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Shooting With Night Vision Goggles and Aiming Lights

Jean L. Dyer, Seward Smith, and Nancy R. McClure
U.S. Army Research Institute

June 1995

U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

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Research Report 1678

Shooting With Night Vision Goggles and Aiming Lights

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Education and Training Technology

FOREWORD

The U.S. Army Research Institute for the Behavioral and Social Sciences conducts training research on critical individual and unit skills to ensure that training in institutions and Army units is maximized and is cost effective. Of particular concern is the training of night skills. These skills are central to the NIGHTFIGHTER research program conducted by the Infantry Forces Research Unit at Fort Benning, Georgia.

This report details a series of experiments on night marksmanship using aiming lights and night vision goggles. The experiments focused on the zeroing problems identified in the 1978 operational test of the aiming light—problems that remained until the ARI research began in 1993. Solutions to the zeroing problems were found using modified live-fire zeroing procedures and new dry-fire zeroing procedures. All the procedures are inexpensive and can be implemented with readily available materials; equipment modifications or new equipment are not needed.

The results have been briefed to the Commandant and Assistant Commandant of the U.S. Army Infantry School and have been presented to the U.S. Marine Corps. The zeroing procedures have been used by the Infantry School's Dismounted Battlespace Battle Lab in their advanced Warfighting Experiments and by some Infantry units.

EDGAR M. JOHNSON
Director

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Charles Thornton of the U.S. Army Infantry School's Dismounted Battlespace Battle Lab at Fort Benning, Georgia, who supported the research project and provided the aiming lights used in all the experiments.

We wish to express our sincere appreciation to Major General Steve Siegfried, Commandant, Fort Jackson, South Carolina, for allowing us to use the location of misses and hits (LOMAH) range at Fort Jackson and to his staff. Without the LOMAH facility, the required experimental data could not have been obtained. Without the tremendous support from his staff, the research could not have been executed. We also thank Tony Labrozzi for providing additional LOMAH targets in the initial research.

Special thanks are given to Sergeant First Class McCarty and Specialist Benoit from the Army Marksmanship Unit at Fort Benning, who made invaluable contributions to the pilot work on the dry-fire zeroing procedures and also provided the control of the range during this period.

Finally, we wish to thank all the soldiers, both the firers and the assistant instructors, who participated in and assisted us in all the data collection efforts. Their support is particularly noteworthy, as it was provided under very adverse weather conditions.

SHOOTING WITH NIGHT VISION GOGGLES AND AIMING LIGHTS

EXECUTIVE SUMMARY

Requirement:

Compared to firing at night with unaided vision, aiming lights used with night vision goggles (NVGs) provide soldiers with a greatly enhanced capability to engage and hit targets. However, good shooting is possible only if the aiming light is zeroed to the rifle and if the firers' NVGs are adjusted for maximum visual acuity. However, aiming lights are difficult to zero. With the current 25-m live-fire zeroing procedures, firers have difficulty getting their initial shot group on the zero target so aiming light adjustments can be made. In addition, due to the bloom of the aiming light in the NVGs and the reduced visual acuity with NVGs, firers have trouble achieving a definitive center of mass aim point from which final aiming light adjustments can be made. The research was conducted to find solutions to these zeroing problems, solutions that would be inexpensive and easy to implement. The research also examined the effect of NVG acuity adjustments on marksmanship.

Procedure:

Two series of experiments were conducted. The first series addressed the issue of achieving a definitive aim point and small shot groups during 25-m, live-fire zeroing with aiming lights. The effects on marksmanship performance of different 25-m zero target configurations designed to improve the firer's aim point, modified zeroing procedures designed to minimize the likelihood of aiming light adjustment errors, and good and poor NVG visual acuity settings were examined. The second series of experiments addressed the issue of how to get initial shot groups on the zero target by using a dry-fire zeroing procedure. The effectiveness of this dry-fire procedure without confirming the zero with live-fire was also examined. In all experiments, both the AN/PAQ-4A and the AN/PAQ-4B aiming lights were used. Except for the baseline experiment and some pilot experiments, the firing was conducted on a location of misses and hits (LOMAH) range. All firers were infantrymen; the same size ranged from 6 to 30, depending on the experiment. Repeated measures experimental designs were used throughout, with each soldier firing under each condition of interest.

Findings:

Compared to the baseline results for both aiming lights, the enhanced live-fire zeroing procedures reduced shot group size, enabled all firers to zero with no more than six shot groups,

and improved the probability of hit at distant targets. However, even with improved zeroing procedures, the shot group size with aiming lights tended to be 1.5 times larger than that achieved during daylight with the rifle sights. Good NVG acuity settings resulted in smaller shot groups than poor settings and better hit performance at range. For both aiming lights, the dry-fire procedure also proved to be a better technique than the manufacturer's mechanical adjustment to get the firer's initial shot groups on the 25-m zero target. In addition, for the AN/PAQ-4A, the dry-fire zero resulted in hit probabilities at a range similar to those achieved with the live-fire zero. However for the AN/PAQ-4B, the appropriate dry-fire zero point was not clearly identified, as target hits at range were higher with live-fire zeroing. Further research is needed with the AN/PAQ-4B to determine the best dry-fire point. Overall, the results showed how marksmanship performance at night can be strongly affected by factors other than the technical characteristics of the aiming light. The quality of the aiming light zero, NVG visual acuity setting, target contrast, and weather conditions are key factors as well. Finally, from a historical perspective, the results showed a clear increase in marksmanship performance, as technology and training have improved, from the time when firers relied on their unaided eye at night.

Utilization of Findings:

Cost-effective solutions to the zeroing problems with aiming lights were identified. These solutions will result in better aim points, better zeros, and more targets hit at range. They will also save time and ammunition during the zeroing process. The revised procedures can be implemented with materials readily available to units and training institutions. In addition, the findings showed that dry-fire zeroing procedures with aiming lights can substitute for live-fire zeroing procedures in emergency deployment situations.

SHOOTING WITH NIGHT VISION GOGGLES AND AIMING LIGHTS

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SHOOTING WITH NIGHT VISION GOGGLES AND AIMING LIGHTS

Introduction

Critical to the success of night operations is the ability to provide precision fire on a target. Soldiers must be trained to shoot accurately and quickly with their rifles. Prior to the introduction of aided night vision devices, effective firing at night with a rifle was limited to very close distances, typically within 50 meters. The ability to hit targets was dependent on soldiers' ability to acquire targets in their sights, which in turn, depended greatly upon the amount of natural and artificial illumination. However, with image intensification technology in the form of night vision sights, such as the AN/PVS-4 and night vision goggles (NVGs) used with aiming lights, soldiers have the capability to shoot with precision at longer distances. However, they must be trained properly before this capability can be fully realized.

The report presents the results of experiments conducted during 1993 and 1994 which addressed training issues related to marksmanship with NVGs and aiming lights. The primary focus was on resolving problems related to zeroing aiming lights to the rifle, but factors affecting firing at range were also examined. The research was conducted as part of the Army Research Institute's (ARI) Infantry Forces Research Unit NIGHTFIGHTER program.

Night Shooting Without NVGs and Aiming Lights

To hit a target at night, the firer must first see it. Then the target must be acquired with the rifle sights. When relying on only the light in the night sky, the probability of detecting targets is extremely low. Hitting targets at the maximum effective range of the rifle is not possible under these conditions. Even at close ranges, the ability to hit targets is affected greatly by the amount of light at night.

The effect of the amount of ambient light on the ability to detect targets and on marksmanship was demonstrated clearly in the Human Resources Research Office's (HumRRO) research on Infantry night fighting skills. How likely are soldiers to detect targets at night with the unaided eye? Nichols and Power (1964) reviewed night detection studies of human targets and vehicles under natural illumination conditions. The most systematic investigation in this review was Taylor's (1960) research. Taylor examined the ability of soldiers to detect stationary targets as a function of the observer's position (standing, kneeling, and prone), the target's position (standing, kneeling, and prone), illumination (full moon and no moon), distance to the target, and night vision training. Soldiers served as the targets. For the no moon condition, targets were placed 5 yd (4.6 m) apart from a distance of 5 to 50 yd (4.6 to 45.7 m). For the full moon condition, targets were placed 10 yd (9.1 m) apart from 20 to 120 yd (18.3 to 109.7 m). All results clearly showed a decrease in the likelihood of detecting targets as the distance to the target increased and as the amount of illumination decreased. Target position also had an effect, with standing targets being the easiest to detect and prone the hardest. The average detection distance under no moon was approximately one-third of the full moon condition. Figure 1 shows the substantial difference in the ability of soldiers to detect targets under these two illumination conditions across all observer and target positions.

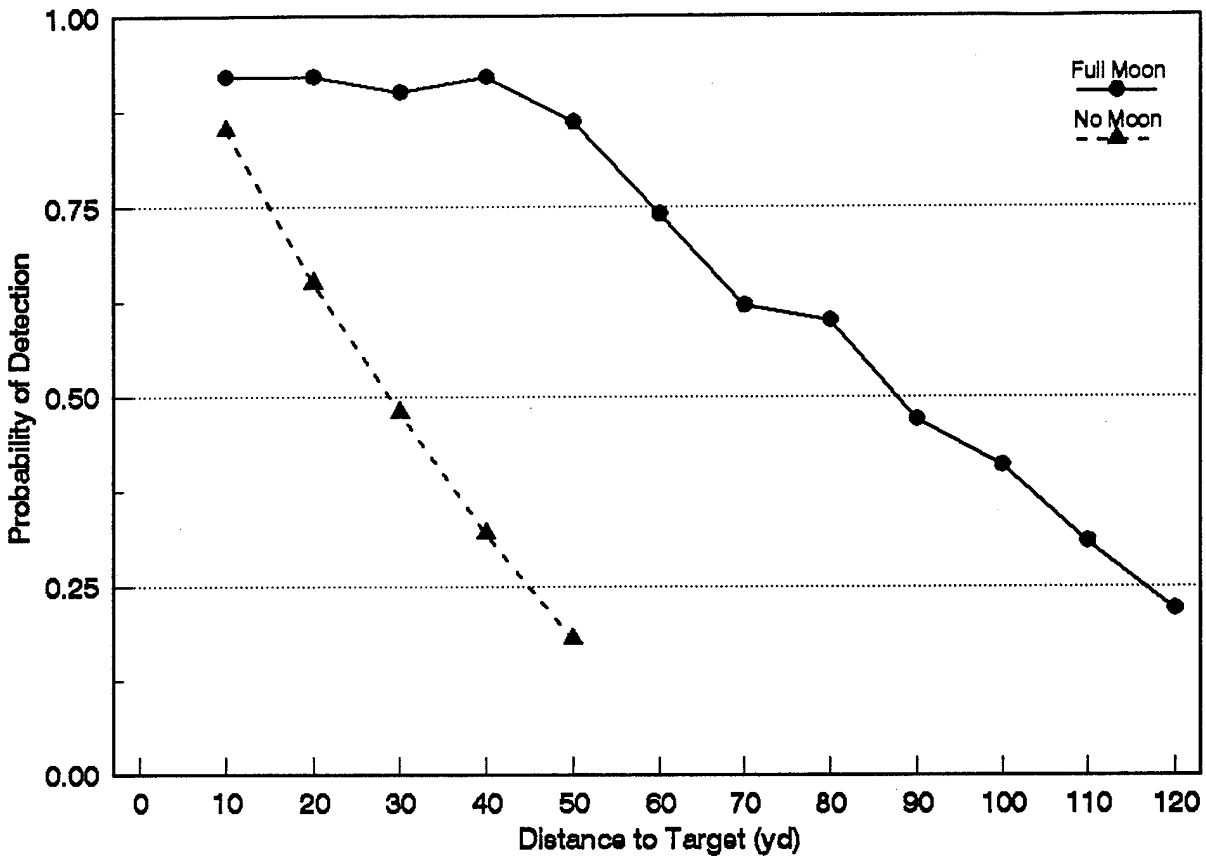


Figure 1. Probability of detection with unaided night vision (from Taylor, 1960). Probabilities were averaged over three observer and three target positions.

Given the limits the night places on soldiers' ability to detect targets with their unaided eye, what is the likelihood of hitting targets under these conditions? Jones and Odom (1954) examined the ability of soldiers to hit E-silhouettes, representing firers in the kneeling position, from 85 to 135 yd (77.7 to 123.4 m) and M-silhouettes, representing firers in a standing position, at 25 to 75 yd (22.8 to 68.6 m) under moonless and moon light conditions with the M1 rifle. The E-silhouettes were all stationary, but had a flashing light to simulate enemy small-arms fire. The M-silhouettes were not lit; that is, were dark. These silhouettes were placed in stationary and two moving configurations, left to right and right to left, to simulate a maneuvering enemy. For the dark targets, the probability of hit (p_h) increased as the illumination at night increased and as the target distance decreased. Under moonless conditions, the p_h was .46 at 25 yd (22.8 m) and .00 at 75 yd (68.6 m). Under moonlight conditions, the p_h was .72 at 25 yd (22.8 m) and .24 at 75 yd (68.6 m). On the other hand, the likelihood of hitting the stationary flashing targets placed at the longer distances was low (p_h less than .08), and it did not vary with target distance nor with the amount of ambient illumination.

Sivy and Taylor (1956) examined the likelihood of hitting E-silhouette targets at night using existing ambient illumination with a 50:50 ratio of ball and tracer rounds with the M1 rifle. No moon, half moon, and full moon conditions were compared, as well as pointing versus aiming firing techniques. Again, the amount of ambient light impacted performance. Based on test results, the authors prescribed firing at 25 yd (22.8 m) under conditions of no moon, firing at 50 yd (45.7 m) under no moon and moonlight conditions, and firing at 75 yd (68.6 m) under full moon only. The p_h approximated .60 at 25 yd (22.8 m) under no moon; .53 at 50 yd (45.7 m) under full moon and .23 under no moon; and .39 at 75 yd (68.6 m) under full moon.

In night fire training, efforts are typically made to increase the firer's ability to detect targets and obtain a good alignment of sights on the target. Such techniques, however, yield mixed results. Bryant, Acchione-Noel, Sala, Reynolds, and Catherson (1983) examined two night fire systems for the M16A1 rifle. The promethium sight was a modification of the M16A1 standard sight, where the front sight post housed a small plastic vial of luminous radioactive material. A modified, enlarged 7-mm rear sight was used. The ranger eye sight was a plastic clip-on front sight with narrow strips of luminous ranger-eye tape attached to the rear surface of the leaves, thereby creating an illuminated, U-shaped area surrounding the front-sight post. Automatic fire in three-round bursts with tracer ammunition was also used. E-silhouettes, slightly illuminated, were placed at 50-m increments from 50 to 200 m. Over all firing conditions, the p_h decreased as the target range increased: .57 at 50 m, .27 at 100 m, .13 at 150 m, and .04 at 200 m. Later, Hunt, Lucariello, Martere, Parish, and Rossi (1987) examined the effects of using a muzzle flash simulator and artificial illumination, which simulated ground and air flares, to aid in target acquisition at night. The targets were E-silhouettes placed at 75 and 175 m. The hit probability with the M16A2 rifle was low; it never exceeded .31 in these tests. The authors recommended an area target be used for night fire training rather than single target exposures of E-silhouettes.

The probability of hit data from these tests are summarized in Figure 2. Additional information on p_h is in Appendix A.

Current Army guidelines on night firing (Department of the Army [DA], 1989) stress training to fire the M16A2 rifle using artificial illumination without a night vision sight, although firing with night vision sights is also discussed. The emphasis on unaided firing is consistent with the current distribution of night equipment in Army units, as there are limited numbers of night vision sights, and they are typically assigned to the automatic riflemen and machine gunners, not to the riflemen.

Night Shooting with NVGs and Aiming Lights

Aiming lights, in conjunction with NVGs, give soldiers a point and shoot capability. Targets can be engaged more effectively at longer ranges than with the unaided eye. Here too, target detection is key to performance. The NVGs, with their light amplification capability, increase the distances at which targets can be detected. With an aiming light that has been zeroed properly to the weapon, the firer simply aims the light on the target and fires. There is no

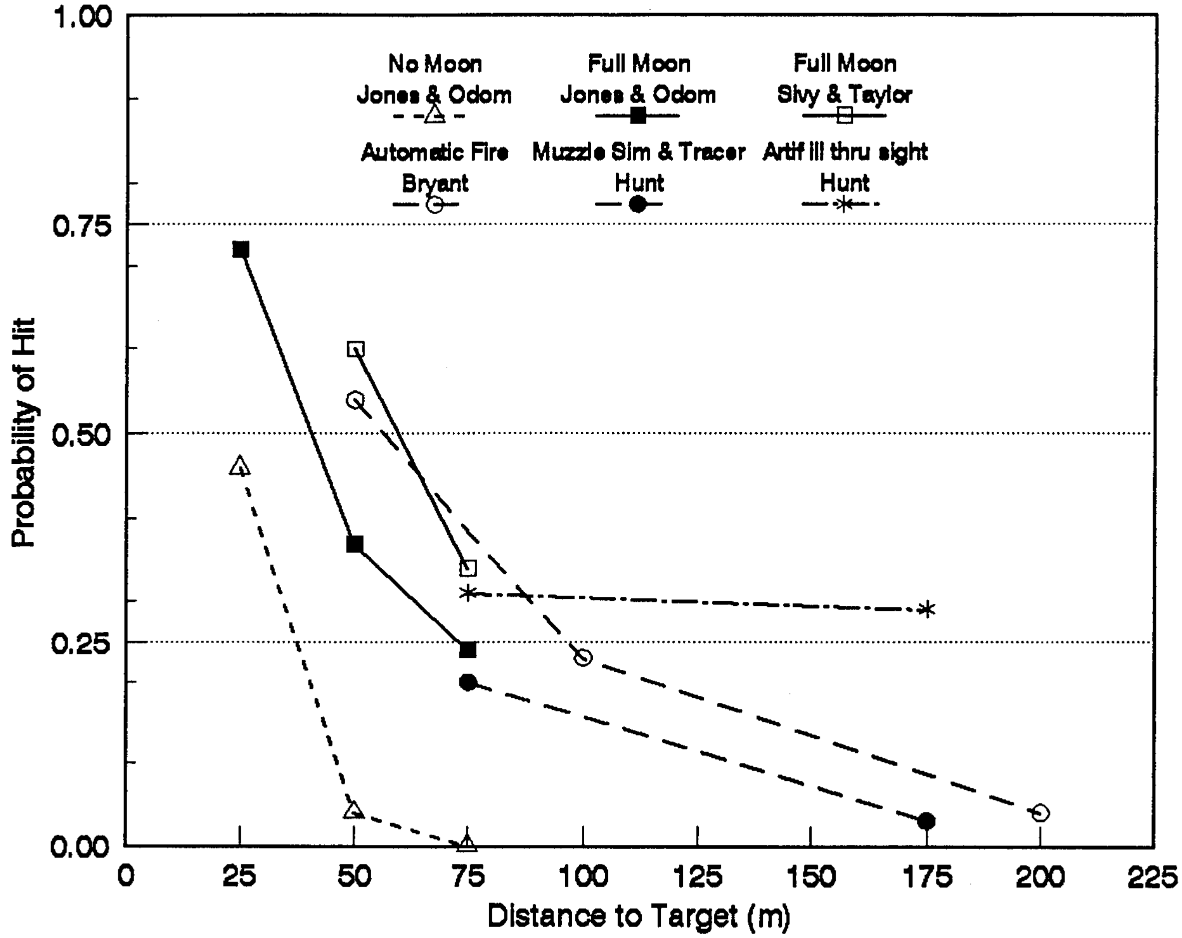


Figure 2. Probability of hit with unaided night vision under various illumination conditions.

requirement to align the weapon sights with the target as is the case with unaided firing. Thus the shooting task is simplified with aiming lights.

Aiming Light Characteristics

Both the AN/PAQ-4A aiming light and its follow-on, the AN/PAQ-4B, were examined in the research reported here. The AN/PAQ-4A is fielded; the AN/PAQ-4B will be fielded soon on a limited basis. The AN/PAQ-4A and AN/PAQ-4B are not identical devices (see Figures 3 and 4). The AN/PAQ-4A is an infrared, light-emitting diode device which produces a relatively diffuse beam, limiting its effectiveness at long ranges. It is battlesight zeroed for 100 m. It is larger than the AN/PAQ-4B and mounts on the rifle's carrying handle. The AN/PAQ-4B uses a laser and projects a brighter and narrower beam than the AN/PAQ-4A. It is battlesight zeroed for 250 m. It is compact, mounting just behind the rifle's front sight assembly. Relative to the rifle's bore, each aiming light sits above and to the left. However, the AN/PAQ-4A sits higher

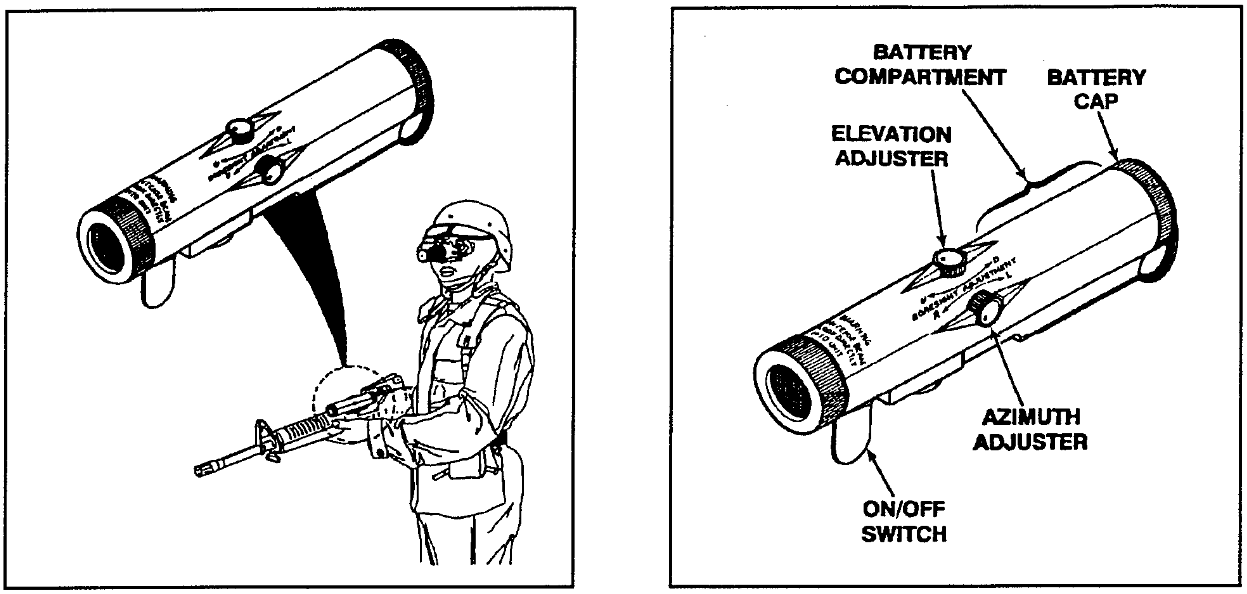


Figure 3. AN/PAQ-4A aiming light.

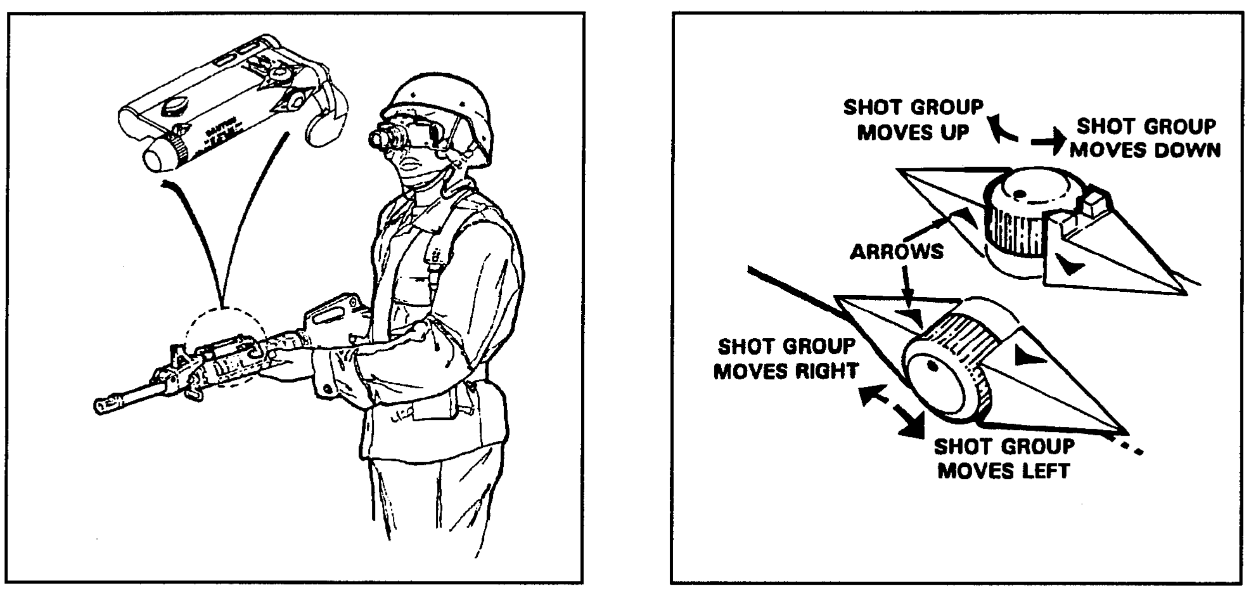


Figure 4. AN/PAQ-4B aiming light.

and is further left of the bore than the AN/PAQ-4B. As the range of the AN/PAQ-4B is longer than that of the AN/PAQ-4A, soldiers should be able to hit targets at greater distances with the AN/PAQ-4B. The range of both aiming devices is reduced by adverse atmospheric conditions such as fog, dust, and smoke. Both devices have separate windage and elevation adjustment knobs.

Probability of Hit

Operational test II of the AN/PAQ-4, a prototype version of the current AN/PAQ-4A, compared probability of hit with the aiming light to the unaided eye (Patterson & Jones, 1978). In this test, soldiers used the M16A1 rifle and the second-generation AN/PVS-5 NVGs. The hit data were greatly affected by the heavy fog and rain, reducing the effective range of the aiming light to 75 m. The p_h was .46 at 25 m, .42 at 50 m, and .15 at 100 m. The control group who fired without the aiming light did not hit any of the targets. In a follow-on test by Banning and Caughley (1979), also with the M16A1 rifle and AN/PVS-5 NVGs, night illumination conditions were better, and the p_h was higher. The p_h was .60 at 50 m, .50 at 75 m, and .48 at 100 m. No tests were available on the AN/PAQ-4B.

Zeroing Aiming Lights

With daytime firing, the quality of the firer's zero is critical. Similarly, the aiming light must be zeroed properly to the firer's rifle. When zeroing an aiming light, the firer points the aiming light at the center mass of the silhouette on the 25-m zero target. The desired bullet impact point, however, is not center mass of the silhouette because the aiming light is offset from the rifle boreline. Bullets must hit the target at a pre-determined offset point unique to the type of aiming light. This point differs for the AN/PAQ-4A and the AN/PAQ-4B as they have different offsets from the rifle boreline and are zeroed for different distances. Aiming light adjustments are made until the shot group is centered over this offset point.

A major unresolved problem with aiming lights, discovered during the operational testing of the AN/PAQ-4 (Patterson & Jones, 1978), is that of zeroing them to the weapon. It was suggested that the zeroing problem could be reduced through the use of a borelight zeroing device, which would, in turn, reduce the time and ammunition requirements for zeroing.

In the test, the mean time for each soldier to zero the aiming light was 101 min; the mean number of rounds to zero was 23. The initial zero efforts were hindered by a gross misalignment of the aiming light and the weapon bore. Firers had to get within 10 ft (3 m) of the zero target in order to have bullets strike paper. Once bullets were on paper at 25 m, the final zero was difficult to obtain because the bloom from the aiming light appeared larger to the firer than the zero target aim point. Firers, therefore, had difficulties in aiming consistently and precisely at the target. No further details were provided on the zeroing procedures.

A follow-on test (Banning & Caughey, 1979) investigated two possible solutions to the zeroing problem. One was the use of borelight mandrels. Mandrels are metal spindles which insert into the bore of the weapon. An aiming light was attached to the mandrel to serve as a borelight. The light from the mandrel and the light from the aiming light attached to the rifle were brought into coincidence at a given range to boresight the system. The other approach involved zeroing at 25 m and using a flashlight to washout the aiming light and improve the sight picture. The M16A1 rifle and AN/PVS-5 NVGs were used throughout. Compared to the operational test results, both procedures required fewer rounds and less time to zero. A mean of 17.4 rounds was required without the mandrel, a mean of 6.6 rounds with the mandrel. The mean time to zero was between 25 and 30 min for each procedure.

A field expedient procedure was recommended in this test as well. This involved zeroing at a 10-m target, eliminating the need for a flashlight. A modified zero target was also recommended. This was a dark background target with a 0.5 in. (1.3 cm) or 0.75 in. (1.9 cm) piece of light colored masking tape that formed a large plus (+) in the center of the target.

The technical manual for the AN/PAQ-4A specifies using a boresight mandrel followed by live-fire confirmation of zero at 25 m (DA, 1990). However, in a recent examination of night fighting equipment (U.S. Army Infantry School Dismounted Warfighting Battle Lab, 1993), difficulties were found in using this procedure with the AN/PAQ-4A. The procedure requires that a second AN/PAQ-4A be used with the boresight mandrel. The light from the second AN/PAQ-4A must stay in the center of the 25-m zero target until the mounted aiming light is adjusted. Some soldiers had to work with the light for more than an hour to get it centered and some were never able to do so. All adjustments were done at night with soldiers wearing NVGs, which compounded the time and accuracy problems.

The AN/PAQ-4B technical manual (DA, 1993) does not specify the use of a borelight, but only that the aiming light be set in a mechanically central position before zeroing. This position is three turns counterclockwise for both knobs after rotating each to its full clockwise position. The corresponding position for the AN/PAQ-4A is five turns counterclockwise for both knobs after rotating each to its full clockwise position.

Another problem, not cited in previous reports, is that the technical manuals state that a click equals a square on the M16A2 25-m zero target. But this is not the case with either aiming light as the lines on the M16A2 zero target do not form squares. The width of the "box" is 1 cm or 0.39 in., while the height is 0.9 cm or 0.35 in. It is important to note that the lines on the zero target for the M16A1 rifle do form 0.25 in. by 0.25 in. (0.635 cm by 0.635 cm) squares. These squares correspond to an adjustment of one click in windage and elevation with the M16A1 rifle.

Aiming light instructions for the M16A2 rifle make no adjustment for the fact that each box on the M16A2 zero target is not a square. In fact, the instructions indicate that the lines on the target can be used to determine the number of aiming light click adjustments for both windage and elevation. The technical manual for the AN/PAQ-4A (DA, 1990) states that one click moves the beam 0.25 in. (0.635 cm) at 25 m and equates this distance to just less than one square. The technical manual for the AN/PAQ-4B (DA, 1993) states that one click moves the beam or shot group 0.4 in. (1 cm) at 25 m and equates this to one square. What are the consequences of this? As shown in Table 1, use of the vertical lines for windage adjustments will result in an underestimation of the number of required clicks for the AN/PAQ-4A; they are satisfactory for the AN/PAQ-4B. Use of the horizontal lines for elevation adjustments will result in an underestimation of the number of required clicks for the AN/PAQ-4A and an overestimation for the AN/PAQ-4B.

Table 1
Aiming Light Adjustment Errors When Using the M16A2 25-m Zero Target Lines as Equivalent to One Click on the Aiming Light

Adjustment	M16A2 Zero Target: Distance between lines	Actual Movement of Aiming Light	
		AN/PAQ-4A: 1 click = 0.635 cm or 0.25 in.	AN/PAQ-4B: 1 click = 1 cm or 0.4 in.
Windage	Vertical Lines: 1 box = 1 cm or 0.39 in.	Adjustment - Too Little	Adjustment - No error or bias
Elevation	Horizontal Lines: 1 box = 0.9 cm or 0.35 in.	Adjustment - Too Little	Adjustment - Too Much

Although these discrepancies are small when considering only one click, they often increase in magnitude during zeroing. For example, if bullets hit the edge of the zero target paper with the AN/PAQ-4A, the windage adjustment could be underestimated by approximately 5 clicks, 3.2 cm, by relying on the vertical lines on the zero target. In addition, because it is difficult to get a precise aim point, bullets often hit off the lined part of the zero target, on the edges of the paper, or completely off the paper target or the target backing. Such large deviations from center mass compound the problem of determining the exact number of clicks required for adjustment.

Target Detection with NVGs

As in firing with the unaided eye, the distance at which targets can be engaged effectively with aiming lights and NVGs depends on the distance at which targets can be detected. Although NVGs allow soldiers to see farther at night than the unaided eye, NVGs have no magnification capability. In addition, the resolution or quality of the goggle image varies with the amount of ambient light, the visual acuity setting on the NVGs, and the image intensification technology of the NVGs. Third-generation image intensification NVGs provide a better image under low light levels than second-generation NVGs. Moonlight conditions result in better images than cloudy nights with no stars and foggy nights. The better the visual acuity setting, the sharper the image. The best visual acuity soldiers can achieve with third-generation NVGs is 20/40; with second-generation goggles it is 20/50 (Miller & Tredici, 1992).

Soechting and Kennedy (1987) examined the probability of detecting actual personnel targets with third-generation AN/PVS-7 goggles from 50 to 400 m under starlight and better illumination conditions. The probabilities were .51, .72, .52, .28, .13, and .26 at 50, 100, 150, 200, 300, and 400 m respectively. The probabilities of detecting targets with second-generation AN/PVS-5 goggles at the same distances were .42, .35, .18, .03, .08, and .02. No information was provided on the visual acuity achieved with either goggle.

To increase the likelihood of detecting targets, firers must adjust their NVGs for best visual acuity. However, Banning and Caughley (1979) reported in their test of the AN/PAQ-4 that the training program for the AN/PVS-5 NVGs was inadequate. Insufficient time was spent on use of the NVGs, and performance standards were not included. Field observations and interviews with soldiers conducted as a part of the NIGHTFIGHTER program as a whole also showed that soldiers are generally not well trained in the various steps necessary to optimize AN/PVS-7 goggles for interpupillary distance, diopter adjustment, and objective lens focus. Unless precise procedures are followed, goggles will not be adjusted properly.

Training deficiencies with the NVGs are due in part to the limited information in the technical manuals. The AN/PVS-7A manual simply says to "turn the eyepiece focus rings on each eyepiece lens for the sharpest view" (DA, 1987, p. 19). No statements are made regarding the requirement to adjust each eyepiece independently, what type of object to focus upon and the desired distance of that object, how to adjust the diopter rings from a constant setting, and how to adjust to avoid eye strain. The AN/PVS-7B manual (DA, 1988) provides more, but still inadequate, information. It does specify to adjust each eyepiece independently. Guidance on how to adjust the diopter ring is limited to "adjust until a bright clear image appears" (p. 3-15).

The Air Force (Antonio & Berkley, 1993; DeVilbiss & Antonio, 1994; DeVilbiss, Antonio, & Fiedler, 1994) has developed specific procedures to maximize the acuity of the goggles and reduce the likelihood of eye strain. This involves adjusting NVG acuity in an indoor test lane, which is sealed from outside light sources. Acuity measurements are taken with individuals standing 6.1 m (20 ft) from an illuminated NVG resolution chart (Figure 5). "This chart is composed of nine square-wave grating patterns with a 95% contrast. Each grating pattern is equivalent to a Snellen acuity level between 20/35 and 20/100. Each orientation of the chart presents a unique ordering of the grating patterns" (DeVilbiss,

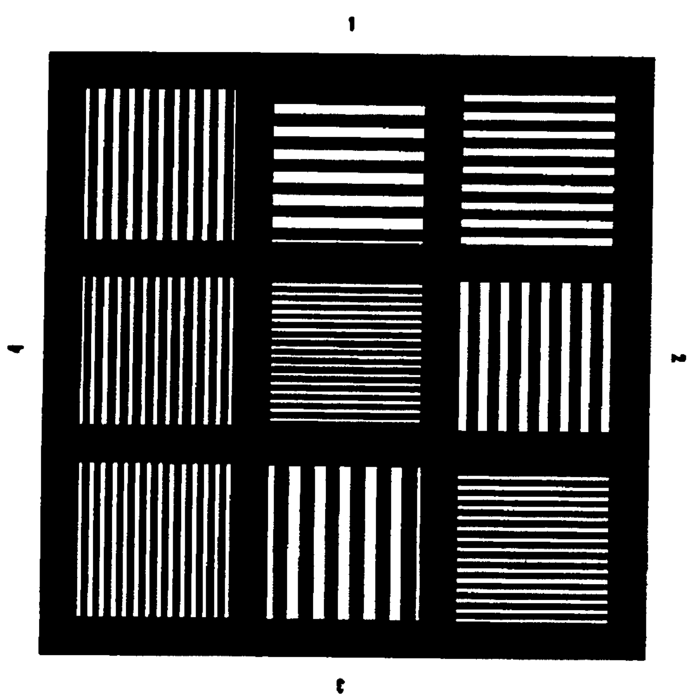


Figure 5. NVG resolution chart.

Antonio, & Fiedler, 1994, p. 706). The chart is lit with a lamp equipped with a standard 7 W bulb and so designed to allow only enough luminance to be emitted to represent quarter moon illumination.

Specific procedures for adjusting the diopter rings and objective focus are required while looking at the chart (Antonio & Berkley, 1993). The NVG user adjusts the diopter rings for each eye independently. With one eye closed, the diopter ring for the open eye is turned fully counterclockwise, then back clockwise until the image just becomes sharp. Stopping at this point is critical, as it reduces eyestrain with extended wearing of the goggles. This procedure is repeated for the other eye. These procedures have been shown to improve the NVG acuity settings for US Air Force crew members (DeVilbiss, Antonio, & Fiedler, 1994) and to be equivalent to acuity measurements taken with a more detailed psychophysical procedure (DeVilbiss & Antonio, 1994).

Research Objectives

In summary, the zeroing problem with aiming lights has two major components. First is the difficulty in boresighting aiming lights to the rifle. It is difficult to get a shot group on the zero target. Initial aiming light adjustments can be made only if the firer knows where bullets have gone in the dark.

The second part of the problem is the difficulty in achieving a definitive center of mass aim point from which the final adjustments can be made. This occurs primarily from the effect light sources have on image intensification devices and the resolution achieved with NVGs. A point of light blooms when viewed through an image intensification device. This blooming effect is particularly large when the light source is close, very bright, or both. The aiming light is zeroed at close range, against a 25-m target. When the aiming light strikes this target, light is reflected in the firer's goggles and blooms, making it difficult to aim consistently at the desired point. In the initial live-fire experiment reported here, firers indicated that the bloom of the aiming light through the goggles typically masked all of the silhouette in the target's center and much of the horizontal and vertical zero lines. Because the best visual acuity a firer can obtain with third-generation NVGs is 20/40, when parts of the zero target can be seen, they are not as sharp and clear as during daylight. NVG visual acuity will be worse than 20/40 under poor illumination conditions and when the firers have been inadequately trained in adjustment procedures. Consequently, zero adjustments with aiming lights are crude at best.

Cumulatively, these problems demonstrate that the standard daytime zeroing procedures are not completely compatible with zeroing aiming lights at night. It was clear that a research program to solve these problems should consider the aiming light, its interface with the rifle, night vision goggles, and the zero target as a total system. In addition, low-cost solutions were desired.

The two goals of the research were:

- To develop a 25-m live-fire aiming light zeroing procedure that would provide a definitive aim point and relatively tight shot groups.

- To develop a dry-fire aiming light zeroing procedure that would result both in a high probability of a firer's first shot group being on the 25-m zero target, and in a zero that could be used without night live-fire confirmation in emergency deployment situations.

Live-Fire Zeroing Procedures

For live-fire zeroing procedures, the critical research issues were to identify techniques to help the firer determine center of target mass and maintain a consistent aim point when zeroing. The zeroing procedures which emerged from this research produced tighter and more accurate shot groups and reduced errors in making adjustments.

Experiment A: Baseline Data Collection

Baseline data on aiming light zeroing procedures and probability of hit at range were obtained as one phase of a larger examination of night fighting equipment conducted by the U.S. Army Infantry School Dismounted Battlespace Battle Lab (1994). One issue examined in the Infantry School effort was whether a pulsating or a steady beam was best. Three aiming lights were compared: the AN/PAQ-4A and the AN/PAQ-4B, which have pulsating beams, and the IRAD 2500, which has a steady beam. The AN/PAQ-4A beam is the weakest of the three aiming lights; the IRAD beam, the strongest. The IRAD data are presented here because the IRAD was an integral part of the experimental design, and the zeroing and firing results were consistent across all aiming lights. The type of beam per se did not affect zeroing procedures, and the type of aiming light was not an issue in the research reported here. At the time of the research, both the AN/PAQ-4B and IRAD were prototype devices; only the AN/PAQ-4A was fielded.

Method

Design. A total of 30 Infantry soldiers from an Infantry battalion at Fort Campbell, KY participated. Each soldier zeroed and fired each aiming light. In order to accommodate all soldiers on the range, six firing orders of 15 soldiers each were conducted, with each soldier firing in three of these orders. In each firing order, five soldiers fired the AN/PAQ-4A, five fired the AN/PAQ-4B, and five fired the IRAD. Soldiers were randomly assigned to firing order.

All soldiers wore third-generation AN/PVS-7B NVGs and fired with the M16A2 rifle. The aiming light exercises occurred on a cloudless night with almost a full moon. Aiming light zeroing began at approximately 2030; firing stopped at 0300. The temperature was about 50 °F.

Zeroing Procedures. Prior to night firing, all soldiers zeroed their M16A2 rifles for 300 m during the day. The zero distance for the aiming lights varied. The AN/PAQ-4A was zeroed for 100 m, while the AN/PAQ-4B and IRAD were zeroed for 250 m.

To zero the aiming lights, 25-m zero targets were modified slightly to provide an improved aim point for all firers. Black, 0.75 in. (1.9 cm), electrical tape was used to extend the vertical and horizontal center of mass lines 6 in. (15.2 cm) beyond the edges of the target. Witness paper was also placed around the zero target to capture all bullets. Firers were allowed a maximum of six attempts (18 rounds) to zero.

For the AN/PAQ-4A and AN/PAQ-4B, firers made an initial dry-fire adjustment of the aiming light 3 m (10 ft) from the 25-m zero target. These points had been established in previous pilot work by the ARI. These adjustments were intended to enable the firers' first shot group to hit the 25-m zero target during live-fire zeroing. The AN/PAQ-4A dry-fire zero point was at the intersection of line 2 down and line 12 left on the M16A2 25-m zeroing target. The AN/PAQ-4B dry-fire zero point was at the intersection of line 3 down and line 6 left on the M16A2 25-m zeroing target. The IRAD initial adjustment was based on manufacturer's guidelines. Soldiers rotated the two knobs on the IRAD to their full counterclockwise position. Then each knob was rotated clockwise five revolutions to adjust elevation and windage to a mechanically centered position.

Live-fire zero confirmation at 25 m was then conducted. For each aiming light, shot groups were adjusted to the appropriate location on the 25-m zero target. For the AN/PAQ-4A, this point was at the intersection of the 9 right line and the 3 down line. For the AN/PAQ-4B, this spot was halfway between the upper 1 and 2 lines and on the 6 line to the right of the target. For the IRAD, the spot was at the intersection of the 0 vertical line and the 3 down line. All zero confirmation points were determined by the aiming light manufacturer.

ARI researchers assisted most of the soldiers in adjusting their AN/PVS-7B night vision goggles before zeroing. The Air Force's high contrast charts (Antonio & Berkeley, 1993) were used in the field with the ambient light available. No formal assessment of visual acuity was made for each soldier.

After zeroing, the size (in cm) of each shot group on each zero target was measured. Shot group size was obtained from each firer's daytime zero target as well.

Firing Procedures. Three live-fire scenarios were used: field fire (18 targets with 20 rounds), qualification (39 targets with 40 rounds), and quick fire (40 targets with 40 rounds). Firing was conducted on an automated range; a target fell immediately after it was hit. In the quick fire scenario, firers engaged one to four targets. The approximate running time for each scenario was 269 sec for field fire, 401 sec for qualification, and 295 sec for quick fire. The maximum score for all scenarios combined was 97. The closest target was 50 m; the most distant was 300 m. A breakout of the target ranges by scenario is given in Table B.1. For each firing order, firers were randomly assigned to firing lanes. Each soldier fired each scenario.

Results

Zeroing. Not all firers zeroed their aiming light within the allotted 18 rounds. Twelve firers (40%) zeroed with all three aiming lights. Only one failed to zero with any aiming light. Eleven (37%) zeroed with two of the three aiming lights (that is, AN/PAQ-4A and AN/PAQ-4B, AN/PAQ-4B and IRAD, or AN/PAQ-4A and IRAD). The remaining six (20%) zeroed with only one light. Table 2 shows the percentage of firers who zeroed with each aiming light by firing order.

Table 2
Percentage of Firers who Zeroed With Each Aiming Light - Experiment A

Order of Fire	AN/PAQ-4A	AN/PAQ-4B	IRAD	Order Total %
1st	40%	60%	70%	57%
2nd	50%	80%	90%	73%
3rd	80%	100%	70%	83%
System Total %	57%	79%	77%	71%

Note. The *n* was 30 for each aiming light, except for the AN/PAQ-4B where it was 29 as one firer withdrew because of illness.

These figures should be interpreted with caution because of several zeroing problems. There were no aids for the assistant instructors to use in determining precisely when a zero had been achieved. The appropriate bullet impact point for each aiming light was not marked on the 25-m zero target. As all impact points were offset from the center of the silhouette, the 4-cm circle centered over this silhouette could not be used directly to assess shot group size. No alternative assessment procedure was provided, allowing the subjectivity of each assistant instructor to influence the zeroing process. Finally, there were occasions when the aiming light knobs were accidently adjusted in the wrong direction, resulting in more rounds required to zero than would have been the case otherwise.

The size of the final shot group for each soldier and each aiming light was measured. The size of all shot groups fired by each soldier was also examined. Table 3 shows the mean shot group size for these two measures as well as the shot group sizes for the daytime zero with the M16A2 rifle sights. In general, the shot groups obtained with the aiming lights were 1.5 times greater than shot groups obtained with the rifle sights. No aiming light produced shot groups as tight as those achieved during the day.

For the final shot group, the mean group size for the rifle sights was significantly smaller than for each of the aiming lights, $F(3, 87) = 7.48$, $p < .001$. There were no statistically significant differences among the aiming lights. The average group size for the aiming lights was 5.2 cm vs 3.5 cm for the rifle sights. For all shot groups, the mean group size for the rifle sights was significantly smaller than for each aiming light, $F(3, 474) = 19.95$, $p < .0001$. The AN/PAQ-4A shot groups were significantly larger than the other two aiming lights, but there were no significant differences between the AN/PAQ-4B and IRAD shot groups.

Table 3
Mean Shot Group Size - Experiment A

System	Mean Shot Group Size (cm)					
	Final Group			All Groups		
	M	*SD*	*n*[a]	*M*	*SD*	*n*[b]
Rifle Sights	3.5	0.8	30	3.8	1.5	122
AN/PAQ-4A	5.8	2.0	30	6.2	3.1	125
AN/PAQ-4B	4.8	1.1	29	5.0	1.9	117
IRAD	5.2	1.9	30	5.7	3.0	114

[a] *n* refers to the number of firers. [b] *n* refers to the total number of shot groups across firers.

The shot group data clearly showed that firers had difficulty achieving shot group sizes with the aiming lights which matched the rifle sight 4-cm standard. Table 4 presents the percentage of shot groups within 4, 5, and 6 cm for each aiming light and the rifle sights. While at least 75% of all rifle sight shot groups were 4 cm or less, 75 to 83% of the aiming light shot groups were 6 cm or less.

Table 4
Cumulative Distribution of Shot Groups - Experiment A

System	% Groups 4 cm or Less	% Groups 5 cm or Less	% Groups 6 cm or Less
Final Shot Group			
Rifle Sights	90%	97%	100%
AN/PAQ-4A	33%	53%	67%
AN/PAQ-4B	41%	79%	93%
IRAD	40%	60%	77%
All Shot Groups			
Rifle Sights	75%	87%	95%
AN/PAQ-4A	37%	51%	68%
AN/PAQ-4B	45%	68%	83%
IRAD	41%	57%	75%

Firing. No differences were found among the aiming lights on overall firing performance, $F(2, 58) = 1.60, p < .21$. The overall probability of hit is shown at the bottom of Table 5. For descriptive purposes, the probabilities of hit for each target distance are also shown. Firing performance clearly decreased as the distance to the target increased. From 100 to 150 m, the p_h decreased by 50%, from approximately .70 to .30. At 175 m and beyond the probabilities of hit were very low.

Table 5
Probability of Hit by Target Distance for Each Aiming Light - Experiment A

Distance (m)	AN/PAQ-4A	AN/PAQ-4B	IRAD
	M (*SD*)	*M* (*SD*)	*M* (*SD*)
50	.82 (.24)	.90 (.15)	.90 (.17)
75	.76 (.35)	.83 (.28)	.74 (.36)
100	.62 (.30)	.76 (.21)	.71 (.29)
150	.32 (.28)	.47 (.31)	.35 (.31)
175	.22 (.35)	.08 (.17)	.18 (.28)
200	.10 (.20)	.09 (.19)	.07 (.16)
250	.02 (.08)	.00 (.00)	.00 (.02)
300	.01 (.04)	.00 (.00)	.01 (.02)
Total	.34 (.14)	.40 (.11)	.37 (.14)

Note. Number of firers per data point was 30. The field fire, qualification, and quick fire scores with the AN/PAQ-4B were estimated for the one firer who withdrew, as the shooting performance was very consistent with the other aiming lights on each scenario, varying by only one and two points. The IRAD score was probably lowered by the attachment of a boresight aperture device on the IRAD during zeroing for the final 20 firers; it was removed during firing at range. The aperture device reduced the bloom and intense brightness of the IRAD beam during zeroing. However, it most likely resulted in the portion of the laser beam visible to the firers on the zero range not being aligned with the full laser beam visible on the firing range, which probably caused a misalignment of the IRAD zero.

Discussion

The shot group results indicated it was unrealistic to expect aiming light shot groups to be as tight as those obtained with the rifle sights during daylight hours. The shot group size for each aiming light was about 1.5 times larger than that with rifle sights. Larger shot groups may be unavoidable due to the inability to obtain 20/20 vision with NVGs, and the blooming that occurs in the NVGs from the aiming light at short ranges. Soldiers reported that the bloom obscured the 4-cm by 7-cm silhouette in the target center. They also reported that striping the target helped them aim. However, very large shot groups, from 12 to 20 cm, still occurred. Not all soldiers zeroed within the 18-round, 6-shot group allotment. Errors occurred in the direction in which the aiming light knobs were adjusted. There was no standardization of the shot group assessments. These findings indicated that further enhancements to the zeroing process were needed.

Experiment B: Pilot Live-Fire Zeroing Procedures

Experiment B examined different 25-m zero target configurations and different lighting conditions. Based on the findings from Experiment A and previous tests (Banning & Caughley, 1979), it appeared that striping the target even further would help ensure that the center mass of the target could be determined when aiming. Also, shining a flashlight on the target should diffuse the bloom of the aiming light in the NVGs. The effectiveness of these factors on shot group size was tested in Experiment B.

Method

Six soldiers, four infantry and two noninfantry, participated. Their ranks were sergeant first class (one), staff sergeant (three), specialist (one), and private first class (one).

Four 25-m zero target configurations were compared. Tape was used to stripe the E-silhouette, dividing it in half vertically and horizontally. The M16A2 zero target was then centered on the stripes, so the stripes extended the center mass lines of the target. The target's 0 horizontal line was extended by about 13 cm on each side; the target's 0 vertical line was extended by at least 33 cm on the top and bottom. The color of the tape varied with the side of the silhouette presented to the firer. When the tan side was presented, the silhouette was striped with black 0.75 in. (1.9 cm) plastic tape. When the olive drab side was presented, white surgical tape of the same width was applied. For each presentation, zeroing was conducted with and without a flashlight directed at or just below the target. The standard L-shaped Army flashlight, XM10, was placed at the firer's position and the clear lens filter was used.

Each soldier fired with both the AN/PAQ-4A and AN/PAQ-4B aiming light at each of the four target configurations. Five-round shot groups were fired instead of the standard three-round shot group to obtain a more reliable assessment of the effects of each target configuration. Firing was terminated after one shot group was on the 25-m target. Shot group size was assessed, and firers indicated which configuration worked best for them. All soldiers had zeroed their rifle for 300 m during the day.

All soldiers wore third-generation AN/PVS-7B goggles. Before firing, they were trained on NVG adjustment by the research staff. Training was given on setting the interpupillary distance, the objective lens focus, and the diopter rings (see Appendix F). Soldiers practiced these procedures in a classroom. Diopter adjustments were made using the Air Force NVG resolution charts. The pinhole cap remained on the goggles to avoid damaging the image intensification tube.

NVG acuity at night was assessed outside on the firing range with the Air Force's NVG resolution chart. Again, the procedures used by the Air Force (DeVilbiss, Antonio, & Fiedler, 1994) were followed, except it was not possible to control the level of illumination. Readings were taken 6.1 m (20 ft) from the chart. Soldiers read each row on the chart from left-to-right and top-to-bottom by stating the direction of each grating pattern ("horizontal," "vertical," or "can't determine"). They were required to read the chart in each of its four orientations. Thus each grating pattern was viewed twice in a horizontal position and twice in a vertical position. Acuity was defined as the best Snellen reading (i.e., the one with the smallest denominator, 20/50 vs. 20/70) that occurred for at least three of the four readings. The acuity for each firer was 20/45 or better, with an average of 20/41.

The data were collected during very cold weather, with the temperature being approximately 20 °F. Data collection started at 1900 and ended at 2330. Because of the cold weather, the NVGs frequently fogged up, and there was frost on the equipment. The ambient light conditions were a half moon and stars. All firing was done at Fort Jackson, SC.

Results

The mean shot group size for each target configuration is in Table 6. A repeated measures ANOVA with the aiming light, flashlight, and stripes-target background as factors showed only a main effect for flashlight, $F(1, 40) = 23.67$, $p < .0001$. Shining a light on the target reduced the shot group size by about 35% ($M = 3.9$ cm, $SD = 1.1$) compared to no light ($M = 6.1$ cm, $SD = 1.9$). There were no differences as a function of the stripes and target background color, but two-thirds of the soldiers preferred the tan side with black stripes. As shown in Table 6, for all but one of the flashlight conditions, 100% of the shot groups were 5 cm or less. Without a flashlight, some soldiers failed to achieve shot groups 6 cm or less.

Table 6
Shot Group Size as a Function of Zero Target Configuration - Experiment B

Aiming Light and Target Configuration	*M* (*SD*)	Cumulative Distribution of Shot Groups		
		% Groups 4 cm or Less	% Groups 5 cm or Less	% Groups 6 cm or Less
AN/PAQ-4A				
Black Tape; Light	3.6 (0.9)	67%	100%	100%
White Tape; Light	3.6 (1.6)	67%	100%	100%
Black Tape; No Light	5.9 (2.5)	33%	50%	50%
White Tape; No Light	6.8 (2.1)	17%	33%	67%
AN/PAQ-4B				
Black Tape; Light	3.9 (0.6)	33%	100%	100%
White Tape; Light	4.5 (1.0)	33%	83%	100%
Black Tape; No Light	6.6 (1.4)	0%	17%	67%
White Tape; No Light	6.0 (1.7)	17%	33%	67%

Note. Five-round shot groups were fired. Each soldier ($N = 6$) used each aiming light under each target configuration.

Based on these results, the preferred 25-m zero target configuration was to shine a flashlight on the tan side of an E-silhouette striped in black. This setup is illustrated in Figure 6. This target configuration was used in Experiments C, D, and F. In addition, soldiers had slightly different preferences for how much light was needed on their target. If the amount of ambient light is high, a flashlight may not be needed.

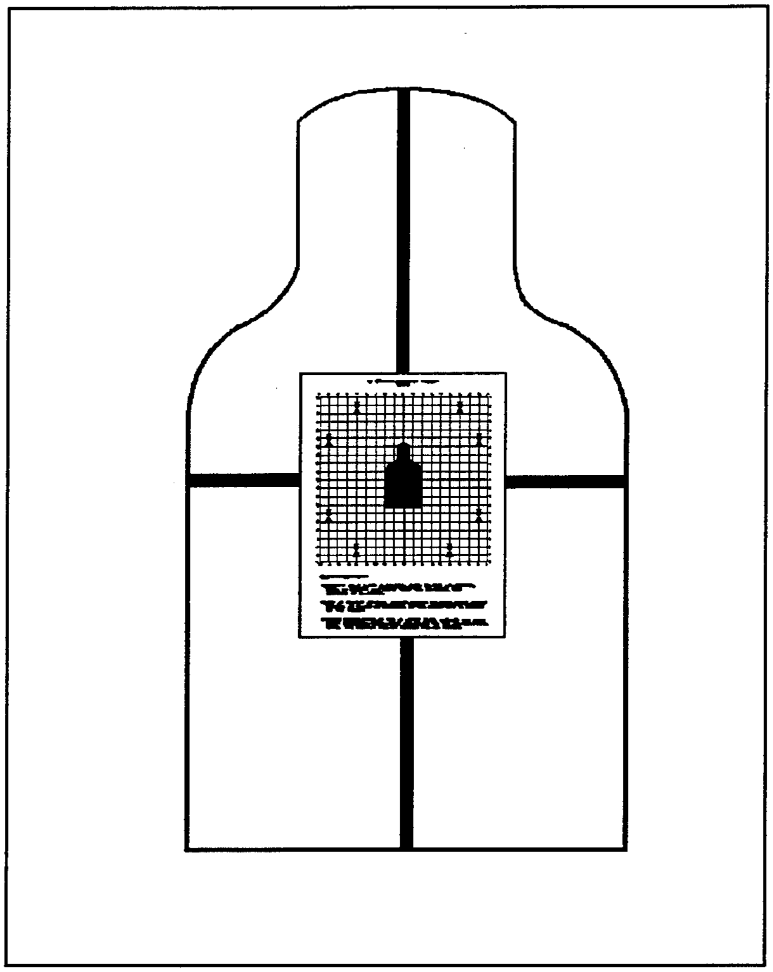


Figure 6. Revised target configuration for zeroing AN/PAQ-4 aiming lights at 25 m.

Experiment C: Revised Live-Fire Zeroing Procedures

Experiment C examined the effectiveness of live-fire zeroing procedures using the preferred target configuration identified in Experiment B. Other procedural changes and zeroing aids were instituted to reduce errors in the direction in which aiming lights were adjusted, to avoid making adjustments before the firer had achieved a consistent aim point, and to ensure standardization in the assessment of shot group size.

Method

Revised Zeroing Procedures. Six new steps were instituted in the zeroing procedures. First, the target was configured as described in Experiment B; that is, the tan side of the E-silhouette was striped the full length, vertically and horizontally, dividing it in half. The zero target was then centered on the silhouette (Figure 6). Firers directed a flashlight at the target from their position during firing.

Second, each 25-m zero target was marked for the appropriate bullet impact point. The purpose of marking the point was to ensure that firers and instructors adjusted the bullets to the correct location. The impact point differs for the AN/PAQ-4A and the AN/PAQ-4B as they have different offsets from the rifle boreline and are zeroed for different distances. The impact point for the AN/PAQ-4B was changed by the manufacturer (DA, 1993) from that used in Experiment A (see page 12). The current impact point specified in the 1993 technical manual is the 'box' bracketed by lines 3 and 6 right and lines 0 and 1 up. The bullet impact points and the targets used in the experiment for each firer are illustrated in Figures 7 and 8.

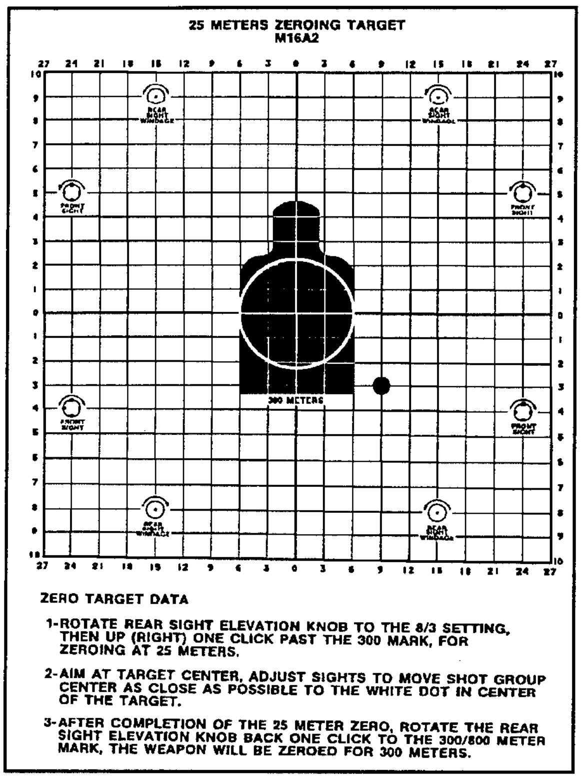


Figure 7. M16A2 rifle live-fire zero target for the AN/PAQ-4A. Bullet impact point is at the intersection of line 9 right and line 3 down; 3.1 cm right and 2.8 cm below target center.

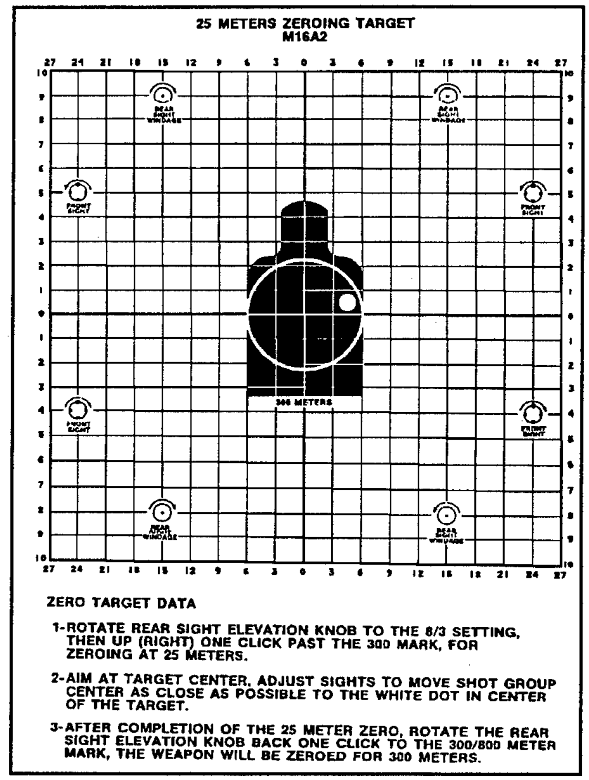


Figure 8. M16A2 rifle live-fire zero target for the AN/PAQ-4B. Bullet impact point is the box bracketed by lines 3 and 6 right and 0 and 1 up; 1.55 cm right and 0.45 cm above target center.

Third, rulers for determining the number of aiming light click adjustments for windage and elevation were constructed. Biases associated with using the lines on the 25-m zero target were discussed previously. The data collection efforts in Experiment A reinforced these problems. Instructors did, in fact, rely on the lines on the zero target for determining the number of click adjustments, even though these estimates were likely to be in error and often difficult to determine when bullets hit on the witness paper rather than the zero target. Rulers for each aiming light, 12 in. (30 cm) long and laminated to withstand the damp night air, were constructed to expedite the zeroing process and result in more accurate adjustments (Figure D.4). They were placed at each 25-m zero-target location.

Fourth, an aiming light knob adjustment guide was made to show the firer which direction to turn the aiming light knobs to adjust bullets on the impact point. Experiment A had shown that the markings on the aiming light knobs were often misinterpreted. Bullets went off the zero target or the E-silhouette, or in the wrong direction because the aiming light knob was turned the wrong direction. The zeroing aid corrected this problem. As illustrated in Figure D.5, the guide shows the movement of the bullet with the M16A2 rifle when aiming light knobs are turned counterclockwise. Bullets go in the opposite direction when the knobs are turned clockwise.

Fifth, because of the large shot groups with the aiming lights, a 5.5-cm criterion was established for night firing. This criterion was based on the baseline data results in Experiment A. A transparency showing the 5.5-cm circle was placed over the bullet impact point for each aiming light to assist firers and instructors to make consistent shot group size judgments.

Sixth, two, three-round shot groups were fired before making any aiming light adjustments. This provided a better indication of the firer's aim point than a single three-round shot group and reduced the likelihood of making premature adjustments.

Design. The firers were 12 noncommissioned officers; four held the rank of sergeant first class, eight held the rank of staff sergeant. All but one were infantrymen. Time in the Army ranged from 97 to 199 months for a mean of 150 months. Two-thirds had previous experience with NVGs; only one had experience with aiming lights. All firers were instructors at Fort Jackson, SC.

Two nights were required to collect the data. Six soldiers fired the first night; the other six fired the second night. All soldiers zeroed their rifles for 300 m during daylight. At night, each soldier fired with the AN/PAQ-4A and the AN/PAQ-4B. Half fired the AN/PAQ-4A first; half the AN/PAQ-4B first. Zeroing and firing at range for each soldier were conducted from 1900 to 2315. Firers zeroed the aiming light first with three-round shot groups. They then fired two series of five rounds each at 75, 175, and 300 m. The 75-m target was an F-silhouette, representing a firer in the prone position; the 175- and 300-m targets were E-silhouettes.

The distance shooting was conducted on a location of misses and hits (LOMAH) live-fire range. The LOMAH is a target system (Figure 9) that detects the supersonic shock wave of the bullet as it passes the plane of the target, determines whether it misses or hits, and then portrays the exact shot location on a video screen located beside the firer. A computer output indicates whether each shot is a hit or miss, and the horizontal and vertical deviations, in mm, from the center mass of the silhouette for each shot. However, when a bullet does not arrive at a target, e.g., hits the ground to the target's front, the LOMAH does not assess misses nor deviation from center mass information. The LOMAH targets at Fort Jackson do not fall when hit. Performance was assessed by shot group size and probability of hit at range.

Assistant instructors at each firing lane helped firers locate targets in their lanes. This was required because of the clutter from the numerous lane markers on the range, making targets at 175 m and beyond difficult to discriminate from the markers. In addition, the ability to detect targets or to discriminate targets from non-targets was not a purpose of the experiment.

Each soldier wore third-generation AN/PVS-7B NVGs. They were trained with the NVG adjustment procedures described in Experiment B. The NVG visual acuity assessment procedures were also the same as those in Experiment B. Acuity readings ranged from 20/45 to 20/60 with a mean of 20/55. On both nights, there was no moon, only stars. The temperature was approximately 28 to 30 °F, which resulted in the NVGs fogging up for many of the soldiers.

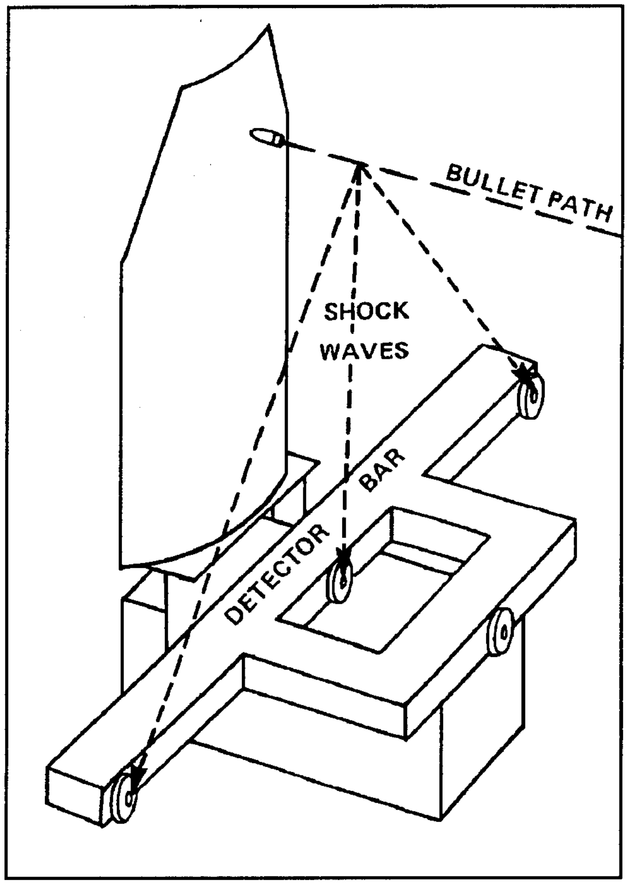


Figure 9. The LOMAH detection system. Not shown is the firing point video equipment that displays results to the firer.

Results

The mean shot group size with the aiming light procedures, as well as the shot group size obtained when the same firers zeroed their rifles during the day, is shown in Table 7. Significant differences were found among the systems on final shot group, $F(2, 22) = 6.27$, $p < .007$. Post hoc tests showed that the daytime and AN/PAQ-4A shot groups were smaller than those with the AN/PAQ-4B. When all shot groups were considered, significant differences also occurred, $F(2, 152 = 15.58$, $p < .0001$. In this case, post hoc comparisons showed that each system differed from each other system, with all daytime shot groups the smallest, the AN/PAQ-4A groups larger, and the AN/PAQ-4B groups the largest.

The difficulty in zeroing at night is illustrated in Table 8 as well. The percentage of soldiers with shot groups within the 4-cm criterion for the aiming lights did not match the levels achieved during daylight, despite the improved zero target configuration. The smaller shot groups achieved with the AN/PAQ-4A may have resulted from the less intense beam, which produces less bloom in the firer's NVGs.

Table 7
Mean Shot Group Size - Experiment C

System	Mean Shot Group Size (cm)					
	Final Group			All Groups		
	M	*SD*	*n*[a]	*M*	*SD*	*n*[b]
Rifle Sights	2.5	0.9	12	2.8	0.9	54
AN/PAQ-4A	2.9	1.0	12	3.6	1.4	48
AN/PAQ-4B	4.1	1.5	12	4.7	2.5	53

[a]*n* refers to the number of firers. [b]*n* refers to the total number of shot groups across all firers.

Table 8
Cumulative Distribution of Shot Groups - Experiment C

Aiming Light	% Groups 4 cm or Less	% Groups 5 cm or Less	% Groups 6 cm or Less
Final Shot Group			
Rifle Sights	100%	100%	100%
AN/PAQ-4A	83%	100%	100%
AN/PAQ-4B	58%	75%	83%
All Shot Groups			
Rifle Sights	93%	96%	100%
AN/PAQ-4A	73%	88%	90%
AN/PAQ-4B	45%	74%	81%

Due to missing data that occurred for some of the soldiers during the distance firing, the sample size for each aiming light was reduced from 12 to 11 firers. For the AN/PAQ-4A, the p_h was .60, .53 and .15 at 75, 175, and 300 m respectively. For the AN/PAQ-4B, the p_h was .61, .37, and .21 at the same distances. These results are discussed in more detail in Experiment F, where they are compared to results from the dry-fire zeroing procedure.

There were several reasons for missing data. In a few instances, there was a failure to permanently record the LOMAH results. The other missing data occurred when misses were recorded but there was no measurement of deviation from center of mass. For example, when a firer shot at the wrong target, the instructor noted the round as a miss, but the LOMAH system for that firer could not record deviation information. Similarly, whenever instructors could tell that a round did not reach the target, they noted the round as a miss, but the LOMAH system can not record deviation information when rounds fall short of the target.

Experiment D: Night Vision Goggle Acuity

An experiment was conducted to assess the impact of NVG visual acuity on shot group size and probability of hit at range. The Air Force's NVG visual acuity charts were used to measure the acuity obtained by each firer with goggles, under the ambient light conditions available, and to manipulate the NVG acuity setting.

Method

The firers were 12 infantrymen. Six held the rank of sergeant first class, five held the rank of staff sergeant, and one was a specialist. Time in the Army ranged from 89 to 235 months for a mean of 189 months. Half had previous experience with NVGs; none had experience with aiming lights.

Two nights were required to collect the data. Six soldiers fired the first night; the other six fired the second night. All soldiers zeroed their rifle at 300 m during the day prior to night firing. At night, each firer zeroed at 25 m and then shot at distant targets with both good and poor NVG visual acuity settings. Half the firers fired with a good acuity setting followed by a poor acuity setting; the other half fired with a poor setting followed by a good setting. Under each acuity setting, all firers shot two series of five rounds each at 75- and 175-m targets. The first series was conducted without assistance in locating the target. During the second series, assistant instructors ensured the firers located the target. The distance shooting was conducted on the LOMAH range at Fort Jackson, SC. Performance was assessed by shot group size and probability of hit.

Each soldier wore third-generation AN/PVS-7B NVGs. Prior to zeroing, soldiers were trained on NVG adjustment procedures using the procedures described in Experiment B. The goggles were deliberately set for good or poor acuity. Good acuity was defined as 20/50 and below, ranging from 20/35 to 20/50 with a mean of 20/43. Poor acuity was defined as 20/60 to 20/70 with a mean of 20/66. There was no overlap in the acuity readings for the two groups.

The difference between the good and poor NVG acuity settings was not as great as desired. Given the ambient light available, it was not possible to get readings at 20/40 or even at 20/45 for all firers. On both nights, there was no moon and clouds sometimes covered the stars. On the second night, there was ambient light from the local airport and stars. Acuity readings for the second night improved slightly, from a mean of 20/45 to a mean of 20/42. On both nights, when soldiers fired in the good condition, every effort was made to achieve the best acuity possible with their NVGs.

On the other hand, the poor acuity settings could have been made worse (e.g., 20/80 or 20/90). It was believed, however, that requiring a poorer setting would have made the firing task too difficult. No Army baseline data were available to determine an appropriate setting. However, based on the Air Force data published after the aiming light research was completed (DeVilbiss, Antonio, & Fiedler, 1994), acuity settings of 20/70 and worse are likely to occur in about 20% of air crew members.

The temperature was approximately 32 to 34 °F. The NVGs did not fog up, but condensation was a problem at times. The experiment started at 1850 and ended at 2230.

Results

Shot group size results are shown in Tables 9 and 10. Results achieved during daylight zeroing are shown for comparison purposes. There was a significant difference on the final shot group, $F(2, 22) = 6.19, p < .0073$. Post hoc comparisons showed that the daytime shot groups were smaller than those achieved with the poor NVG acuity setting; no differences occurred between the two acuity settings for the final shot group. When all shot groups were considered, there was also a significant difference, $F(2, 174) = 29.60, p < .0001$. In this case, post hoc comparisons showed that each condition differed from each other condition, with all daytime shot groups the smallest, larger groups occurred with the good visual acuity setting, and the largest groups occurred with the poor visual acuity setting.

Table 9
Mean Shot Group Size - Experiment D

	Mean Shot Group Size (cm)					
	Final Shot Group			All Shot Groups		
Condition	*M*	*SD*	*n*[a]	*M*	*SD*	*n*[b]
Rifle Sights	2.5	0.9	12	2.6	0.9	60
Good NVG Acuity	3.6	1.9	12	4.1	1.7	58
Poor NVG Acuity	4.9	2.6	12	5.0	2.3	59

[a]*n* refers to the number of firers. [b]*n* refers to the total number of shot groups across firers.

As expected, there was a significant decrease in the probability of hit as distance to the target increased from 75 m to 175 m (see Table B.7). However, analysis of the hit data also showed a significant interaction, $F(1, 10) = 7.59, p < .0203$, between target distance and whether the firer had assistance. At 175 m, when help was provided, the probability of hit (p_h) was higher than with no help, while at 75 m, assistance did not make a difference in performance. Of interest was a three-way interaction among target distance, assistance, and NVG acuity, which was significant at $\alpha = .10$, $F(1, 10) = 4.06, p < .075$. At 75 m, the p_h was higher with good acuity than with poor acuity settings, while at 175 m, the critical factor was assistance provided to the firer. At 175 m, regardless of the acuity setting, those who had help shot better than those who did not have help (Table 11). A graph of these results is in Appendix B (Figure B.1).

Table 10
Cumulative Distribution of Shot Groups - Experiment D

Condition	% Groups 4 cm or Less	% Groups 5 cm or Less	% Groups 6 cm or Less
Final Shot Group			
Rifle Sights	92%	100%	100%
Good NVG Acuity	75%	83%	92%
Poor NVG Acuity	50%	50%	67%
All Shot Groups			
Rifle Sights	92%	98%	100%
Good NVG Acuity	55%	74%	90%
Poor NVG Acuity	41%	54%	70%

Table 11
Probability of Hit With Good and Poor NVG Acuity Settings - Experiment D

Type of Assistance	Combined Acuity Conditions		Good Acuity		Poor Acuity	
	75 m *M* (*SD*)	175 m *M* (*SD*)	75 m *M* (*SD*)	175 m *M* (*SD*)	75 m *M* (*SD*)	175 m *M* (*SD*)
Without Help	.61 (.37)	.29 (.38)	.76 (.28)	.27 (.37)	.47 (.39)	.32 (.40)
With Help	.59 (.39)	.54 (.31)	.63 (.45)	.59 (.31)	.56 (.33)	.49 (.32)

An assessment was also made of the deviations of the rounds from center mass of the target. Complete data on whether rounds tended to go high and to the right, high-left, low-right, or low-left are presented in Tables B.8 and B.9. Graphic illustrations of the locations of hits and misses are shown in Figures B.2 through B.5. In three instances, some misses were quite distinct from the others, being much further to the right or much higher. These outliers were due to a single firer, although the specific individual was different in each case. When these outliers were not considered, the general tendency was for a greater dispersion of misses at 175 m than at 75 m. Again, some missing data occurred in this experiment for the same reasons as cited in Experiment C.

Dry-Fire Zeroing Procedures

The other major problem in zeroing aiming lights is getting bullets on the target so the appropriate adjustments can be made. As indicated in the tests of the prototype version of the AN/PAQ-4A (Banning & Caughley, 1979; Patterson & Jones, 1978) and later tests as well (U.S. Army Infantry School Dismounted Warfighting Battle Lab, 1993), this is a critical issue.

Although equipment solutions, such as an improved borelight or engineering fix to ensure that the aiming light has a good mechanical zero, are an option, the intent of the dry-fire experiments was to develop a solution which did not require an engineering change or additional equipment. The goals were a dry-fire procedure which would achieve a satisfactory hit probability without live-fire zeroing for use in emergency deployment situations, as well as one which would enable firers to hit the 25-m zero target the first time.

The dry-fire zeroing procedure is, in a sense, a reversal of the live-fire 25-m zeroing procedure. During live-fire zeroing, the firer points the beam of the aiming light at center mass of the target, fires, and checks whether the bullets hit the impact point. If not, the aiming light is adjusted according so the bullets will "move" in the appropriate direction. On the other hand, during dry-fire zeroing the firer aims constantly at the center mass of a target with the rifle sights as during daylight, while a buddy wearing NVGs adjusts the aiming light to hit a pre-determined laser or beam point on the target. The firer must be close to the target in order to aim through rifle sights in low-light conditions.

The critical research problems were determining the laser point for the each aiming light, and designing a simple target for use at night and in dim lighting, both indoors and outdoors. The target had to be placed at a distance where the beam from both aiming lights was relatively small, but not so close that click adjustments would be insensitive to bullet deviations at range. In addition, the dry-fire zero procedures had to account for the unique parallax of each aiming light to the rifle bore and the trajectory of the bullet for the desired battlesight zero distance.

Experiment E: Preliminary Tests of Dry-Fire Zeroing Procedures

Several preliminary tests were required to identify the appropriate dry-fire, laser zero point for each aiming light.

Preliminary Test #1

In the initial effort, two expert shooters from the U.S. Army Marksmanship Unit (AMU) zeroed the M16A2 rifle during the day for 300 m. At night, they zeroed the aiming lights at range, 100 m for the AN/PAQ-4A and 250 m for the AN/PAQ-4B. Once the aiming light was zeroed at range, they then aimed center mass with iron sights at the standard zero target placed a short distance away. The spot where the beam from the aiming light hit the target was marked.

From this initial effort, a 3-m (10-ft) dry-fire zero point was established for both aiming lights. This procedure was used prior to the live-fire zeroing in Experiment A. But the findings from Experiment A showed a need to re-examine this distance, and therefore, the precise location of the aiming light points for the dry-fire zero procedure. The 3-m distance was too close. Considerable variability in shot group location at 25 m resulted during the live-fire zeroing process. A greater distance from the target during the dry-fire zeroing process was determined as necessary in order to be more sensitive to the horizontal and vertical adjustments associated with each click on the aiming lights.

Preliminary Test #2

Work with the two AMU shooters resumed. This time a dry-fire zeroing distance of 8 m (26 ft 4 in), equivalent to eight M16A2 rifle lengths, was used. Again, laser points were determined for the dry-fire zero target. However, it was clear that it was necessary to conduct these tests on a range that provided immediate and precise feedback on target location to be confident in the procedure. A larger number of firers was also needed to verify the dry-fire laser zero point.

Six soldiers at Fort Jackson, SC participated in this research, the same soldiers as in Experiment B. The LOMAH range at Fort Jackson had permanent targets at 75, 175, and 300 m only. For purposes of this preliminary test, portable LOMAH stations were installed to increase the number of target distances from three to seven. One lane had targets at 50, 100, and 250 m. A second lane had targets at 100 and 200 m. The third lane had targets at 75, 175, and 300 m. Each soldier fired both the AN/PAQ-4A and the AN/PAQ-4B aiming lights. Two nights were required to collect the data on the dry-fire zero point. All firers wore third-generation AN/PVS-7B goggles. The NVGs were adjusted for visual acuity each night. Ten of the 12 readings were 20/45 or less, with two readings being 20/60. The weather was slightly below 32 °F, which created some problems as the NVGs tended to fog up. The sky was partially overcast. Firing was conducted from 1900 to 2330.

Soldiers zeroed their aiming lights at range. For the AN/PAQ-4A this was 100 m; for the AN/PAQ-4B this was 250 m. As with the AMU shooters, the firers then aimed center mass with the rifle sights at the standard zero target placed 8 m away. The spot where the aiming light's laser hit the target was marked.

Based on data from all firers, including the AMU shooters, the adequacy of two dry-fire laser zero points was examined for each aiming light. Two points were identified for each aiming light, as the laser-point data from the firers were not identical. The next step was to fire at range using both dry-fire zero points with each aiming light. Each of the six soldiers adjusted each aiming light to each dry-fire zero point and fired at range. Targets at 50, 100, and 250 m were used. On the basis of the probability of hit results and the horizontal and vertical deviations from center mass provided by the LOMAH system, a single dry-fire laser zero point was selected for each aiming light. This point was then used in Experiment F which compared dry-fire and live-fire zeroing procedures.

Another part of this preliminary test was to check the adequacy of the manufacturer's mechanical adjustment for getting initial bullets on paper. For the AN/PAQ-4A, this was five turns counter clockwise for both knobs after rotating each to its full clockwise position. For the AN/PAQ-4B, this position was three turns counter clockwise after rotating each knob to the full clockwise position. Each soldier fired with each aiming light at the 25-m zero target. The percentage of soldiers hitting the zero target the first time was 67% for the AN/PAQ-4A and 33% for the AN/PAQ-4B. In addition, some limited firing was conducted from 50 to 300 m with the aiming lights using the manufacturer's mechanical adjustment. Half the soldiers failed to hit any targets at range. These findings showed great inconsistency in the manufacturer's mechanical adjustment for both types of aiming lights.

Experiment F: Revised Dry-Fire Zeroing Procedures

Experiment F compared the effectiveness of the dry-fire zeroing procedures to live-fire zeroing at 25 m in terms of the likelihood of hitting the zero target with the first shot group, probability of hit at range, and deviation of rounds from center mass of the target. The dry-fire laser point used for each aiming light was that determined to be the best from the preliminary tests.

Method

The dry-fire zero procedure, as used in Experiments C and D, was a means of adjusting the aiming light initially for zeroing purposes, as opposed to using the manufacturer's procedure which had proved unsatisfactory in the preliminary tests. The data on the 24 firers from these two experiments were also used to determine the likelihood of getting the initial shot group on the 25-m zero target. These results are presented here because they are directly relevant to the adequacy of the dry-fire zero procedure.

However, the primary purpose of Experiment F was to compare the probability of hitting targets at distance using 25-m live-fire and 8-m dry-fire zeroing procedures. The twelve soldiers participating in this experiment were the same as those in Experiment C. The live-fire zeroing described in that experiment was, in fact, counterbalanced with dry-fire zeroing.

Soldiers zeroed each aiming light with both dry-fire and live-fire procedures. The order of zeroing was counterbalanced. The p_h after each zeroing procedure was examined with two series of five shots at 75, 175, and 300 m on a LOMAH range. It is important to stress that after the dry-fire zero, soldiers immediately fired at the distance targets; no live-fire adjustments were made at 25 m. The live-fire procedures were as reported in Experiment C.

The dry-fire zero targets used for each aiming light are shown in Figure 10. Aiming light adjustments were made using the buddy system described previously. These adjustments were made during both twilight and night conditions, as the experiment started at 1900 and ended at 2315.

Results

The percentage of soldiers hitting the 25-m zero target with the first shot group after placing a dry-fire zero on their M16A2 rifle is given in Table 12.

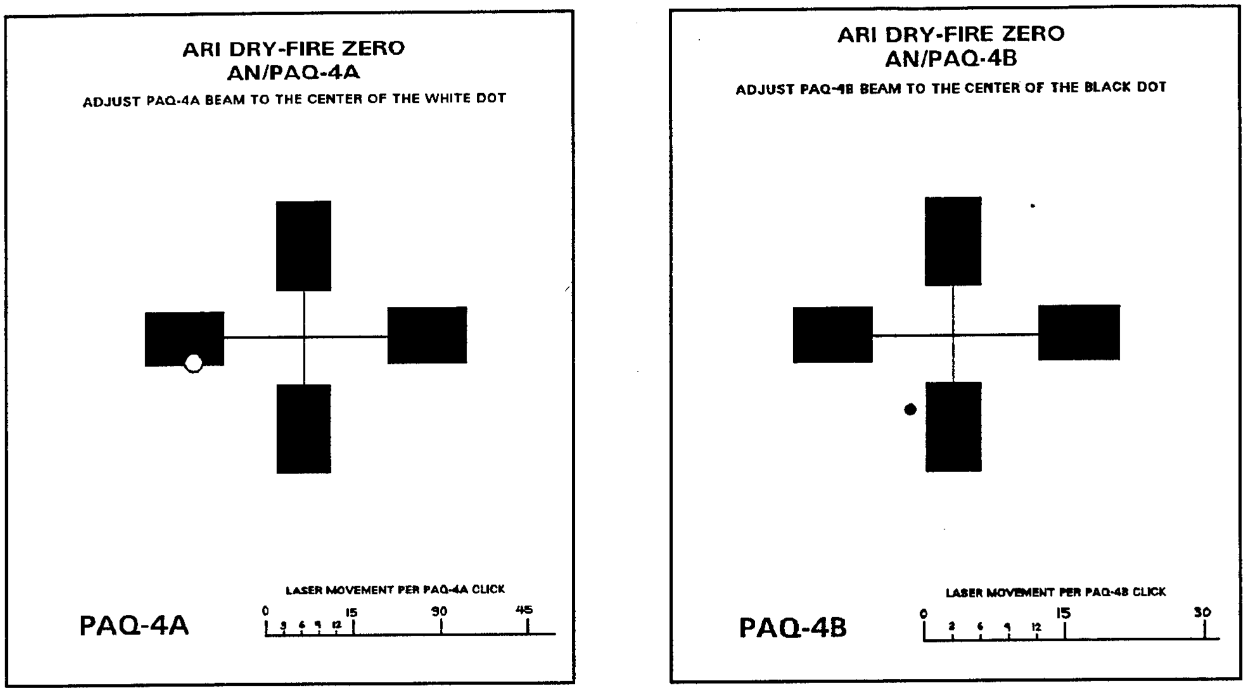


Figure 10. Dry-fire zero targets for AN/PAQ-4A and AN/PAQ-4B. Neither target is drawn to scale in this figure. The size and distance of the black rectangles from center mass are critical to accurately placing the iron sights of the rifle on the dry-fire zero target. For the AN/PAQ-4A target, the white dot indicating where the laser should hit is 9 mm below and 41 mm left of center mass of the target. For the AN/PAQ-4B, the black dot indicating where the laser point should hit is 27mm below and 17 mm left of center mass of the target.

Table 12.
Percentage Soldiers Hitting 25-m Zero Target Immediately After Dry-fire Zeroing - Experiments C and D

Experiment	Aiming Light	
	AN/PAQ-4A % (*n*)	AN/PAQ-4B % (*n*)
C -- Live-fire phase only	75% (12)	58% (12)
D -- Good and poor acuity	-----	100% (12)
Total	75% (12)	79% (24)

The p_h with the AN/PAQ-4A, using live-fire zeroing, averaged .43 over 75, 175, and 300 m (Table 13). With the 8-m dry-fire procedure, the p_h over the same distances was .37, a nonsignificant difference. For the AN/PAQ-4B, the p_h with live-fire zeroing was .40, whereas the dry-fire zeroing procedure yielded a lower p_h of .19, a significant difference, $F(1, 120)$ =

14.19, $p < .0003$. For both aiming lights, the probability of hit decreased as target distance increased (See Table B.10).

Table 13
Probability of Hit With Live-Fire and Dry-Fire Zeroing Procedures - Experiment F

25-m Live-Fire Zero			8-m Dry-Fire Zero		
75 m *M* (*SD*)	175 m *M* (*SD*)	300 m *M* (*SD*)	75 m *M* (*SD*)	175 m *M* (*SD*)	300 m *M* (*SD*)
AN/PAQ-4A					
.60 (.31)	.53 (.31)	.15 (.19)	.55 (.36)	.41 (.38)	.13 (.24)
AN/PAQ-4B					
.61 (.30)	.37 (.33)	.21 (.27)	.30 (.38)	.19 (.34)	.09 (.19)

Note. *N* is 11 firers for each target distance and aiming light combination.

The direction of the hits and misses from center mass was examined by determining whether the shots were high and to the right, high and to the left, low and to the left, or low and to the right. The percentage of hits falling in each direction was calculated for each aiming light as a function of zeroing procedure and target distance. The same calculations were done for misses. Complete results are presented in Tables B.11 and B.12. The locations of the hits and misses are illustrated in Figures B.6 through B.11.

For the AN/PAQ-4A, the graphs of the windage and elevation deviations indicate similar patterns of round dispersion for each zeroing procedure (Figures B.6, B.7, and B.8). The probability of hit results were also similar. In contrast, there was a bias in the dry-fire zeroing point for the AN/PAQ-4B, which resulted in bullets going high and to the right at each target distance, but clearly so at 175 and 300 m (Figures B.10 and B.11). Further research is needed to determine the appropriate dry-fire zero point for the AN/PAQ-4B. However, the utility of the dry fire procedure for getting initial shot groups on paper was demonstrated. The AN/PAQ-4A results show that once the appropriate point is determined, the dry-fire procedure can be used in emergency situations or as a field expedient technique.

Summary and Conclusions

An overview of all experiments described in this report is in Table 14. The date of the test, its location, the number of firers, and the primary purpose are presented.

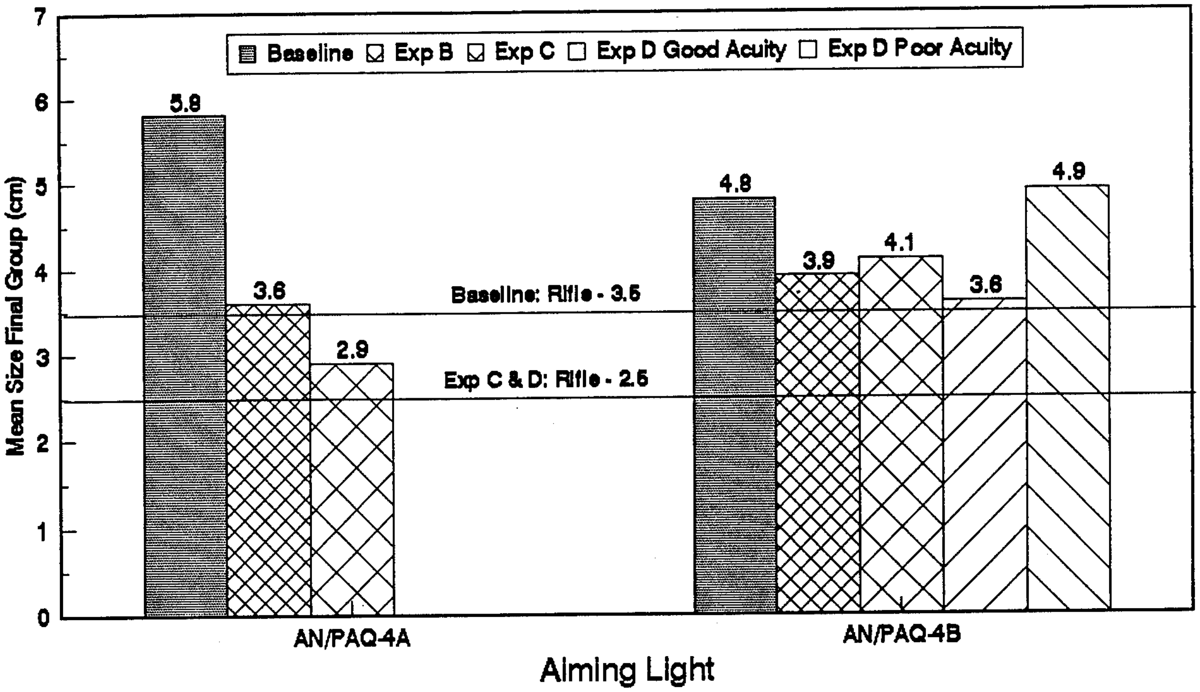
The results from the experiments showed that the enhancements and modifications to the live-fire zeroing procedures reduced shot group size, enabled all firers to zero with no more than six shot groups, and improved the probability of hit. The dry-fire procedure also proved to be a better technique of getting the firer's initial shots on the 25-m zero target than the manufacturer's mechanical adjustment.

Table 14
Summary of Aiming Light Experiments

Experiment	Date and Location	*N*	Purpose
A: Baseline	September 1993 Ft Campbell	30	Obtain probability of hit for aiming lights. Compare shot group size for daylight zero to aiming light zero at night.
B: Pilot Live-Fire Zero	January 1994 Ft Jackson	6	Compare effectiveness of different 25-m live-fire zero target configurations.
C: Revised Live-Fire Zero	February 1994 Ft Jackson	12	Examine effectiveness of revised 25-m live-fire zero target on shot group size.
D: NVG Acuity Comparisons	February 1994 Ft Jackson	12	Compare good and poor NVG acuity settings on shot group size and probability of hit.
E: Preliminary Dry-Fire #1	August 1993 Ft Benning	2	Determine 3-m dry-fire zero point. Used in Experiment A.
E: Preliminary Dry-Fire #2	November 1993 Ft Benning January 1994 Ft Jackson	2 6	Determine 8-m dry-fire zero point. Verify 8-m dry-fire zero point. Determine adequacy of manufacturer's mechanical aiming light adjustment for initial shot group. Probability of hit after zeroing at range with aiming lights was also obtained. Same soldiers as Experiment B.
F: Revised Dry-Fire and Live-Fire Zeroing Procedures	February 1994 Ft. Jackson	12	Compare effectiveness of 25-m live-fire zero to 8-m dry-fire zero procedure. Determine adequacy of dry-fire zero adjustment for initial shot group.

Shot Group Size

The results for shot group size are summarized in Figure 11. For the final shot group, the revised zero procedures consistently yielded smaller shot group sizes. The only exception was when soldiers fired with a poor visual acuity adjustment on their goggles. The same pattern existed when all shot groups were compared. Of interest is the trend for the shot group size for the AN/PAQ-4B to be larger than that for the AN/PAQ-4A, although the reverse occurred during the baseline experiment. As mentioned previously, the more intense beam from the AN/PAQ-4B, which results in a stronger blooming effect in the goggles, may be the primary factor accounting for this difference. The data also show that, despite improved zeroing procedures, shot group size with the aiming lights was typically 1.3 to 1.6 times larger than the daylight zeros. Thus it



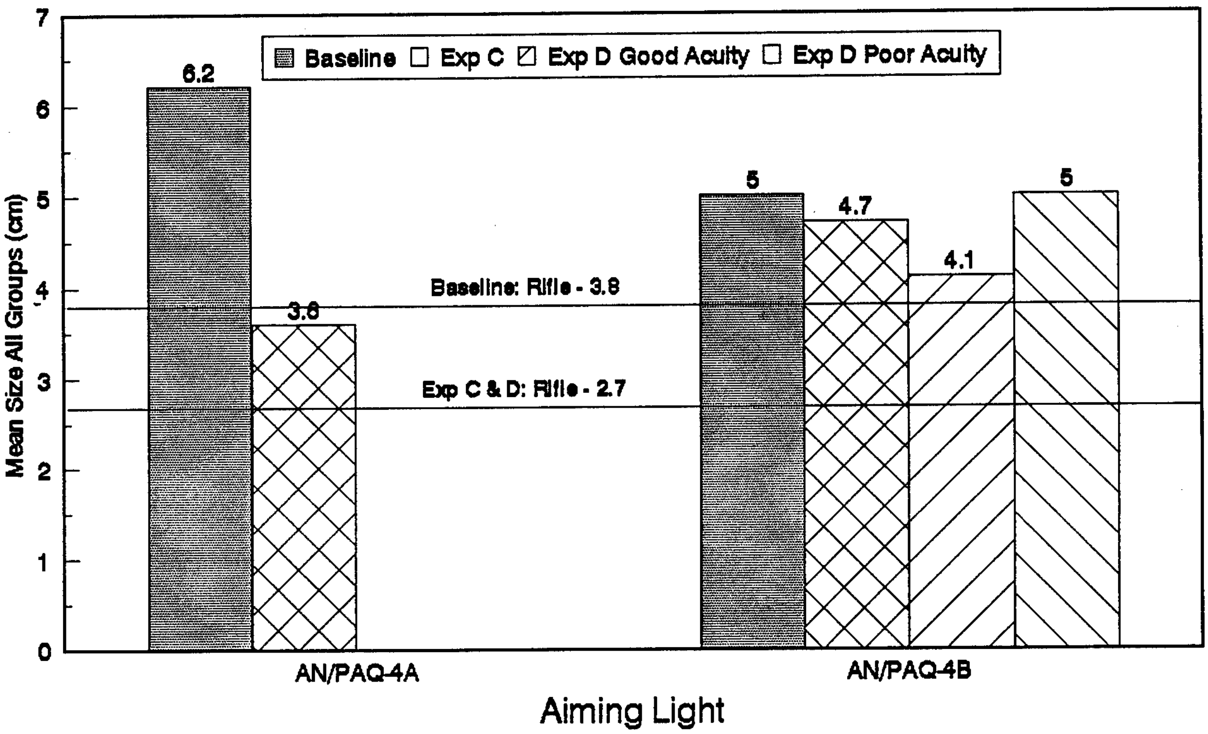


Figure 11. Size of shot groups in all experiments. In Experiment B, only one shot group was assessed; this is treated as the final group in the upper graph for both aiming lights. No goggle acuity conditions are shown for the AN/PAQ-4A as the goggle experiment was conducted with the AN/PAQ-4B only.

appears there is no guarantee that revised zeroing procedures can match the sizes achieved during the day. Although it may be possible to reduce the bloom through NVGs by an engineering change to the aiming lights, larger shot groups may still be inevitable because of the inability to achieve 20/20 visual acuity with NVGs.

Figure 11 also shows that the shot groups for daylight zeroing were larger in the baseline experiment than in the later experiments. There could be several reasons for this. Marksmanship skill and experience could be one. The firers in the later experiments were generally more senior than those in the baseline. Another factor could have been who made the decision when a soldier had zeroed. In the baseline experiment it was unit personnel; in the other experiments it was research personnel. However, any differences in the criteria employed would most likely affect the size of the final shot group, not all the shot groups.

Probability of Hit

The probabilities of hit for each aiming light are illustrated in Figure 12. This figure includes the baseline data, both the live-fire and dry-fire zero data from Experiment F, and performance achieved with the aiming lights when zeroed at range. The latter data were collected from the six soldiers participating in Experiment B. The AN/PAQ-4A was zeroed at 100 m; the AN/PAQ-4B at 250 m. Complete details on this side test are in Appendix C.

The results reflect the wide variety in firing performance that can be achieved. Clearly, the best performances were achieved after zeroing the aiming lights at range. It was under these circumstances that the advantages of the AN/PAQ-4B beyond 200 m was most apparent. These results also indicate that the revised live-fire zero procedures, used in conjunction with some quality control over firers' NVG acuity settings, produced higher hit performance at the targets beyond 150 m compared to the baseline condition.

In examining Figure 12, the conditions under which the performance data were obtained should be considered. The data were not collected under identical conditions. That is, the same firers, the same range, the same weather, etc. did not exist across the different experiments, except for the dry- and live-fire comparisons. The major differences in the firing conditions across the experiments are presented in Table 15.

The best conditions for firing occurred during Experiment A, the baseline. There was a full moon and the temperature was moderate. However, the "system" was not fine-tuned at that point. The zeroing procedures were still inadequate, and not all NVGs were adjusted properly. During the other experiments, the ambient light was less, thereby reducing the NVG acuity that could be obtained, and the cold temperature tended to fog the firers' NVGs. It is difficult to assess the relative difficulty of target detection on the two ranges. From one perspective, the automated range may have been more difficult as the targets were exposed for a limited time, although the soldiers were able to hear and/or see when targets came up. Yet on the LOMAH range, the range markers were frequently very difficult to discriminate from the actual targets, which, because of the design of the range, were always up and visible. Under most experimental conditions, assistant instructors helped firers locate targets. Experiment D, where assistant

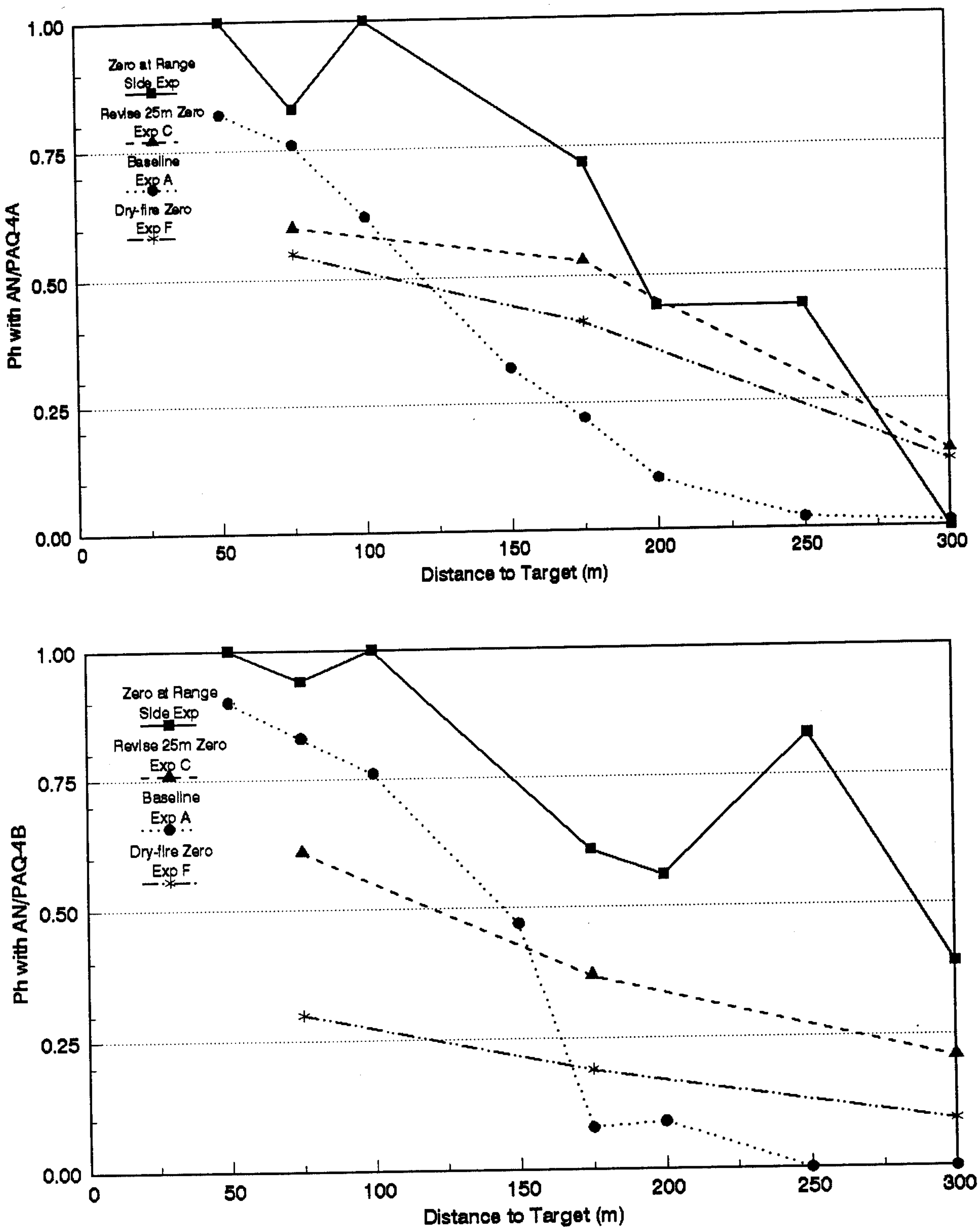


Figure 12. Probability of hit in all experiments.

Table 15
Summary of Firing Conditions

Firing Conditions	Experiment			
	A	B	C and F	D
Ambient Light	Full moon; clear	Half moon; stars	Stars	Variable with clouds and stars
Temperature	50 °F	20 °F	28 to 30 °F	32 to 34 °F
NVG Acuity	Not assessed	20/40; Some NVGs fogged up	20/55; Some NVGs fogged up	Systematically varied Good - 20/43 Poor - 20/66
Type of Range	Automated; Targets fell when hit	LOMAH; Targets did not fall when hit	LOMAH; Targets did not fall when hit	LOMAH; Targets did not fall when hit
Time	2030-0300	1900-2330	1900-2315	1850 - 2230

instructor guidance was systematically varied, clearly showed that this guidance had a positive effect at the longest range. If more ambient light had been available, perhaps this factor would not have had as great an impact on the performance at range. In summary, none of the data in any experiment was obtained under optimal conditions. However, all the findings reinforce one of the basic assumptions underlying the research --- that night firing with aiming lights and NVGs needs to be treated as a system. Any of several key factors can have a major impact upon performance.

Initial Shot Group

With the dry-fire zeroing procedure, firers were more likely to have their initial shot groups on the 25-m zero target than they were using the mechanical adjustment recommended by the manufacturer. For the AN/PAQ-4A, the percentage of firers hitting the zero target the first time increased from 67% to 75%; for the AN/PAQ-4B, the percentage increased from 33% to 79%. Even though the mechanical zero should align the beam accurately within the aiming light device, misalignment of the mounting bracket or rifle parts can mean misalignment of the entire system.

Additional support for the effectiveness of the dry-fire zeroing procedure was shown in Experiments D and F. In no case was there a problem in getting firers zeroed, as had been the case in the baseline experiment. In Experiments D and F, before firers were required to live-fire zero at 25 m, they had gone through the dry-fire zero process. Therefore, most firers were hitting the 25-m zero target with their first shot group. Time and resources were not wasted in getting rounds on paper. Once on paper, the zeroing process itself was more efficient because of the improved 25-m target configuration.

NVG Acuity

Observations made during the experiments showed that many soldiers did not know how to adjust their goggles appropriately. In addition, once they were shown the correct procedures, many required additional practice to acquire this skill. The strongest evidence of this came during Experiment B where the same soldiers fired three consecutive nights. On the first night, some gave inconsistent acuity readings with the charts; there were fewer problems the second night; on the final night, all provided consistent readings. The average acuity on the three nights was 20/47, 20/43, and 20/41, respectively. Only on the last night did each soldier achieve consistent readings of 20/45 or better.

As indicated earlier, the intent in Experiment D was to achieve at least a 20/45 acuity adjustment for every firer under the good NVG acuity condition in order to have a clear distinction between the good and poor settings. There are at least two reasons why this was not possible. First, the ambient light conditions were not optimum for achieving this level of acuity in a field setting. Second, there may have been insufficient time for some soldiers to become skilled in adjusting their goggles properly.

The NVG data reinforce the importance of target detection in shooting performance at night. The good acuity setting helped in locating the targets at 75 m, but did not aid at the longer range of 175 m in this particular experiment. When assistance in locating targets was provided, firing performance was better at both distances with good NVG acuity. This finding was not necessarily expected, but reinforces the assumption that better acuity probably provides a better aim point once a target is detected. In comparison to the baseline data obtained for the AN/PAQ-4B in Experiment A, the probability of hit at 175 m was at least 3 times higher. The lower level of performance in Experiment A may reflect both the inability to have every firer zeroed and to adjust every firer's NVGs properly.

Finally, additional support for the importance of good NVG acuity for hitting distant targets was found in comparing AN/PAQ-4A results in Experiment C to those in Experiment D. Assistance in locating targets was provided to firers in both experiments. In Experiment C, the average acuity setting was 20/55; in Experiment D the average good acuity setting was 20/43. Although the probability of hit was the same at 75 m (p_h = .62), it was 1.3 times higher at 175 m with the better acuity setting achieved in Experiment D (.59 versus .45).

Advantages of Aiming Lights and NVGs

When comparing marksmanship performance in the aiming light experiments reported here to previous marksmanship research with unaided night vision, it is almost like "night and day." In the earliest research using only the ambient light at night, there was simply no attempt to shoot beyond 75 yd (68 m) (Jones & Odom, 1954). The hit probability was low; no greater than .24 under a full moon and no hits were achieved under no moon conditions. In contrast, the closest targets used in the aiming light experiments were 50 and 75 m, where the probability of hit was consistently above .60. Even when efforts were made to improve marksmanship performance with special sights, tracers, and artificial illumination (Bryant et al., 1983; Hunt et al., 1987), performance was not high. The highest performance without NVGs was achieved by Bryant et al. However, Figure 13 shows the sharp decline in marksmanship performance beyond 50 m which occurred in this test.

Use of NVGs without aiming lights enables firers to see targets, but does not aid in hitting them. A small pilot study was conducted of assault firing at 25 and 100 m. Using only NVGs, the firer never hit a 0.8- by 1-m paper target backing at either 25 or 100 m. By contrast, when firing offhand with NVGs and with either the AN/PAQ-4A or the AN/PAQ-4B, 100% of the rounds were on an E-silhouette at 25 m. At 100 m with the AN/PAQ-4B, 64% of the rounds were on the silhouette; all hit the paper backing. With the AN/PAQ-4A, 45% of the rounds were on the silhouette and 75% hit the paper backing.

The research reported here clearly shows that the night vision goggle and aiming light combination enables firers to achieve a high hit probability at close range and to maintain a relatively high hit probability at longer ranges. Marksmanship is best at long range when improved zero procedures are used and firers adjust their goggles for good visual acuity. Figure 13 shows the increase in marksmanship performance as technology and training have improved over a period of 40 years.

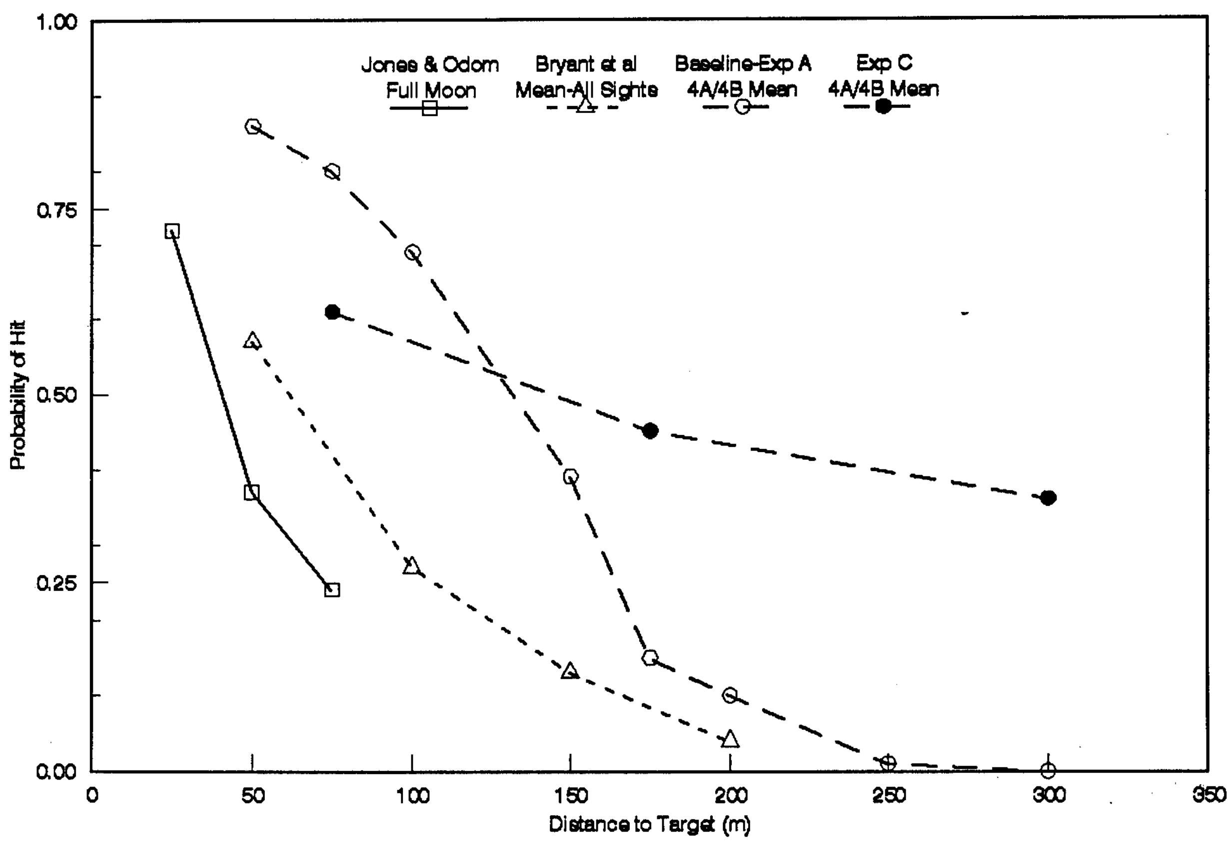


Figure 13. Probability of hit with unaided night vision, special sights, and NVGs/aiming lights.

Recommendations

The two research objectives were:

- To develop a 25-m live-fire aiming light zeroing procedure that would provide a definitive aim point and relatively tight shot groups.

- To develop a dry-fire aiming light zeroing procedure that would result both in a high probability of a firer's first shot group being on the 25-m zero target, and in a zero that could be used without night live-fire confirmation in emergency deployment situations.

The first objective was clearly met. Improvements can be made to live-fire zeroing procedures for aiming lights which result in better aim points, better zeros, and more targets hit at range. These changes will also save time and ammunition during the zeroing process. Fewer errors will be made in adjusting aiming lights. The recommended procedures to follow and the aids to use in conducting 25-m live-fire zeroing of aiming lights are described in Appendix D. These procedures are a cost-effective solution to the live-fire zeroing problem.

Dry-fire procedures can also be successful. The appropriate dry-fire zero point was found for the AN/PAQ-4A, but was not clearly identified for the AN/PAQ-4B when the need is to shoot without live-fire zero confirmation. However, if the intent is to increase the likelihood of getting first rounds on the 25-m live-fire zero target, then both aiming light dry-fire targets are valuable tools. The recommended procedures for the dry-fire zero process are in Appendix E. Further research is planned to determine the best dry-fire zero point for the AN/PAQ-4B aiming light.

The findings clearly show that a soldier's ability to hit targets at night is not solely the result of the technical characteristics of the aiming light. Other critical factors, which were demonstrated to affect performance and must be considered in training and in combat, are the adequacy of the aiming light zero, the visual acuity obtained with the goggles, target contrast, and weather conditions (amount of ambient light, temperature).

All the zeroing procedures developed and tested are inexpensive and can be implemented with readily available materials. On the other hand, many proposed solutions to the aiming light zero problem involve boresight devices, redesign of the aiming light, or both. The findings show that zeroing problems can be solved without special equipment.

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APPENDIX A

PROBABILITIES OF HIT AND DETECTION AT NIGHT
FROM PREVIOUS RESEARCH

Table A.1
Probability of Detecting Human Targets With the Unaided Eye (Taylor, 1960)

Distance (yd)	Condition	
	No Moon	Full Moon
10	.85	---
20	.65	.92
30	.48	.90
40	.32	.92
50	.18	.86
60	---	.74
70	---	.62
80	---	.60
90	---	.47
100	---	.41
110	---	.31
120	---	.22

Note. Probabilities were averaged across all observer and target positions.

Table A.2
Probability of Detecting Human Targets With NVGs (Soechting & Kennedy, 1987)

Distance (m)	Type of Goggle	
	AN/PVS-7 (3rd generation)	AN/PVS-5 (2nd generation)
50	.51	.42
100	.72	.35
150	.52	.18
200	.28	.03
300	.13	.08
400	.26	.02

Note. Light levels varied throughout the test.

Table A.3
Probability of Hitting Personnel Type Targets With the M1 Rifle (Jones & Odom, 1954)

Condition	Distance (yd)					
	25	35	45	55	65	75
No Moon	.46	.31	.14	.04	.01	.00
Moon	.72	.56	.44	.37	.27	.24

Table A.4
Probability of Hitting Personnel Type Targets With the M1 Rifle (Sivy & Taylor, 1956)

Condition	Distance (yd)		
	25	50	75
Starlight			---
Aiming	.53	.21	
Pointing	.65	.25	
Quarter Moon			---
Aiming	.60	.26	
Pointing	.57	.32	
Half Moon	---		
Aiming		.30	.15
Pointing		.36	.25
Full Moon	---		
Aiming		.47	.45
Pointing		.60	.34
Mean	.61	.35	.30

Note. Means estimated from graphed data. The pointing technique was defined as "the firer in the prone position places the butt of the rifle to his shoulder, holds his head high, keeps both eyes open, and points the rifle at the target. He then deliberately depresses the muzzle to compensate for a known tendency to fire high" (p. 2). No formal definition of the aiming technique was given, but the report implied that the firer used the standard daylight aiming procedures.

Table A.5
Probability of Hitting Personnel Type Targets With the M16A1 Rifle (Bryant et al., 1983)

Condition	Distance (m)			
	50	100	150	200
Automatic Fire[a]	.54	.23	.10	.04
Ranger Eye Sighting System	.55	.25	.13	.04
Promethium Sighting System	.62	.33	.17	.05
Mean	.57	.27	.13	.04

[a] Probability of hit per 3-round burst.

Table A.6
Probability of Hitting Personnel Type Targets With the M16A2 Rifle (Hunt et al., 1987)

Condition	Distance (m)		
	75	175	300
Experiment 1 - Muzzle flash simulator			
No tracers	.07	.01	---
1:2 ratio of ball to tracer ammunition	.20	.03	---
Experiment 2 - Artificial Illumination			
Over the sight aiming technique	.16	.02	---
Through the rear aperture sighting technique	.31	.29	---
Experiment 3 - Artificial Illumination & Muzzle Flash			
Over the sight aiming technique	.13	.02	---
Over the sight aiming and feedback after each shot	.19	.03	---
Mean	.18	.07	---

Table A.7
Probability of Hitting Personnel Type Targets With the M16A1 Rifle, AN/PAQ-4 Aiming Light, and the AN/PVS-5 NVGs (Banning & Caughley, 1979; Patterson & Jones, 1978)

Test	Distance (m)				
	25	50	75	100	150
Patterson & Jones[a]	.46	.52	---	.15	.02
Banning & Caughley	---	.60	.50	.48	---

[a] Fog and rain at night.

APPENDIX B

DATA TABLES AND FIGURES FOR EXPERIMENTS A THROUGH F

Table B.1
Number of Targets by Range and Scenario - Experiment A

Range (m)	Field Fire	Qualification	Quick Fire	Total
50	0	5	5	10
75	6	0	0	6
100	0	9	9	18
150	0	11	9	20
175	6	0	0	6
200	0	7	8	15
250	0	4	5	9
300	6	3	4	13
Total	18	39	40	97

Table B.2
Analysis of Variance on Shot Group Size for Aiming Lights and Rifle Sights - Experiment A

Source	*df*	*MS*	*F*	*p*
Final Shot Group				
Between subjects				
Firer	29	61.81		
Within subjects	90			
System (A)	3	22.23	7.48	.0010
A x S within-group error	87	2.97		
All Shot Groups				
System	3	124.59	19.95	.0001
S within-group error	474	6.24		

Table B.3
Analysis of Variance on Total Score for Aiming Lights - Experiment A

Source	*df*	*MS*	*F*	*p*
Between subjects				
Firer	29	1.33		
Within subjects				
Aimlight (A)	2	41.94	1.60	.2100
A x S within-group error	58	26.23		

Table B.4
Analysis of Variance on Shot Group Size for 25-m Zero Target Configurations - Experiment B

Source	*df*	*MS*	*F*	*p*
Within subjects				
Aiming Light (A)	1	261.33	1.02	.3190
Tape Color (B)	1	0.33	0.00	.9714
Flashlight (C)	1	6075.00	23.67	.0001
A x B	1	4.08	0.02	.9003
A x C	1	24.08	0.09	.7610
B x C	1	52.09	0.20	.6548
A x B x C	1	120.33	0.47	.4975
A x B x C x S within-group error	40	256.67		

Table B.5

Analysis of Variance on Shot Group Size for Aiming Lights and Rifle Sights - Experiment C

Source	*df*	*MS*	*F*	*p*
Final Shot Group				
Between subjects				
Firer	11	149.97		
Within subjects				
Aiming System (A)	2	803.44	6.27	.0070
A x S within-group error	22	128.20		
All Shot Groups				
Aiming System (A)	2	4791.28	15.58	.0001
A x S within-group error	152	307.46		

Table B.6

Analysis of Variance on Shot Group Size for Good and Poor NVG Acuity and Rifle Sights - Experiment D

Source	*df*	*MS*	*F*	*p*
Final Shot Group				
Between subjects				
Firer	11	1686.58		
Within subjects				
Acuity (A)	2	1686.58	6.19	.0073
A x S within-group error	22	272.28		
All Shot Groups				
Acuity (A)	2	8658.44	29.60	.0001
A x S within-group error	174	292.47		

Table B.7

Analysis of Variance on Probability of Hit With Good and Poor NVG Acuity - Experiment D

Source	*df*	*MS*	*F*	*p*
Between subjects				
NVG Acuity Order (A)	1	0.66	2.49	.1459
S within-group error	10	0.26		
Within subjects				
Acuity Level (B)	1	0.27	1.31	.2783
B x A	1	0.63	3.10	.1090
B x A x S within-group error	10	0.20		
Distance to Target (C)	1	0.85	11.80	.0064
C x A	1	0.04	0.61	.4544
C x A x S within-group error	10	0.07		
Assistance (D)	1	0.32	1.66	.2265
D x A	1	0.08	0.44	.5230
D x A x S within-group error	10	0.19		
B x C	1	0.15	2.24	.1652
B x C x A	1	0.01	0.17	.6916
B x C x A x S within-group error	10	0.07		
B x D	1	0.01	0.10	.7578
B x D x A	1	0.03	0.48	.5059
B x D x A x S within-group error	10	0.07		
C x D	1	0.43	7.59	.0203
C x D x A	1	0.24	4.29	.0652
C x D x A x S within-group error	10	0.06		
B x C x D	1	0.21	4.06	.0715
B x C x D x A	1	0.00	.01	.9121
B x C x D x A x S within-group error	10	0.05		

Table B.8

Deviation of Rounds From Center of Target Mass With Good and Poor NVG Acuity: Direction and Magnitude of Deviation for Hits and Misses - Experiment D (no assistance)

Direction of Rounds	75 m			175 m		
	%	Magnitude (mm)		%	Magnitude (mm)	
		X	Y		X	Y
Hits - Good Acuity						
High-right	48	6.8	7.0	25	9.3	19.9
High-left	12	-6.3	8.9	00	---	----
Low-left	09	-2.5	-4.2	15	-2.6	-10.5
Low-right	31	8.3	-4.9	60	9.9	-11.4
Hits - Poor Acuity						
High-right	49	8.6	6.9	09	16.1	8.2
High-left	11	-2.6	14.5	13	-1.5	13.6
Low-left	19	-8.5	-3.6	32	-13.8	-32.4
Low-right	21	12.0	-4.1	46	10.3	-9.2
Misses - Good Acuity						
High-right	95	31.9	27.1	44	56.3	27.4
High-left	05	-21.3	61.3	10	-23.4	48.3
Low-left	00	---	---	00	----	----
Low-right	00	---	---	46	60.1	-11.6
Misses - Poor Acuity						
High-right	86	33.3	25.8	75	88.9	81.4
High-left	14	-47.2	53.6	00	----	----
Low-left	00	----	----	00	----	----
Low-right	00	----	----	25	34.3	-14.9

Note. Values in table represent means per firer.

Table B.9

Deviation of Rounds From Center of Target Mass With Good and Poor NVG Acuity: Direction and Magnitude of Deviation for Hits and Misses - Experiment D (with assistance)

Direction of Rounds	75 m			175 m		
	%	Magnitude (mm)		%	Magnitude (mm)	
		X	Y		X	Y
Hits - Good Acuity						
High-right	50	6.8	6.8	31	7.6	13.3
High-left	29	-4.3	7.1	38	-8.4	13.0
Low-left	00	----	----	03	-17.0	-10.4
Low-right	20	13.3	-4.9	28	13.5	-6.5
Hits - Poor Acuity						
High-right	37	8.1	5.9	49	9.8	15.2
High-left	27	-3.8	10.2	29	-6.0	14.7
Low-left	06	-3.4	-4.1	11	-5.6	-13.8
Low-right	30	9.0	-4.1	11	17.2	-23.8
Misses - Good Acuity						
High-right	60	10.8	19.3	49	31.9	30.3
High-left	36	-18.3	45.4	22	-26.2	21.6
Low-left	00	----	----	14	-37.6	-18.1
Low-right	04	30.9	-1.4	15	40.8	4.1
Misses - Poor Acuity						
High-right	74	20.1	23.9	49	36.8	28.9
High-left	26	-6.1	18.6	29	-37.0	45.0
Low-left	00	----	----	00	----	----
Low-right	00	----	----	09	50.8	-14.9

Note. Values in table represent means per firer.

Table B.10
Analysis of Variance on Probability of Hit With Live-Fire and Dry-Fire Zeroing - Experiment F

Source	*df*	*MS*	*F*	*p*
AN/PAQ-4A				
Within subjects				
Zero Procedure (A)	1	0.14	1.43	.2345
Distance to Target (B)	2	2.33	24.31	.0001
Shot Sequence (C)	1	0.02	0.24	.6236
A x B	2	0.03	0.35	.7077
A x C	1	0.04	0.37	.5466
B x C	2	0.06	0.61	.5472
A x B x C	2	0.07	0.71	.4918
A x B x C x S within-group error	120	0.10		
AN/PAQ-4B				
Within subjects				
Zero Procedure (A)	1	1.38	14.19	.0003
Distance to Target (B)	2	1.01	10.40	.0001
Shot Sequence (C)	1	.02	.23	.6361
A x B	2	.10	1.03	.3617
A x C	1	.02	.23	.6361
B x C	2	.01	.08	.9273
A x B x C	2	.14	1.48	.2324
A x B x C x S within-group error	120	.10		

Table B.11

Deviation of Rounds From Center of Target Mass With the AN/PAQ-4A: Direction and Magnitude of Deviation for Hits and Misses - Experiment F

Direction of Rounds	75 m			175 m			300 m		
	%	Magnitude (mm)		%	Magnitude (mm)		%	Magnitude (mm)	
		X	Y		X	Y		X	Y
Hits - 25-m Live-Fire Zero									
High-right	29	6.2	4.3	29	7.5	15.9	10	0.7	2.0
High-left	32	-6.6	7.7	16	-7.9	12.4	35	-14.7	19.8
Low-left	12	-5.5	-3.6	26	-15.2	-16.9	32	-11.4	-21.0
Low-right	27	8.5	-3.3	29	11.9	-11.4	23	12.1	-22.8
Hits - 8-m Dry-Fire Zero									
High-right	36	5.7	9.1	21	6.6	17.2	23	9.9	2.4
High-left	23	-5.8	8.5	12	-7.1	17.1	13	-10.5	8.8
Low-left	07	-5.2	-3.5	21	-12.8	-11.0	17	-11.3	-18.0
Low-right	34	11.3	-4.6	46	12.4	-17.4	47	11.7	-14.3
Misses - 25-m Live-Fire Zero									
High-right	60	25.5	32.7	37	35.5	35.1	20	58.7	35.4
High-left	35	-31.1	19.9	13	-39.0	36.1	33	-43.6	32.5
Low-left	03	-44.9	-2.5	27	-39.7	-10.2	26	-53.2	-15.1
Low-right	00	---	---	23	39.4	-14.1	21	59.7	-16.1
Misses - 8-m Dry-Fire Zero									
High-right	58	27.0	41.2	47	44.6	31.8	37	57.0	41.3
High-left	39	-17.4	46.0	18	-21.1	50.3	24	-111.7	51.1
Low-left	00	---	---	15	-32.7	-11.1	13	-61.8	-24.9
Low-right	03	33.5	-1.6	19	28.8	-12.2	26	51.4	-18.9

Note. Values in table represent means per firer.

Table B.12

Deviation of Rounds From Center of Target Mass With the AN/PAQ-4B: Direction and Magnitude of Deviation for Hits and Misses - Experiment F

Direction of Rounds	75 m			175 m			300 m		
	%	Magnitude (mm)		%	Magnitude (mm)		%	Magnitude (mm)	
		X	Y		X	Y		X	Y
Hits - 25-m Live-Fire Zero									
High-right	39	5.9	7.8	19	7.7	12.2	36	9.1	19.4
High-left	34	-4.4	8.0	17	-8.4	18.9	33	-9.4	18.8
Low-left	11	-6.7	-2.7	22	-8.8	-9.3	14	-8.3	-13.5
Low-right	16	9.0	-4.4	41	11.3	-15.0	17	13.2	-15.2
Hits - 8-m Dry-Fire Zero									
High-right	24	2.4	7.5	26	9.2	11.7	40	4.3	26.3
High-left	57	-6.8	7.3	31	-14.8	9.6	00	---	---
Low-left	02	-3.5	-2.3	34	-11.0	-11.8	33	-16.5	-6.8
Low-right	17	19.2	-7.8	09	12.9	-14.0	27	6.8	-12.8
Misses - 25-m Live-Fire Zero									
High-right	48	28.0	32.7	32	31.4	36.6	44	47.3	42.8
High-left	46	-19.4	25.6	44	-32.3	26.0	42	-52.3	50.3
Low-left	03	-62.0	-6.9	13	-36.0	-10.5	08	-65.4	-19.7
Low-right	04	36.7	-5.6	11	36.2	-12.1	06	49.5	-7.8
Misses - 8-m Dry-Fire Zero									
High-right	53	40.4	65.8	39	78.2	80.0	42	135.0	133.2
High-left	45	-14.9	38.0	47	-36.9	41.8	44	-53.1	83.0
Low-left	00	---	---	06	-40.6	-24.5	10	-40.3	-3.6
Low-right	03	50.2	-5.6	09	38.2	-7.6	03	66.6	-11.7

Note. Values in table represent means per firer.

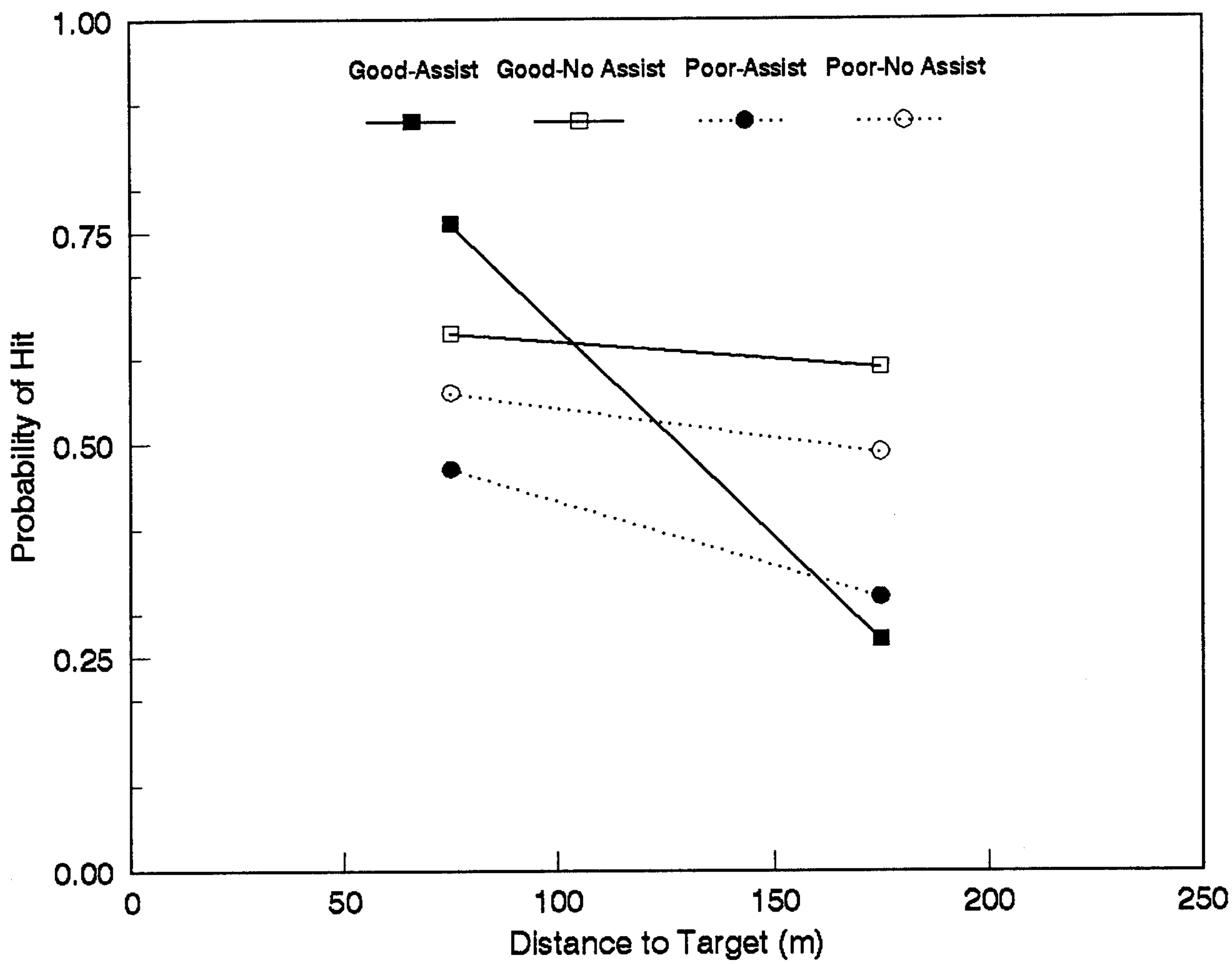
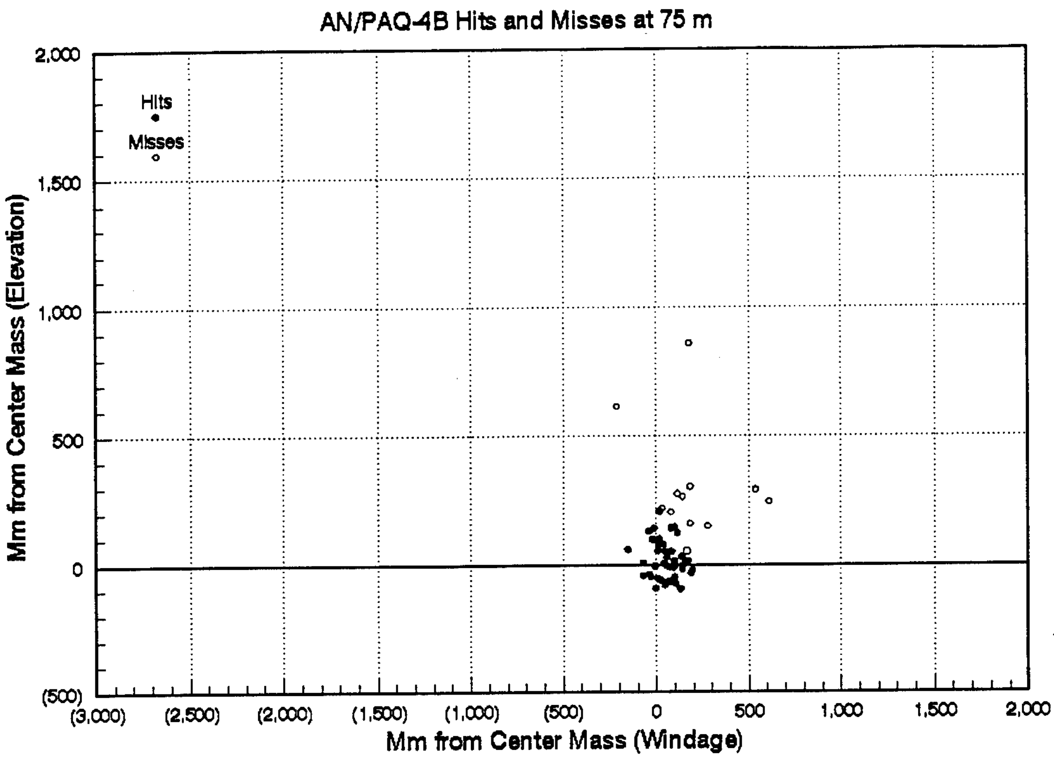


Figure B.1. Probability of hit with good and poor NVG visual acuity - Experiment D.



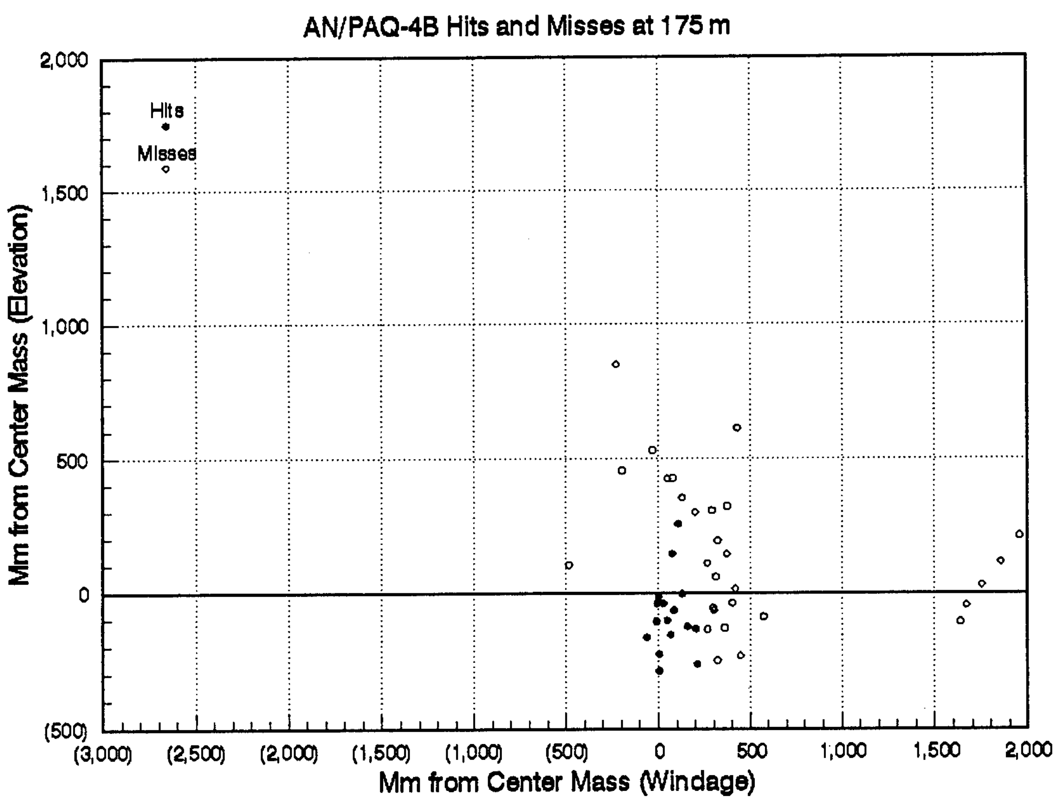
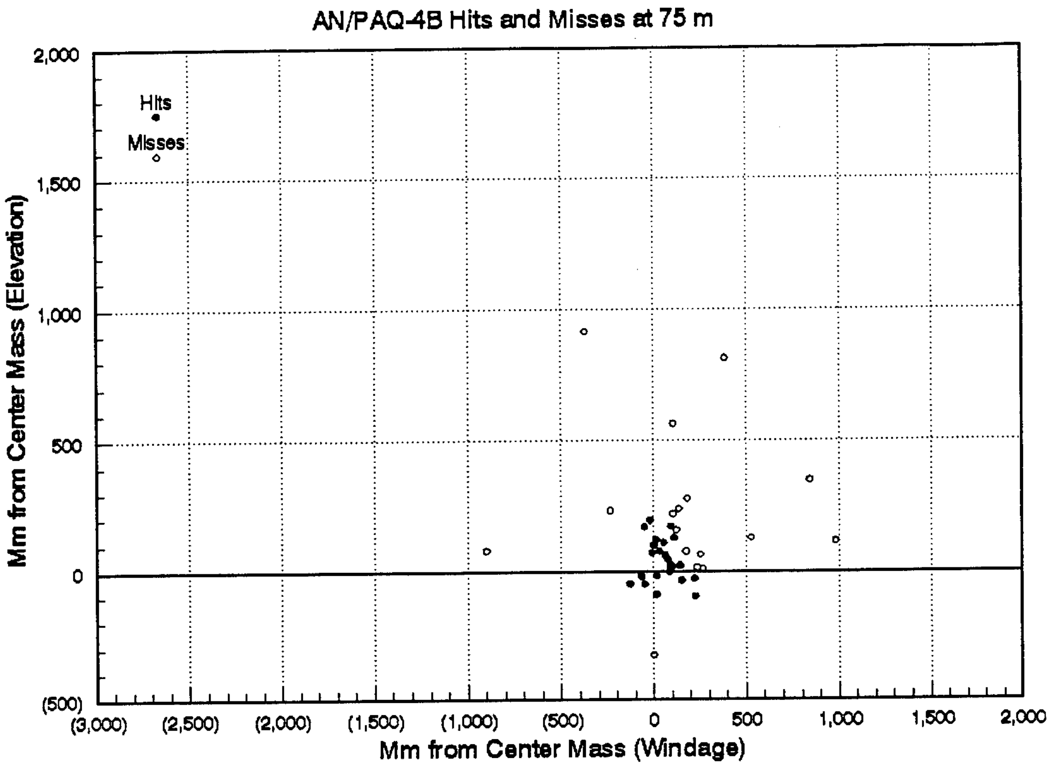


Figure B.2. Hits and misses with good NVG acuity and no assistance - Experiment D. At the 175-m target, a single firer had the five misses at 1500 to 2000 mm to the right of center mass.



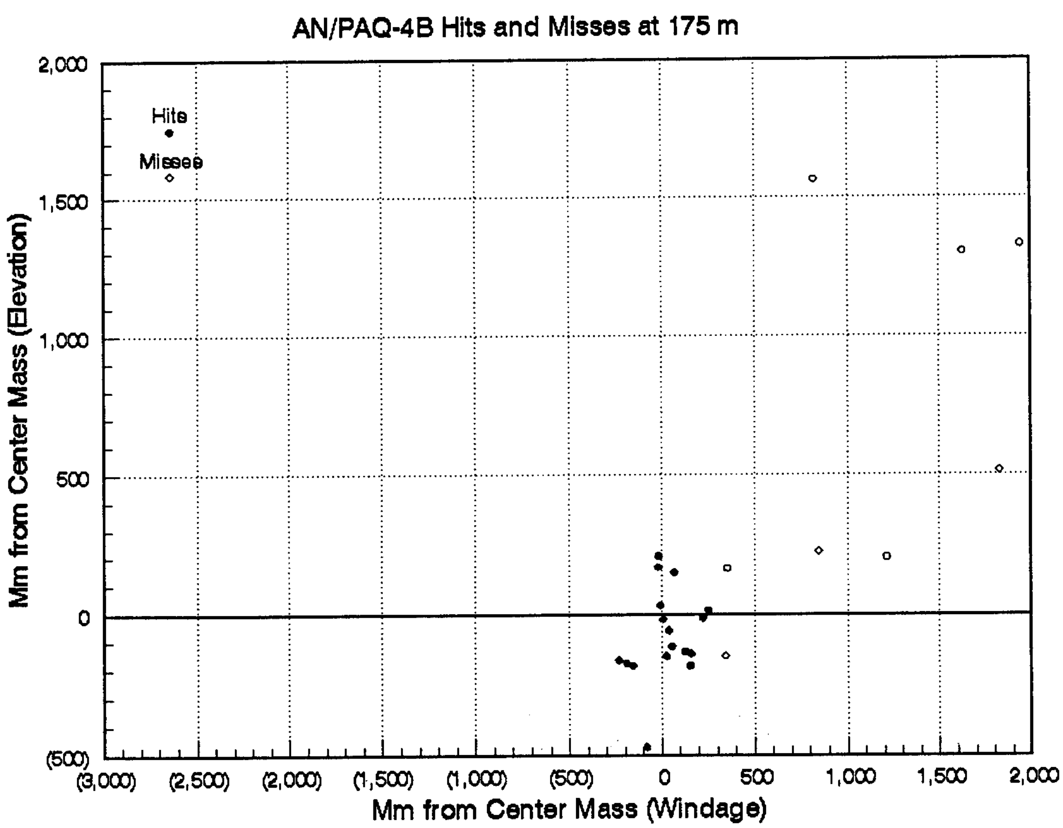
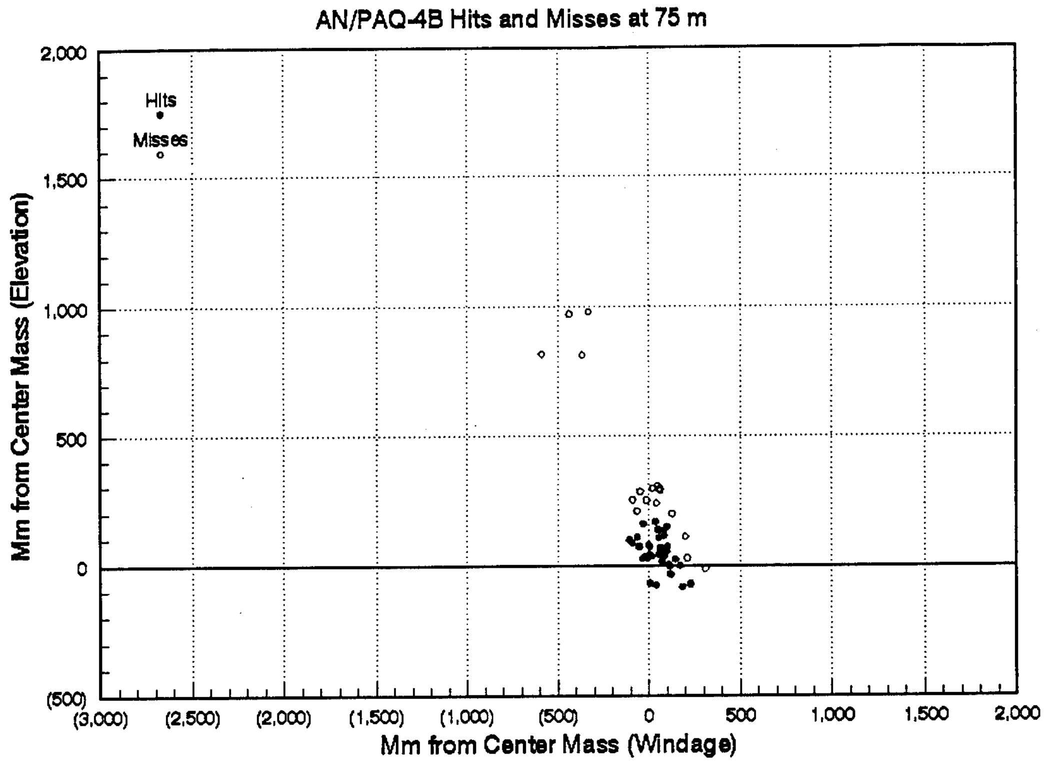


Figure B.3. Hits and misses with poor NVG acuity and no assistance - Experiment D.



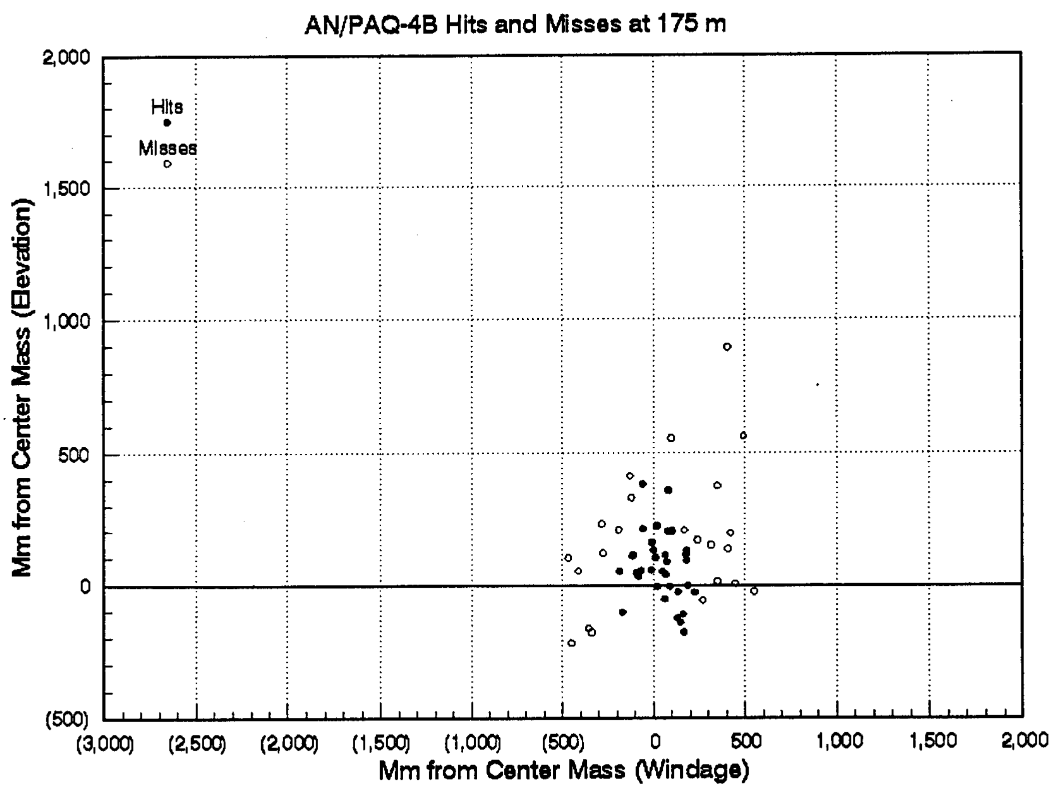
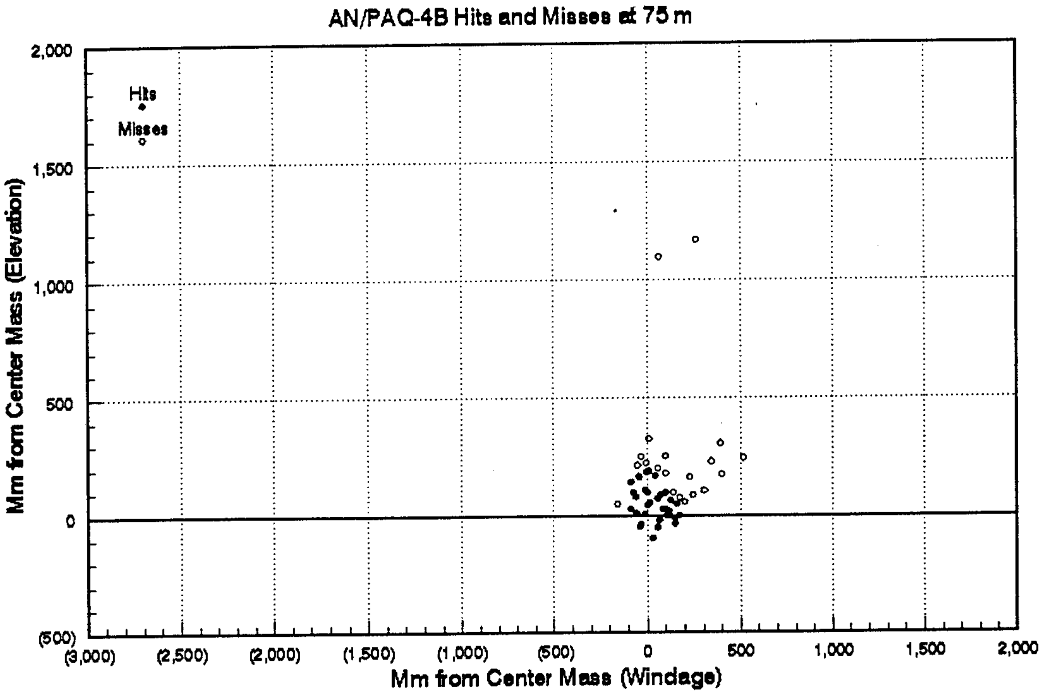


Figure B.4. Hits and misses with good NVG acuity and assistance - Experiment D. At the 75-m target, a single firer had the 4 misses at 800 to 1000 mm above center mass.



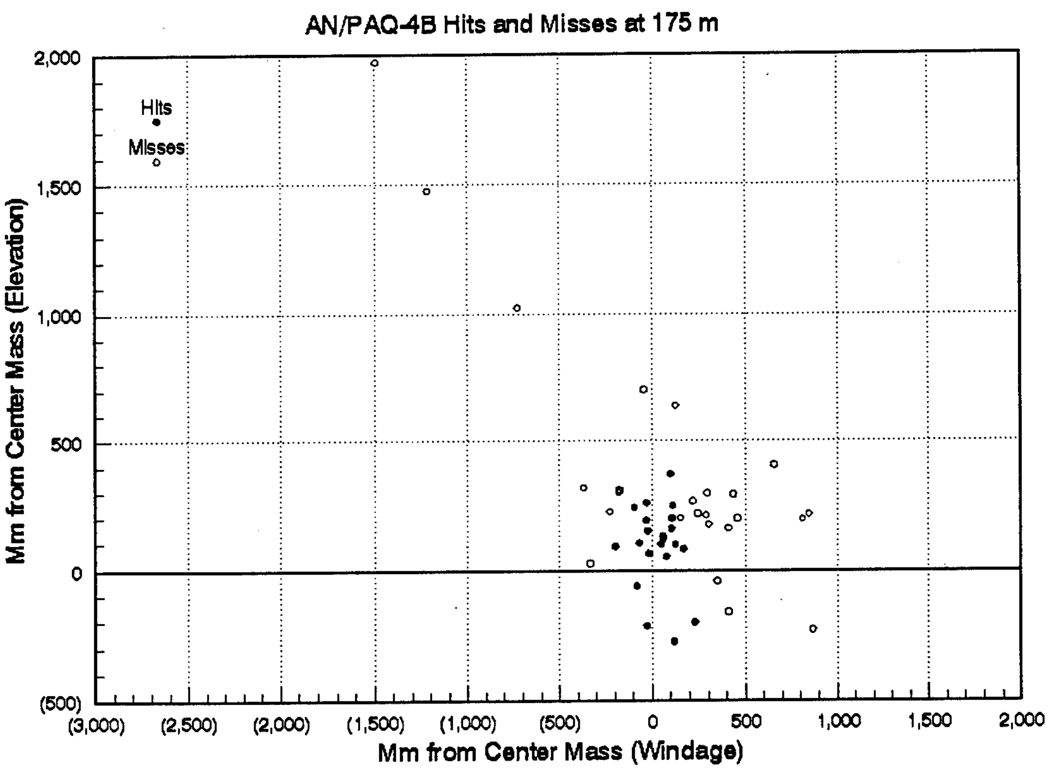


Figure B.5. Hits and misses with poor NVG acuity and assistance - Experiment D. At the 75-m target, a single firer had the 2 misses at 1000 mm above center mass.

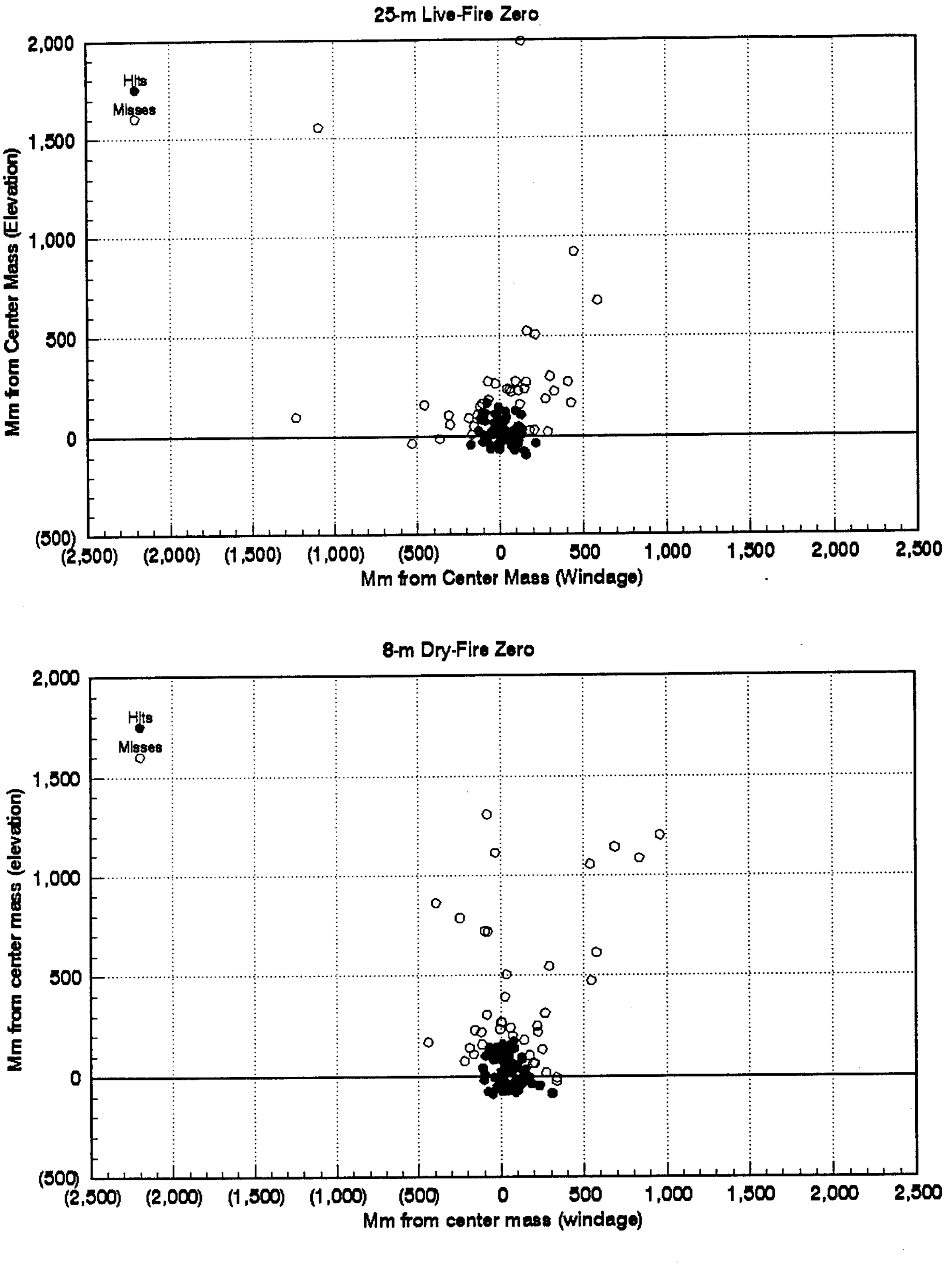
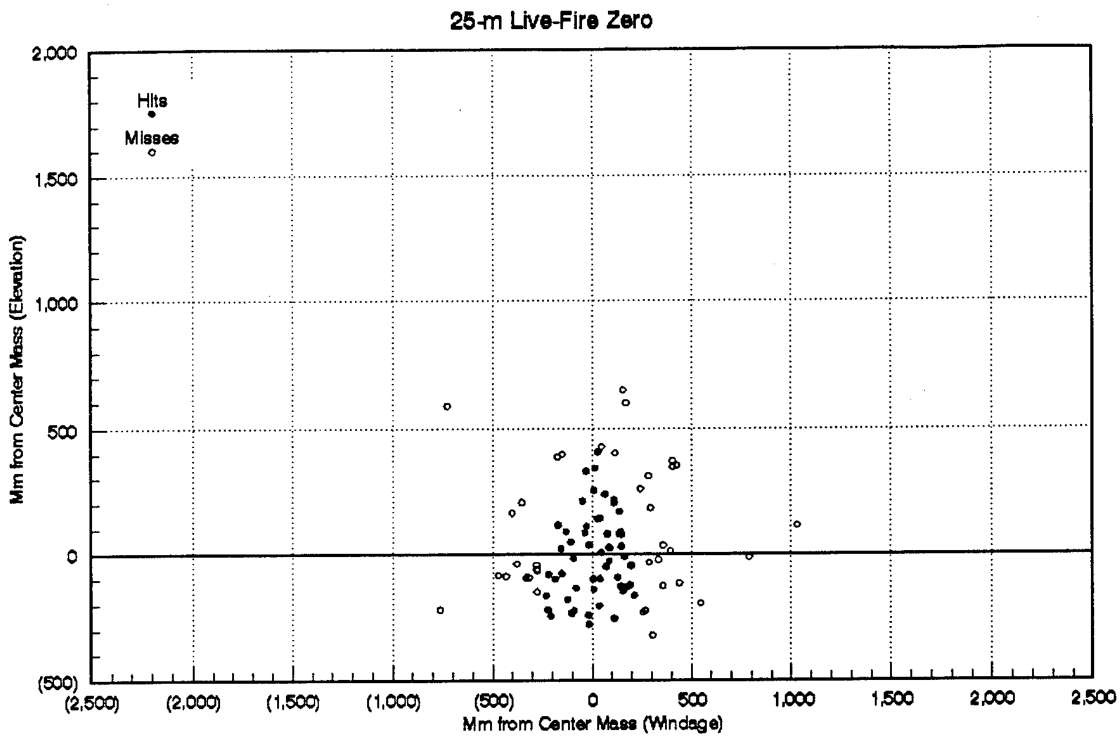


Figure B.6. AN/PAQ-4A hits and misses at 75 m with 25-m live-fire and 8-m dry-fire zeroing procedures - Experiment F.



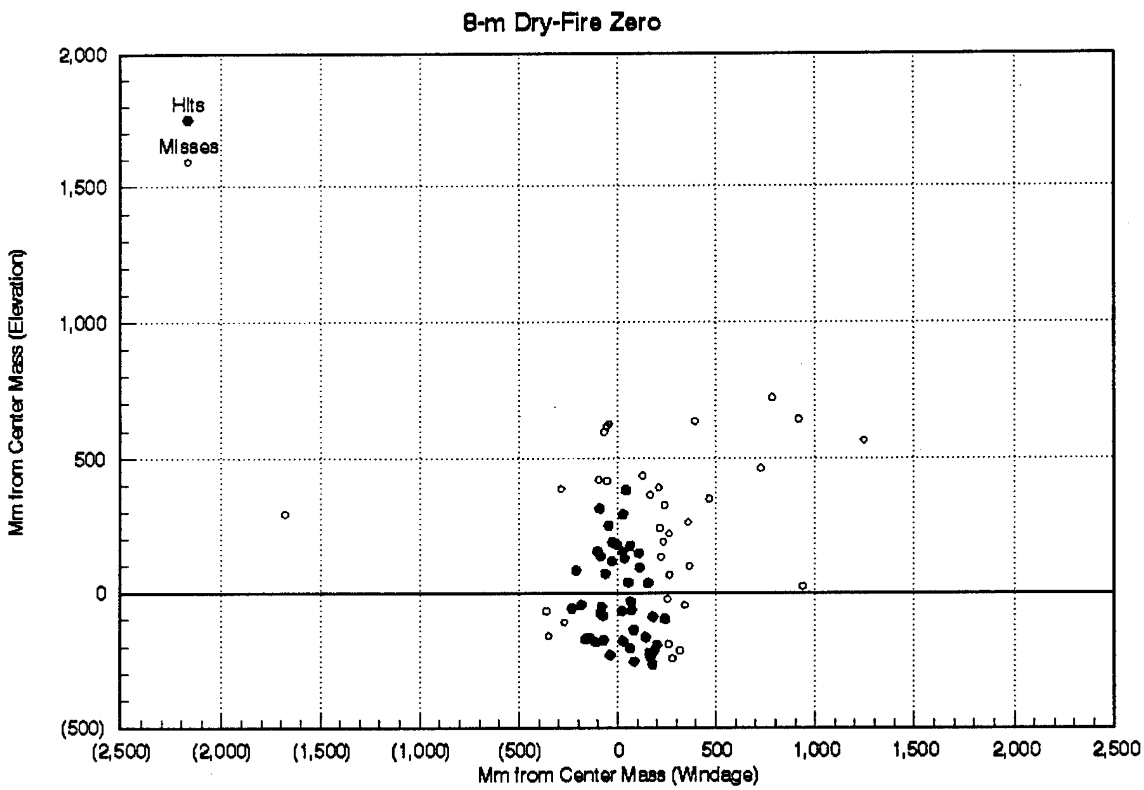


Figure B.7. AN/PAQ-4A hits and misses at 175 m with 25-m live-fire and 8-m dry-fire zeroing procedures - Experiment F.

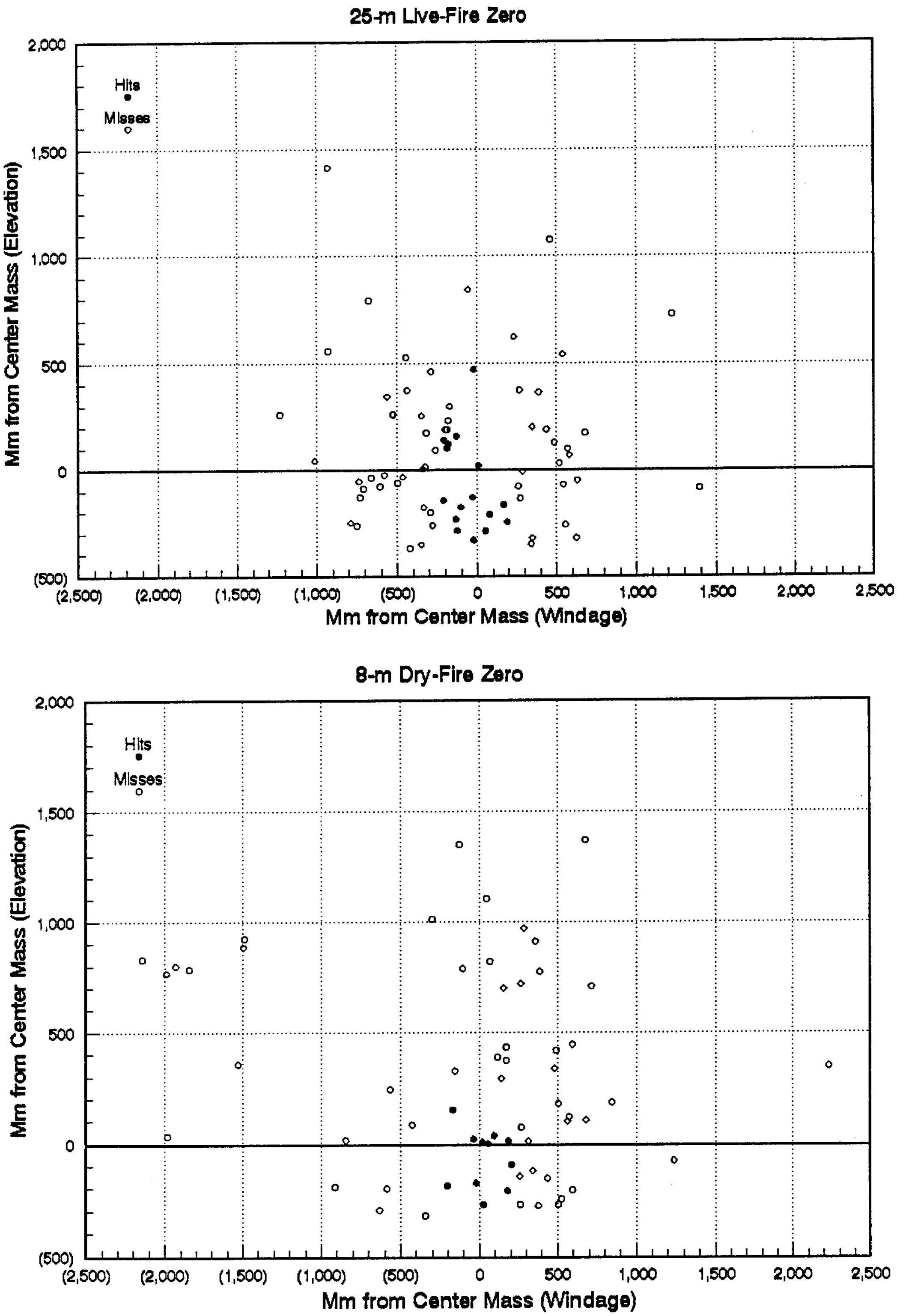
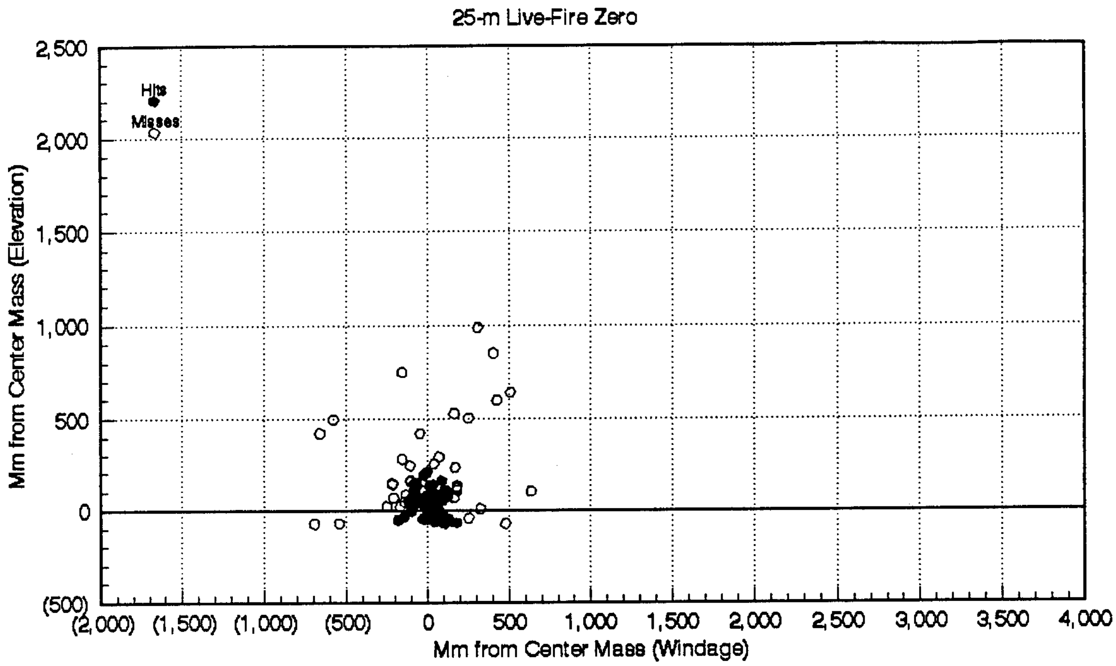


Figure B.8. AN/PAQ-4A hits and misses at 300 m with 25-m live-fire and 8-m dry-fire zeroing procedures - Experiment F.



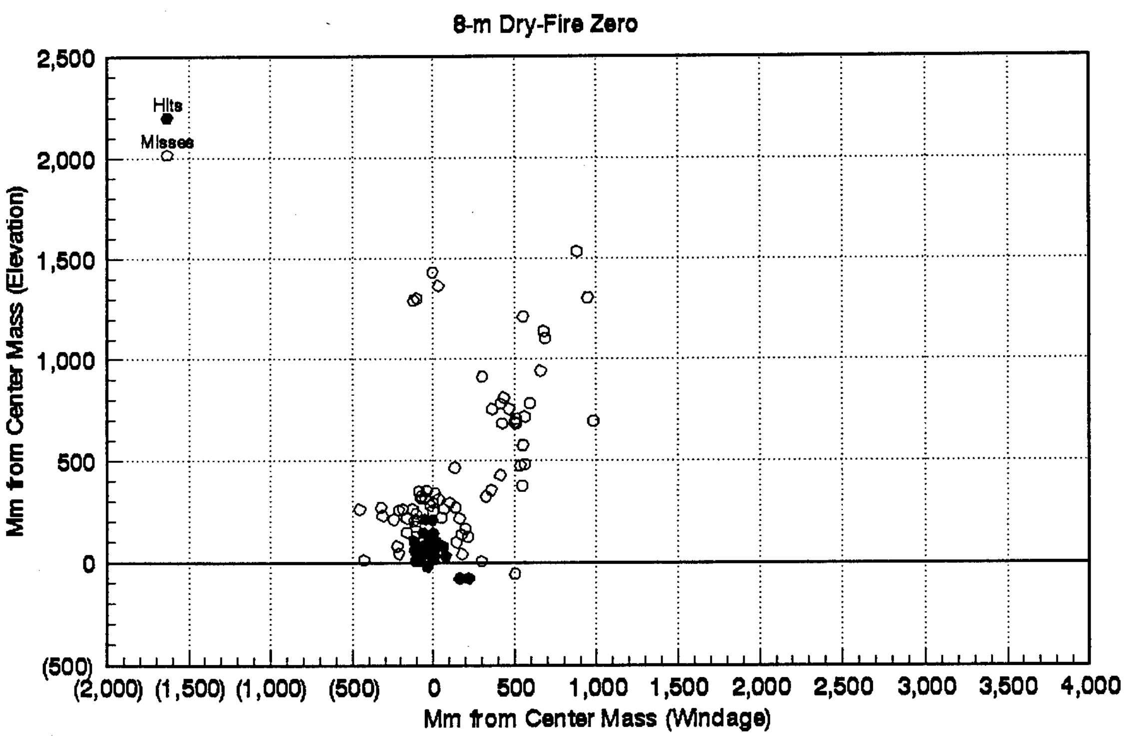
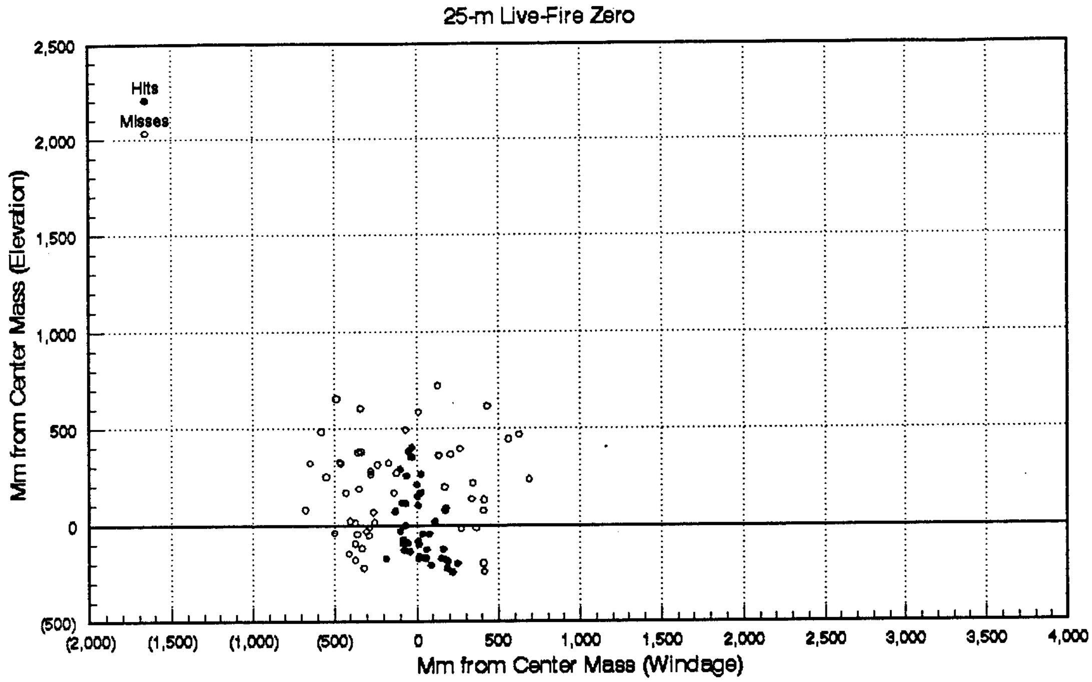


Figure B.9. AN/PAQ-4B hits and misses at 75 m with 25-m live-fire and 8-m dry-fire zeroing procedures - Experiment F.



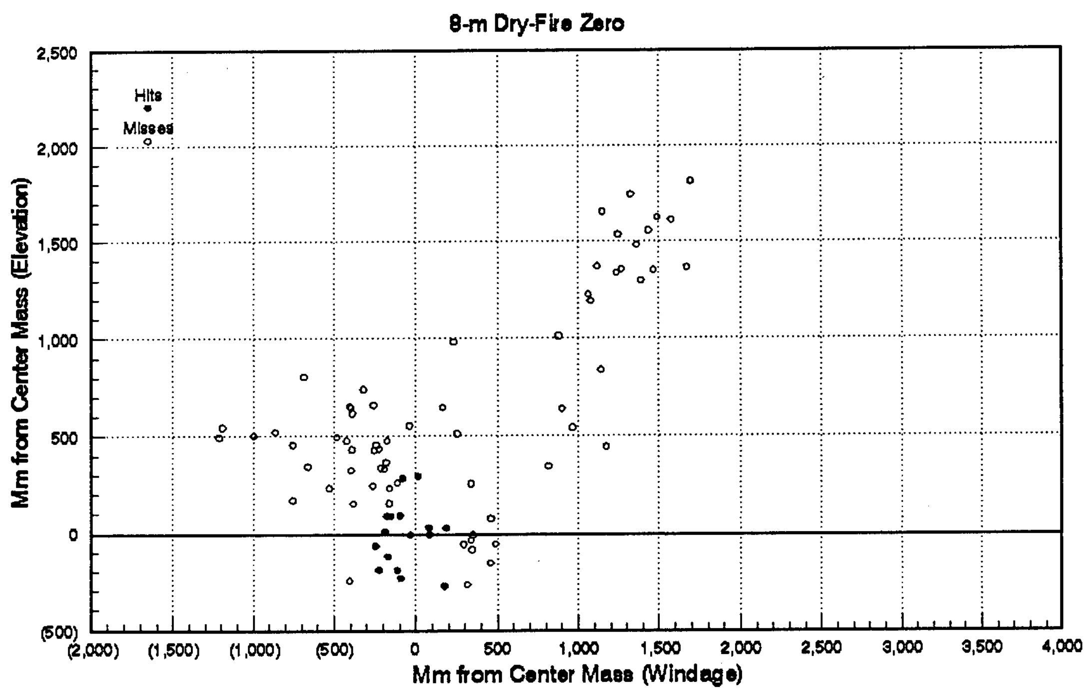
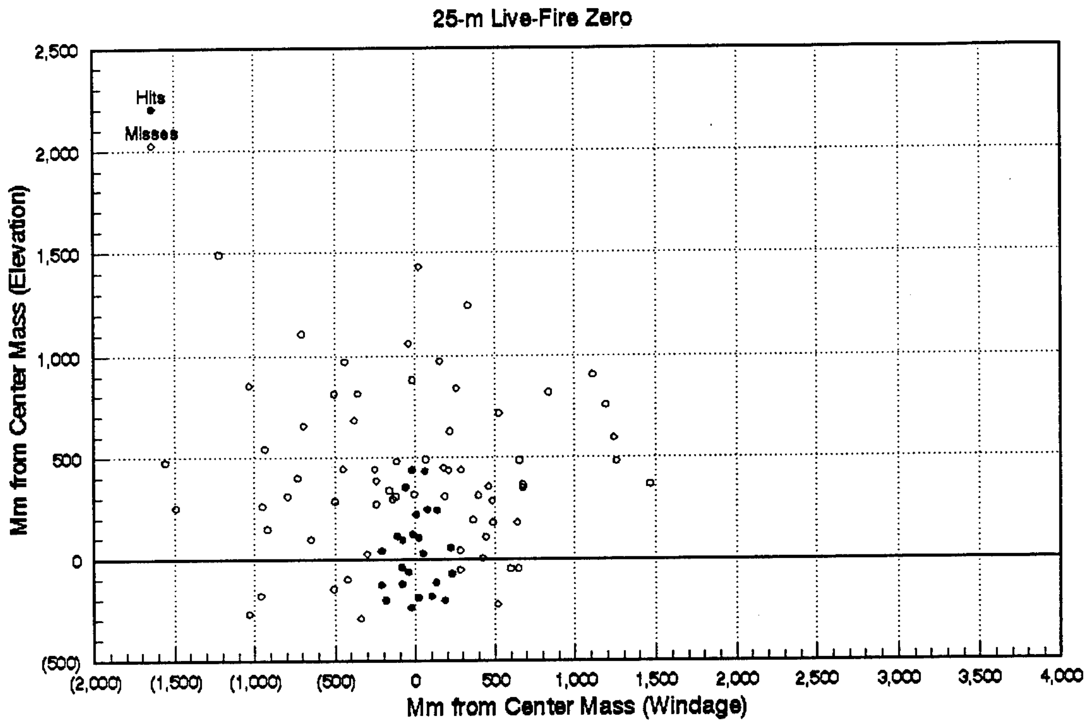


Figure B.10. AN/PAQ-4B hits and misses at 175 m with 25-m live-fire and 8-m dry-fire zeroing procedures - Experiment F.



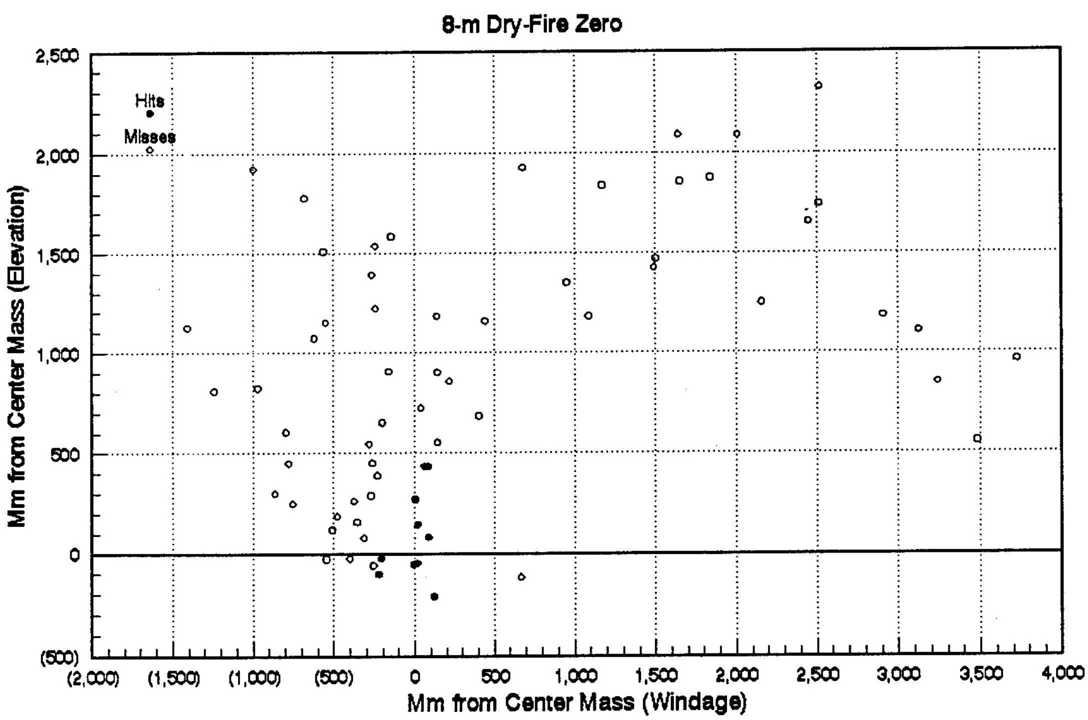


Figure B.11. AN/PAQ-4B hits and misses at 300 m with 25-m live-fire and 8-m dry-fire zeroing procedures - Experiment F.

APPENDIX C

SIDE TEST: ZEROING AIMING LIGHTS AT RANGE

A side test was conducted in Experiment B to determine the probability of hit with aiming lights when the zeroing was done at range. Confirmation of the 25-m zero at range is specified for daylight zeroing of the rifle (DA, 1989, FM 23-9). However, this procedure is not specified in the technical manuals for aiming lights. There are probably good reasons for this. It is very time consuming to walk down range in the dark to check targets, adjust the aiming light if necessary, fire again, and check the target again. However, the LOMAH range made it extremely easy to determine the effects of aiming light adjustments and when a firer had zeroed at range.

The six firers participating in Experiment B and in Preliminary Test 2 of Experiment E battlesight zeroed their aiming light. The AN/PAQ-4A was zeroed at 100 m; the AN/PAQ-4B at 250 m. Three rounds were then fired at targets which were placed 50 to 300 m from the firer's position. One lane had targets at 50, 100 and 250 m. A second lane had targets at 100 and 200 m. The third lane had targets at 75, 175, and 300 m. Firing with the two aiming lights was counterbalanced, and firing on the three lanes was counterbalanced within each firing order. The data were collected on two nights. All firers wore third-generation AN/PVS-7B goggles. The NVGs were adjusted for visual acuity each night. Ten of the twelve readings were 20/45 or less, with two readings being 20/60. The temperature was slightly below 32 °F, which created some problems as the NVGs tended to fog up. The sky was partially overcast. Firing was conducted from 1900 to 2330. The probabilities of hit are in Table C.1.

Table C.1
Probability of Hit After Live-Fire Zeroing at Range With the AN/PAQ-4A and AN/PAQ-4B

Distance (m)	AN/PAQ-4A[a]	AN/PAQ-4B[b]	Both Aiming Lights
50	1.00	1.00	1.00
75	0.83	0.94	0.89
100	1.00	1.00	1.00
175	0.72	0.61	0.67
200	0.44	0.56	0.50
250	0.44	0.83	0.64
300	0.00	0.39	0.19
Mean	0.63	0.76	0.70

Note. Two lanes had 100 m targets. The p_h for each was the same.

[a] Every firer had at least one hit in each target through 175 m. At 200 and 250 m, 4 out of the 6 firers hit targets.

[b] Every firer had at least one bullet in each target at each distance except for 300 m. Four of the six firers hit the 300 m target.

An ANOVA was conducted using aiming light and distance as repeated factors (Table C.2). There were significant main effects for both factors: target distance, $F(6, 70) = 16.12$, $p < .0001$, and aiming light, $F(1, 70) = 5.29$, $p < .0244$. As would be expected the probability of hit decreased as the distance to the target increased. The overall probability of hit with the AN/PAQ-4B ($M = .76$) was higher than that with the AN/PAQ-4A ($M = .63$), consistent with the greater range of the AN/PAQ-4B.

Table C.2
Analysis of Variance on Probability of Hit When Aiming Lights Were Zeroed at Range

Source	*df*	*MS*	*F*	*p*
Within subjects				
Aiming Light (A)	1	0.34	5.29	.0244
Distance to Target (B)	6	1.03	16.12	.0001
A x B	6	0.11	1.77	.1179
A x B x S within-group error	70	0.06		

Although, there was no significant interaction between aiming light and target distance, the clearest distinction between the range capabilities of the two aiming lights was shown at the farthest distances (Figure C.1). The probability of hit for each aiming light was high and equivalent out to 100 m. From 100 to 200 m, performance decreased by 50%. Beyond 200 m, the longer range capability of the AN/PAQ-4B became evident, with no hits achieved at the longest distance of 300 m with the AN/PAQ-4A.

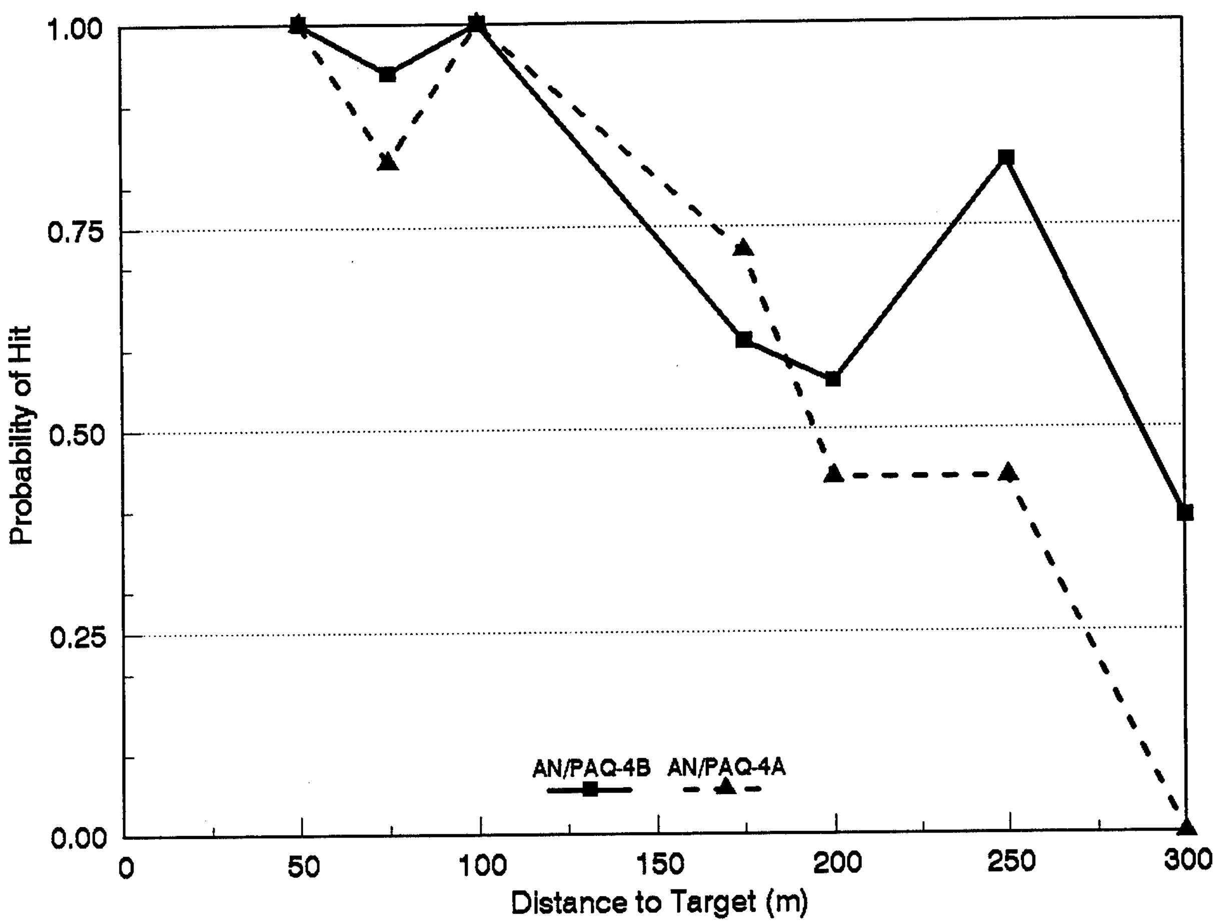


Figure C.1. Probability of hit with the AN/PAQ-4A and AN/PAQ-4B after zeroing at range (100 and 250 m respectively).

APPENDIX D

LIVE-FIRE ZEROING PROCEDURES

The live-fire zeroing procedures for both the AN/PAQ-4A and AN/PAQ-4B make three critical assumptions. First, the firer has a good 300-meter daytime zero on the M16A2 rifle using the standard 25-meter zeroing procedure. Second, initial aiming light adjustments have been made so the firer's bullets are "on paper" at 25 meters at night. Third, the firer's night vision goggles are adjusted for the best visual acuity.

The zeroing procedures recommended here are those identified in the research as successfully overcoming live-fire zeroing problems, enabling firers to zero within a minimal number of rounds, producing relatively small shot group sizes, and producing good hits at range. The procedures involve several additional preparation steps beyond those cited in the technical manuals for the aiming lights. All procedures can be implemented easily and with materials readily available within a unit.

Preparation for Zeroing

The first step is to modify the 25-meter zero target to help the firer determine center mass of the target and maintain a consistent aim point when zeroing. Use the tan side of a cardboard E-silhouette and stripe the full length and width of the cardboard with 3/4 inch black electrical tape. These stripes should divide the E-silhouette in half, vertically and horizontally. Center and staple the 25-meter zero target at the intersection of these black stripes. The zero target can be removed from the E-silhouette and replaced as needed. Figure D.1 depicts this target configuration.

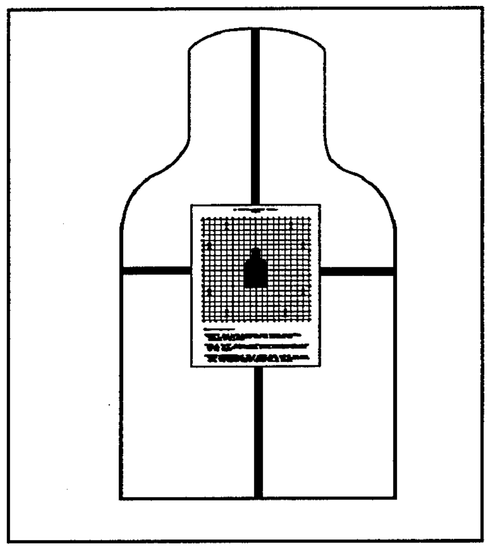


Figure D.1. Target setup for zeroing AN/PAQ-4 aiming lights at 25 m.

The second step is to mark the correct bullet impact point on the 25-meter zero target. When zeroing an aiming light, the firer points the aiming light at the center mass of the 25-meter zero target silhouette. The firer does not look through the rifle sights, but merely observes the laser beam with night vision goggles, points the beam at the target, holds it steady, and squeezes the trigger to engage the target. Bullets must hit the target at a pre-determined point. Aiming light adjustments are made until the shot group is centered over this point. This point differs for the AN/PAQ-4A and the AN/PAQ-4B as they have different offsets from the rifle boreline and are zeroed for different distances. The AN/PAQ-4A is zeroed for 100 meters; the AN/PAQ-4B has a longer range and is zeroed for 250 meters. Mark the bullet impact point on the zero target as indicated in Figures D.2 and D.3 to ensure bullets are adjusted to the right location for each aiming light.

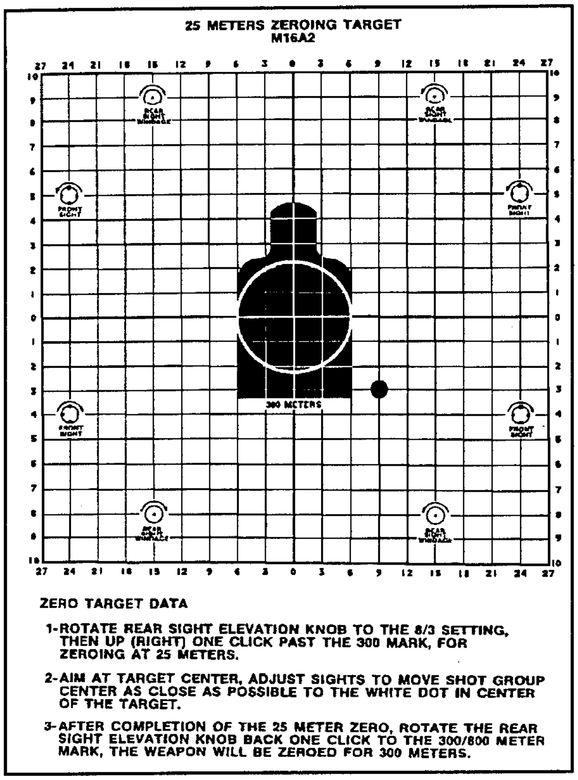


Figure D.2. M16A2 rifle live-fire zero target for the AN/PAQ-4A. [Bullet impact point is at the intersection of line 9 right and line 3 down.]

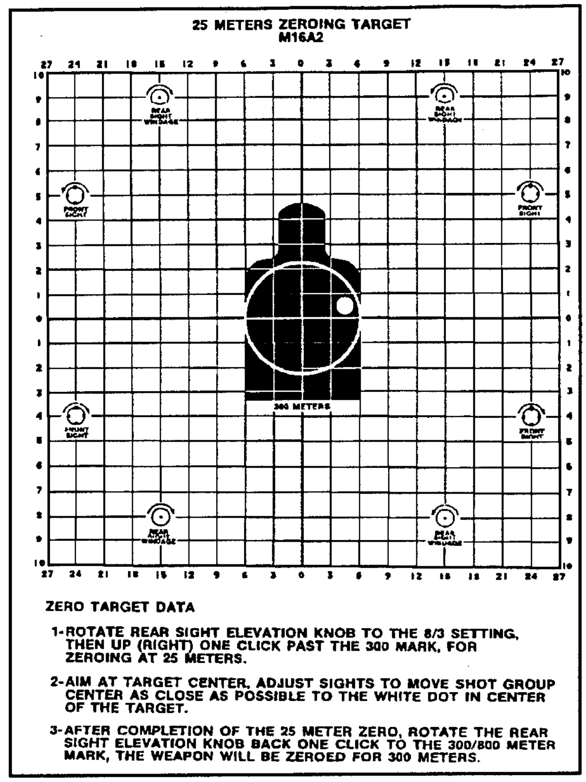


Figure D.3. M16A2 rifle live-fire zero target for the AN/PAQ-4B. [Bullet impact point is the "box" bracketed by lines 3 and 6 right and lines 0 and 1 up.]

The third step is to construct a <u>ruler for determining the number of aiming light click adjustments for windage and elevation</u>. The vertical and horizontal lines on the M16A2 zero target <u>should not</u> be used. They do not correspond exactly to the click size for either aiming light, and they do not form squares on the target. Therefore, these lines cannot be used to determine the number of clicks to adjust the aiming light up or down and right or left. Laminated rulers, that withstand the damp night air, should be constructed to reduce errors in the windage and elevation adjustments and to expedite the zeroing process. The rulers for each aiming light are illustrated in Figure D.4, but are not to scale.

> Be aware that each click of either AN/PAQ-4A knob will move the bullet strike by only 1/4 inch (both elevation and windage), not about 1 centimeter as the markings on the M16A2 target show.
>
> Be aware that each click of either AN/PAQ-4B knob will move the bullet strike by 1 centimeter (both elevation and windage), so ignore the 3, 6, 9, 12, etc. markings at the top and bottom of the M16A2 zero target.

A 12-inch ruler works well for determining the distance between the correct bullet impact point and center mass of the shot groups. Label the rulers as shown to ensure they are used with the correct aiming light (Figure D.4). During zeroing, place a ruler at each 25-meter zero target location.

The fourth step is to make a training aid showing which direction to turn the aiming light knobs to adjust bullets on the bullet impact point. Experience has shown that the markings on the aiming light knobs can be misinterpreted. Bullets can suddenly go off the zero target, off the E-silhouette, or in the wrong direction because the aiming light was adjusted incorrectly. A training aid such as that shown in Figure D.5 corrects this problem. For the AN/PAQ-4B, this aid, as illustrated, is appropriate only when used with the M16A2 rifle. It does not apply to weapon systems where the AN/PAQ-4B is mounted in a different position relative to the bore of the weapon.

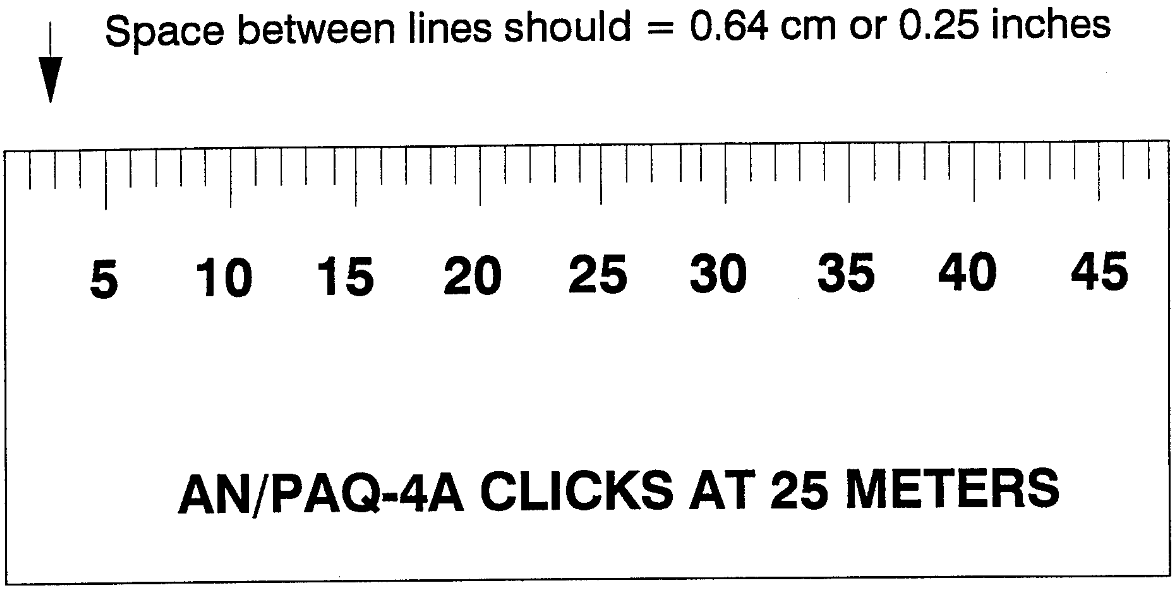
The final step is to make a transparency showing the appropriate shot group size. This is needed for two reasons. First, the 4-centimeter circle marked on the 25-meter target is not centered over the bullet impact point for either aiming light. Second, firers cannot be as precise at night as during the day. The 4-centimeter shot group is an unrealistic standard for night firing, given the reduced visual acuity at night through goggles and the difficulties in aiming consistently. A 5.5-centimeter criterion is better. A laminated see-through or transparent training aid marked with a black 5.5-centimeter circle should be used to help apply this criterion to the bullet impact point.

Zeroing Procedures

Use the standard Army flashlight to light the target. The flashlight helps diffuse the bloom of the aiming light in the goggles and provides a more definitive aim point. Place the flashlight near the firer in a supported position such as a V-notched stake. The flashlight can be pointed directly at center mass of the target or slightly below the target, according to the firer's preference. If the amount of ambient light in the night sky is high, a flashlight may not be needed.

Fire two, three-round shot groups before making any aiming light adjustments. This will provide a much better indication of the firer's aim point than a single three-round shot group. This procedure will avoid making premature adjustments and "chasing bullets" in the dark. Triangulate and number each shot group. Do not adjust the aiming light unless the firer is shooting consistently and the aim point can be determined.

Use the aiming light ruler to determine the number of clicks in windage and elevation required to move the strike of the bullet to the desired impact point. Use center mass of the shot group for these measurements. Check the knob adjustment guide to ensure adjustments are made in the correct direction.



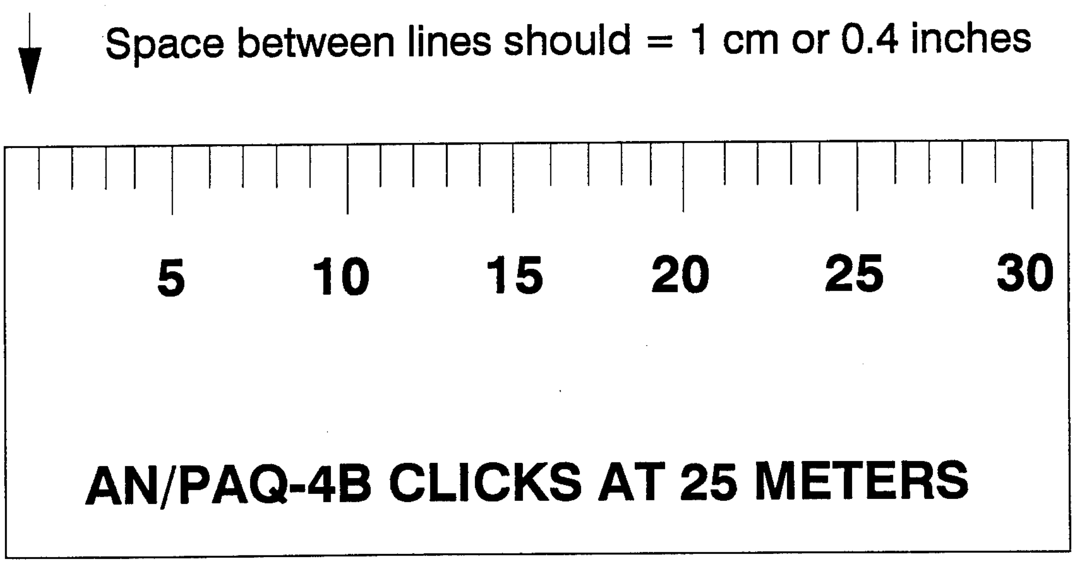


Figure D.4. AN/PAQ-4A and AN/PAQ-4B aiming light rulers for the 25-meter live-fire zero. The rulers are not to scale.

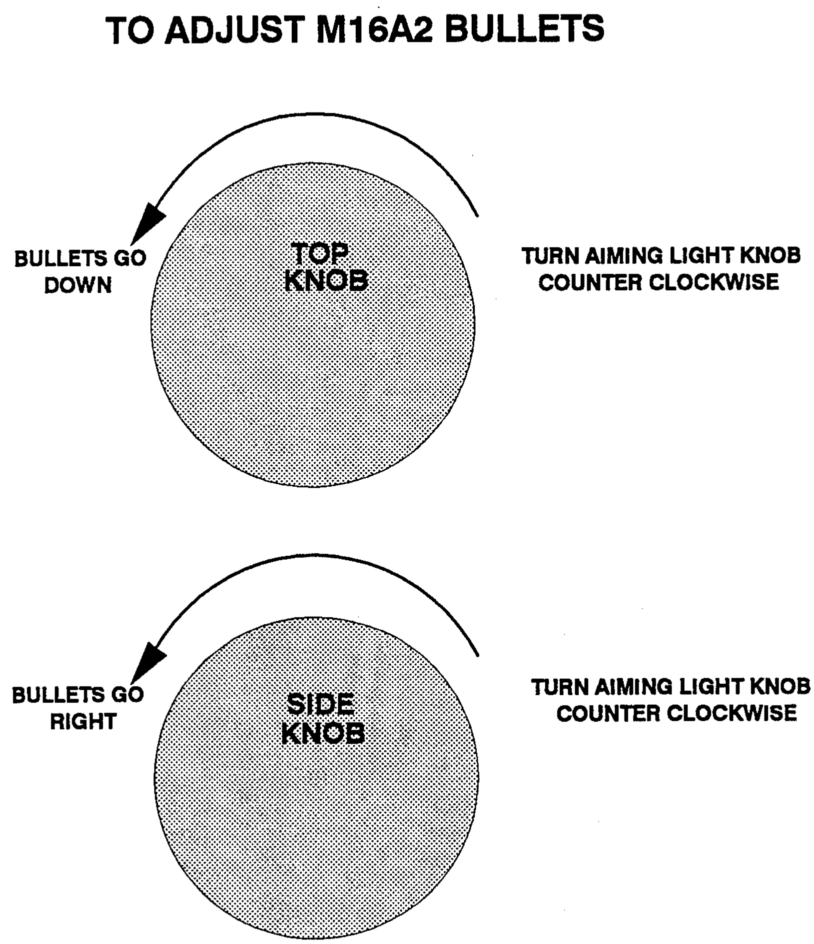


Figure D.5. Aiming light knob adjustment guide. The guide shows the movement of bullets with the M16A2 rifle when aiming light knobs are turned counterclockwise. Bullets go in the opposite direction when the knobs are turned clockwise.

Center the shot group size transparency (the 5.5-centimeter circle) over the bullet impact point to evaluate each shot group. All bullets should be within the circle and as close to the impact point as possible.

Finally, fire no more than four shot groups per 25-meter zero target in order to accurately assess shot groups. The wide dispersion of bullets frequently makes it difficult to mark shot groups distinctly and can result in an incorrect adjustment. Put up a new 25-meter zero target after this point.

Checklist

The following checklist summarizes the steps that should be taken when zeroing an aiming light. It assumes that all the training aids and target modifications have been made.

Prepare for Zeroing with Aiming Lights

- Zero the M16A2 rifle for 300 meters during daylight hours
- Use a striped E-silhouette
- Use a 25-meter zero target marked with the correct bullet impact point
- Center the 25-meter zero target on the stripes on the E-silhouette
- Place the aiming light ruler and shot group size transparency at each 25-meter zero target location
- Place the aiming light knob adjustment guide at each firer's position

Zeroing Procedures at Night with Aiming Lights

- Be sure the rifle is set properly for zeroing at 25 meters; 1 click up from the 300 meter setting
- Shine a flashlight on the 25-meter zero target from the firer's position, as needed
- Fire and mark two, three-round shot groups before making the first aiming light adjustment
- Use the aiming light ruler to determine the number of clicks for windage and elevation adjustments
- Check the knob adjustment guide to ensure the adjustments are made in the correct direction
- Use the shot group size transparency to evaluate size
- Put up a new 25-meter zero target after firing four shot groups

When finished, move the elevation knob on the M16A2 rifle down one click to ensure the sights are aligned for 300 meters. At this point, the rifle sights are battlesight zeroed for 300 meters; the AN/PAQ-4A is zeroed for 100 meters; the AN/PAQ-4B is zeroed for 250 meters.

These procedures will result in better aim points, better aiming light zeros, and more target hits at range. They will also save time and ammunition during the zeroing process. Fewer errors will be made in adjusting the aiming light. Do not omit steps; each is critical.

APPENDIX E

DRY-FIRE ZEROING PROCEDURES

The system developed by ARI for dry-fire zeroing an AN/PAQ-4A or AN/PAQ-4B for M16A2 rifle night-time shooting is described in this appendix. The firer begins with a good 300 meter iron-sight, daytime zero (performed using the standard 25-meter procedure). Then, in the dark or in subdued light, the firer uses the iron sights to aim center mass on the ARI cross-hair target located eight M16A2 rifle lengths from the muzzle of the rifle. A buddy, wearing night vision goggles, observes the target and adjusts the firer's AN/PAQ-4 knobs until the laser beam spot is exactly centered over the designated adjustment point marked on the cross-hair target. The buddy can walk forward to the target to see the spot location clearly and then return to the rifle to make any necessary adjustments. Another option is to have a third individual, wearing night vision goggles, stand near the target and call out adjustments to the firer and the buddy.

The ARI AN/PAQ-4 dry-fire zeroing procedure probably works best indoors in subdued lighting, even in a lighted hallway or room. This can be accomplished using the pinhole cover on the AN/PVS-7B night vision goggles. The procedure works well at twilight time out of doors. It is also possible to zero in darkness by using a flashlight to illuminate the target (and possibly the rifle sights) so the firer can align the sights and see the target. The procedure can be carried out virtually any place where there is about thirty feet of space.

Daylight Zero

Any rifle intended for night-time zeroing should also be properly zeroed for daytime firing. In the daylight, zero the M16A2 rifle for 300 meters using the standard 25-meter zeroing procedure (rear sight set to the 300 meter setting plus one click up toward 400 while zeroing). Use this setting for all 25-meter firing.

Preparation for Zeroing

The first step is to prepare the dry-fire zero target. The recommended targets for each aiming light are illustrated below, with a full-sized copy included in this appendix as well. Adjusting the AN/PAQ-4A laser spot to the designated spot in Figure E.1 will result in a 100-meter aiming light zero. Adjusting the AN/PAQ-4B laser spot to the designated spot in Figure E.2 will result in a 250-meter aiming light zero. It must be stressed, however, that the point shown in Figure E.2 was not shown to be entirely satisfactory for achieving hitting distant targets in the research reported here. Therefore, use of this dry-fire zero target for the AN/PAQ-4B should be followed by live-fire zero confirmation until a more satisfactory point is determined.

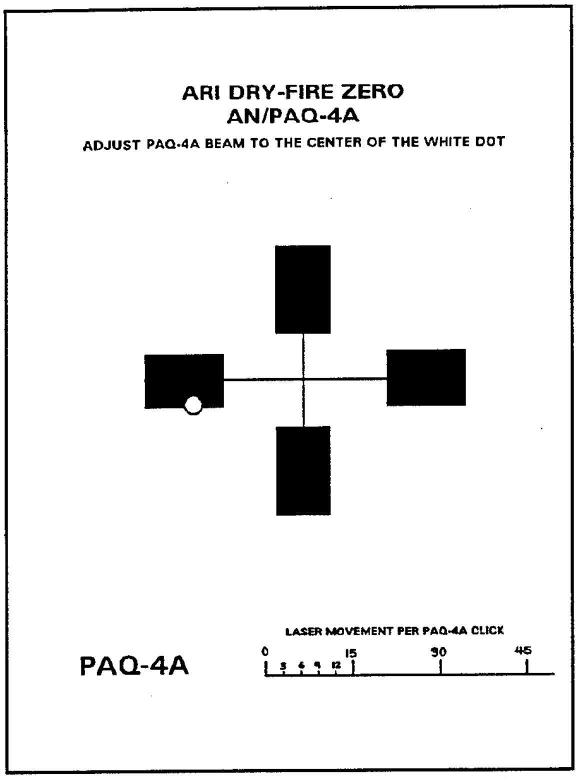


Figure E.1. ARI dry-fire zero target for the AN/PAQ-4A aiming light. The white dot is marked 9 mm below and 41 mm left of center mass of the target.

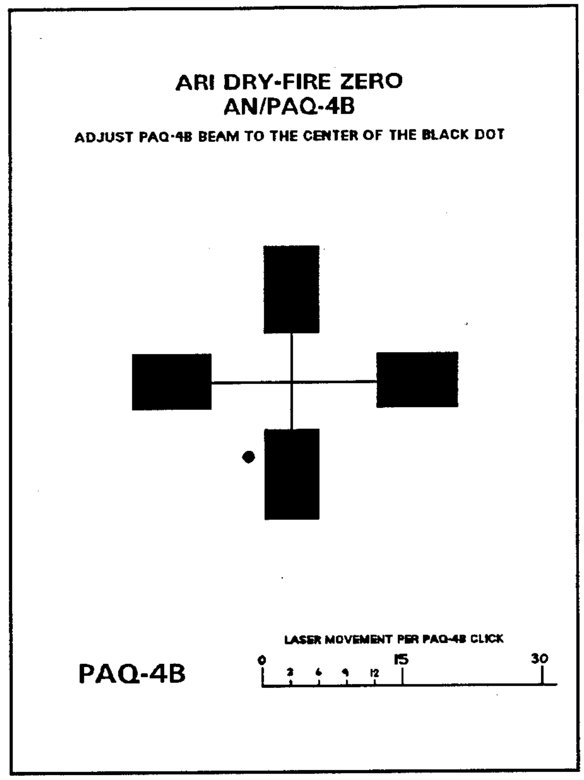


Figure E.2. ARI dry-fire zero target for the AN/PAQ-4B aiming light. The black dot for the laser point is marked 27 mm below and 17 mm left of center mass of the target.

The second step is to locate an area with subdued lighting that has a vertical surface (e.g., wall, tree) on which to attach the dry-fire zero target. Then measure a distance of 26 feet 4 inches, eight M16A2 rifle lengths, from that vertical surface to the muzzle of the firer's M16A2 rifle.

The third step is to set up a supported aiming position at this firing position. The firer must hold the rifle very steady during the AN/PAQ-4 spot adjustment procedure. The nighttime zero can be performed as soon as it is dim enough for a buddy to see the laser spot clearly with night vision goggles while standing near the target.

Zeroing Procedures

The aiming light zeroing procedure is easiest if two soldiers work together. Be sure the rifle is clear and on safe. The firer, who has a daylight zeroed rifle, gets into a very steady supported position and lines up the iron sights at center mass on the dry-fire zeroing target. Be sure the rifle is set for 300 meters (the 3 setting on the rear sight). The buddy will adjust the AN/PAQ-4 knobs to move the spot until it is exactly on top of the white dot (or black dot) on the target. If it is too dark to see through the iron sights, use flashlight(s) to illuminate the target and perhaps the sights themselves if necessary.

The first step is to establish the correct point of aim. Figure E.3 shows the correct point of aim to use with the dry-fire zero target. The firer aligns the rifle sights and places the front sight post exactly at the intersection of the lines as shown in Figure E.3. The firer cannot see the intersecting lines. But with the target, the firer can easily center the front sight post beneath the top black rectangle and place the top of the sight post exactly half way up either of the side black rectangles. This gives the firer an easily achieved and definitive aim point. In instructing firers on the dry-fire procedure, this figure should be used to ensure they understand where to aim their sights.

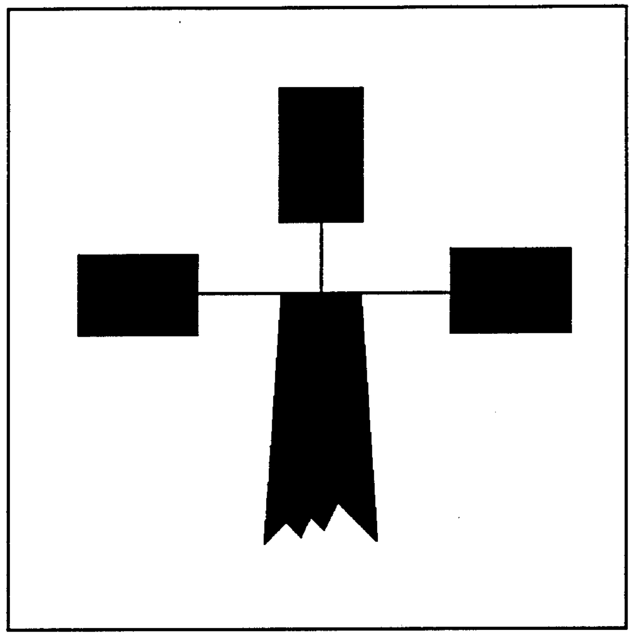


Figure E.3. Correct point of aim for the ARI zeroing target.

The firer must hold the rifle steady in order to adjust the aiming light to the correct laser point on the target. If fatigue occurs, a short break should be taken.

The second step is to determine where the aiming light beam hits the dry-fire zero target. The buddy doing the beam spot adjustment uses night vision goggles to see the beam spot. The buddy should try the goggles with and without the pinhole cap on to determine which gives the clearest view of the spot while standing close to the target. Sometimes, it may be more efficient to have a third soldier designated to stand at the dry-fire zero target and call out the adjustments to the firer and buddy at the "firing line." Use the ruler at the bottom of the target to determine the number of clicks required for changes in windage and elevation.

The third step is to adjust the aiming light so the beam hits exactly on the dry-fire laser point. For the AN/PAQ-4A, this is the white dot in Figure E.1. For the AN/PAQ-4B, this is the black dot in Figure E.2. The buddy should use the "screw analogy" to adjust the beam. The top knob on the AN/PAQ-4A/B adjusts the spot up and down. Using the screw analogy, if the top knob were a screw, turning it clockwise would cause it to screw down. Therefore, turning the knob clockwise will adjust the spot down. Likewise, turning a screw counterclockwise would cause a screw to come up and out of the hole. So the top knob turned counterclockwise will cause the beam spot to go up. The knob on the left side of the AN/PAQ-4A/B adjusts the spot left and right. If the knob were a screw, turning it clockwise would cause it to screw in (therefore to go to the right). So, turning the knob clockwise will cause the beam spot to move to the right (and counterclockwise--to the left). Remember what a screw would do to determine which way to turn either knob to move the laser spot.

Top knob: clockwise = down into the screw hole; counterclockwise = up and out of the screw hole
Side knob: clockwise = into the screw hole; counterclockwise = out of the screw hole

In adjusting the beam, the buddy must move back and forth to the target to see the beam spot location very clearly. Make the necessary adjustments while the firer has a very steady position. Then have the firer relax, get a good center mass aim again, and recheck the accuracy of the spot placement.

Checklist

Prepare for Zeroing

- Zero the iron sights for 300 meters.
- Set the sights of the daylight zeroed rifle to 300 meters.
- Use an AN/PAQ-4A "ARI DRY-FIRE ZERO" target or an AN/PAQ-4B "ARI DRY-FIRE ZERO" target.

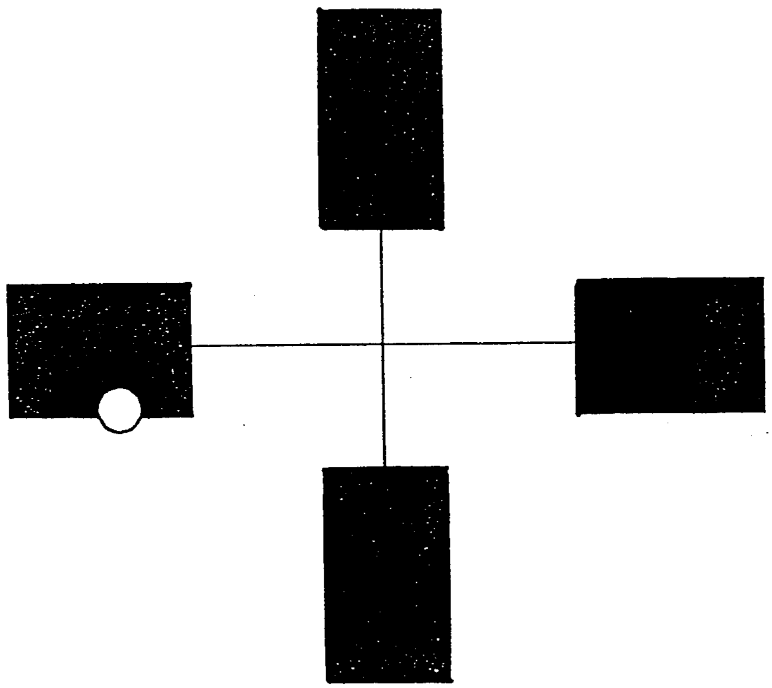
Zeroing Procedures

- Be certain the rifle is cleared and on safe.
- With a steady supported position, aim the iron sights exactly center mass from 26 feet 4 inches away (8 M16A2 rifle lengths) at the appropriate dry-fire zero target.
- Use a flashlight to illuminate the target and/or the rifle sights, if necessary.
- Have a buddy, wearing night vision goggles, adjust the laser beam spot until it covers the white dot on the AN/PAQ-4A target or the black dot on the AN/PAQ-4B target. Be sure the goggles are properly adjusted for clear vision.
- Place a third individual with goggles near the target to determine where the beam of the aimlight falls on the target. Have this individual call out the necessary adjustments to the firer's buddy.
- Use the "screw analogy" to adjust the knobs. Use the ruler on the target to determine the number of required clicks.
- Take a brief rest, and recheck the adjustment.

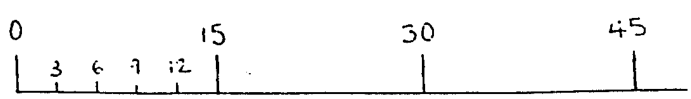
With this ARI zero procedure, initial shot groups should be on the 25-meter zero target during live-fire zero confirmation with both aiming lights. In addition, with the AN/PAQ-4A adjustment, targets should be hit at 100 meters and perhaps out to 200 meters without live-fire confirmation. However, since the best dry-fire point was not clearly identified for the AN/PAQ-4B, live-fire zero confirmation should be conducted after adjusting to the laser point specified in Figure E.2.

ARI DRY-FIRE ZERO
AN/PAQ-4A

ADJUST PAQ-4A BEAM TO THE CENTER OF THE WHITE DOT



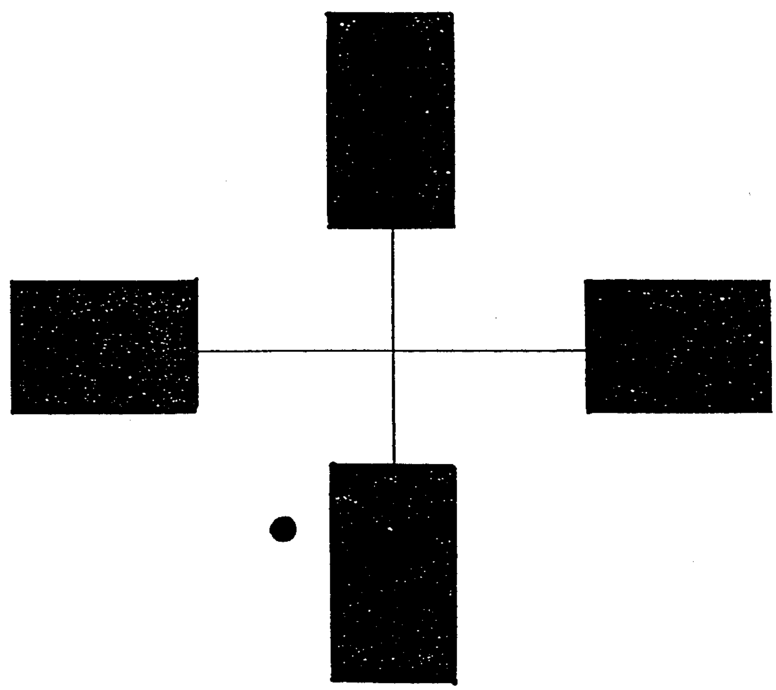
LASER MOVEMENT PER PAQ-4A CLICK



PAQ-4A

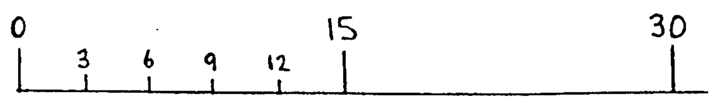
ARI DRY-FIRE ZERO
AN/PAQ-4B

ADJUST PAQ-4B BEAM TO THE CENTER OF THE BLACK DOT

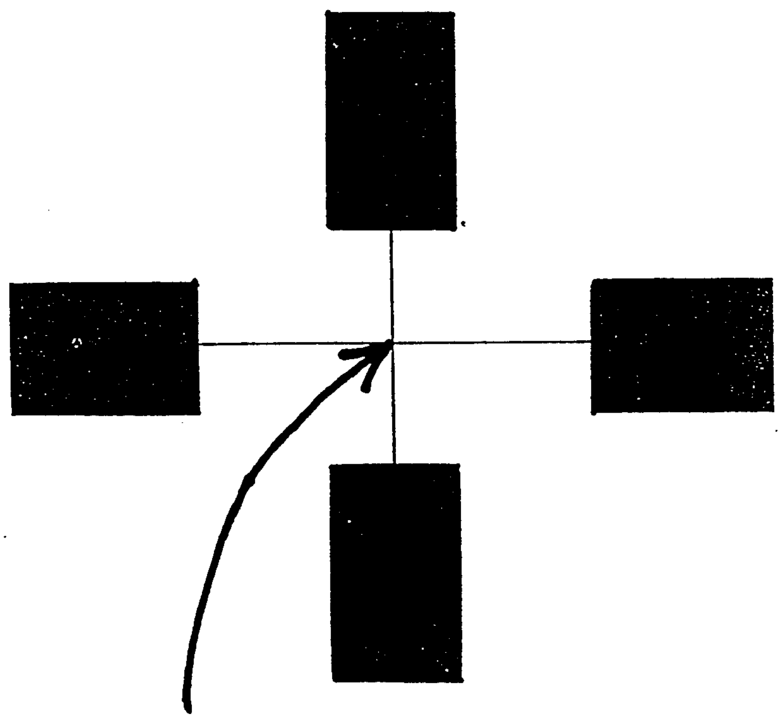


LASER MOVEMENT PER PAQ-4B CLICK

PAQ-4B

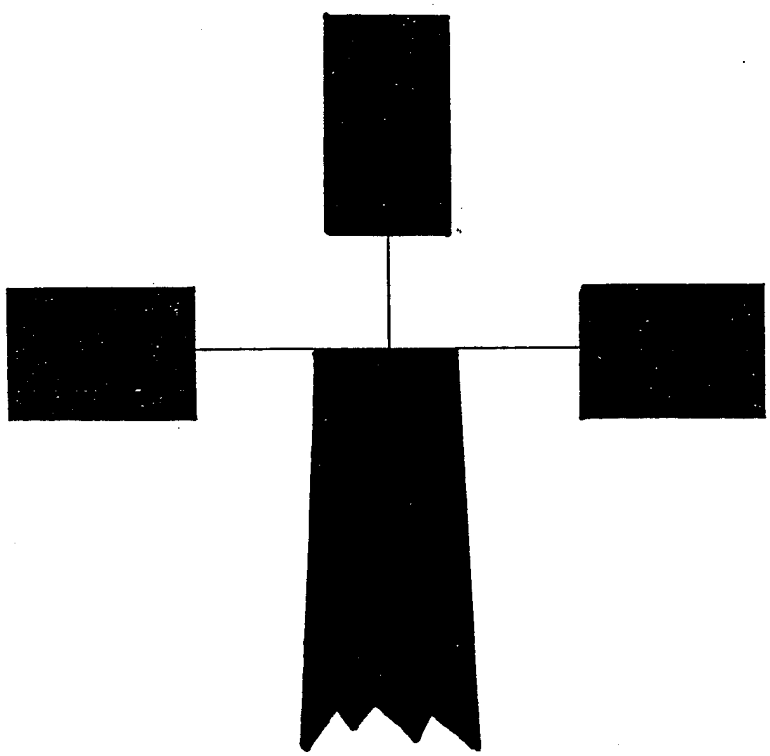


ARI DRY-FIRE ZERO AIM



PLACE FRONT SIGHT EXACTLY IN THE CENTER OF THE BLACK RECTANGLE!

ARI DRY-FIRE ZERO AIM



FRONT SIGHT POST
IN CORRECT POSITION
CENTER MASS UP/DOWN
CENTER MASS LEFT/RIGHT

APPENDIX F

NIGHT VISION GOGGLE ADJUSTMENT PROCEDURES

ADJUSTMENTS REQUIRED

- EYE RELIEF

  Eye relief refers to the distance from the eye to the night vision goggles (NVGs). It affects the field of view.

- INTERPUPILLARY DISTANCE (IPD)

  The IPD is the distance between the two eyes. This distance should correspond to the distance between the two eyepiece lenses on the NVG.

- DIOPTER ADJUSTMENT RINGS ON THE EYEPIECE LENSES

  In place of glasses, the NVGs have adjustable, built-in lenses designed to correct simple refractive errors. Whether using NVGs with or without glasses, the diopter setting for each eye must be adjusted correctly. Otherwise, eyestrain can result. The diopter adjustments do not compensate for astigmatism.

- OBJECTIVE LENS

  The objective lens is used to focus for distance. It has a focal range from 10 inches to infinity.

- ALL ADJUSTMENT PROCEDURES ASSUME THE GOGGLES ARE MOUNTED PROPERLY ON THE HEAD HARNESS.

STEP 1. EYE RELIEF ADJUSTMENT

The appropriate adjustment provides the maximum field of view, which is 40°. This is approximately an 80% loss of the normal field of view, which is 180°.

Move the goggles on the head harness by pressing the socket release button. The optimum adjustment is about 18 mm, as close to the eye or glasses as possible.

STEP 2. INTERPUPILLARY DISTANCE (IPD) ADJUSTMENT

The two eyepieces on the NVGs move left and right (in and out) to accommodate to the distance between your eyes.

Move the eyepieces to correspond to the distance between the centers of your eyes.

If your eyes are close together, you may have to move the eyepieces in.
If your eyes are far apart, you may have to move the eyepieces apart.

Close one eye and look at a distance with the other eye. If the eyepiece is centered over your eye, a full, "green" circle should be seen. You should not see an oval or any blurred edges. Move the eyepiece so these conditions are met.

If the outside edges are blurred, the IPD is too small; move the eyepiece out.
If the inside edges are blurred, the IPD is too large; move the eyepiece in.
Refine the adjustment until all edges are the same.

Repeat for the other eye.

The two eyepieces should be centered on the goggles after these adjustments are made.

STEP 3. EYEPIECE LENS (OR DIOPTER) ADJUSTMENT

This adjustment determines the visual acuity you have with your goggles. Adjust one eye at a time.

When using the NVG resolution chart, place the chart 20 feet away from you. Set the focus of the objective lens so the charts are as clear as possible

When in the field, look at a far object - at least 30 feet away. Pick an object that presents a high contrast at night and will present a distinct image when in focus. When looking at a far object in the field, you must turn the objective focus lens all the way to the left so it is set for the maximum distance.

Examples of high contrast objects
- A black line on a white piece of paper
- Black on white road signs
- The trunk of a tree seen against a twilight sky
- The edge of a building or a roof line against a clear sky
- A star in the sky

Close one eye, whether using the NVG charts or in the field.
- With the other eye open and looking at the object or chart, turn the diopter adjustment ring all the way to the left. This will make the image blurry.
- Then slowly turn the diopter adjustment ring to the right until the image comes to the best focus possible.
- When the image is clear, **STOP**. Do **not** go beyond the initial clear focus.

Repeat the process for the other eye.

When using the NVG charts, check the focus on the objective lens after adjusting both diopter rings, and repeat the diopter adjustments to ensure the best visual acuity.

Notes.
Failure to properly adjust the diopter adjustment ring can result in eyestrain.
It should not be necessary to change the diopter setting during night operations. The setting adjusts for refractive errors in your eyes (nearsightedness, farsightedness). It does not focus for distance.

The amount of ambient illumination will affect the visual acuity you can achieve with NVGs. The best acuity you can expect with third-generation goggles is 20/40.

STEP 4. OBJECTIVE LENS ADJUSTMENT

During night operations, always adjust the objective lens for the desired distance to ensure objects are clear.

The lens is very sensitive at close distances; a slight movement can make things blurry or clear.

When the objective lens is turned all the way to the left, it is focused for the maximum distance, or what is often called the infinity setting. Close objects (e.g., your feet) will be blurred with this setting.

Note. In Experiments B through F, the NVG resolution chart was used before firing to adjust all soldiers' NVGs and to determine the visual acuity which was achieved. The field expedient techniques cited on page F-3 were not used.

EDITING TASK SHEET

Publication Number RR 1678 PBNUM ______

DATIME CODE ______

AUTHOR 1 Dyer

Title Shooting with night vision goggles

Instructions:

☒. Prepare front-end material as shown on SOP or as provided.

☒. Folio in nonreproducible blue pencil for xeroxing

☒. Prepare DD Form 282.

☒. Prepare DTIC Form 50.

~~☐. Prepare original copy for offset printing and folio in black lead pencil.~~

☒. Return original and 2 good copies of final copy.

Make covers and TP.

POC: H. SURLES, 274-9323/24

Date out ______ Contractor Reference Number ______

Date returned ______

DIRECTOR, ARI ID:703-274-5674 JUL 10,95 6:17 No.001 P.06
[RECEIVED 04/19 00:16 1900 AT 7036834915 PAGE 6 (PRINTED PAGE 6)]