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AIMING POINT DISPLACEMENT FROM FIRING A RIFLE FROM THE OPEN-BOLT POSITION

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The displacement of a gunner's point of aim when firing a rifle from both the open bolt and closed bolt position was measured in dry-fire and live-fire tests. Results of the dry-fire test showed a shift of the aiming point upwards and to the right for right-handed gunners and upwards and to the left for a left-handed gunner. Aiming error dispersions were substantially larger for open bolt versus closed bolt. These effects were more pronounced when firing from the standing position versus firing from the prone position. The time history of aiming error from

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20. ABSTRACT (Continued)

trigger pull to cartridge firing was measured for the open bolt firings. Live-fire test results were inconclusive due to large round-to-round dispersions of the test weapon, an XM19 rifle.

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AIMING POINT DISPLACEMENT FROM FIRING A RIFLE FROM THE OPEN-BOLT POSITION

INTRODUCTION

Firing an automatic rifle from the open-bolt position offers some potential advantages over firing from the closed-bolt position. Because there is no round in the chamber between firings, it could (a) eliminate "cook-off," (b) reduce the possibility of a round "freezing up" in the chamber, (c) reduce the need for heat sinking at the chamber, and (d) protect the sabot from the deleterious effects of the hot chamber when using special purpose rounds. The higher firing pin energy when firing with the open bolt would also reduce first round misfires.

One disadvantage of firing from the open bolt is a possible reduction in first round accuracy compared to firing from closed bolt. The mass of the bolt and firing pin assembly sliding forward causes the rifle to pitch up and be displaced from the initial aim point. Also, the delay between trigger pull and the round being fired is longer for the first round from open bolt firing compared to the first round for closed bolt.

In order to determine the magnitude of the differences in first round delivery accuracy between closed bolt and open bolt firing, an experiment was conducted to measure dry-fire and live-fire accuracy. The XM19 Special Purpose Infantry Weapon (SPIW) which fires the XM645 sabot round was selected for testing since it could be modified easily to fire from either the open or closed bolt position.

The dry-fire portion of the experiment was conducted to obtain a precise measurement of the effect on first round delivery of the open versus the closed bolt exclusive of other system errors. The measure here was the shift in aim point from trigger pull until the firing pin impacted a dummy cartridge.

Previous experience indicated that live firing with the XM19 might not produce accurate measures of the effect of open-bolt firing. The round-to-round dispersion of the XM645 ammunition is approximately 1 mil LSD from a Mann barrel; the gunner aiming error is on the order of 1 mil LSD and the additional effect on dispersion due to the weapon is a function of the condition of the stripper and barrel. Thus, the overall dispersion would be between 1.5 to 2 mils LSD, and might mask the effect of open bolt unless a large number of rounds could be fired.

In addition, the dry-fire subtest could provide a time history of the shift in aim point from trigger pull. These data would be useful in simulations which attempt to assess weapon performance using computer models of the weapon and the shooter.

PURPOSE

The purpose of this experiment was to measure and compare the first round delivery error of a rifle firing from open bolt and from the closed bolt.

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PHASE I – DRY-FIRE

Method

Subjects

Eight laboratory personnel were the test subjects. All subjects had some degree of previous firing experience. Seven subjects were right-handed, the other left-handed. Only one subject had previous experience firing the XM19.

Weapon

The tested weapon was XM19 SN 6 which was supplied, under loan, by the Aircraft Armaments Corporation (AAI), Cockeysville, MD. The weapon was equipped with two trigger groups; one to fire the weapon from the closed-bolt position, the other (modified by AAI) to fire the weapon from the open-bolt position. The tested weapon (shown with an infrared detector mounted below the muzzle) and the two trigger groups are shown in Figure 1. The heat sink and radiator were removed from the weapon to simulate the change in weight possible for firing with the open bolt. A pickup for the guide rod was fabricated and installed in place of the heat sink to allow a round to be inserted in the chamber.

Closed and Open Bolt Firing

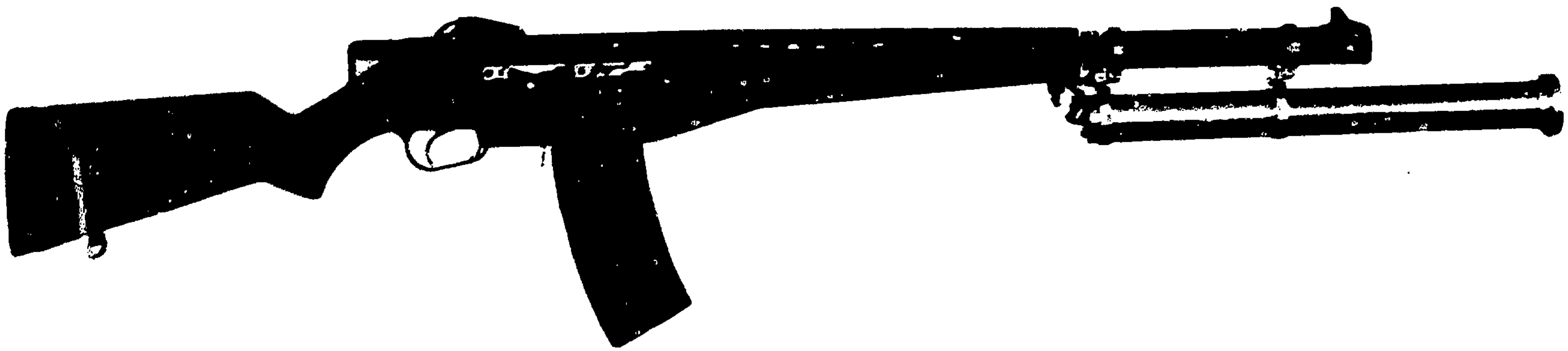
Closed-bolt firing is used with the M1, M14 and M16 rifles where a round is resting in the chamber, the bolt is closed and just the firing pin or hammer is released when the trigger is pulled. With open-bolt firing, the entire bolt and carriage assembly is seared at the rear of the weapon and the bolt rests against a round in the magazine. When the trigger is pulled, the bolt slides forward stripping a round from the magazine, carries it forward and inserts it into the chamber at which time the bolt stops its forward motion and the firing pin strikes the round.

Ammunition

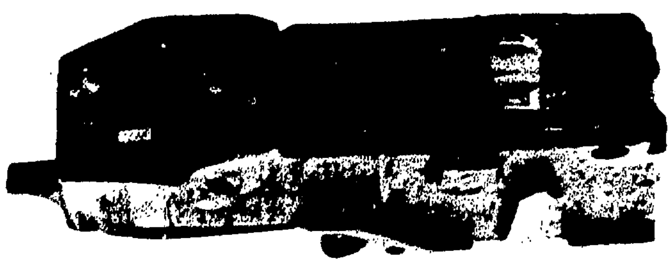
Dummy rounds of XM645 ammunition were weighted (115-120 grams) to simulate the weight of live rounds and maintain the effect of the bolt stripping a round from a magazine. Since these rounds were not damaged when the firing pin struck them, they were reusable.

Firing Range

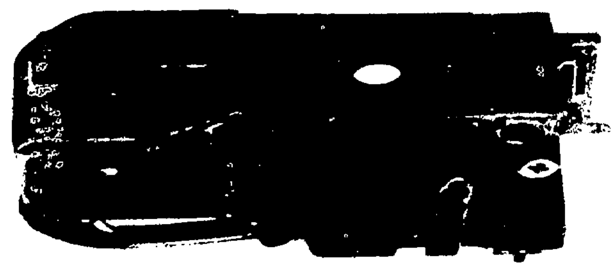
A room in Building 520 (US Army Human Engineering Laboratory [HEL]) was used as the dry-firing test range to provide a controlled ambient light level necessary for target visibility and infrared source calibration. A subject-to-target range of 282 inches was used (the maximum of the room dimensions).



a. XM19 weapon with IR detector.



b. Trigger group used for closed-bolt firing.



c. Trigger group used for open-bolt firing.

Figure 1. Instrumented XM19 weapon and trigger groups.

Instrumentation

Aiming Error Measurement Technique

Data from the US Army Ballistic Research Laboratory showed that for closed-bolt firing, it takes about 15 milliseconds for the bolt and firing pin to move forward and fire the first round. On subsequent rounds, it takes 19 milliseconds for the bolt to move from the full rear position (where the buffer spring is compressed), pick up a round, chamber it and fire it. An estimate of 30 to 40 milliseconds was obtained for bolt travel on the first round from the open-bolt position.

To obtain the required data for these rapid bolt movements, a technique used by Kramer (1) in measuring antitank system tracking error was used. This instrumentation scheme uses a pulsed infrared source as a target and a two-axis detector mounted on the weapon to provide a continuous readout of the angular position of the weapon relative to the target.

Target/IR Source

The target was a miniature light bulb[1] mounted directly below an infrared (IR) light source.[2] They were positioned behind a lens at a distance slightly greater than the focal length of the lens to provide a cone or IR illumination impinging in a circle of approximately 2 feet radius at the gunner. The bulb was the gunner's point of aim.

IR Detector

A linear two-axis Schottkey barrier silicon photodiode was used for the IR detector. It was mounted at the rear of a 2-inch diameter, 13-inch long tube with a collimating lens placed at the front of the tube. This in turn was attached to the rifle in line with, and a few inches below, the barrel as shown in Figure 1. External electronics processed and recorded the detector output as aiming error in elevation and azimuth and total signal output which was a measure of source intensity.

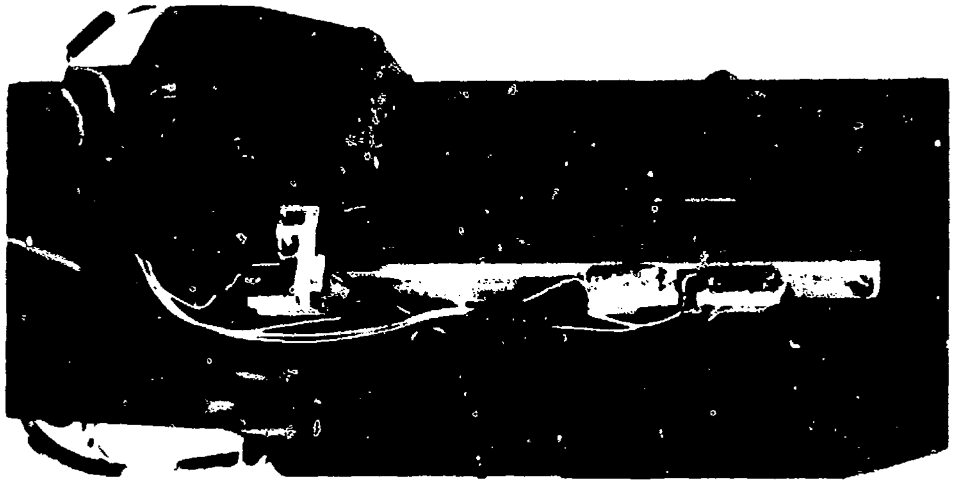
Reference Markers

In order to measure rifle displacement from the aim point for each trigger pull, two reference points were needed: the point of aim when the trigger was pulled, and the point of aim when the firing pin struck the cartridge. Since the charging handle of the XM19 rifle is directly connected to the firing pin assembly, the necessary measurements could be taken from the movement of the charging handle when the weapon was fired.

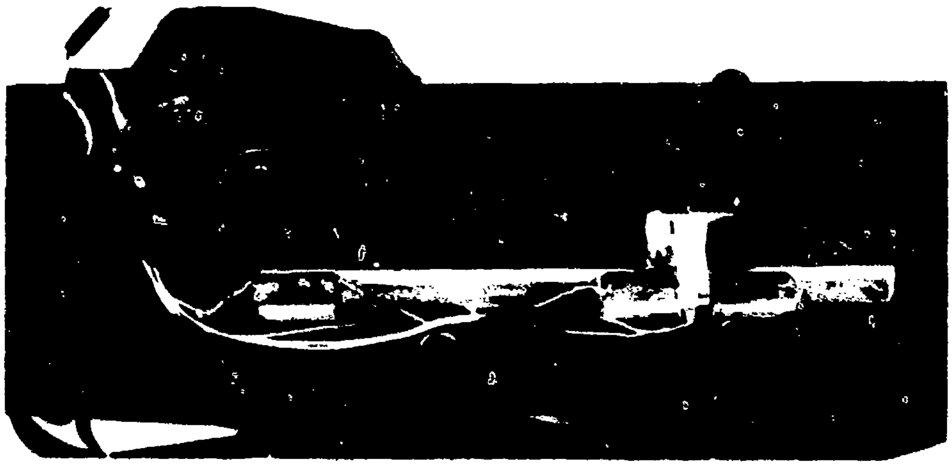
A new charging handle was fabricated to eliminate the loose fit of the old charging handle and an Alnico magnet was attached to it. Small induction coils were positioned on the rifle so that they were directly below the magnet when: (a) the rifle was cocked in the open-bolt position; (b) the rifle was cocked in the closed-bolt position; and (c) the charging handle was fully forward (when the round is fired). Figure 2 shows the charging handle (and

[1]IEE, C1, 5-volt miniature lamp.

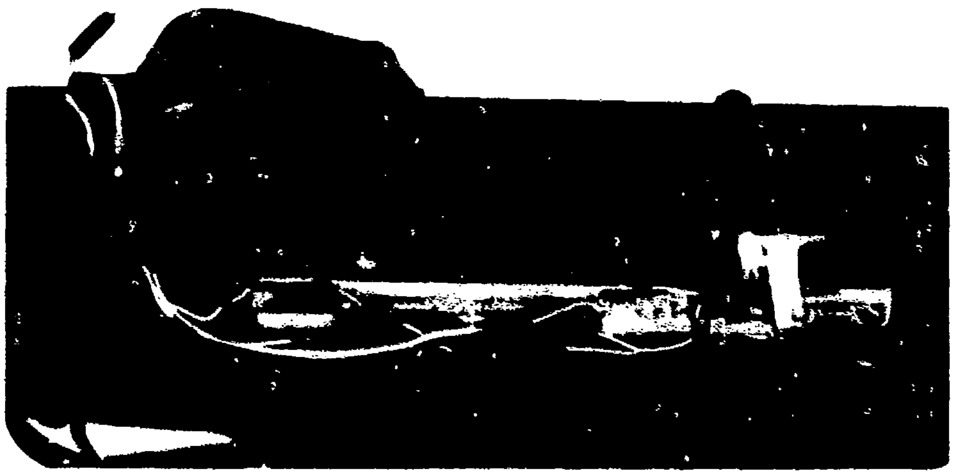
[2]Monsanto Light Emitting Diode, ME2, 9000 Å wavelength.



a. Rifle cocked in open-bolt position.



b. Rifle cocked in closed-bolt position.



c. Position after firing.

Figure 2. Instrumented charging handle--for measurement of bolt position.

instrumentation) in the three positions. Movement of the magnet over each coil induced a voltage in the coil which was recorded with external electronics.

The azimuth, elevation, signal intensity, trigger pull and firing signals were recorded with a 14-channel instrumentation tape recorder operated at 60 inches per second. Another channel was used for voice recording to identify each data run.

System Calibration

A mount with adjustments for azimuth and elevation was fabricated to hold the rifle for calibration. Linearity of the output signal for azimuth and elevation were within a few percent. Calibration was performed twice prior to data collection and twice after data collection and the readings averaged to determine a calibration factor.

The source intensity varied an average of 10 percent due to changes in the gunner's stance and the alignment of the target in relation to the gunner. Since the detector output is directly proportional to source intensity, an intensity calibration factor could be computed and incorporated into the overall system calibration factor.

Test Conditions

Subjects fired from closed bolt and open bolt in two firing positions, standing and prone, for a total of four test conditions. Previous data showed the aiming error and the resultant dispersion is greater for standing than for prone firing. Since any perturbation introduced into the weapon system; e.g., the mass of the bolt sliding forward in the open-bolt configuration would cause an increase in dispersion, the four test conditions could be assigned an *a priori* rank order of increasing dispersion.

1. Closed-bolt prone (CP)

2. Closed-bolt standing (CS)

3. Open-bolt prone (OP)

4. Open-bolt standing (OS)

The test conditions were assigned to the subjects using the matrix in Figure 3. Each subject was tested individually firing his assigned sequence of test conditions. Ten shots were fired (dry-fired) for each condition.

Subject	Test Conditions			
	1	2	3	4
1 and 5	OS	CS	CP	OP
2 and 6	OP	CP	CS	OS
3 and 7	CS	OS	OP	CP
4 and 8	CP	OP	OS	CS

Figure 3. Dry fire test matrix.

Procedure

The subjects were tested individually, each subject firing a particular serial ordering of the four test conditions. The conditions were explained to the subject, and he was told to aim at the visible light source and squeeze the trigger as if he were firing live rounds at a target.

Prior to data collection, each subject dry-fired 10 rounds for familiarization, four closed bolt and six open bolt. The target was adjusted for each subject so that the subject's line of sight to the visible light source was nearly horizontal and the IR source position optimized. A different adjustment had to be made between standing and prone positions to compensate for the change (approximately 1 foot) in height of the weapon from the ground.

A magazine loaded with 40 dummy rounds was used for each test condition. With the subject in position ready to fire a round, the recorder was turned on and the command to aim and fire was given. The subject then aimed and fired at the target. The recorder was turned off after the round was fired. When 10 rounds had been fired at a condition, there was a short pause during which test personnel would change trigger groups, adjust the target, and reload the magazine.

Results

General

The recorded data were played back at one-eighth speed (7.5 inches per second) through a direct print oscillograph operated at 50 cm per second. Measurements of galvonometer deflection were obtained in fiftieths of an inch for elevation, azimuth, and IR source intensity. These readings were converted into mils in elevation and azimuth using the system calibration factor.

The readings in mils at trigger pull were subtracted from the readings in mils when the firing pin struck the round for both azimuth and elevation to obtain the change in aim point. Data for each round and the mean are shown by subject for each firing mode and firing position in Figures 4 through 11.

An examination of these figures show that for all closed bolt firings, the aim point was displaced only a small distance between trigger pull and the round being "fired." The displacement of the aiming point for open bolt, by comparison, was much larger. For right-handed gunners, it was up and to the right and for the sole left-handed gunner, it was up and to the left. Also, it was greater when firing from the standing position compared to firing from the prone position.

Means ($\bar{x}$, $\bar{y}$) and standard deviations (Sx, Sy) in azimuth and elevation were computed by test condition and subject (N=10). The mean radial error (MRE), radial standard deviation (RSD) and linear standard deviation (LSD) were also computed. Data were combined by condition (N=80) in elevation and the above statistics recomputed. For azimuth, the data for the only left-handed gunner (Subject 6), were not included when the data was combined (N=70) for the open-bolt firings since this subject's response was opposite to the right-handed gunners. These statistics are listed by subject and condition in Table 1.

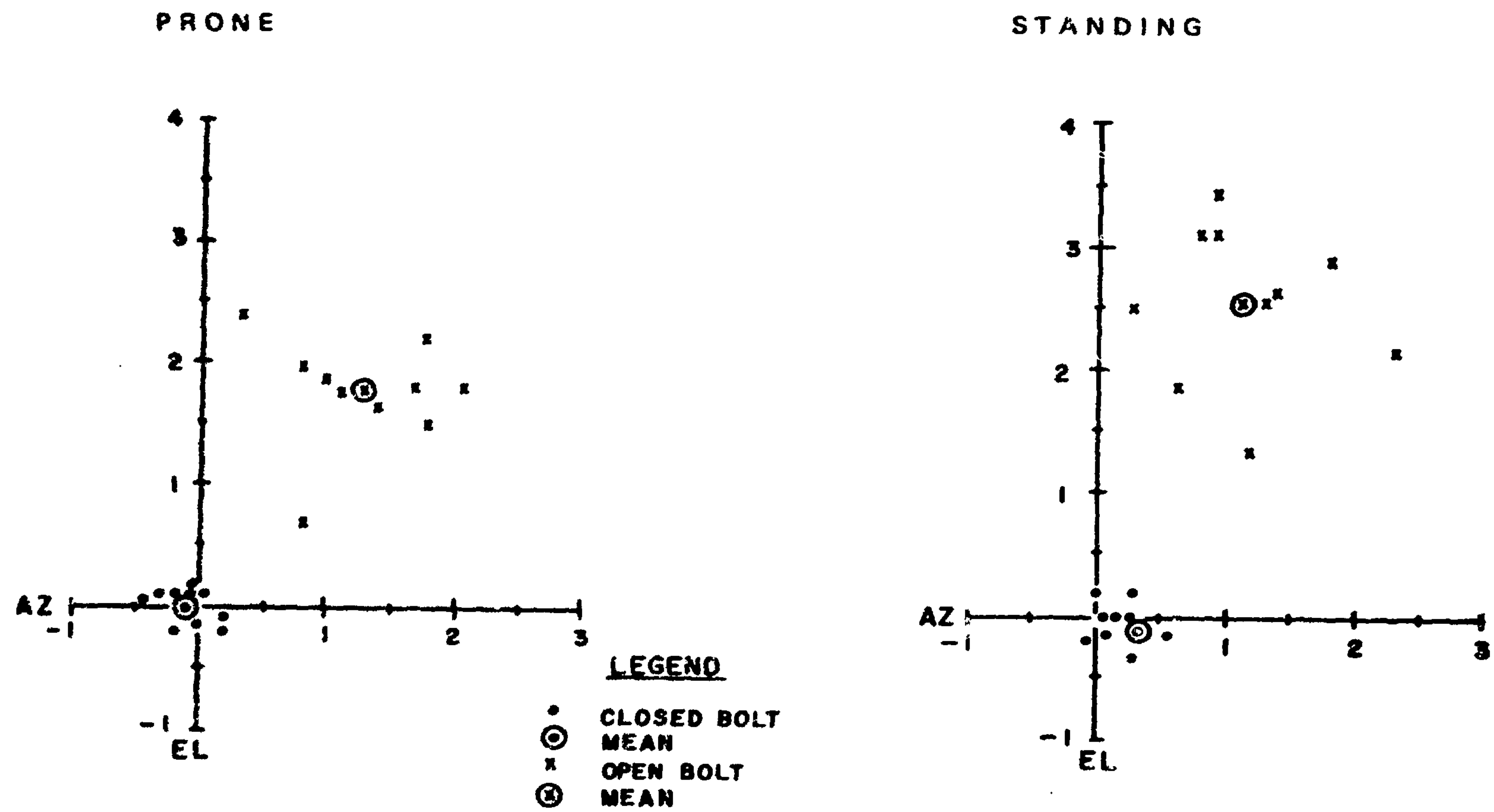


Figure 4. Aiming point displacement shot pattern—Subject 1.

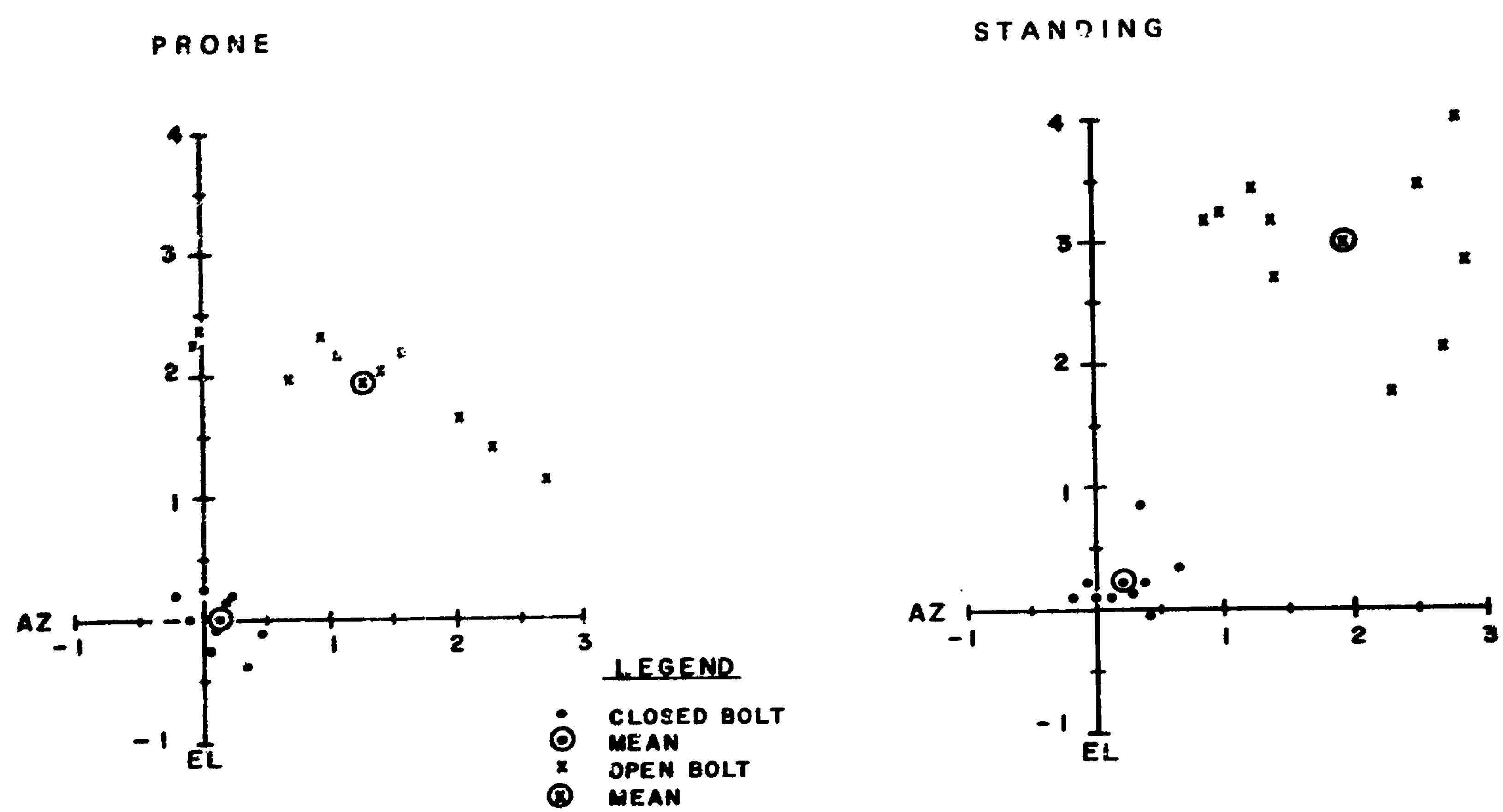


Figure 5. Aiming point displacement shot pattern—Subject 2.

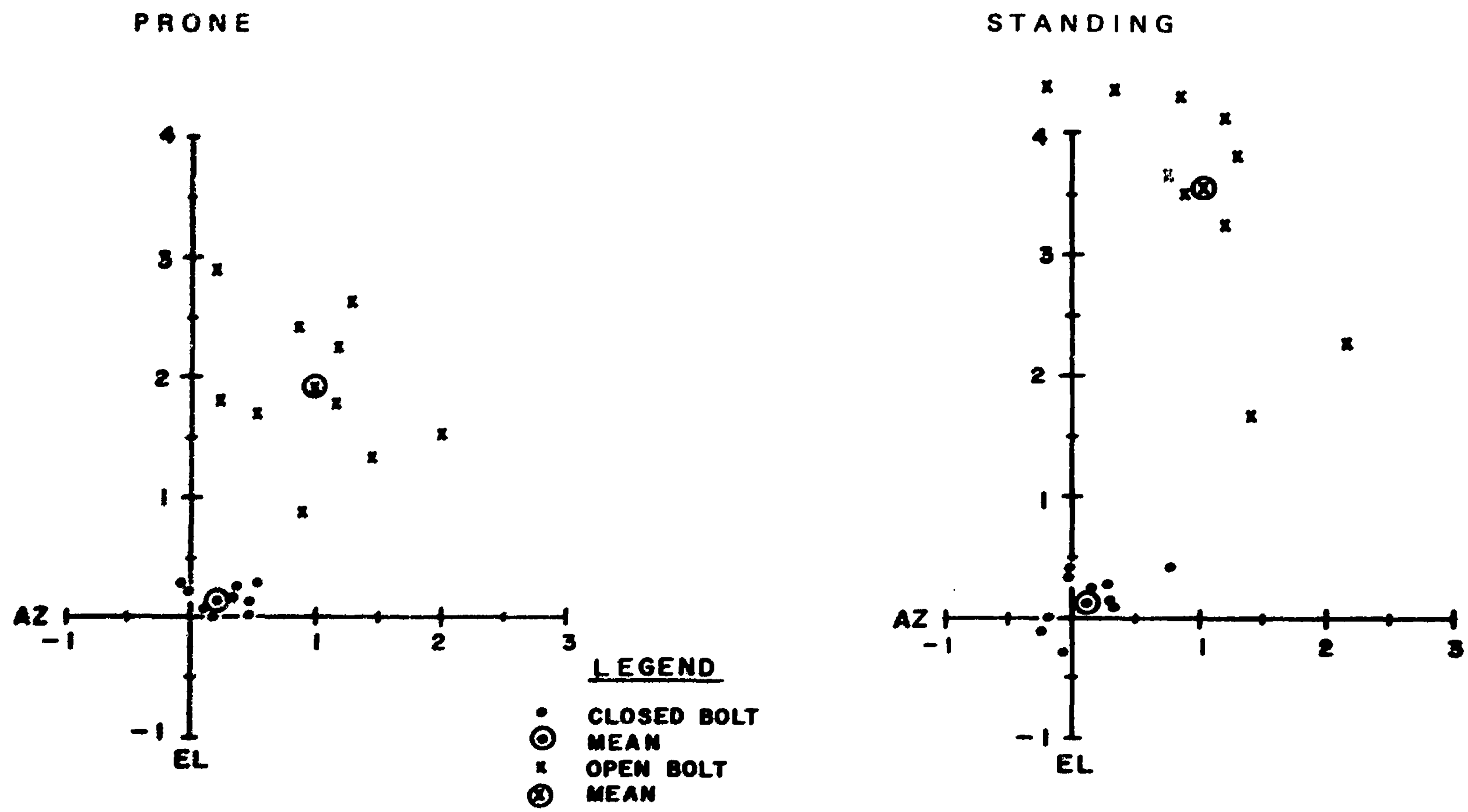


Figure 6. Aiming point displacement shot pattern—Subject 3.

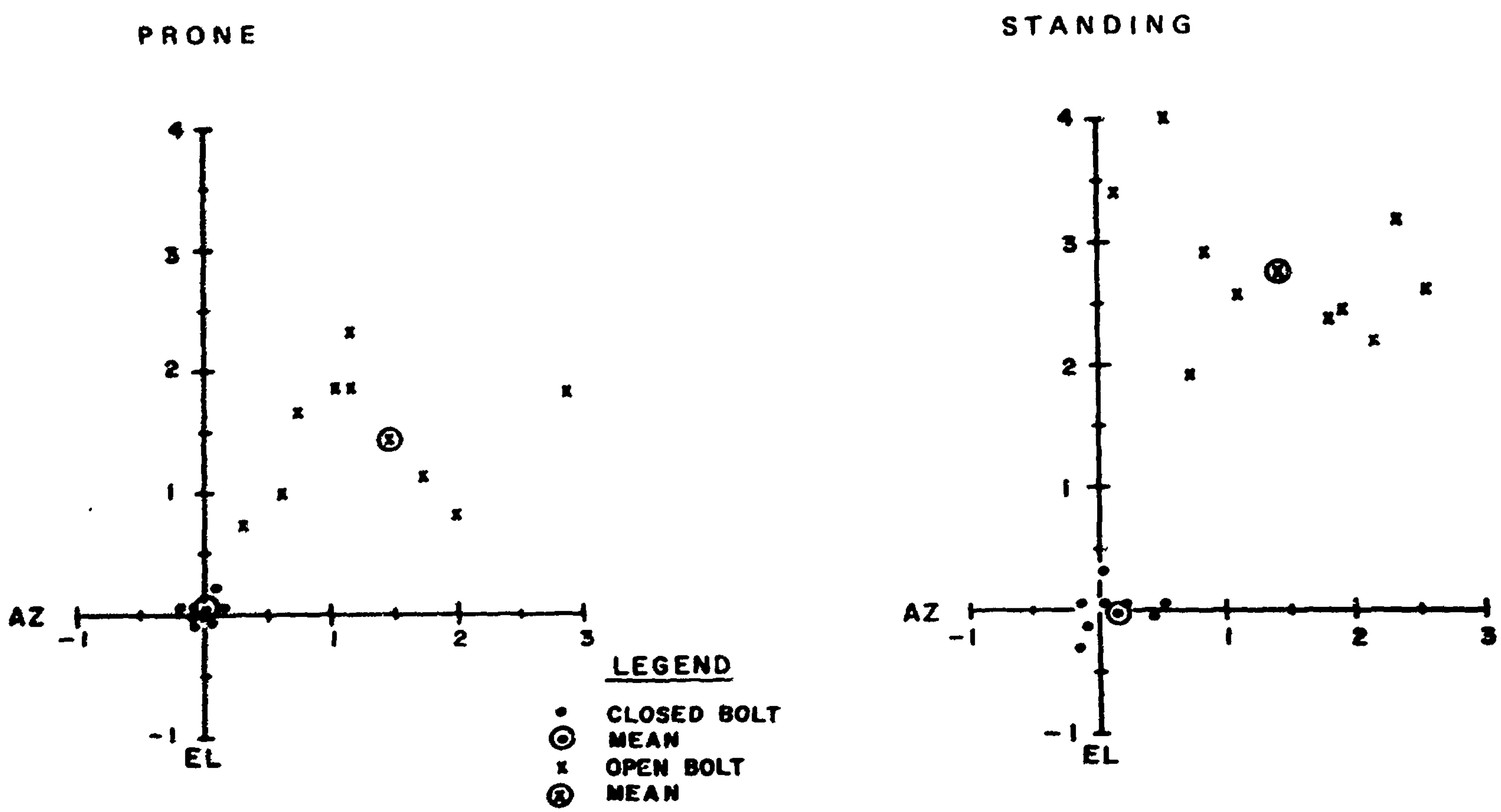


Figure 7. Aiming point displacement shot pattern—Subject 4.

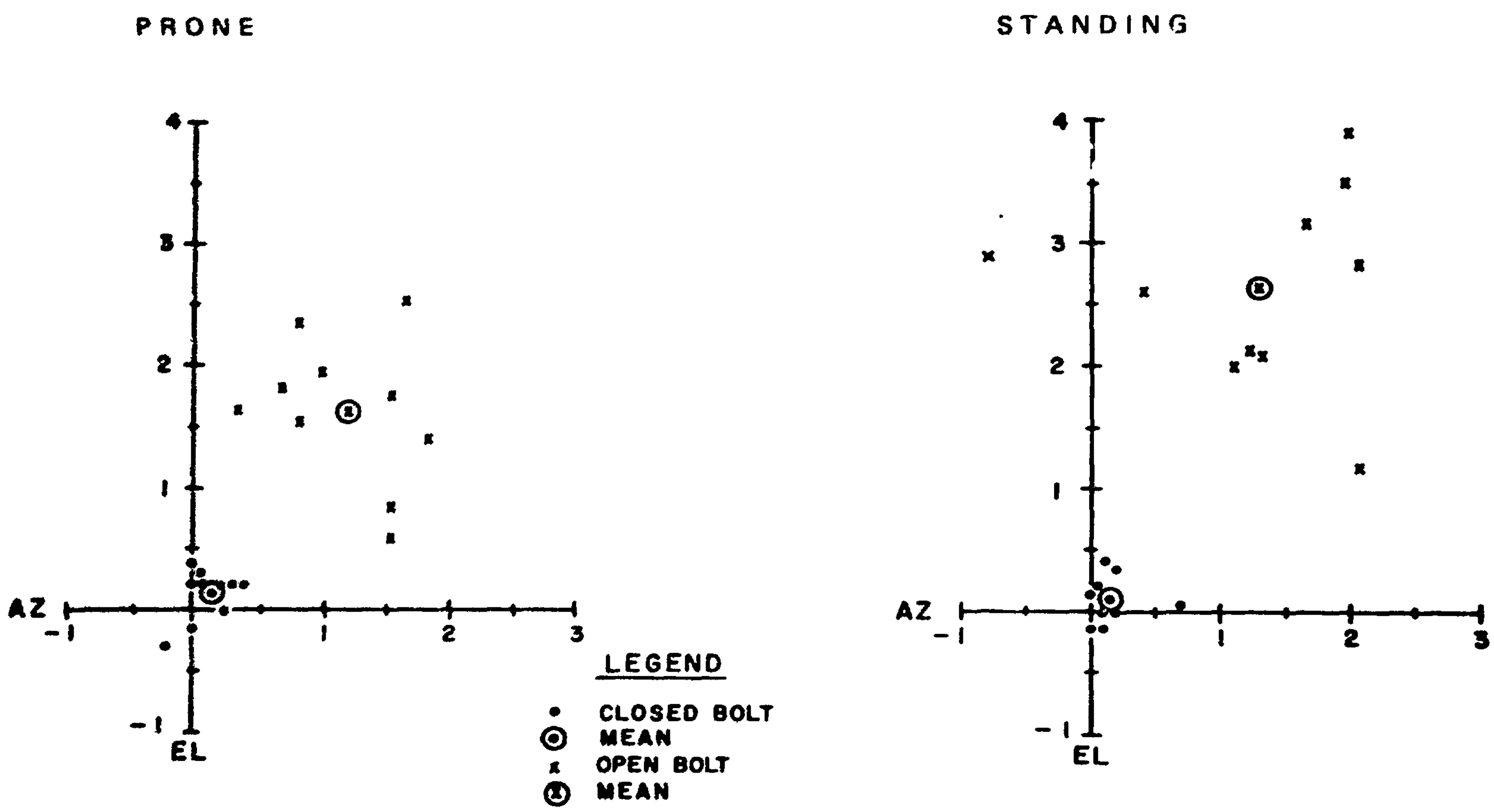


Figure 8. Aiming point displacement shot pattern—Subject 5.

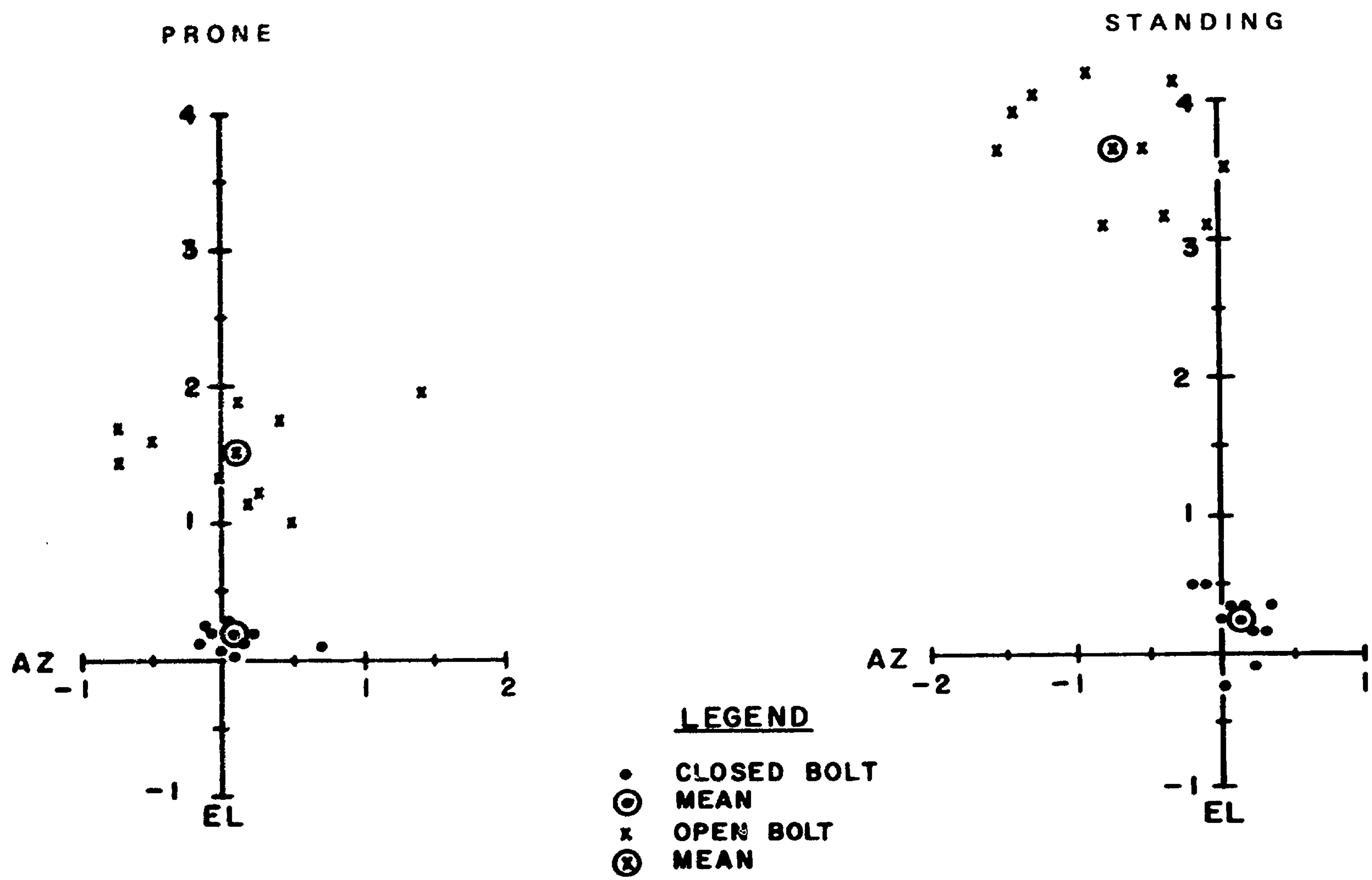


Figure 9. Aiming point displacement shot pattern—Subject 6.

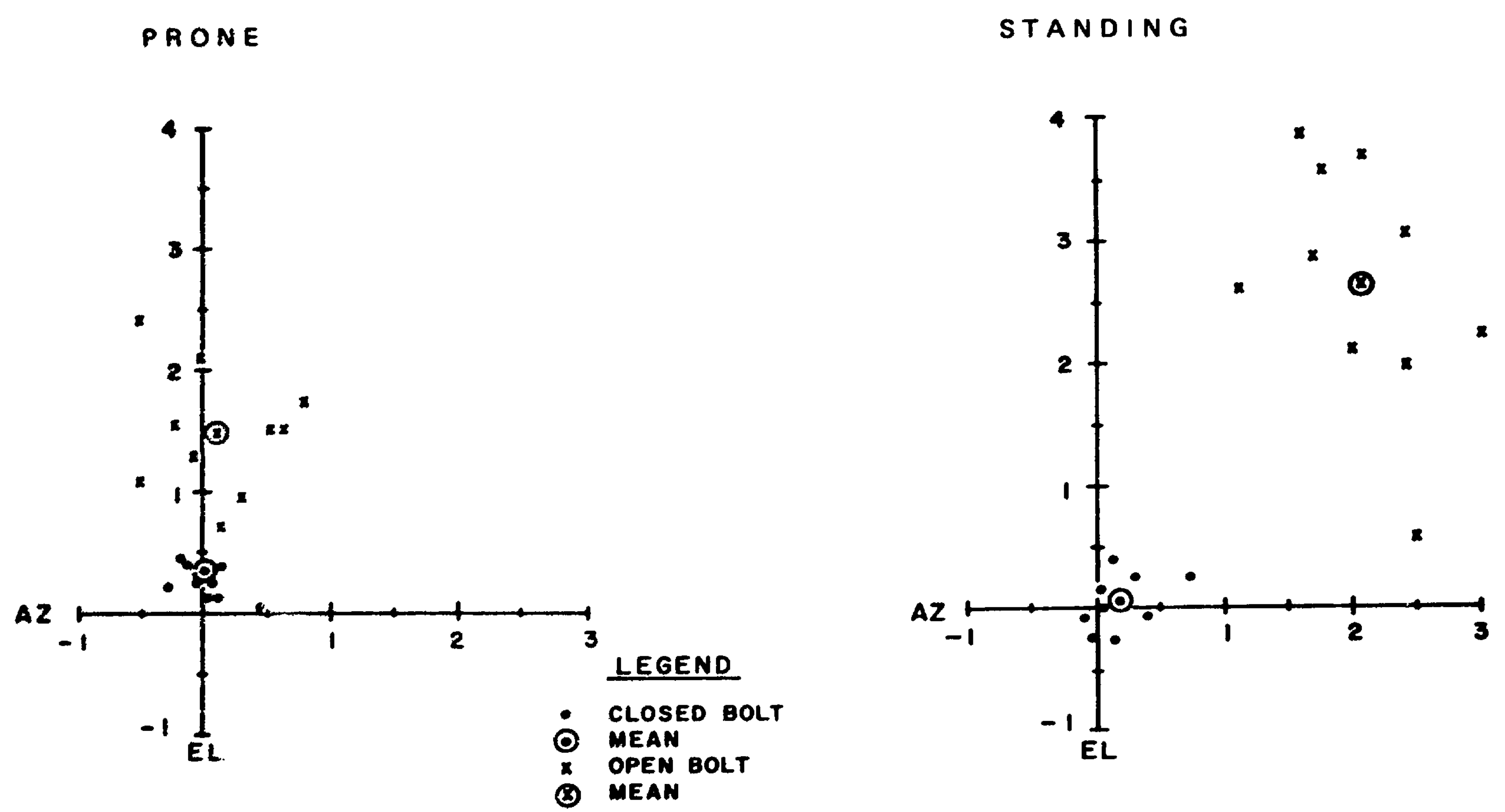


Figure 10. Aiming point displacement shot pattern—Subject 7.

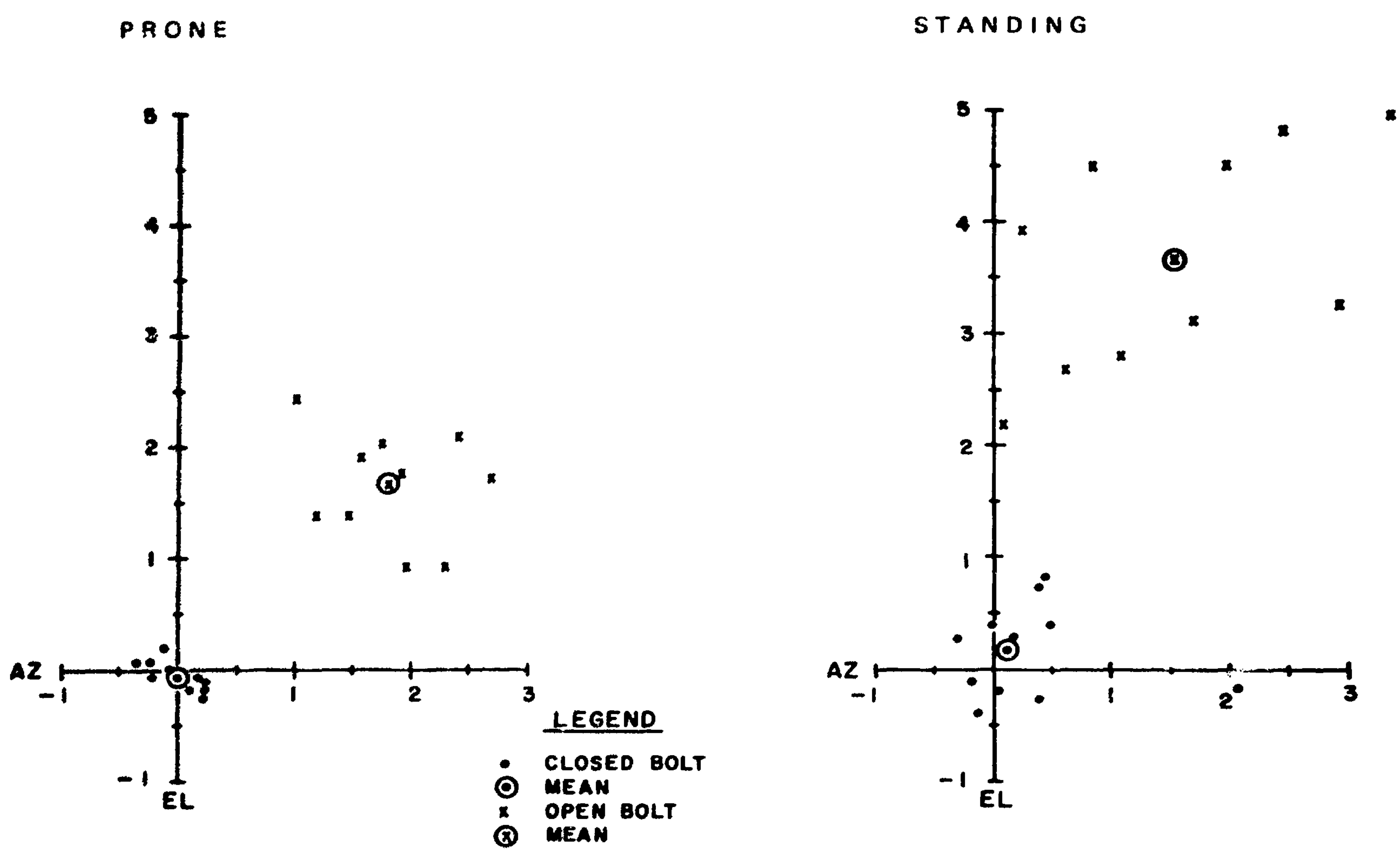


Figure 11. Aiming point displacement shot pattern—Subject 8.

TABLE 1

Summary Statistics for Phase I Dry Firing

CP Subject No.	Elevation		Azimuth				
	Mean	SD	Mean	SD	MRE[a]	RSD[b]	LSD[c]
1	.02	.14	-.05	.19	.22	.24	.17
2	-.01	.21	.11	.20	.26	.29	.21
3	.13	.11	.24	.22	.31	.25	.18
4	.03	.09	.01	.10	.10	.13	.09
5	.17	.14	.12	.11	.26	.18	.13
6	.13	.08	.11	.23	.23	.24	.17
7	.24	.13	.03	.19	.30	.23	.16
8	-.06	.14	.00	.21	.23	.25	.18
Total	.08	.16	.07	.20	.23	.25	.18
OP							
1	1.77	.45	1.30	.56	2.25	.72	.51
2	1.94	.42	1.27	.93	2.50	1.02	.72
3	1.91	.63	1.00	.56	1.80	.84	.59
4	1.42	.53	1.49	.91	2.16	1.05	.74
5	1.63	.60	1.20	.50	2.12	.78	.55
6	1.49	.31	.12	.65	1.60	.72	.51
7	1.47	.50	.12	.46	1.54	.68	.48
8	1.66	.50	1.85	.54	2.54	.74	.52
Total	1.66	.51	1.18	.81	2.06	.96	.68

[a]Mean Radial Error
[b]Radial Standard Deviation
[c]Linear Standard Deviation

(Continued)

TABLE 1 (Continued)

Summary Statistics for Phase I Dry Firing

CS Subject No.	Elevation		Azimuth				
	Mean	SD	Mean	SD	MRE[a]	RSD[b]	LSD[c]
1	-.03	.15	.14	.18	.20	.23	.16
2	.19	.25	.21	.25	.35	.35	.25
3	13	.23	.14	.30	.37	.38	.27
4	-.01	.17	.10	.23	.23	.29	.21
5	.10	.18	.14	.20	.25	.27	.19
6	.19	.24	.10	.17	.34	.29	.21
7	.04	.21	.22	.24	.31	.32	.33
8	.18	.42	.14	.29	.48	.51	.36
Total	.10	.25	.15	.23	.31	.34	.24
OS							
1	2.55	.63	1.14	.58	2.85	.86	.61
2	2.97	.65	1.93	.80	3.62	1.03	.73
3	3.51	.92	1.02	.63	3.74	1.12	.79
4	2.75	.62	1.43	.84	3.21	1.04	.74
5	2.62	.80	1.30	.91	3.06	1.21	.86
6	3.64	.43	-.70	.55	3.73	.70	.49
7	2.64	.99	2.10	.54	3.49	1.13	.80
8	3.65	.98	1.55	1.13	4.06	1.50	1.06
Total	3.04	.87	1.50	.78	3.49	1.17	.83

(Concluded)

A graphical presentation of means and SDs of aim point shift are shown in Figure 12 to facilitate comparisons among test conditions.

Statistical tests on difference between means (t-tests) and variances (F-tests) for the combined data (total) were conducted using the a priori ranking. The results in Table 2 show that the means and SDs are significantly greater for open bolt versus closed bolt. Both the means and SDs are significantly greater in the elevation plane for open-bolt firing from the standing position versus the prone position. In the azimuth plane, only the mean is significantly greater.

Aiming Point Time History for Closed Bolt

To obtain the time history of the change in aim point for the open-bolt firing mode, data for two representative subject, subjects 3 and 4, were examined. Eight of the 10 rounds for each subject and firing position were selected for data reduction on the basis of record clarity. The data were sampled at 2 millisecond intervals from 10 milliseconds before trigger pull until 54 milliseconds after trigger pull. The aiming point of the weapon at trigger pull was used as a zero reference, the readings at each time interval for the eight rounds were averaged and graphed, and smooth curves fit to the data to obtain the time histories shown in Figures 13 and 14.

Insight into the displacement versus time shown in the figures can be obtained from a description of the events occurring between trigger pull and the round being fired.

When the trigger is pulled, the bolt which is seared directly behind the round, starts forward relatively slowly because it is held back by the round in the magazine. The bolt strips the round from the magazine and then moves forward at a higher velocity. The rearward force of the buffer spring causes the weapon to rotate about the shoulder upwards and to the right (right-handed gunners). About 30 milliseconds after trigger pull (about 10 milliseconds before firing) the round is rammed into the chamber. This forward force tends to rotate the weapon downwards, but appears to have little effect in azimuth. About 5 milliseconds later, the restoring force of the gunner's left hand (forward hand) causes the weapon to pitch upwards once again. The firing pin completes its forward motion and the round is fired about 5 milliseconds later (40 milliseconds after trigger pull), where the rifle is still rotating upwards. About 8 milliseconds after the firing pin strikes the round, the weapon rotates downward due to gravity and the restoring force of the gunner's hands.

When firing from the prone position, the weapon has reduced displacement from the initial aim point compared to the standing position. This appears reasonable considering the greater stability offered by the prone position. However, about 35 milliseconds after trigger pull, the azimuth displacement is more negative (below the target) from the prone position than from the standing position. The reason is unknown.

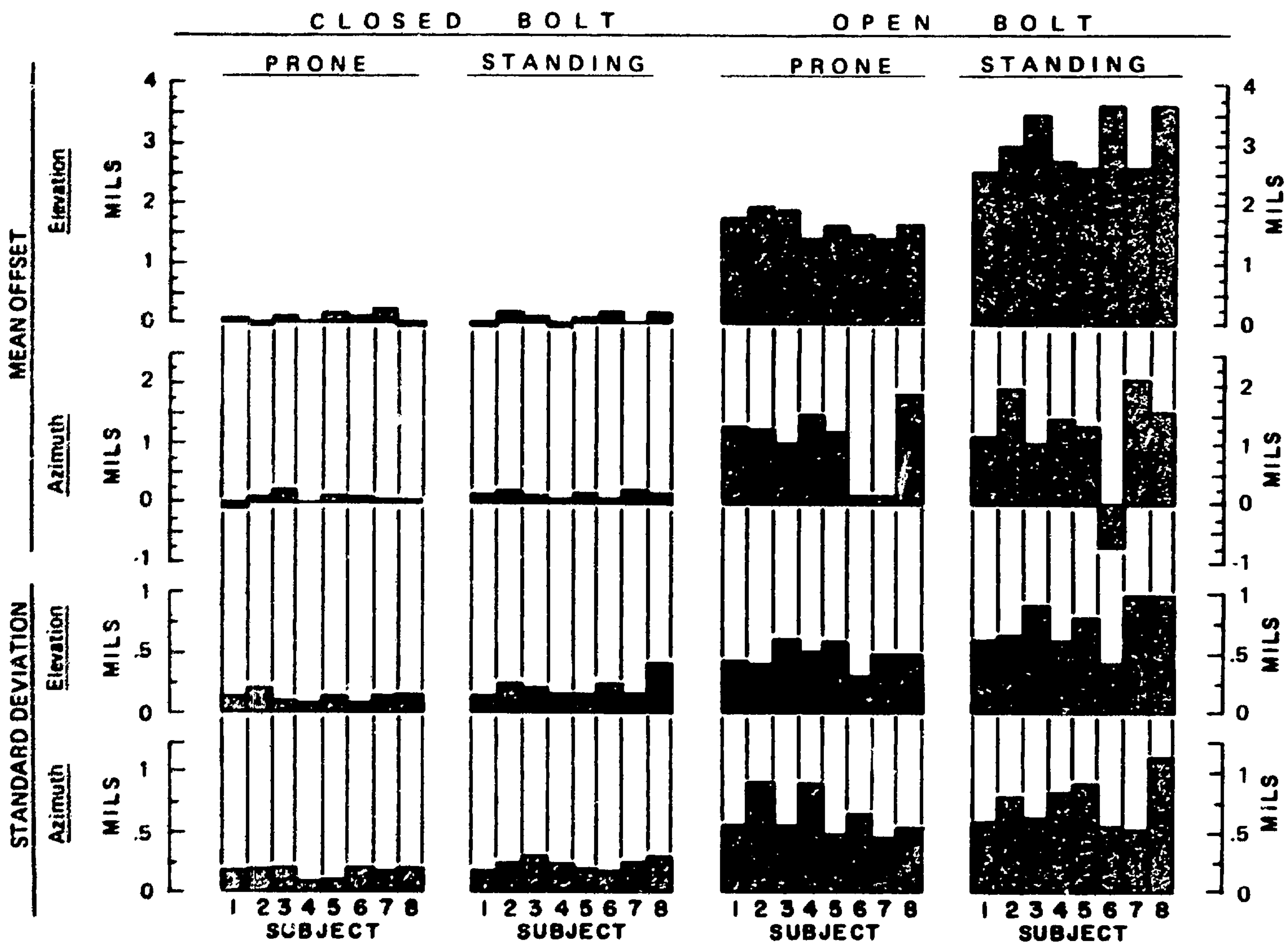


Figure 12. Aiming error offset means and SDs in the dry fire test.

TABLE 2

"t" and "F" Tests

	$\bar{x}_{OP} - \bar{x}_{CP}$	t	$F = S^2_{OP}/S^2_{CP}$
Elevation	1.58	26.4**	10.1**
Azimuth	1.11	16.9**	16.4**
	$\bar{x}_{OS} - \bar{x}_{CS}$	t	$F = S^2_{OS}/S^2_{CS}$
Elevation	2.94	15.6**	12.1**
Azimuth	1.35	13.9**	12.1**
	$\bar{x}_{OS} - \bar{x}_{OP}$	t	$F = S^2_{OS}/S^2_{OP}$
Elevation	1.38	12.2 **	2.9**
Azimuth	.32	2.38*	1.1 (1/F)

$t_{.995,158} = t_{.995,68} = 2.6$

$t_{.995,158} = 2.3$

$F_{.995,80,80} = F_{.995,70,70} = 1.8$

**Denotes significance at .5% level.

*Denotes significance at 1% level.

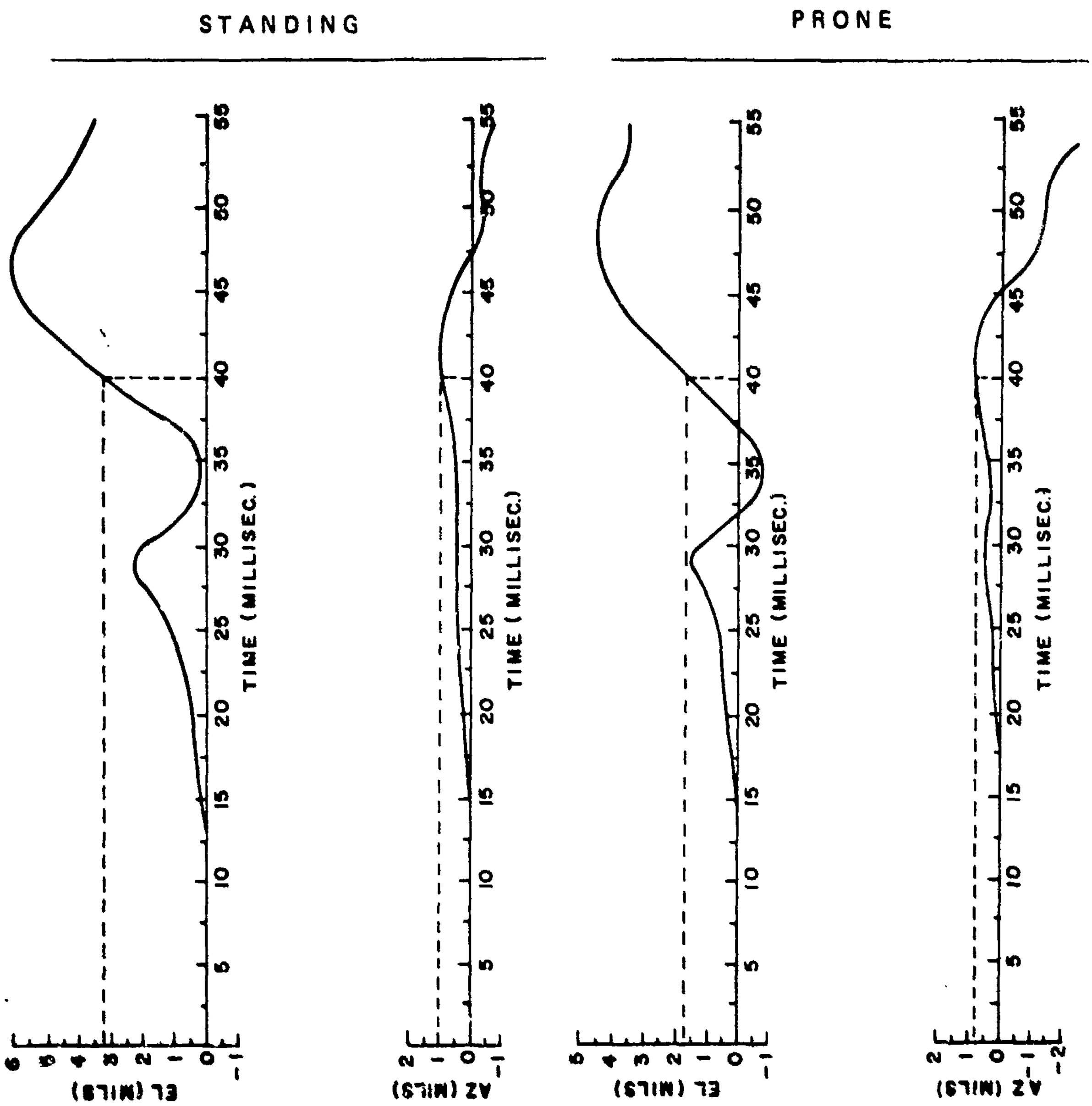


Figure 13. Aiming point time history for open-bolt firing—Subject 3.

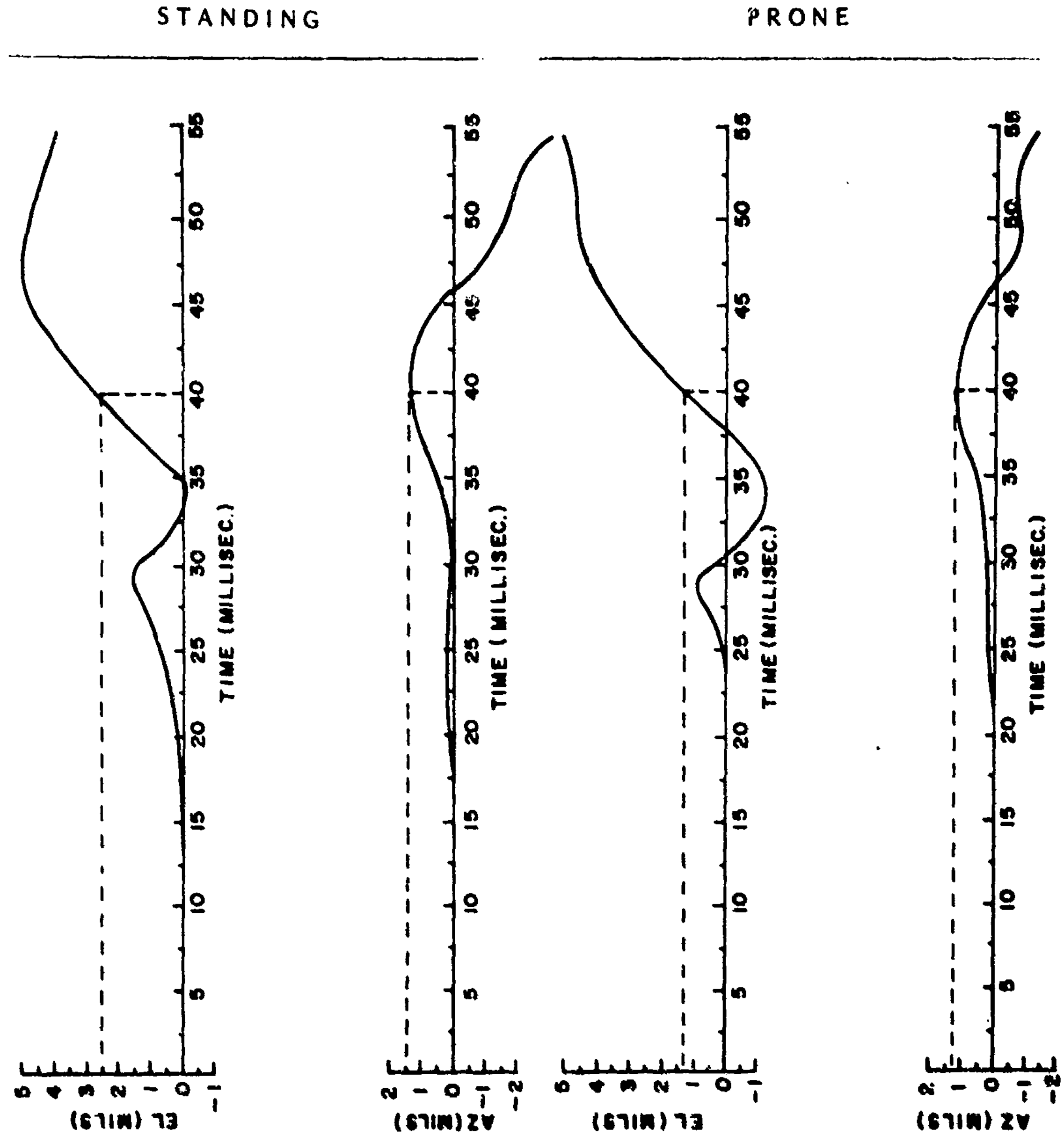


Figure 14. Aiming point time history for open-bolt firing—Subject 4.

PHASE II– LIVE FIRE

Method

Weapon

Two new XM19 rifles, SN50 and SN51, were forwarded by AAI for the test. Since dispersions between rifles of this type are markedly different, one weapon (SN50) was selected for the test and the other was a back-up.

Pre-Test Fire

Prior to delivery of the weapons, an AAI representative fired two 10-round shot groups from weapon SN50 in the standing position from both closed bolt and open bolt. The target was an 8-inch diameter circle stencilled on a large sheet of paper positioned 100 meters down range (i.e., a 2.2-mil diameter target). The ammunition lot was ML29.

Test Area

The test firing was conducted at the HEL outdoor target range.

Subjects

Two subjects, one a civilian HEL employee and the other an Army captain, were tested. Both had previous experience at HEL's range firing the M-16. Neither had ever fired the XM19.

Target

A 1-inch circle on a 21-inch square target represented a 1-mil diameter aim point at the 25-meter range used in the test.

Ammunition

The entire test was fired using XM645 ammunition, lot number 3096-7.

Conditions

The four conditions of Phase I were examined using a matrix which represented four replications of the test conditions for each subject (Figure 15). The subjects alternated between conditions and fired 10 rounds per condition.

Replication	Subject	Condition			
1	1	CP	OS	CS	OP
	2	OP	CS	OS	CP
2	1	CS	OP	CP	OS
	2	OS	CP	OP	CS
3	1	OP	CS	OS	CP
	2	CP	OS	CS	OP
4	1	OS	CP	OP	CS
	2	CS	OP	CP	OS

Figure 15. Phase II live fire test matrix.

Procedure

Since the trigger group used for open-bolt firing would allow for firing only in the full automatic mode, only a single round was loaded in the magazine for the open-bolt firing. In order to maintain identical conditions between open and closed bolt firing, magazines loaded with a single round were also used for closed-bolt firing.

With a subject at the appropriate firing condition, the subject inserted a magazine (one round) into the weapon, manually cocked the weapon, aimed and fired. The magazine was removed, a new one inserted and the above procedure repeated until 10 rounds (10 magazines) had been fired.

Prior to data collection, each subject was allowed to fire three rounds at each test condition for familiarization.

A new target was used for each 10-round shot group.

Results

Test Procedure

The test was interrupted at the end of the second replication due to the high round-to-round dispersion for all shot groups and a detectable increase in dispersion as the test progressed. In order to confirm the large dispersion (which was caused by wear of the stripper), a 10-round shot group was fired from a bench rest position with the closed bolt. Visual inspection of the target showed a dispersion of the same order of magnitude as any of the 10-round groups previously fired.

Two 10-round shot groups were then fired with weapon SN51. Visual inspection of the targets showed a lower dispersion for this weapon compared to weapon SN50. However, since this dispersion was still too large, testing was terminated.

Data Reduction and Statistical Tests

Missed distance from the target center in azimuth and elevation for each round was measured to the nearest twentieth of an inch and converted to mils. The targets were examined for possible outliers and means, standard deviations and linear standard deviations were computed for each 10-round trial both with and without the suspected outliers. All trials for a condition were combined and the above computations made for this total.

All means and standard deviations in the tables to follow are in mils. Unless otherwise noted, the number of rounds in each trial is 10, and the number of rounds in the total is 10 times the number of trials contained in the total.

F and t tests were conducted by condition. Since none of the F tests showed significant differences, these tests are not shown in the tables.

Pre-Test Firings

The shot patterns for the pre-test firing are shown in Figures 16 and 17. Whereas shot patterns shown for the dry-fire test are referenced to the gunner's aim point at trigger pull, these shot patterns are referenced to the center of the target. Therefore, the displacement of the mean point of impact for the closed bolt firing is viewed as an offset of the sight relative to the barrel (i.e., the weapon and sight were not bore-sighted).

Table 3 shows the statistics computed for these data. The difference between mean offset in elevation for open and closed bolt firing (2.4 mils) is close to the difference recorded in the dry-fire test. The difference in azimuth is smaller and is not statistically significant.

Phase II Firing Data

Summary statistics for the live firing in Phase II are shown in Table 4 for all data, and in Table 5 with suspected outliers removed. As previously stated, none of the SDs differed significantly among conditions in Phase II. The differences among mean points of impact (Table 6) in elevation are within a few tenths of a mil of those measured in the dry fire test and are statistically significant. The differences in azimuth between closed and open bolt are relatively small and not statistically significant. The mean point of impact for the open bolt standing position is displaced more than 1 mil to the left of the mean point of impact for open bolt prone position. A similar difference is seen between prone and standing position for the open bolt condition (Table 4).

Bench Rest Firing Data

Data for the bench rest firings (closed bolt) conducted at the end of Phase II are shown in Table 7. Although one would expect dispersions from a bench rest to be smaller than from the prone position, the opposite is shown. This may be caused by some type of failure of the stripper. The mean point of impact in elevation (relative to the target center) is very close to that measured for the closed bolt prone test condition in Phase II (-2.98 versus -2.94 mils). However, the offsets in azimuth are nearly the same magnitude but in different directions and are displaced to the right in Phase II and displaced to the left for the bench rest firing. The fact that extreme

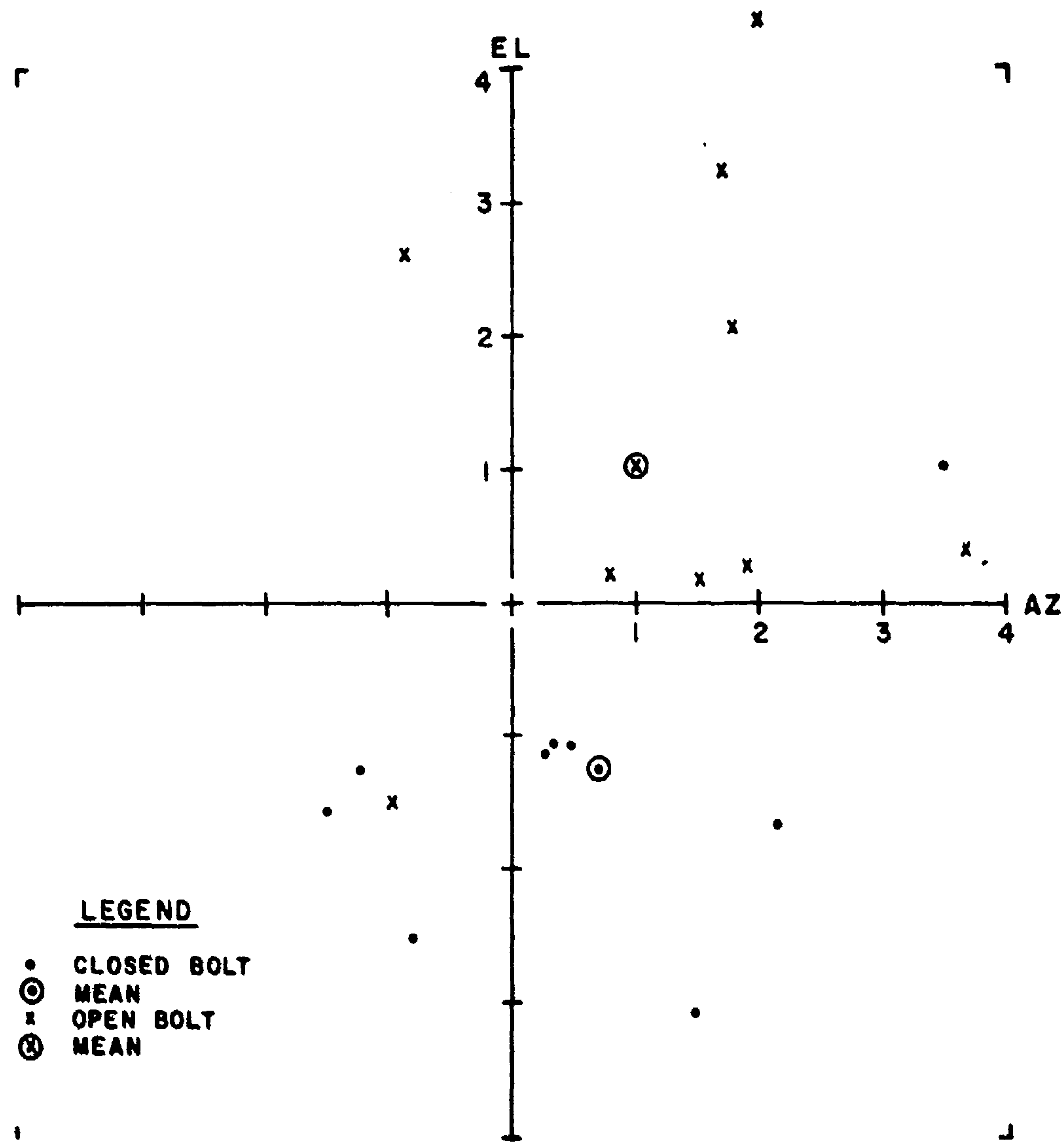


Figure 16. Phase II pre-test shot patterns—Trial No. 1.

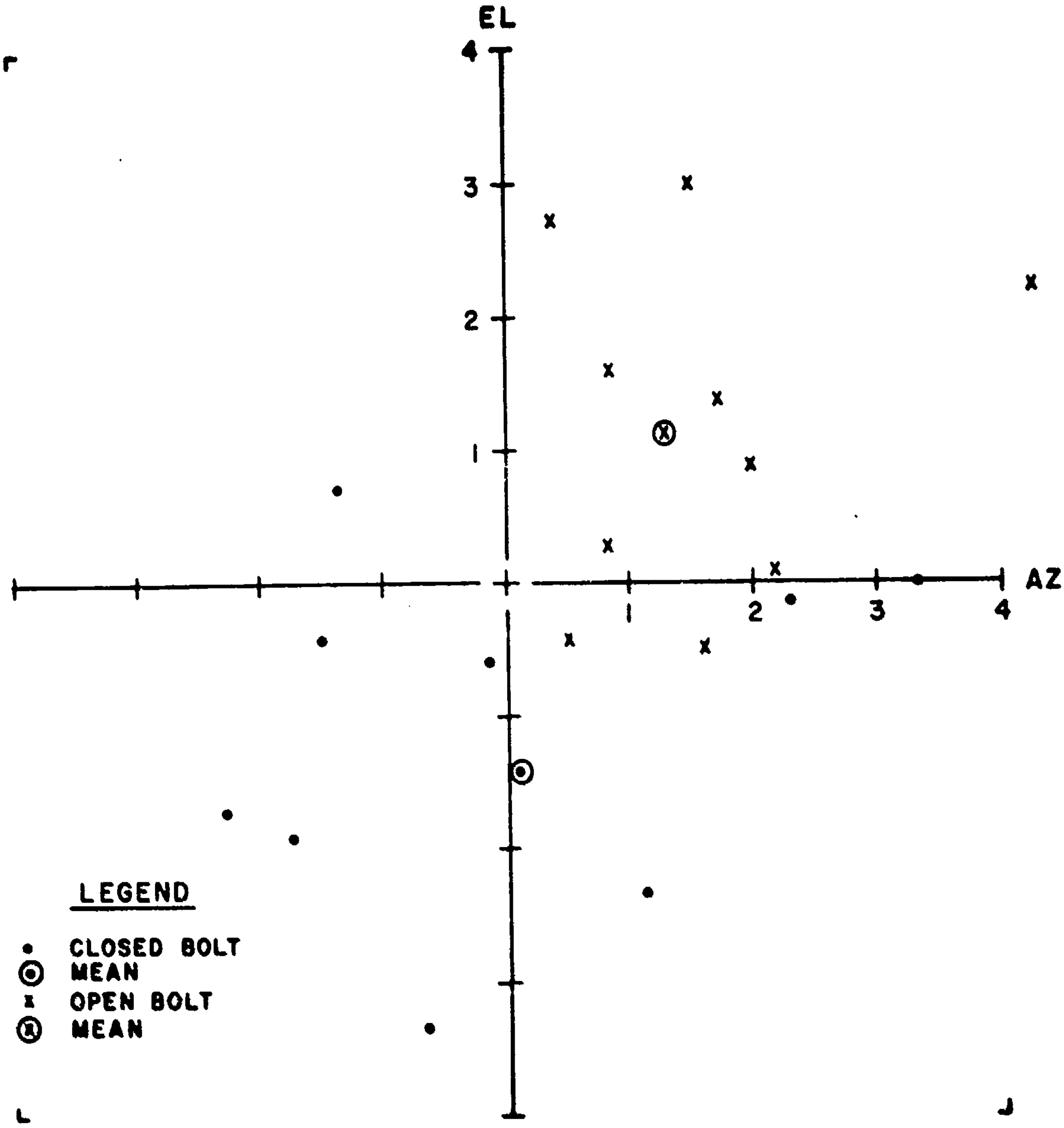


Figure 17. Phase II pre-test shot patterns—Trial No. 2.

TABLE 3

Summary Statistics for Phase II Pre-Test Firings

	Elevation		Azimuth		LSD
Cond - CS	Mean	SD	Mean	SD	
Trial 1	-1.26	1.16	.72	1.47	1.32
Trial 2	-1.44	1.65	.03	1.88	1.77
Total	-1.35	1.39	.38	1.68	2.18
Cond - OS					
Trial 1	1.04	1.98	1.02	1.63	1.81
Trial 2	1.12	1.26	1.30	.62	.99
Total	1.08	1.61	1.16	1.20	2.01

t Test	$\bar{x}_{OS} - \bar{x}_{CS}$	t	
Elevation	2.43	5.1	Significant at .5% level
Azimuth	.78	1.70	Not significant

$t_{.995,38} = 2.71$ $\qquad t_{.95,38} = 1.69$

TABLE 4

Summary Statistics for Phase II Live Firing—All Data

	Elevation		Azimuth		LSD
Cond - CP	Mean	SD	Mean	SD	
Trial 1					
S1	-2.48	.91	1.70	1.89	1.48
S2	-2.26	2.00	.77	2.94	2.51
Trial 2					
S1	-3.89	1.35	1.90	1.99	2.36
S2	-1.00	2.27	.99	3.99	2.83
Total	-2.40	1.94	1.34	2.76	2.38
Cond - OP					
Trial 1					
S1	-1.28	2.26	1.67	2.10	2.18
S2	-2.85	3.15	2.44	2.71	2.94
Trial 2					
S1	- .20	2.15	1.40	2.05	2.10
S2	-1.54	2.84	1.69	1.31	2.21
Total	-1.46	2.70	1.80	2.05	2.40
Cond - CS					
Trial 1					
S1	-2.18	2.30	- .60	2.47	2.39
S2	-1.06	3.04	1.70	2.73	2.89
Trial 2					
S1	-2.37	2.09	- .85	2.59	2.35
S2	-1.05	1.20	.57	1.86	1.57
Total	-1.66	2.25	.20	2.55	2.40
Cond - OS					
Trial 1					
S1	- .11	1.98	.83	2.39	2.19
S2	1.42	1.79	.82	1.43	2.62
Trial 2					
S1	- .18	2.28	.54	.93	1.74
S2	.63	1.81	-1.13	1.80	1.80
Total	.44	2.00	.26	1.84	1.92

TABLE 5

Summary Statistics for Phase II Live Firing--Suspected Outliers Removed

		Elevation		Azimuth		LSD
Cond - CP	N	Mean	SD	Mean	SD	
Trial 1						
S1	9	-2.44	.96	1.26	1.34	1.17
S2	9	-3.88	1.44	1.41	1.32	1.38
Trial 2						
S1	9	-1.94	1.83	1.37	2.37	2.12
S2	9	-3.51	2.48	1.83	2.04	2.27
Total	36	-2.94	1.86	1.46	1.75	1.80
Cond - OP						
Trial 1						
S1	10	-1.28	2.26	1.67	2.10	2.18
S2	9	- .71	1.50	1.79	1.72	1.62
Trial 2						
S1	9	-1.65	1.04	.09	1.80	1.47
S2	9	- .71	1.18	1.52	1.27	1.22
Total	37	-1.09	1.57	1.27	1.82	1.70
Cond - CS						
Trial 1						
S1	9	-2.26	2.42	-1.30	1.18	1.90
S2	8	-2.06	1.80	.85	1.59	1.70
Trial 2						
S1	9	-2.77	1.76	-1.32	2.25	2.02
S2	9	- .97	1.25	.15	1.38	1.32
Total	35	-2.01	1.89	- .44	1.83	1.80
Cond - OS	N					
Trial 1						
S1	8	.10	2.18	- .18	1.25	1.77
S2	10	1.42	1.79	.82	1.43	2.62
Trial 2						
S1	9	.37	1.58	.45	.94	1.30
S2	9	.34	1.65	-1.53	1.35	1.51
Total	36	.59	1.80	- .08	1.51	1.66

TABLE 6

Phase II "t" Tests

	$\bar{x}_{OP} - \bar{x}_{CP}$	t
Elevation	1.85	4.56*
Azimuth	.07	.17
	$\bar{x}_{OS} - \bar{x}_{CS}$	
Elevation	2.60	5.98*
Azimuth	.36	.91
	$\bar{x}_{OS} - \bar{x}_{OP}$	
Elevation	1.68	4.22*
Azimuth	-1.35	3.43*

$t_{.995,71} = t_{.995,69} = 2.65$

*Denotes significance at .5% level

TABLE 7

Summary Statistics for Post Test Bench-Rest Firings from the Closed Bolt

		Elevation		Azimuth		LSD
Weapon	N	Mean	SD	Mean	SD	
SN 50	10	-2.98	2.46	-1.51	3.63	3.10
SN 51						
Trial 1	10	- .87	2.53	2.08	1.24	1.99
Trial 2	10	-1.08	3.27	1.30	2.94	3.11
SN 51(Outliers Removed)						
Trial 1	8	- .97	1.01	1.91	1.34	1.19
Trial 2	9	-2.01	1.54	2.14	1.40	1.47

excursions for the rounds fired from the bench rest were 7.5 mils to the left and 5.6 mils to the right makes the bench rest data suspect. It is believed that the mean displacement to the left for the bench rest firing is due primarily to the stripper and the resultant large dispersions.

DISCUSSION

Table 8 provides a comparison of differences in means among the test conditions for dry fire and live fire. The offsets in elevation are well ordered and are comparable between Phase I and Phase II. On the other hand, the differences in azimuth offset appear to be random. Data for the dry firing test are the more reliable of the two phases. The large dispersion measured in the live fire test and the random nature of the azimuth offsets raises doubts about the credibility of all of the live fire data. This is due to the peculiarities of the XM19 weapon and primarily, the effect of the stripper on round-to-round dispersion.

The displacement of the point of aim when firing from the open bolt is directly related to the mass of the bolt, the force of the buffer spring and the vertical offset between the barrel and the point where the butt plate rests against the gunner's shoulder. If the bolt mass, spring force or vertical offset are reduced, the displacement of the point of aim would be reduced. Therefore the performance measures obtained in this experiment pertain only to the tested weapon. The results can only be regarded as providing guidance in evaluating the effect on rifle performance of firing from the open bolt with other rifles.

TABLE 8

Differences Between Means—All Test Firings

		Phase I	AAI	Phase II
OS - CS	Elevation	2.94*	2.43*	2.60*
	Azimuth	1.35*	.78	.36
OP - CP	Elevation	1.58*		1.85*
	Azimuth	1.11*		.07
OS - OP	Elevation	1.38*		1.68*
	Azimuth	.32		-1.35*

*Indicates significant differences at the .5% level.

CONCLUSIONS

Rifle firing from the open bolt has the following effect on first round performance relative to closed-bolt firing:

1. It displaces the aiming point upwards and to the right for right-handed gunners and upwards and to the left for left-handed gunners.

2. The displacement is greater when firing from the standing position compared to firing from the prone position.

3. The aiming error dispersions are increased substantially which in turn increases the overall weapon dispersion.

The general results recorded in this experiment apply only to the tested weapon. A weapon with different bolt mass, spring force and vertical offset will produce similar results but of a different magnitude.

RECOMMENDATIONS

The shift in aiming point for the first round should be accounted for in the design or analysis of rifles firing from the open bolt. Since the magnitude of the shift in aiming point depends on the mass of the bolt, spring force and offset between barrel and butt plate, the effect could be reduced by suitable design of the weapon. Also, if the weapon has a large inherent dispersion (e.g., the XM19) or is a short range weapon, the effects of open bolt may be insignificant.

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2. Vrana, N.M. A hybrid computer model of the XM19 weapon. Memorandum Report No. 2313, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1973.