a change in the natural position of the shooter's eye, thereby affecting the way Soldiers align the sights of a weapon when aiming. This study examined the differences in shooting performance for a Soldier firing a weapon using various eye positions due to changes in butt stock height and width. These eye positions simulated the effects of different helmet and facial protection systems, which may interfere with the normal cheek-to-stock weld between the shooter and the weapon, thereby altering eye position relative to the sight. The shooting tasks encompassed firing at targets between 10 and 300 m under time-pressure, using four different eye positions with 2 different sighting systems (iron sights and M68). In summary, hit percentage and shot radial error data showed that a 3 cm eye position offset degraded performance for both sighting systems compared to the baseline. However, with the M68 sight, shooting performance with the 1 cm and 2 cm offsets were not significantly lower than in the baseline condition, whereas the 2 cm and, to a lesser degree, the 1 cm offsets for the iron sight showed degraded performance over the baseline condition. Results from this study will allow developers to estimate shooting degradation that may be caused by facial protection systems that influence the normal cheek-to-stock weld.

15. SUBJECT TERMS

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- Thomas Fry and Douglas Struve for providing range support to collect the live firing shooting data at M-Range.
- Neal Ware for programming the range computer for the target scenarios, running the range computer, and for conducting shooting performance data reduction.

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1. Project Background

In 2010, the U.S. Army funded an Army Technology Objective (ATO) called "Helmet Electronics and Display System – Upgradeable Protection," or "HEADS-UP." The goal of the HEADS-UP ATO is to leverage multiple science and technology (S&T) efforts in the areas of ballistic materials (transparent and non-transparent), mask and filter development, high-resolution miniature displays and sensors to design a modular-integrated headgear system that takes into primary consideration center of gravity and moment of inertia for a well-balanced, physically fightable, Soldier acceptable headgear system. Head-borne protection and functional capabilities will be designed for this effort as an integrated platform, utilizing Soldier-centric design principles. This should demonstrate an optimization of weight and sub-component integration for the helmet system.

There are significant weapon compatibility constraints to consider when employing such headgear. McKee and Tack[1] (2010) showed that helmets with integrated mandibular guards alter the eye position of the shooter by up to about 3 cm in vertical distance, and up to 3 cm in horizontal distance. This difference in eye position is likely to cause a significant impact on the aiming process and shooting performance. However, the difference between firing performance with the normal eye position versus a modified eye position may be dependent on the sighting system used. This study examined the effect of modified eye position while using the M68 Close Combat Optic (CCO) reflex sight, as well as using traditional iron sights. Examining both sighting systems was important because some sighting systems are more sensitive to changes in eye position than others. For instance, the M68 CCO sight eliminates parallax given its singular referent for target alignment – a red dot subtending 4 min of visual angle (MOA). Given the requirement to align rear-aperture, front-post and target with the corresponding iron sight system, the M68 may in turn be more forgiving of a modified eye position that causes lateral displacement. Such effects were the experimental focus for both a short-range reflexive firing scenario as well as an aimed firing scenario with more distant targets.

The goal of this study was to characterize any shooting performance difference between different eye position conditions that might be caused by facial or mandibular protection systems. This study did not introduce facial protection systems as a means of modifying eye position because of the potential confounds between the different facial protection concepts and other factors that could affect shooting performance (e.g., obfuscation of the target due to fogging of eye-protection). Instead, butt stocks that displaced the position of the cheek weld both laterally and vertically relative to the shooter's normal cheek position were used to precisely modify eye position while minimizing potential confounds for marksmanship performance.

[1]McKee, K. W.; Tack, D. W. Face Shield Integration and Butt-stock Adjustability. DRDC Toronto, 2010.

Using these modified buttstocks, this effort in effect empirically isolated the impact of modifying eye position on marksmanship performance. Given the task-criticality of employing accurate fire for both mounted and dismounted operations, the results of this effort may yield considerable influence over the design of future facial protection and chemical/biological mask systems.

2. Synopsis

The addition of facial protection to helmet systems will likely cause a change in the way Soldiers "cheek" a weapon, directly causing a change in the natural position of the shooter's eye. This study examined the differences in shooting performance for a Soldier firing a weapon using various eye positions due to changes in cheek position. These eye positions simulated the effects of different helmet and facial protection systems, which may interfere with the normal cheek-to-stock weld between the shooter and the weapon, thereby altering eye position relative to the sight. The shooting tasks employed in this study encompassed firing at targets between 10 and 300 m under time-pressure, using four different eye positions with 2 different sighting systems. The main goal of this study was to determine how modified eye position affects shooting performance using various sighting systems. Results from this study will allow developers to estimate the shooting degradation that may be caused by any facial protection system that may influence the normal cheek-to-stock weld.

3. Participants

Fifteen current and prior-service participants from across the military services (U.S. Army, Navy, Marine Corps, and Air Force) were asked to participate 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 a rifle within the past year. Those participants who were prior-service military were currently under contract as gun crew for the Aberdeen Test Center and were experienced shooters.

3.1 Pretest Orientation and Volunteer Agreement

Test participants who volunteered for the study were given an orientation on its purpose and the details of their participation. They were briefed on the experimental objectives and procedures, were told how results will be used, and what benefits the military can expect from this investigation. Any questions that participants voiced regarding the study were answered accordingly. The test participants were asked to complete an Informed Consent Form. Its contents were explained verbally, and they 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.

3.2 Demographics and Visual Acuity

Participants provided their personal demographic information using the Demographic Data Form (appendix A). All experimental participants were current or former enlisted service members from the U.S. military, with representation from each branch of service (U.S. Army, Navy, Marine Corps, and Air Force) and ranging in rank from E-3 to E-7 (junior enlisted to junior/senior non-commissioned officers (NCOs). All participants were male, and all had qualified within the last year using the M4 carbine (one participant at *marksman*, eight at *sharpshooter*, and six at the *expert* level). 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 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. All participants were familiar with the rear-aperture/front-post iron sight configuration traditionally featured on M16/M4 weapon system variants. Only one of the 15 participants was left-handed, though three experimental participants expressed left-eye dominance (i.e., two participants were "cross-dominant"). Visual acuity performance for all participants was 20/20, with one participant aided by corrective contact lenses.

3.3 Anthropometry

Anthropometric data was collected from each participant. Summary anthropometric statistics are shown in table 1. The following measures were recorded:

- stature
- weight
- acromial height
- bizygomtic breadth
- head breadth
- head circumference
- head length
- interpupillary breadth

Table 1. Summary anthropometric statistics collapsed across experimental participants.

	N	Minimum	Maximum	Mean	Std. Deviation
Height (cm)	15	168.8	194.0	177.89	7.309
Weight (lbs.)	15	185.0	265.0	212.87	26.654
Acromial Height (cm)	15	138.0	160.4	147.11	7.597
Bizogymatic Breadth (cm)	15	12.3	15.2	14.15	0.743
Head Breadth (cm)	15	14.6	16.3	15.58	0.500
Head Circumference (cm)	15	55.8	59.6	57.73	1.144
Head Length (cm)	15	18.2	20.6	19.68	0.692
Interpupillary Breadth (mm)	15	56.0	70.5	64.70	3.867

4. Objectives

- To quantify the effect that modifying the eye position of the shooter had on the ability to hit targets at various ranges in both the reflexive firing and aimed firing scenarios.
- To examine if the effect of modified eye position was different for iron sights compared with the M68 CCO reflex sight, for both reflexive firing 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 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 m 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 semiautomatic 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-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. HRED's M-range shooting performance research facility.

Figure 2. Olive Drab (O.D.) "E"-type silhouette 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 stock. Equipped with a shorter barrel, collapsible stock and optional accessory rails, it provides Soldiers operating in close-quarters with improved handling and the capability to rapidly and accurately engage targets, day or night. A shortened variant of the M16A2 rifle, the M4 also provides the individual Soldier operating in close quarters the capability to engage targets at extended range with accurate, lethal fire.

Figure 3. M4 Carbine.

5.3 Modified Buttstocks

M4 buttstocks were modified in order to relocate the shooter's eye position when firing the weapon. Example images of the modified buttstocks are shown in figure 4. These buttstocks were used to keep the shooter's eye in the normal position (baseline condition), move the shooter's eye up by one cm and laterally by one cm (1,1 condition), move the shooter's eye up by two cm and laterally by two cm (2,2 condition), and move the shooter's eye up by three cm and laterally by three cm (3,3 condition). These buttstock modifications were performed by Colt Canada, based in Kitchener, Ontario, Canada. Additional material was molded onto the buttstock to cause the cheeking of the weapon (and eye position) to be displaced away from the standard position.

5.4 Sighting Systems

Since sight parallax may have a significant effect on shooting performance with a modified eye position, two sighting systems were used in this study. Iron sights, given the requirement to align the rear-aperture with the front-post relative to the target, are considered quite sensitive to changes in eye position and were thus well suited for employment as a sighting system condition.

Figure 4. Examples of the baseline, 1,1 cm, 2,2 cm, and 3,3 cm buttstocks used to modify the eye position of the shooter.

The other sight used was the M68 CCO reflex sight. This sight is widely considered less sensitive to changes in eye position within the marksmanship research community because it uses a singular collimated red dot as a reticle for alignment with the target object. This aiming dot is thought to remain on the target with slight movements of the eye position when the weapon does not move. Figure 5 provides a photograph of the iron sights and M68 reflex sight.

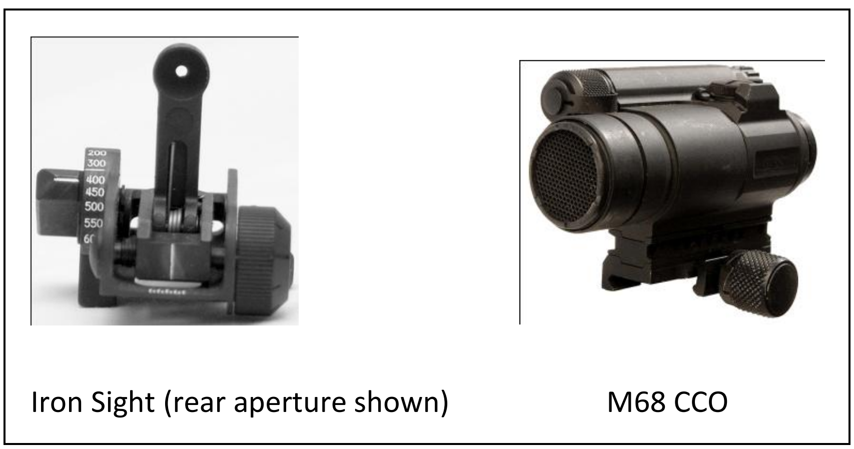

Figure 5. Iron sight rear aperture and the M68 CCO reflex sight.

6. Experimental Design

6.1 Experimental Conditions

There were four eye position conditions in this study. These eye positions were manipulated by using different buttstocks that moved the normal cheek-to-stock weld away from the normal position both vertically and laterally. The following eye positions were used in this study:

- Baseline – Normal M4 buttstock
  - 1,1 - eye position moved 1 cm horizontally and 1 cm vertically
  - 2,2 - eye position moved 2 cm horizontally and 2 cm vertically
  - 3,3 - eye position is moved 3 cm horizontally and 3cm vertically

Figure 6 is a graphical representation of the four cheek weld and subsequent eye positions that were used for a right-handed shooter. Independent variables included weapon sighting systems, eye position, and target ranges. The two weapon sight conditions employed were standard iron sights and the M68 CCO reflex sight. Each sight was implemented for each eye position condition in this study. Target ranges for reflexive firing trials were 10, 25, and 50 m, while target ranges for the aimed fire portion of the study were 100, 200, and 300 m. Exposure time (i.e., the time the target was exposed for acquisition) was set at 3.0 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.

6.3 Training and Testing Sequence

Soldiers fired in all experimental conditions over the course of roughly 7 h. To account for practice and order effects, the order in which the Soldiers fired in the conditions was counterbalanced (see appendix B). First, Soldiers zeroed two M4 carbines (one with an iron sight and one with an M68 sight). Experimental participants were then issued the weapon in the first experimental condition in their individually prescribed firing condition sequence (e.g., 1,1 buttstock coupled with M68 CCO). Soldiers then performed the aimed firing trials with the given experimental condition (figure 7). Soldiers completed one training trial and one test trial with each eye position/sighting system combination.

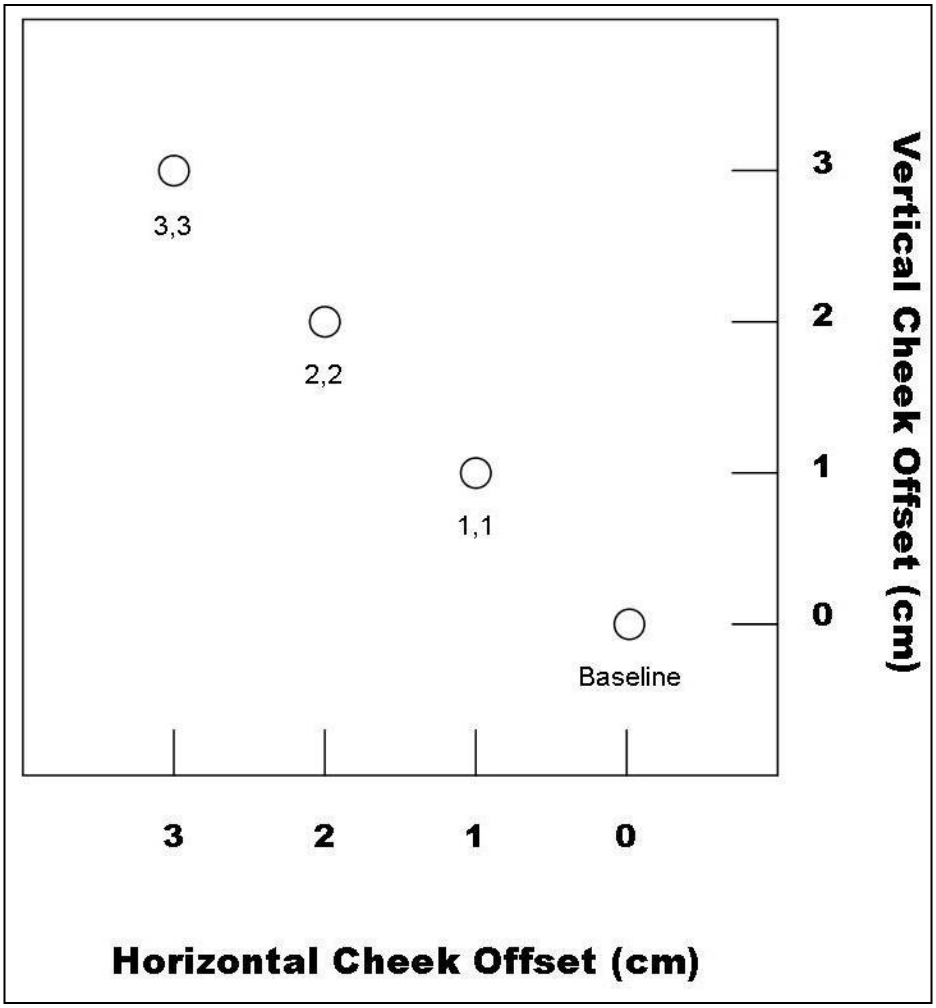

Figure 6. Baseline (i.e., standard) cheek offset, as well as the horizontal and vertical cheek offset displacement distances employed during the study are illustrated above. Note that eye position used to align sighting systems with a target are directly affected by the initial offset of the cheek relative to the longitudinal axis of the weapon barrel.

Figure 7. Soldier firing the M68 sight in the 3,3 cm eye position condition.

During the aimed fire trials, participants fired from the foxhole supported firing position at target ranges of 100, 200, and 300 m with10 targets appearing at each range. 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. Soldiers were told to aim at the marked center-of-mass position on the target, with accuracy scored by proximity of the round relative to that point. Shooters were also timed on how long it took them to fire each round (target engagement time).

Soldiers then proceeded to the reflexive firing task. Soldiers completed one training trial followed by one trial for the reflexive firing portion of the study. During the reflexive firing trials, targets appeared at ranges of 10, 25, and 50 m with an exposure time of 3.0 s. A total of 30 targets were presented (10 at each range). Soldiers 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 aimed shot. The aim point was a marked center of mass location on the target. Soldiers were told to aim at a marked center-of-mass position on the target, with accuracy likewise scored by proximity of the round relative to that point. Target engagement times were also recorded by the system. After participants completed each aimed firing and reflexive firing condition sequence, they completed a post-firing questionnaire (appendix C).

After a rest period of at least 10 min, the participant continued with the next experimental condition. This was repeated until the participant completed all the conditions. Test Participants participated in the study from ~0800 to 1500 h. Test participants completed all firing over a one-day period.

7. Independent Variables

The independent variables for this study were:

- Eye position - baseline, 1,1 cm, 2,2 cm, and 3,3 cm,
- Weapon sights - Iron sights and M68 reflex sight,
- Range to target - 10, 25, and 50 m (reflexive fire) and 100, 200, and 300 m (aimed fire).

8. Dependent Variables

The dependent variables for this study were:

- 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. First, descriptive statistics on the dependent measures of hit percentage, radial error, and time to shot, were calculated for each variable in both the reflexive fire and aimed fire portions of the study. Next, independent 2 (weapon sight) X 4 (eye position) X 3 (range to target), 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.

When shots were fired at a target and were not picked up by the shot location detection system, the shot was treated as a missing value and not used in the data analyses. Due to not using a value for the shots outside the detection envelope, the shot radial error was underestimated in most cases. In several analyses with a high percentage of missing values, this conservative method significantly underestimates the shot radial error.

10. Results

10.1 Objective shooting Performance Data

10.1.1 The Effect of Eye Position and Sight on Aimed Fire

For the target hit percentage data, sight type ($F(1, 14), = 28.38, p = 0.000$) and eye position ($F(3, 42) = 33.91, p = 0.000$) were found to have significant effects. The eye position x sight interaction was also found to be significant, $F(3, 42) = 7.66, p = 0.000$, relative to target hit percentage (figure 8). Tukey post-hoc analyses showed that for the M68 sight, the 3,3 cm condition had significantly lower hit percentage than the other three eye positions. However, for the iron sight, there was a significant difference in hit percentage between each of the eye position conditions, with eye positions farther from the stock resulting in lower hit percentages. The degraded performance for iron sight conditions as eye position were displaced further from baseline likely accounts for much of the main effect of eye position, and may account for the main effect of sight as well.

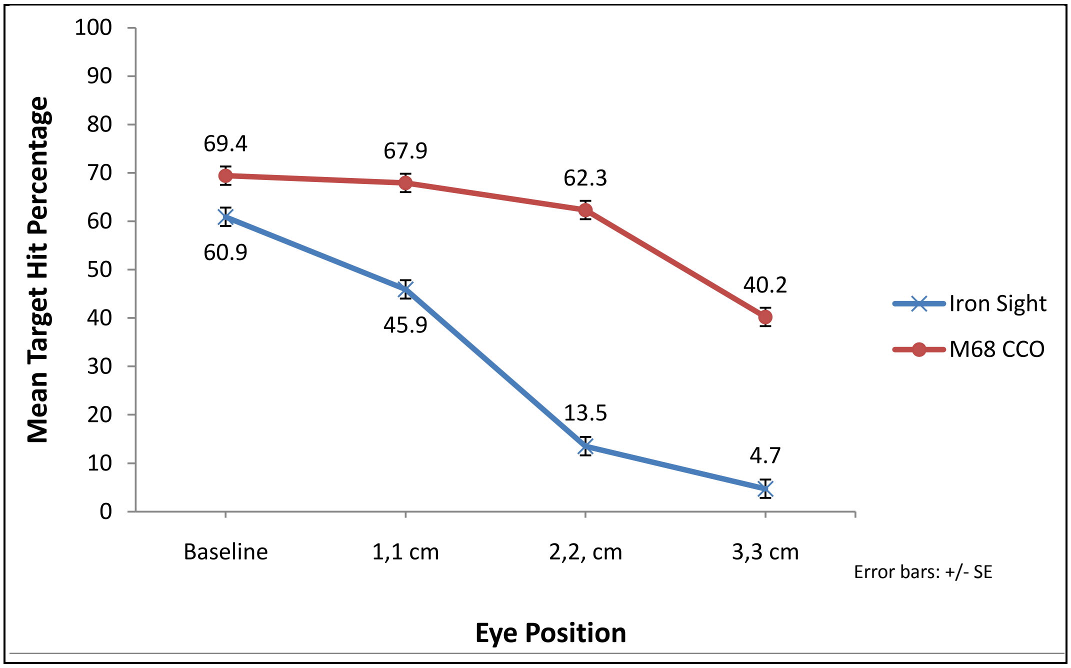

Figure 8. The effect of eye position condition x sight on mean target hit percentage for the aimed fire shooting task.

For the target radial error data, main effects of sight (F(1, 14), = 19.73, p = 0.001) and eye position (F(3, 42) = 19.32, p = 0.000) were found relative to the mean distance of the shot from the center of mass of the target. A significant interaction of eye position x sight was also found, F(3, 42) = 8.76, p = 0.000, relative to the distance of the shots from the center of mass of the target (figure 9). Tukey post-hoc analyses showed that for the M68 sight, the 3,3 cm condition had significantly higher radial error than the other three eye positions and the baseline condition was significantly different from the 2,2 cm condition. For the iron sight, the 2,2 cm and 3,3 cm conditions had significantly higher radial error than the baseline or 1,1 cm conditions. As shown in figure 9, the 2,2 cm and 3,3 cm conditions for the iron sight had similar missed distances. This result occurred because of the high number of shots that were outside the shot detection envelope (no shot detected). Because all of the shots outside the detection envelope were not factored into the radial error means, the radial error is substantially underestimated for certain conditions (e.g., iron sights with 3,3 cm). For iron sights, the missing values percentage was 87.4% for 3,3 cm, 54.7% for 2,2 cm, 20% for 1,1, and 15.7% for the baseline condition. In the M68 sight condition there were far fewer shots outside of the shot detection envelope with 35.8% missing for 3,3 cm, 13.5% for 2,2 cm, 15.8% for 1,1, and 15.4% for the baseline condition.

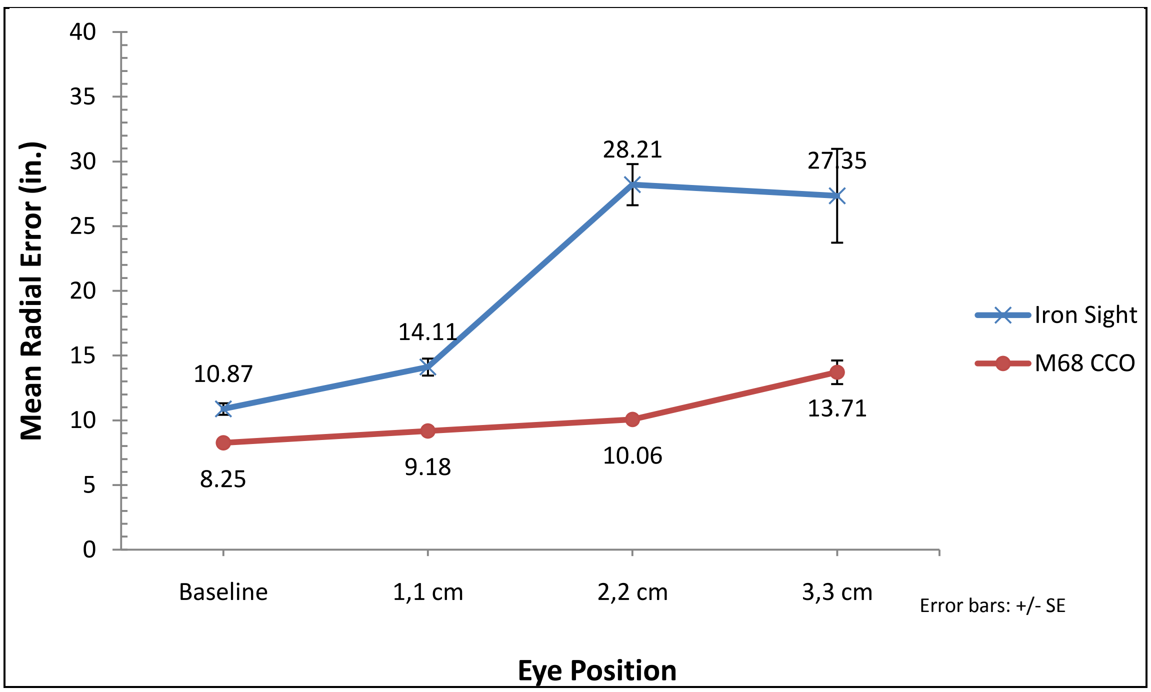

Figure 9. The significant effect of eye position x sight on the mean radial error of the shot for the aimed fire shooting task.

With respect to target engagement time data, a main effect of eye position (F(3, 42) = 5.64, p = 0.002) was found relative to target engagement timing. There was no significant difference found between sight type and engagement time. A significant interaction of eye position x sight was also found, F(3, 42) = 7.64, p = 0.000, relative to target engagement timing (figure 10). Post hoc Tukey analyses showed that there were no significant differences in engagement time between eye position conditions when using the M68 sight. However, for the iron sight, the shot time in the 3,3 cm condition was shorter than in all other conditions, and the shot time in the 2,2 cm condition was shorter than the baseline or 1,1 cm condition.

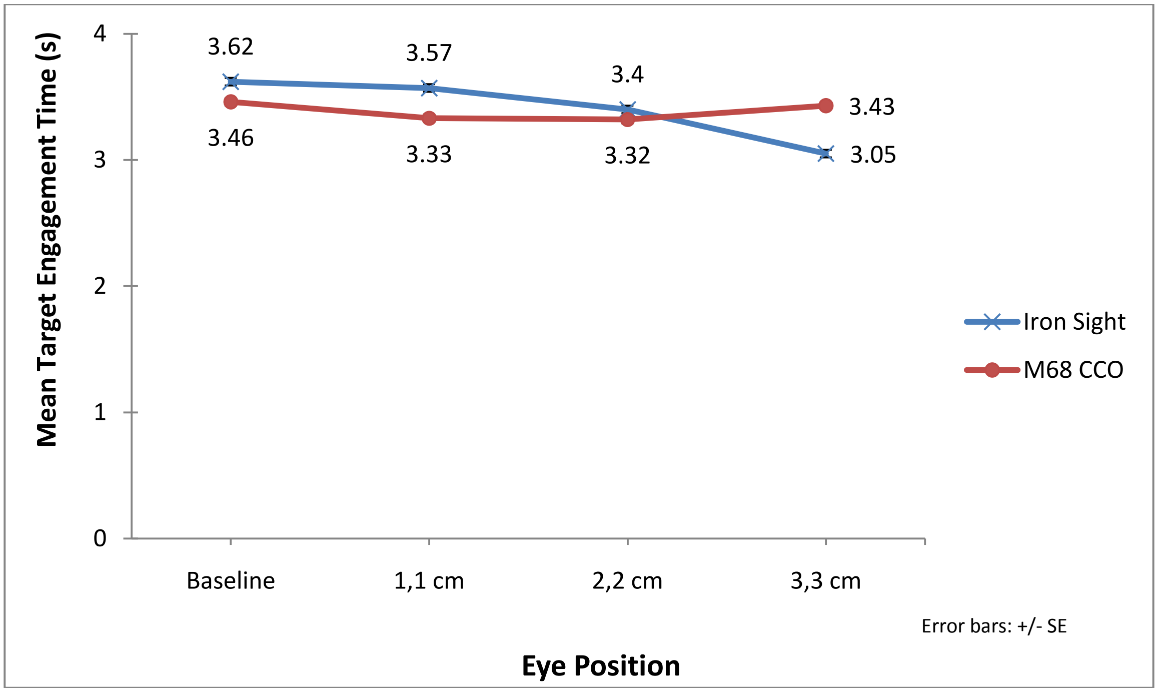

Figure 10. The significant interaction effect of eye position x sight on mean target engagement time for the aimed fire shooting task.

10.1.2 The Effect of Eye Position and Sight on Reflexive Fire

For the target hit percentage data, main effects of sight ($F(1, 14)$, = 60.80, $p = 0.000$) and eye position ($F(3, 42) = 42.96$, $p = 0.000$) were recorded. The interaction effect of eye position x sight was also found to be significant, $F(3, 42) = 13.20$, $p = 0.000$, on target hit percentage (figure 11). The Tukey post-hoc analyses showed that for the M68 sight, the 3,3 cm condition had significantly lower hit percentage than the other three eye positions. For iron sight conditions, the 3,3 cm condition had a significantly lower hit percentage than all other eye positions. Also, the 2,2 cm eye condition had a significantly lower hit percentage than the 1,1 and baseline eye positions. The significant main effect of sight is likely due to the severe degradation in hit percentage that occurred in the 2,2 cm and 3,3 cm conditions with the iron sight.

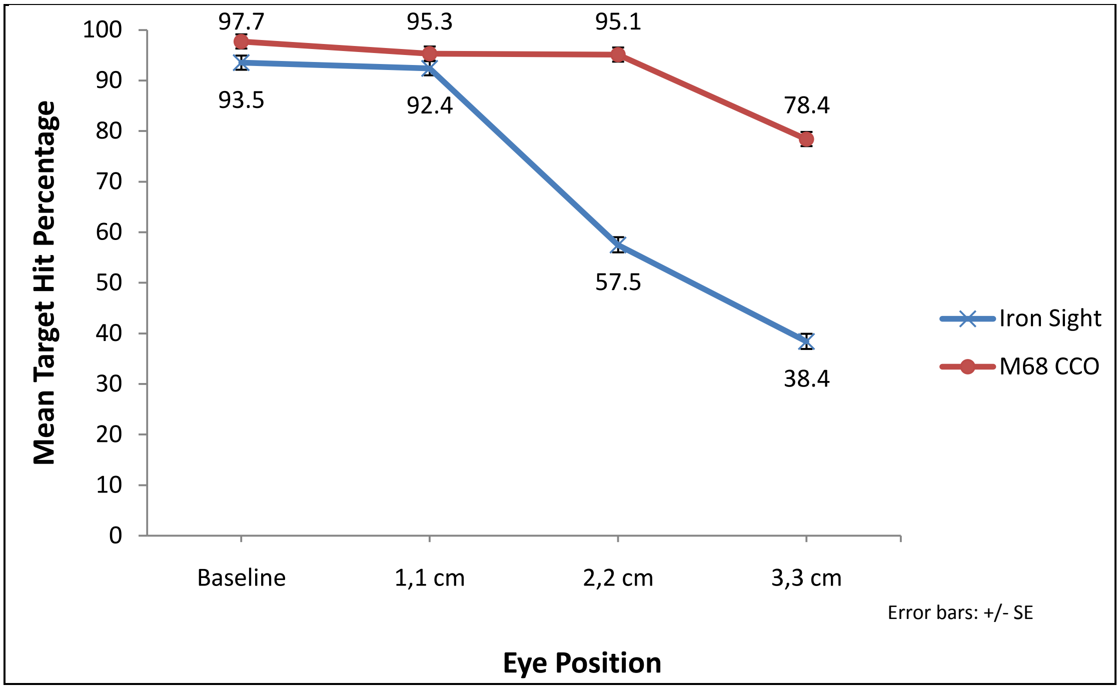

Figure 11. The significant interaction effect of eye position x sight on mean target hit percentage for the reflexive firing shooting task.

For the target radial error data, main effects of sight (F(1, 14), = 23.84, p = 0.000) and eye position (F(3, 42) = 30.62, p = 0.000) were found relative to mean distance of the shot from the center of mass of the target. The interaction effect of eye position x sight was also found to be significant, F(3, 42) = 7.59, p = 0.000 on the distance of the shots from the center of mass of the target (figure 12). Tukey post-hoc analyses showed that for the M68 sight, the 3,3 cm condition reflected significantly higher radial error than the other three eye position conditions. However, for the iron sight, both the 2,2 cm condition and 3,3 cm condition had significantly higher radial error than the baseline and 1,1 cm conditions. Also, the 3,3 cm condition had significantly higher radial error than the 2,2 cm condition. As in the aimed fire data, shots that were outside the shot detection envelope were not factored into the means for radial error. Therefore, the radial error is underestimated; especially in conditions where there were a high number of shots outside the detection envelope. For iron sights, the missing values percentage was 24.4% for 3,3 cm, 10.2% for 2,2 cm, 3.6% for 1,1, and 4.4% for the baseline condition. In the M68 sight condition there were far fewer shots outside of the shot detection envelope with 4.9% missing for 3,3 cm, 3.1% for 2,2 cm, 2.7% for 1,1, and 1.8% for the baseline condition.

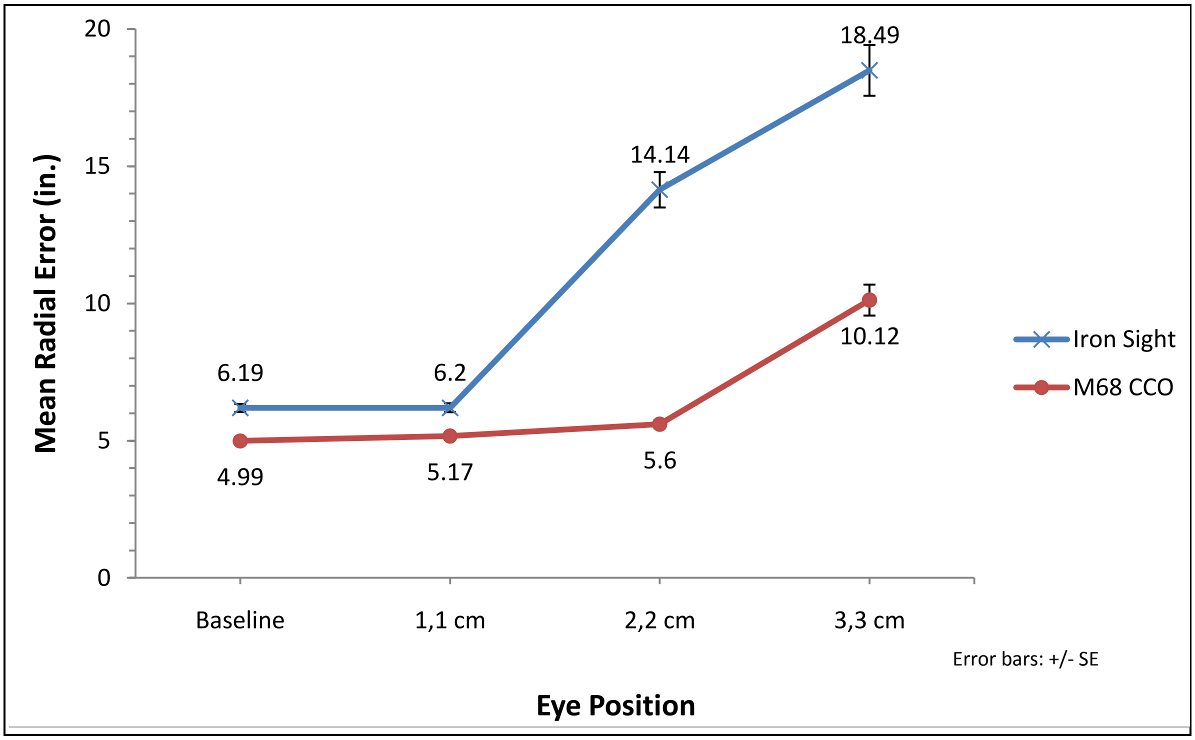

Figure 12. The significant effect of eye position x sight on the mean radial error of the shot for the reflexive firing shooting task.

For target engagement time data, a main effect of sight ($F(1, 14)$, = 20.04, $p = 0.001$) was observed with the target engagement time for the iron sights significantly longer than for the M68 sight. There was no significant difference found for eye position on engagement time. The interaction effect of eye position x sight was also found to be significant, $F(3, 42) = 4.48$, $p = 0.008$, relative to target engagement time (figure 13).

Tukey post-hoc analyses showed that for the m68 sight, the target engagement times were significantly longer in the 3,3 cm condition than all other eye position conditions. For the iron sights, both the 3,3 cm and 2,2 cm conditions had significantly shorter engagement times than the baseline and 1,1 cm eye position conditions.

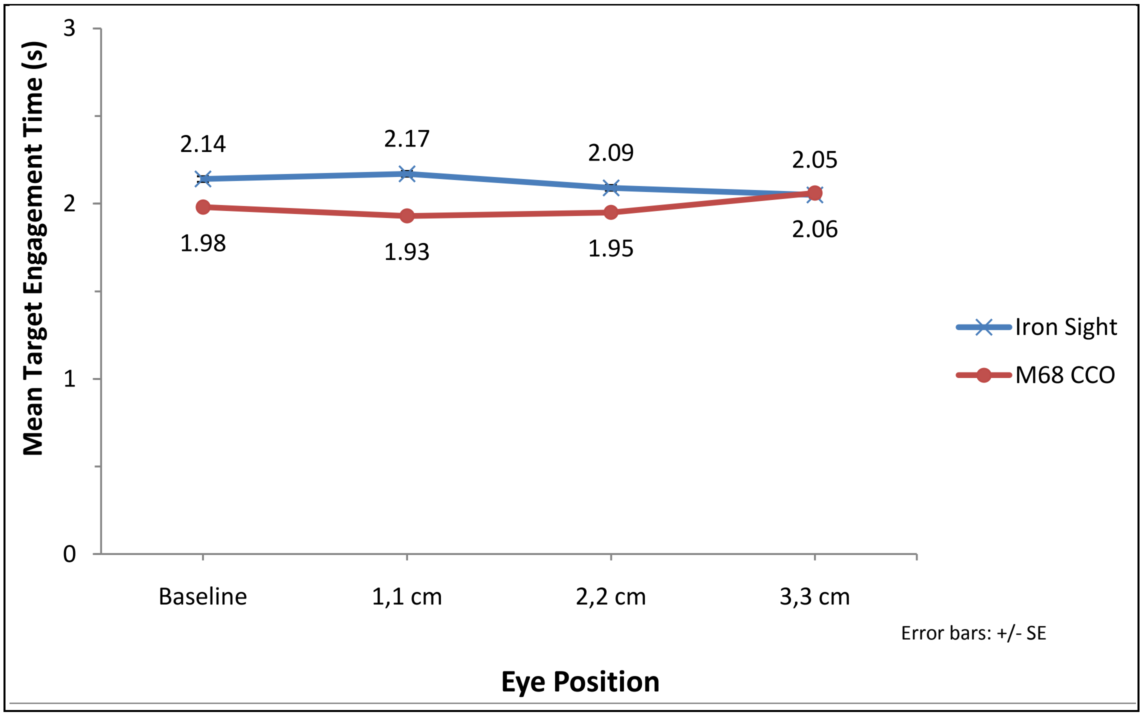

Figure 13. The significant interaction effect of eye position x sight on mean target engagement time for the reflexive firing shooting task.

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 get a sight picture and to rate amount of head tilt, weapon cant, and cheek weld pressure that was used during weapon fire. Results are summarized graphically, across experimental participants, in figures 14–22.

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

Yes No

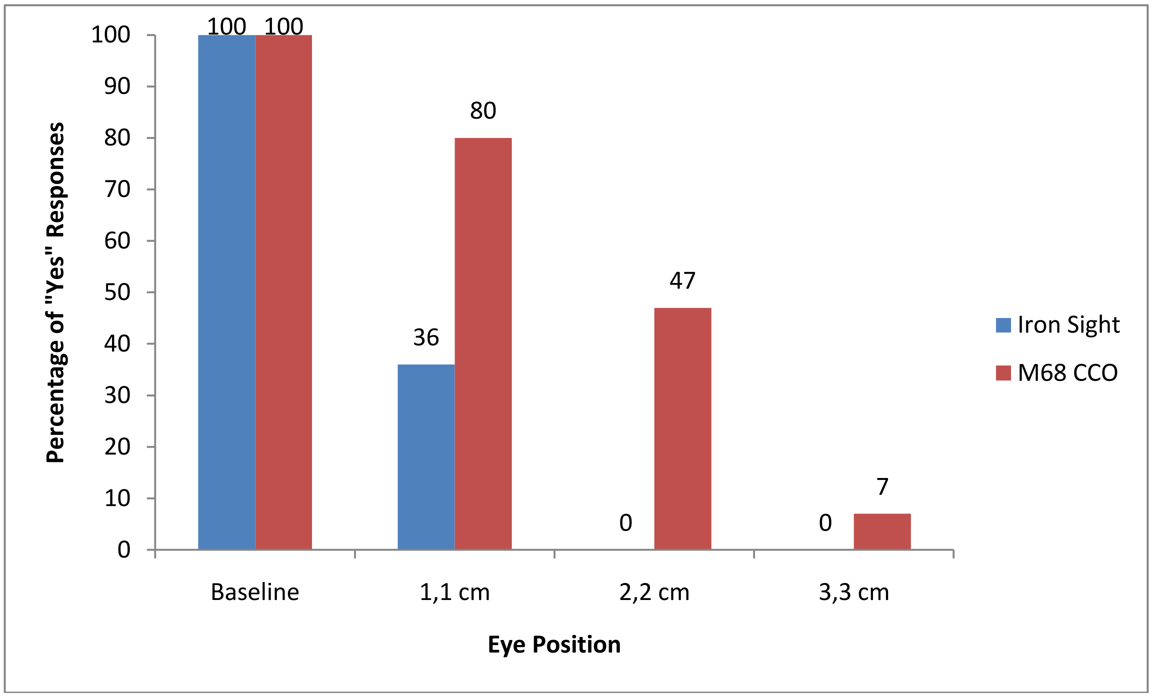

Figure 14. Percent of test participants reporting that they could cheek the weapon normally by sight and eye position.

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

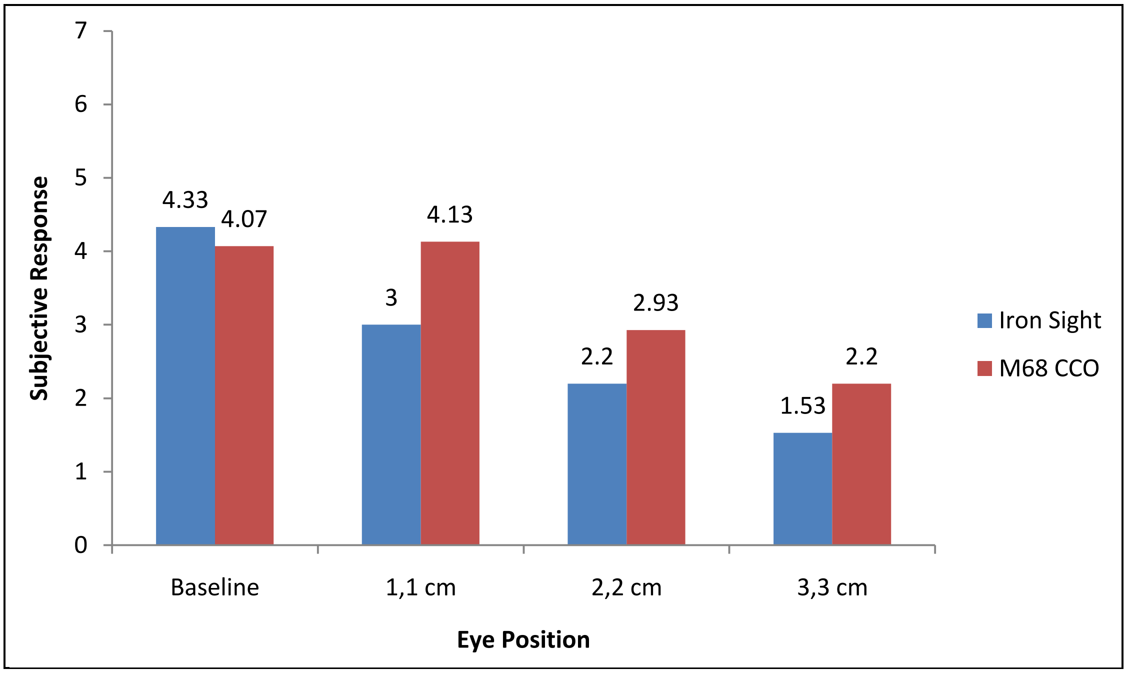

Figure 15. Rating of cheek pressure required.

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

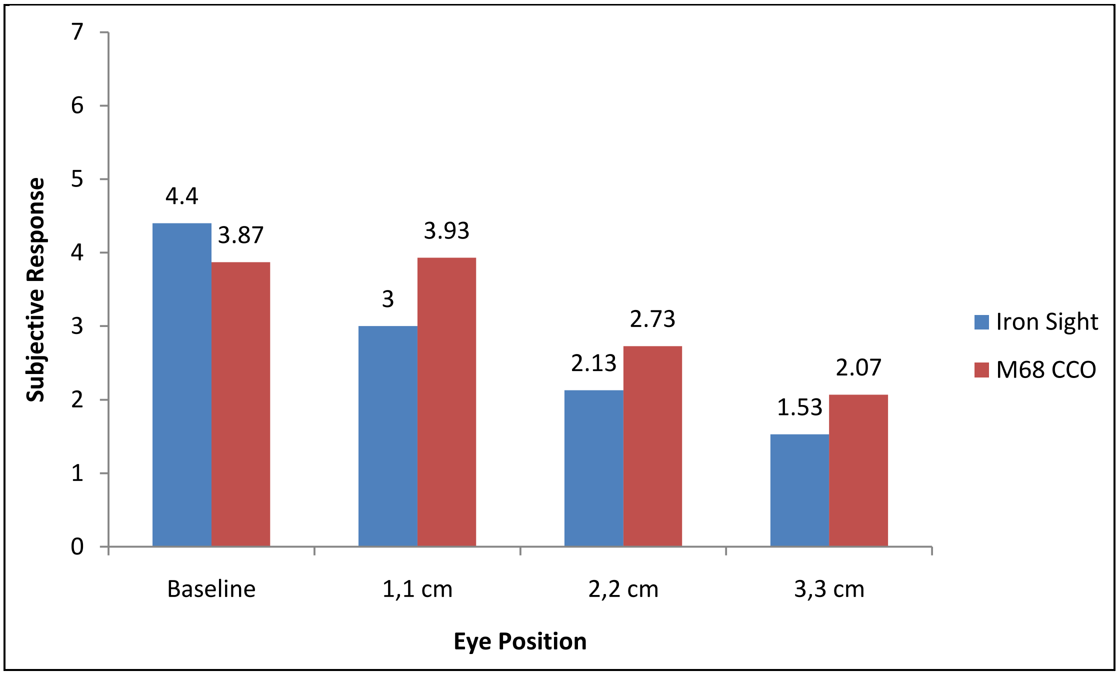

Figure 16. Rating of head tilt required.

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

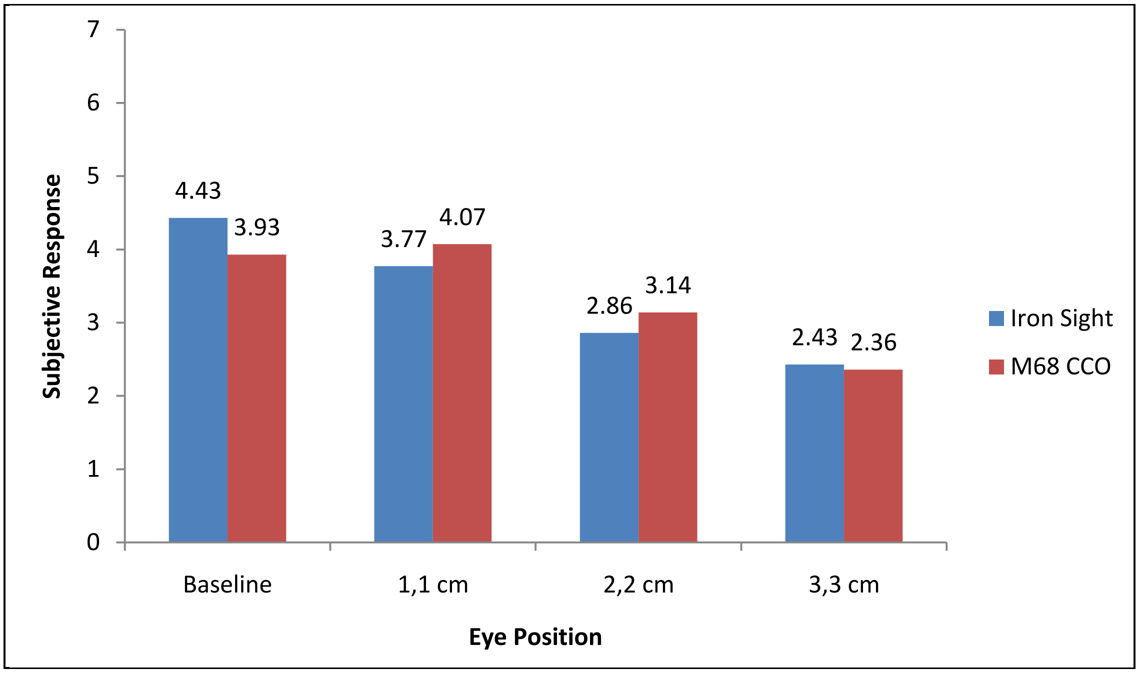

Figure 17. Rating of weapon cant required.

5. Ability to get a normal sight picture

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

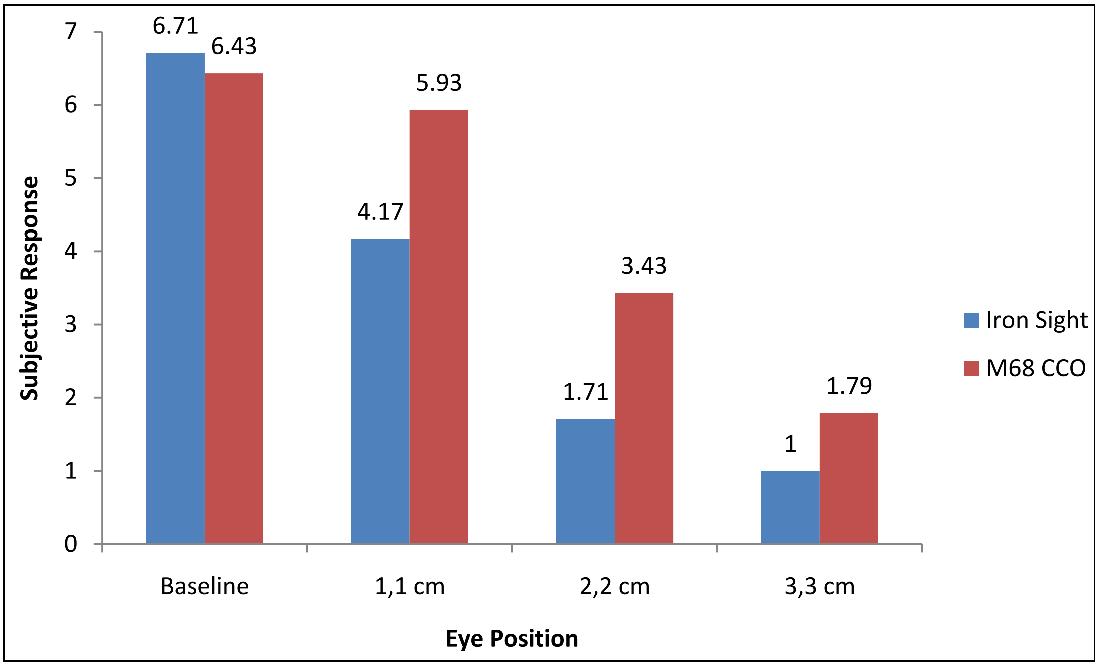

Figure 18. Rating of ability to get a normal sight picture.

6. Ability to obtain a good sight picture given combat time constraints

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

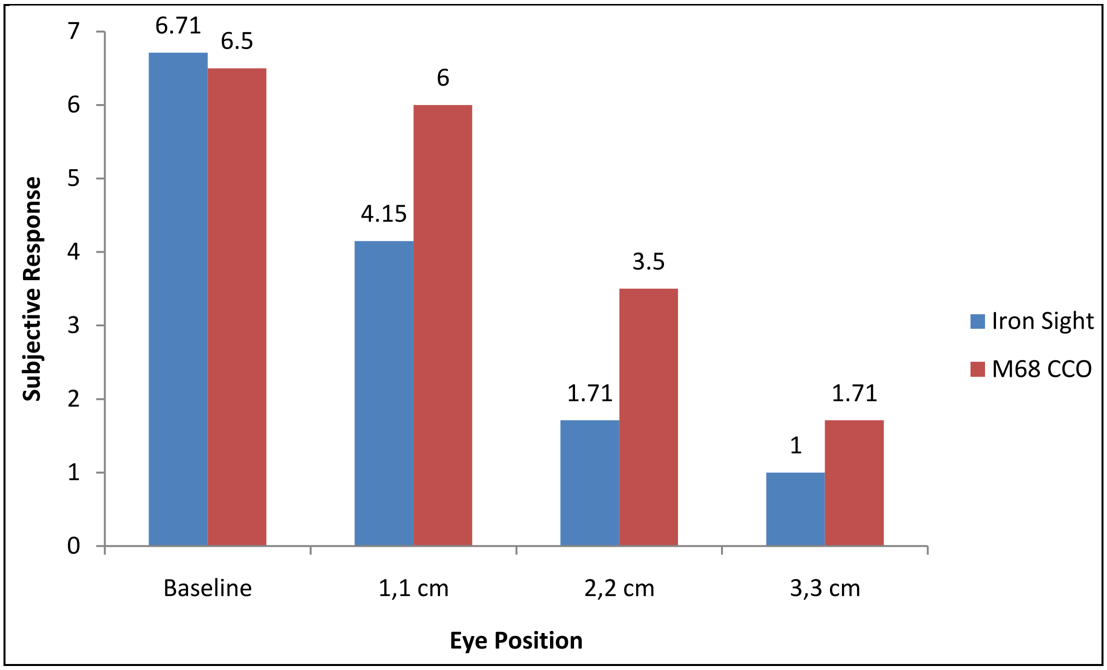

Figure 19. Rating of ability to get a good sight picture given combat time constraints.

7. Ability to get a consistent sight picture

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

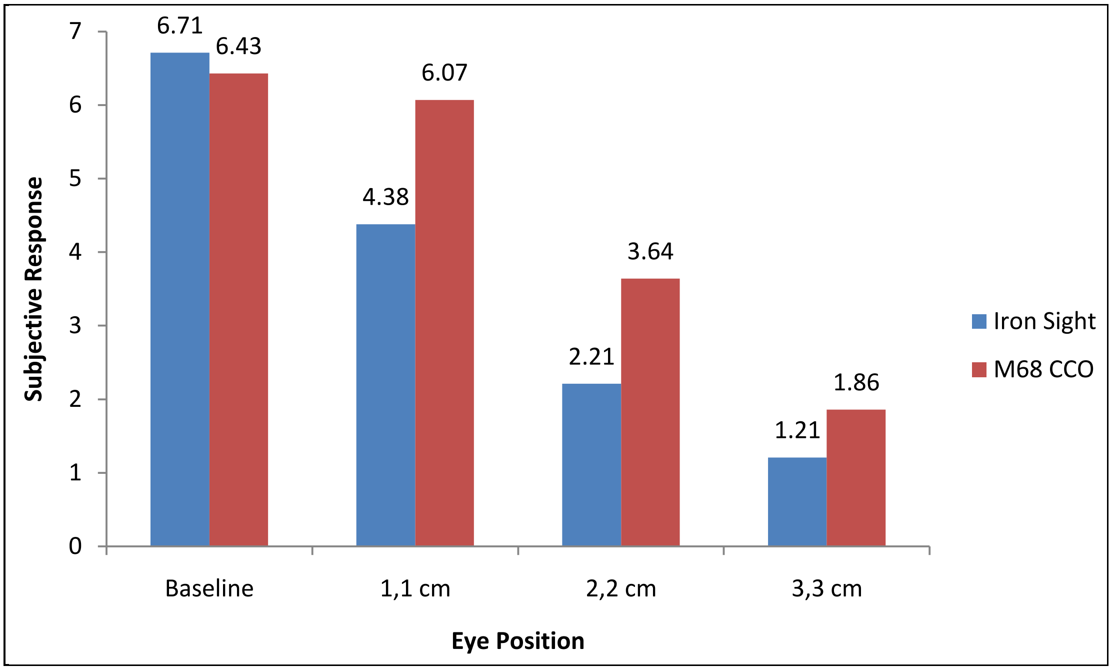

Figure 20. Rating of ability to get a consistent sight picture.

8. 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 buttstock did slip out of position)

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

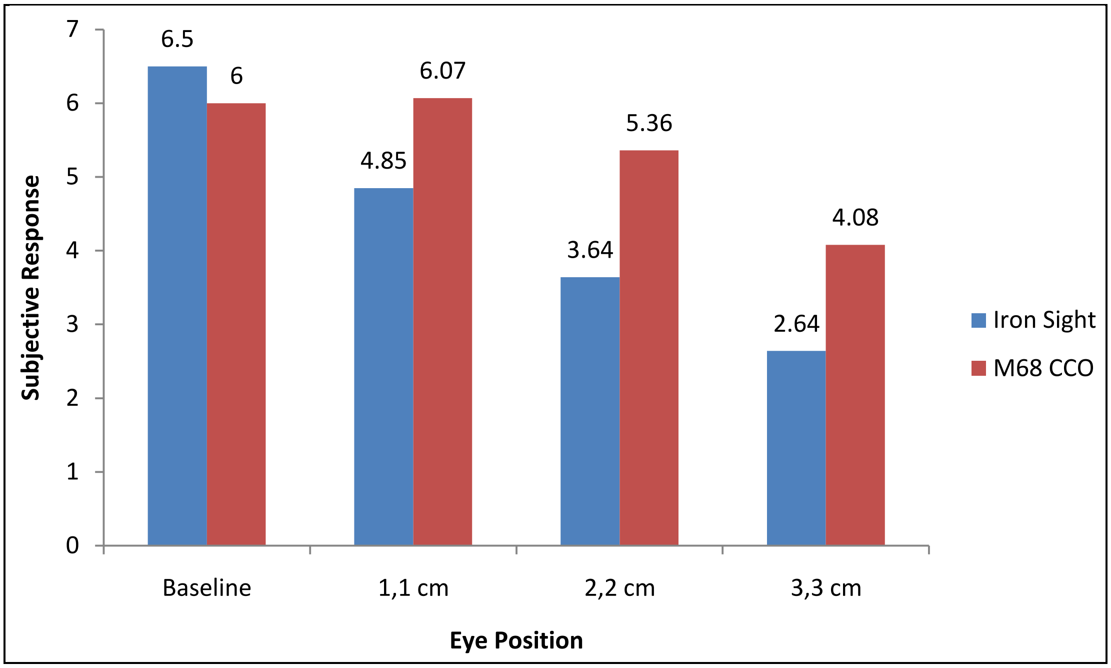

Figure 21. Rating of stability of the buttstock while firing.

9. Ability to attain a comfortable firing position

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

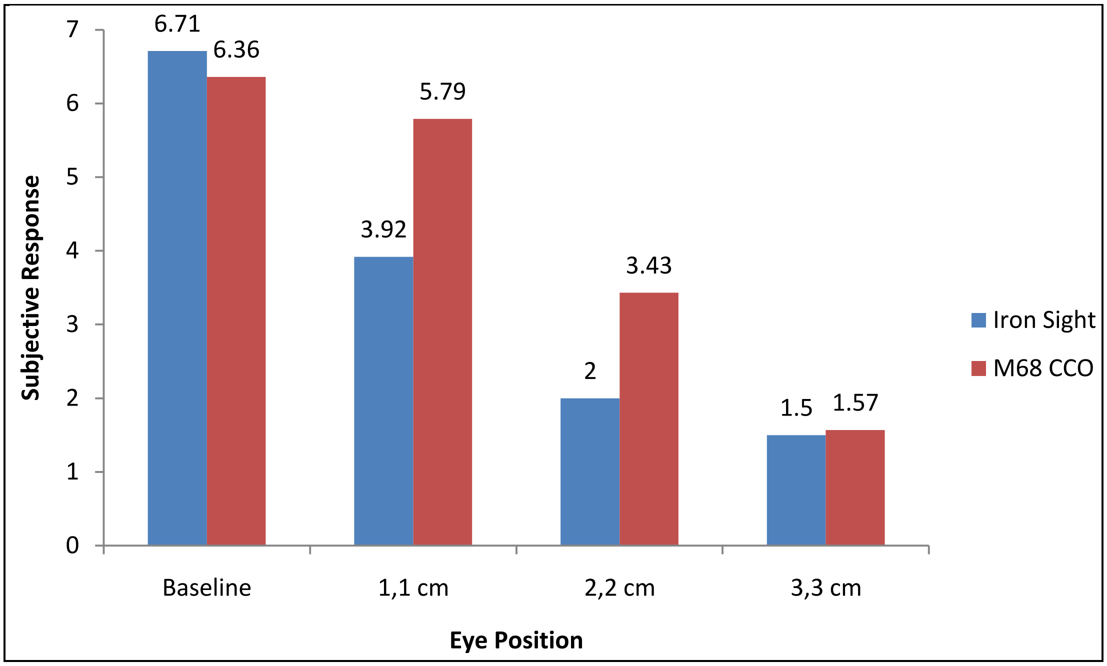

Figure 22. Rating of ability to attain a comfortable firing position.

11. Discussion

The effects of eye position and sight on shooting performance were both robust and consistent for this study. The effect of pushing the eye away from the sight, as you might expect to happen with a chemical protection mask or by adding facial protection, caused degraded performance with both the iron sight as well as the M68 sight. The hit percentage data for aimed fire (100, 200, and 300 m targets) from a foxhole supported firing position showed a significant degradation in performance with the iron sight for each successive eye position move away from the baseline (1,1, cm, 2,2 cm, and 3,3 cm). This result was predicted due to the fact that the eye to sight alignment is especially critical when using iron sights, given the requirement to align the rear-aperture, the front sight-post and the target center-of-mass to achieve accurate fire. The aimed fire hit percentage data showed there was also degradation in shooting performance using the M68 sight but only when the eye position was at the 3,3 cm condition. The shot radial error data for the aimed fire task followed the same pattern as the hit percentage data. The only difference was in the iron sight data where the 3,3 cm condition did not have a significantly higher aiming error than the 2,2 cm condition. This was probably due to the fact that a large percentage of the 3,3 cm data was outside the shot detection envelope and were counted as missing values. Researchers feel that if the misses could have been accurately recorded the mean radial distance for the 3,3 condition would have been in excess of 50 in.

The aimed fire target engagement timing data showed that for the M68 sight, there were no significant differences in engagement time for each of the different eye position conditions. However, the iron sight, 2,2 cm and 3,3 cm conditions revealed faster engagement times than the baseline and 1,1 cm conditions. This result seemed to be due to the fact that shooters were not able to position their eye properly for the 2,2 cm and 3,3 cm eye position conditions with the iron sights, given the aforementioned requirement to align three referents in order to achieve accurate marksmanship. Therefore, shooters generally sighted the weapon over the top of the sights as best they could and fired at the target. This quick pointing method resulted in quicker engagement times for these conditions but may have contributed to the poor accuracy for these conditions.

The results for the hit percentage data on the reflexive firing task was very similar to that of the aimed fire task. For iron sights, the 2,2 and 3,3 cm conditions had significantly poorer hit rates than the baseline or 1,1 cm condition with the 3,3 significantly lower than the 2,2 cm condition. For the M68 sight, only the 3,3 cm eye position showed degraded performance compared to the other 3 eye positions. The mean radial shot error data followed the same pattern of significance as did the hit percentage data.

The reflexive fire target engagement time data showed that for the M68 sight, the 3,3 cm eye position condition had significantly slower target engagements times than the other 3 eye position conditions. For the iron sight, the 3,3 cm condition and 2,2 cm condition had significantly faster target engagement times. The difference between these two sights was probably due to the fact that the farther eye positions with the iron sights were not possible to properly see through the sights, so shooters just pointed the weapon while looking over the top of the sights. This results in quicker, less-accurate firing. For the M68 sight, shooters generally tried, with difficulty, to use the sight even in the 3,3 cm condition, possibly leading to the longer recorded target engagement times.

The subjective data showed that there was a large difference in the ability of the participants to cheek the weapon normally in the M68 sight conditions compared to the iron sight conditions. In the 1,1 cm eye position condition, 80% of the participants felt they could cheek the weapon normally and still get a good sight picture using the M68 compared to 36% when using the iron sights. In both the 2,2 and 3,3 cm eye positions none of the participants felt they could cheek the weapon normally and get a good sight picture with iron sights compared to 47% in the 2,2 cm condition and 7% in the 3,3 cm condition with the M68.

The subjective data also showed that the M68 sight was generally a more forgiving sight for eye positions and participants generally reported less cheek pressure and less head tilt than iron sights to get a good sight picture. The subjective results also showed that at the 3,3 cm eye position, the ability to get a normal sight picture was rated in the "moderately bad" to "very bad" categories for both sighting systems. The subjective results showed a general trend to rate the iron sights poorly at the 2,2 and 3,3 cm eye positions and the M68 sight poorly only at the 3,3 cm eye position.

In summary, the hit percentage and shot radial error data showed firing in the 3,3 cm eye condition revealed degraded performance for both sighting systems compared to the baseline. However, with the M68 sight, shooting performance in the 1,1 cm and 2,2 cm conditions were generally not significantly lower than in the baseline condition, whereas the 2,2 cm and, to a lesser degree, the 1,1 condition for the iron sight showed degraded performance over the baseline condition. This result was expected due to the fact that the M68 uses a collimated dot that is designed to be tolerant of different eye positions, whereas the iron sight requires a consistent eye position and resultant sight picture to be fired effectively.

12. Conclusions

The results of this study show that the cheek weld position and subsequent eye position of the shooter can have a significant effect on shooting performance. It was clear from the results that a 3,3 cm shift in the eye position caused serious degradation in shooting performance. Even when using the M68 sight, which by design requires less consistency in eye position in order to achieve accurate fire, performance for the 3,3 cm eye position condition was extremely degraded. For the iron sights, there was a significant degradation in performance even at the 1,1 cm offset, with severe impact recorded for both the 2,2 and 3,3 cm offsets. The information derived from this research effort clearly shows the negative shooting implications of outwardly shifting a shooter's cheek weld and eye position by more than ~2 cm in the vertical and horizontal planes. Efforts must be made to minimize shifting of the eye position, especially when considering chemical protection or facial protection system designs that may cause a shift in the cheek weld and eye position by more than ~2 cm. Reducing the degradation effects through changes in weapon buttstock design or by offsetting the weapon sights may also be a potentially viable mitigation approach toward weapon compatibility. However, the implications these changes may yield when masks are removed may be likewise detrimental unless quick conversion to a standard configuration is incorporated in the design.

Appendix A. Demographic Data Form

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

DEMOGRAPHIC DATA FORM

Participant Number ________

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

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

Time in current MOS ________________

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 a left-handed ____or right-handed ____rifle shooter? (Check one)

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

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

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

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

9. 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 Eye Position and Weapon Sight

Table B-1. Counterbalanced order of eye position and weapon sight for each test participant.

Participant Number	Trials							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	A	B	H	C	G	D	F	E
2	B	C	A	D	H	E	G	F
3	C	D	B	E	A	F	H	G
4	D	E	C	F	B	G	A	H
5	E	F	D	G	C	H	B	A
6	F	G	E	H	D	A	C	B
7	G	H	F	A	E	B	D	C
8	H	A	G	B	F	C	E	D
9	H	G	A	F	B	E	C	D
11	F	E	G	D	H	C	A	B
13	D	C	E	B	F	A	G	H
14	C	B	D	A	E	H	F	G
15	B	A	C	H	D	G	E	F
16	A	H	B	G	C	F	D	E
17	G	F	H	E	A	D	B	C

Note: A - Iron – Baseline; B - Iron – 1,1; C - Iron – 2,2; D - Iron – 3,3; E –M68 – Baseline; F –M68 – 1,1; G –M68 – 2,2; H –M68 – 3,3.

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:

List of Symbols, Abbreviations, and Acronyms

ACH	advanced combat helmet
ACOG	Advanced Combat Optical Gunsight
ANOVA	analyses of variance
ATO	Army Technology Objective
CCO	Close Combat Optic
HEADS-UP	Helmet Electronics and Display System – Upgradeable Protection
HRED	Human Research and Engineering Directorate
HSD	Honestly Significant Difference
IBA	interceptor body armor
MOA	minute of visual angle
MOS	Military Occupational Specialty
NCO	non-commissioned officer
O.D.	Olive Drab
S&T	science and technology
SOP	standard operating procedure

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