REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1997	Technical Report

4. TITLE AND SUBTITLE
The Effect of Gender, Rifle Stock Length, and Rifle Weight on Military Marksmanship and Arm-Hand Steadiness

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Medical Research and Materiel Command
Fort Detrick
Frederick, MD 21702-5012

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The purpose of this study was to assess the effects of gender, rifle stock length and weapon weight upon marksmanship performance and arm-hand steadiness. Thirteen female and fifteen male soldiers were recruited. Performance on the Noptel marksmanship simulator showed no gender differences in marksmanship with the M16A2 rifle (standard) and the M4 carbine (a lighter rifle). Reducing the stock length from 10.3" to 7.0" significantly improved marksmanship scores for both male and female soldiers. Weapon weight was a critical factor; shot group tightness was better with the lighter M4 carbine (6.9 lbs) versus the heavier M16A2 rifle (8.4 lbs). Similar findings were found with arm-hand steadiness measures: shorter and lighter weapon configurations permitted better steadiness regardless of gender. Overall stock length and weapon weight should be considered in any new combat weapon design. Further investigation of these effects during live-fire with standard Army issued ammunition is warranted to confirm the generalizability of these results.

14. SUBJECT TERMS
marksmanship, rifle, gender differences, M16A2 rifle, M4 carbine, anthropometry, psychomotor performance, eye hand coordination, steadiness

15. NUMBER OF PAGES
61

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

TECHNICAL REPORT T9

THE EFFECT OF GENDER, RIFLE STOCK LENGTH, AND RIFLE WEIGHT ON MILITARY MARKSMANSHIP AND ARM-HAND STEADINESS

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BACKGROUND

The primary purpose of this study was to determine if a gender difference in marksmanship performance was detectable between male and female soldiers and if reducing weapon weight and stock length could improve marksmanship. Previous studies have suggested that there are gender-related differences in marksmanship performance and that these differences may be related to upper body strength and endurance. It has also been suggested that by reducing rifle stock length, marksmanship performance could be improved by improving the stability of the shooter.

There is currently little quantitative data available regarding differences between male and female soldier marksmanship performance with the standard U.S. Army issued weapon, the M16A2 rifle. Recently, the U.S. Army began issuing a smaller lighter version of the M16A2 rifle, the M4 carbine, to selected units. The M4 carbine is similar in many respects to the M16A2 except that it is substantially shorter and lighter, facilitating use by highly mobile Special Forces units and soldiers, such as Tank crew personnel and Military Police units, who must carry weapons in confined spaces.

The M16A2 rifle and M4 carbine provide readily available Army issued weapons which allow adjustment of stock length and two conditions of weapon weight. Weapons for use in this study were provided by Colt Manufacturing Inc., Hartford, CT, through a Cooperative Research and Development Agreement with the U.S. Army Research Institute of Environmental Medicine.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Kevin Kaminski of Colt Manufacturing Inc. for his technical support and loan of weapons. Thanks to COL Joel Hiatt for his continued support during the course of this work. We also want to thank the soldiers who volunteered for this project for their superior effort and dedication during the course of the study. A special thanks to SPC Todd S.J. Parent for his efforts initially as a subject, and as a research assistant for the last half of the study.

EXECUTIVE SUMMARY

The purpose of this study was to assess gender differences in marksmanship performance and the effects of reducing rifle stock length and weapon weight upon marksmanship performance and arm-hand steadiness. Thirteen female and fifteen male soldiers were recruited and completed the study. No gender difference in marksmanship performance was observed with either the M16A2 rifle or the M4 carbine. Reducing stock length from 10.3" to 7.0" significantly improved marksmanship scores, and reduced the distance of the center of mass of the shot groups from the center of the target for both genders. Shot group tightness was significantly better with the M4 carbine (6.9 lbs) versus the M16A2 rifle (8.4 lbs).

No significant gender difference was observed in arm-hand steadiness between male and female soldiers. However, shorter stock lengths (7.0" and 8.8") significantly reduced mean time off target in the arm-hand steadiness task for both genders. Time off target was also significantly reduced with the M4 carbine overall versus the M16A2 rifle. The number of errors counted was significantly less with the 7.0 inch stock versus both the 8.8 and 10.3 inch stock lengths, and errors were significantly reduced overall with the M4 carbine versus the M16A2 rifle. Subjects rated the M16A2 weapon configurations (stock lengths 7.0, 8.8, 10.3, and 11.0") harder to use and reported feeling more fatigued following testing with these weapons versus the M4 . The M4 carbine was rated easier to use and more comfortable than the heavier M16A2. Significantly more pain and discomfort was reported by subjects following testing with the M16A2 configurations versus the M4 carbine.

This study suggests that no gender difference exists between male and female soldiers shooting the M16A2 rifle and M4 carbine. The data indicate that reducing stock length and weapon weight improve overall marksmanship and arm-hand steadiness for both men and women. Overall stock length and weapon weight should be considered in any new combat weapon design as they do appear to significantly impact marksmanship. Further investigation of these effects during live-fire with standard Army issued ammunition is warranted to confirm these results.

INTRODUCTION

Since the early 1970s the number of women serving in the U.S. Army has increased fivefold. Over this period of time increasing numbers of female soldiers have been exposed to hostile forces during combat deployments. In 1983 female military police personnel deployed with the XVIII Airborne Corps in Grenada for Operation *Urgent Fury*. During Operation *Just Cause* in Panama (1989), nearly 800 women deployed. During Operations *Desert Shield/Desert Storm* (1990-1991), more than 26,000 women served in the Persian Gulf region and 4 female combat casualties were reported (Hasenhauer, 1992; 1994). Women are currently serving in several combat support units including air defense artillery, field artillery, and engineering (Hasenhauer, 1994).

Current governmental policy prohibits women from participating in direct ground combat (i.e., infantry or armor units). However, women are increasingly becoming involved in situations where they may face enemy forces. In spite of the growing number of women in the U.S. Army and their changing roles, there is a scarcity of published scientific information regarding female marksmanship performance with the current standard U.S. Army rifle, the M16A2 (Colt Manufacturing Inc., Hartford, CT).

Following training with either the M16A1 or M16A2, women were reported to score significantly lower than men when tested on a firing range (Thompson et al., 1980; Heiss, 1991). However, women have been shown to have greater hand-steadiness than men, and hand-steadiness has been shown to be correlated with marksmanship performance on the standard United States Marine Corps rifle marksmanship course (Hudgens et al., 1988; Malone, 1964). Aiming point fluctuations, which are an indication of arm/hand steadiness, have also been positively correlated with shot group dispersion during live firing (Lee and Yuan, 1995). Gender differences may be due to differences in upper body strength, stature, and arm length. Women have been reported to have 45% to 56% the maximal lift capacity of men in a single maximum effort lift to 132 cm (Vogel, 1989). Likewise, female isometric grip strength is only 61% to 63% that of males (Vogel, 1989; Clarke, 1986; Teves, et al., 1985). Direct comparison of grip strength and endurance has shown that women have lower initial grip strength than men and have lower absolute endurance (Clarke, 1986).

Since shooting performance has been shown to decline with increasing bouts of exercise intensity and increasing muscle fatigue (Hoffman et al., 1992), it seems possible, *a priori,* to suggest that during extended bouts of shooting, women may fatigue faster than men, thus leading to reduced accuracy (hitting where you're aiming) and precision (consistency of aiming) during shooting. Alternatively, less upper body strength may affect the ability of women to hold a weapon steady. A recent report by Johnson and Merullo (1996) supports this hypothesis. They found that after 1.5 hours of sentry duty, the number of targets hit by women was fewer than at the beginning of the session and significantly fewer than that of men (Johnson and Merullo, 1996).

It has been suggested that reducing rifle weight and stock length can significantly alter rifle holding posture and improve shooting performance (Lee and Yuan, 1959). These improvements in marksmanship accuracy and precision are most likely due to stabilization of the shooter-rifle system (Iskra et al., 1988), possibly by bringing the center of mass of the weapon closer to the shooter.

The standard U.S. Army rifle, the M16A2, weighs 8.9 lbs and has a stock of fixed length. The U.S. Army has recently begun issuing a smaller, lighter version of the M16A2, the M4 carbine, to select units. The M4 carbine is similar in many respects to the M16A2 except that is substantially shorter (with a collapsible stock) and lighter (6.9 lbs), facilitating use by highly mobile special Forces units and soldiers, such as Tank crew personnel and Military police units, who must carry weapons in confined spaces. The availability of these two U.S. Army issue weapons provides the capability of systematically assessing variations in stock length and weight on soldier performance. The primary purpose of this study was to determine if reducing weapon weight and stock length could improve marksmanship, and to determine if there is a gender difference in marksmanship performance as a function of weapon weight and/or stock length.

METHODS

SUBJECTS

Fifteen male and thirteen female volunteers (age 18-39 years) were recruited for this study. Written informed consent was obtained from each participant following a detailed briefing. The briefing included a review of the study objectives, a description of the protocol and procedures, and advisement of the right to terminate participation at any time during the course of the study. All test subjects were medically screened prior to participation in testing procedures. All men and women volunteers were tested for normal correctable vision (20/20 Snellen); only those prospective test volunteers with acceptable vision participated in marksmanship testing. Test subjects were recruited from the U.S. Army Soldier Systems Command (SSCOM) human research volunteer pool and from the local military personnel. No pregnant soldiers were used for this study.

Since it has been previously shown that hand-steadiness in women decreases only during premenses, no testing was done during this phase of the menstrual cycle. Each female subject was given a calendar to track their menstrual cycle. The menstrual phase was defined relative to menses as follows: mid-cycle (days 8-14 prior to menses), premenses (1-7 days prior to menses), menses (days of menstrual flow), and post-menses (days 1-7 after menses). This method of tracking menstrual cycle has previously been used successfully to assess changes in hand-steadiness in normally cycling women (Hudgens et al., 1988).

WEAPON CONFIGURATIONS AND TESTING

Four basic configurations of M16A2 rifles and M4 carbines each were used for the study: 1) a standard M16A2 rifle with a fixed 11" stock, weight 8.9 lbs, 2) an M16A2 rifle fitted with the adjustable stock (7, 8.8, or 10.3"), 3) an M4 carbine fitted with a fixed 11" stock and 4) an M4 carbine with an adjustable stock (7, 8.8, or 10.3"), weight 6.9 lbs (Table 1; Figure 1). Prior to testing, magazines were loaded with dummy rounds to simulate the approximate weight of a fully loaded weapon.

TABLE 1

WEAPON CONFIGURATIONS				
Weapon	Total Length (inches)	Stock Length (inches)	Weight (pounds)	Center Mass of Weapon (measured from butt-end in inches)
M16A2	35.6	7.0	8.4	18.8
M16A2	37.4	8.8	8.4	19.3
M16A2	38.9	10.3	8.4	19.4
M16A2	39.6	11.0	8.9	19.0
M4	29.8	7.0	6.9	14.2
M4	31.6	8.8	6.9	15.6
M4 carbine	33.1	10.3	6.9	16.6
M4 carbine	33.8	11.0	7.9	16.1

The M4 carbine is a smaller more compact version of the M16A2 rifle. The M4 carbine was designed with a shorter barrel (14.5") than the M16A2 (20 inch barrel) in order to reduce the weapon weight. The sighting and function of M4 carbine is the same as the M16A2, since the same receiver, bolt, hammer, and trigger assemblies are used in the M4 carbine.

NOPTEL MARKSMANSHIP SIMULATOR

Rifle marksmanship was quantified with a laser marksmanship simulator (Noptel ST-1000; Oulu, Finland) attached to either the M4 carbine or M16A2 rifle (Colt

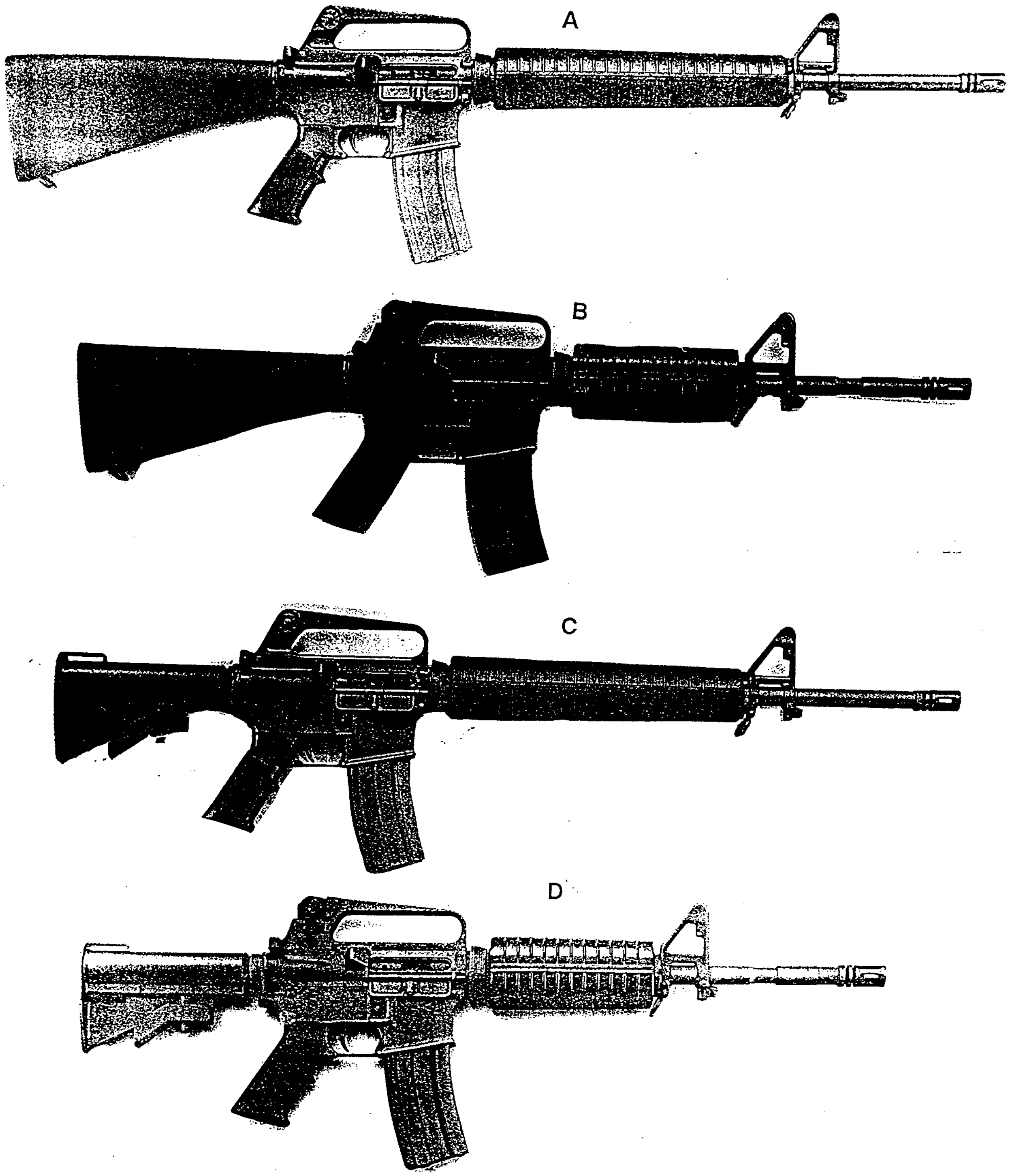


Figure 1. Weapon configurations. A. Standard M16A2 Rifle with a fixed 11 inch stock. B. M4 Carbine with fixed stock, 11 inches. C. M16A2 with collapsible stock; fully closed position shown (7.0 inches). D. Standard M4 Carbine with adjustable stock (fully closed position is shown; length 7.0 inches). The collapsible stock on the M16A2 and fixed stock on the M4 Carbine are modifications made for this study for the sake of experimental comparison. The weapons are not manufactured by Colt Inc. in these configurations.

Manufacturing Inc., Hartford, CT). Prior to testing, volunteers were familiarized on the Noptel Marksmanship Simulator using each of the weapon configurations. Volunteers were administered one 10-shot practice trial for each weapon configuration. A trial consisted of waiting for a signal to fire, sighting the target, and pulling the trigger. This was repeated 10 times to complete the trial. During familiarization with the weapons, marksmanship accuracy, precision and hold were emphasized. The marksmanship parameters assessed were the distance from center of mass (DCM), shot group tightness (SGT), and total point score (Figure 2). Subjects were tested while dry-firing the weapons in a standing position for all weapon configurations. Following a "ready" signal and a 3-15 second (randomly varied) preparatory interval, a red LED light positioned 16 cm to the lower left of the target was illuminated as the signal to shoot. During testing, a total of 80 shots were taken over a 20 minute session. Subjects remained standing during the entire session. The weapon was held at waist height and raised to shoot when the light signal was given.

The Noptel simulator consists of a laser transmitter, an optical glass laser sensor target, a personal computer, a printer, Noptel software, and the rifle (Figure 3). The laser transmitter emits a continuous 0.55 mm, 0.8 μm wavelength invisible beam that allows aiming positions to be monitored and recorded throughout the sighting and shooting process. A vibration sensor in the laser detects when the weapon is dry-fired. Shot location of the laser is recorded via its position on an optical laser glass sensor target located 5 meters from the subject. A paper target with a 2.3 cm diameter circle on it was placed directly above the glass sensor and acted as the aiming point. This simulated a 46 cm diameter target at 100 meters, which is similar to the standard 49 cm military E-type silhouette target at 100 meters. During testing all subjects were required to wear the U.S. Army issue Battle Dress Uniform and Kevlar vests and helmets.

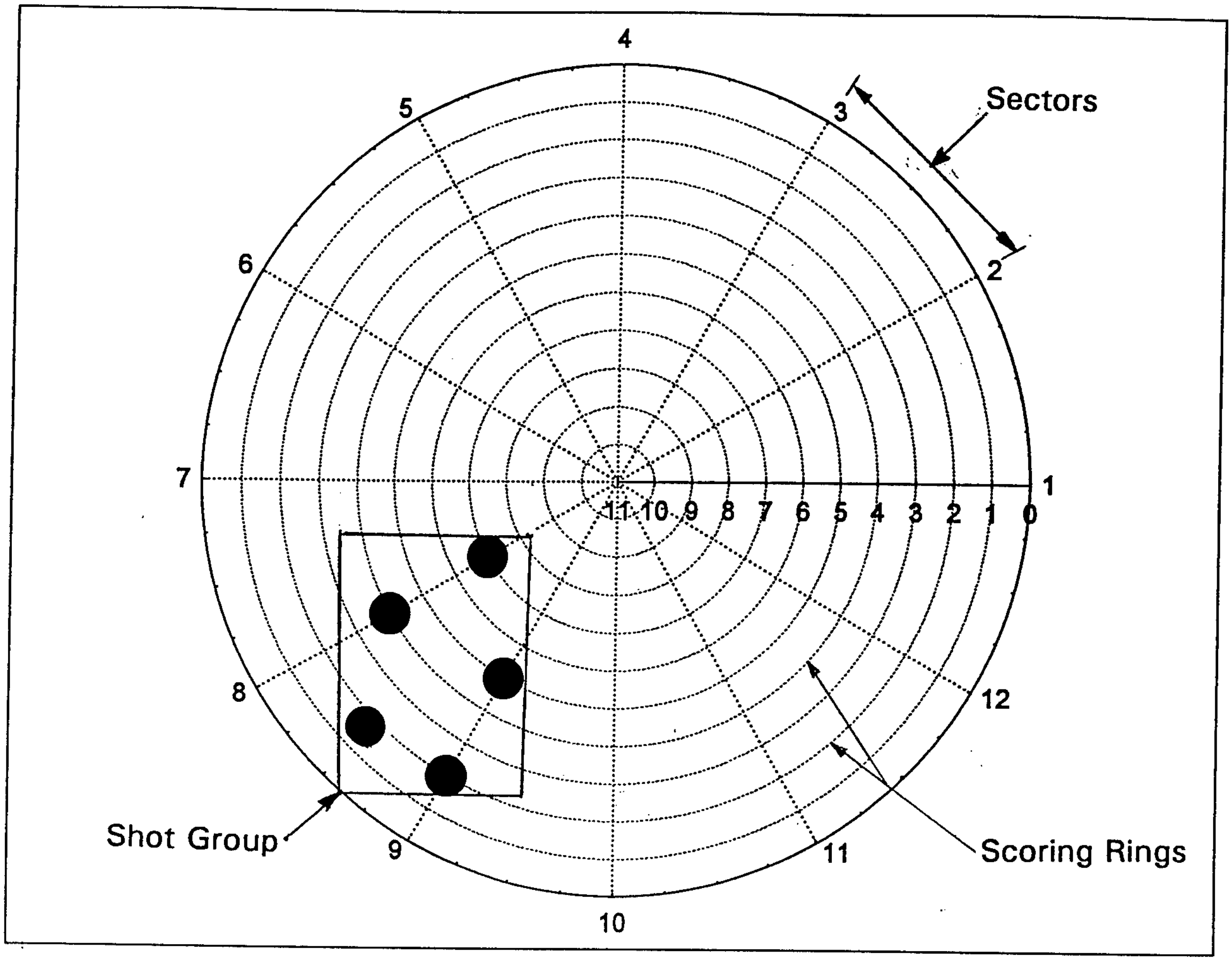


Figure 2. Noptel Marksmanship Simulator Screen. Each "shot" activates the Noptel laser and is recorded by an optical glass laser sensor target which is connected to a personal computer with Noptel software. The algorithm used to analyze the data divides the target into 12 equally divided "sectors." Each sector is subdivided by scoring rings which decrease in value from the maximum of eleven (a bulls eye) to zero (a miss). In this example, a "shot group" is based on 5 consecutive shots; during testing, 80 shots were used as the base. The following parameters were used for assessing marksmanship: 1. Distance from Center of Mass (DCM) is the mean distance (mm) of a shot group from the center of the target. 2. Shot Group Tightness (SGT) is the area (mm^2) of the shot group. 3. Total score is the sum of scores for all shot groups.

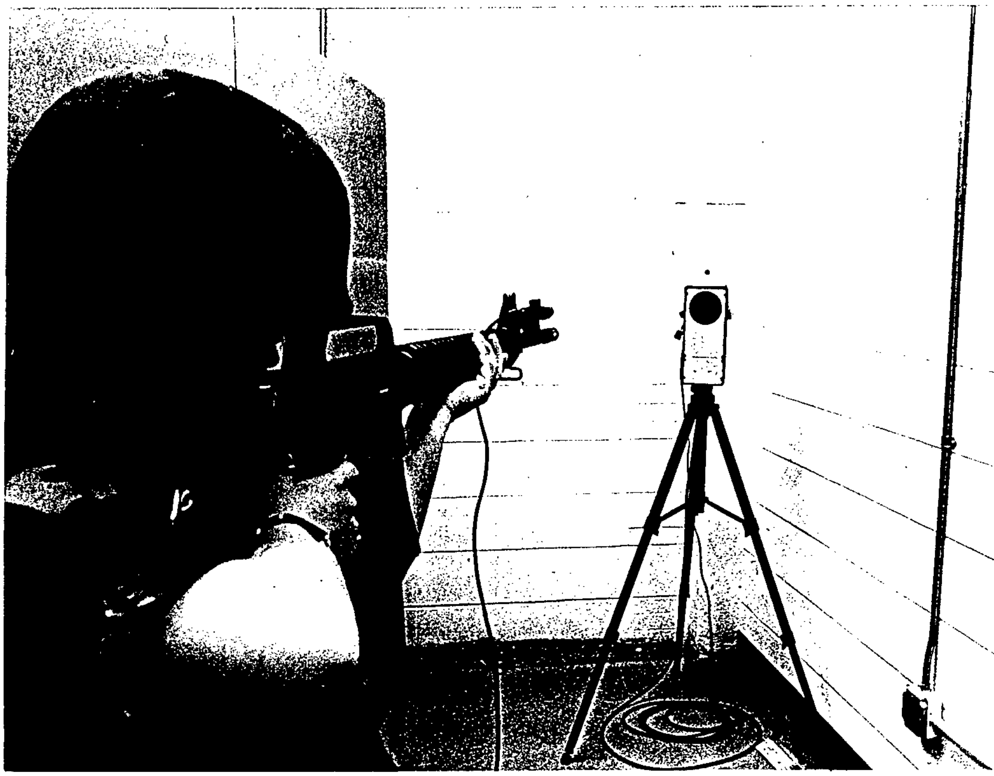


Figure 3. Female soldier shooting the Noptel laser marksmanship system. The soldier in the foreground is holding an M16A2 rifle with a collapsible stock. The Noptel laser can be seen on the front end of the weapon. The soldier aims at the small dot on the target paper located over the laser sensor which stands on top of the tripod.

ARM-HAND STEADINESS

Arm-hand steadiness was defined for this study as the ability to maintain the muzzle end of the weapon in a steady position with the weapon held at the shoulder in a standing position. Arm-hand steadiness was measured with a modified Gardner Steadiness Tester (Lafayette Instrument Company; Figure 4). The subject being tested stood in front of a metal plate mounted on a tripod set to the subject's shoulder height. The metal plate had a 4 mm hole in it. A 2 mm diameter metal stylus was attached to the end of the weapon being tested, and the subject was asked to keep the stylus in the hole without touching the sides of the hole for one minute. An electrical timer recorded the total amount of time the stylus was in contact with the side of the hole (referred to as time off target). In addition, a counter recorded the number of times the stylus hit the side of the hole. The number of times the stylus hit the side of the hole was recorded as the number of errors. Arm-hand steadiness was assessed for each weapon immediately following marksmanship testing.

ANTHROPOMETRY

Anthropometric, body composition, and maximal strength test measurements were made to describe the sample in relation to typical Army populations. Height (measured from the floor to the top of head) was measured with the subject in a standing position. Weight was recorded in kilograms. In addition to height and weight, the following anthropometric measures were taken:

a) sleeve outseam - the straight-line distance between the acromion landmark on the tip of the right shoulder and the stylion landmark on the right wrist.

b) arm length - the vertical distance from acromion to the tip of the middle finger.

c) shoulder-elbow length - the vertical distance from the acromion to the bottom of the elbow, measured with the elbow bent 90 degrees and the lower arm horizontal.

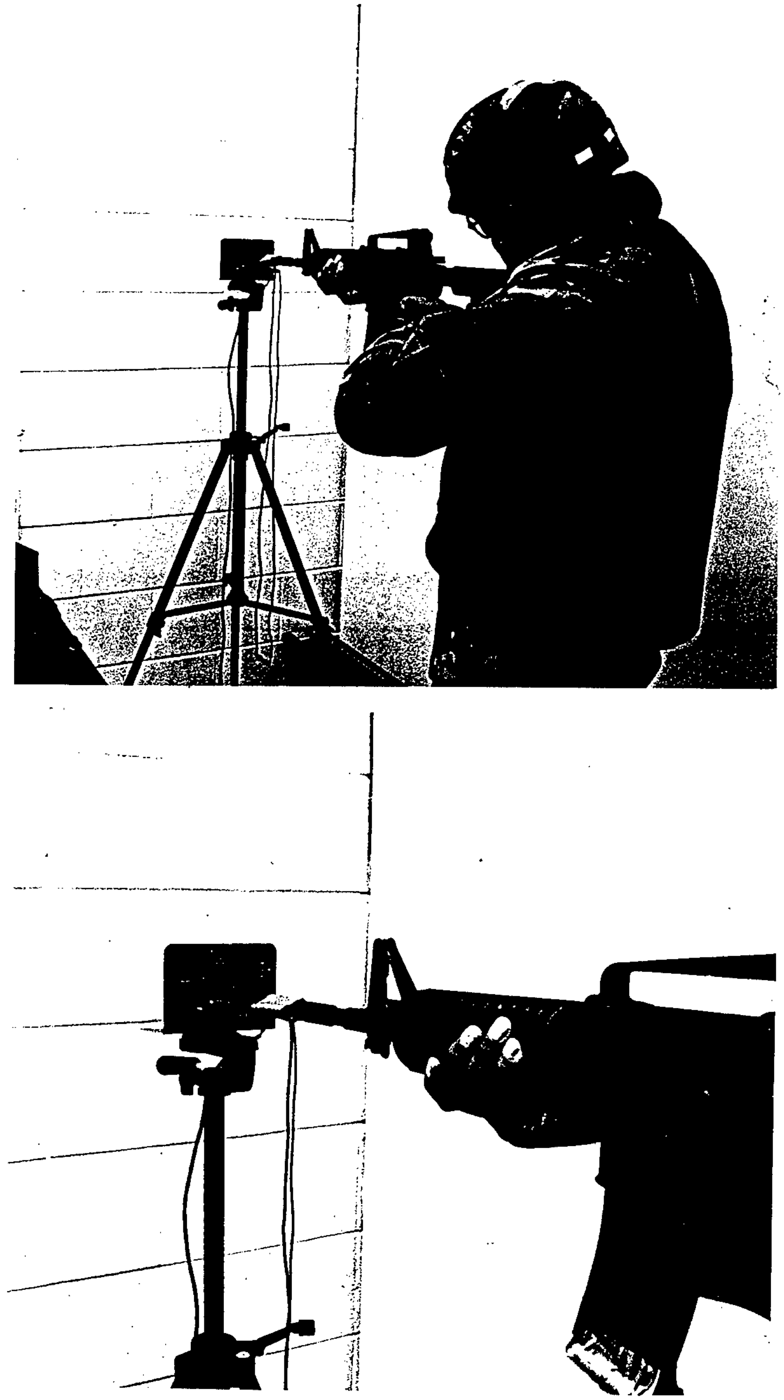


Figure 4. Arm-hand Steadiness Device. A. Arm-hand steadiness for each weapon was tested by attaching a 2 mm stylus to the end of the weapon and having subjects hold the weapon at shoulder height (standing shooting position) while holding the stylus in a 4 mm hole. The steadiness of the subject was assessed by the amount of time the stylus was not in the center of the hole (time off target) and the number of times the subject hit the side of the hole (errors). B. Close-up picture of stylus and metal plate.

d) radiale-stylion length - the distance from the radiale to stylion measured parallel to the long axis of the freely hanging lower arm.

e) elbow-grip length - the distance from the tip of the bent elbow to the center of the clenched fist.

f) hand length - the distance from the distal wrist crease to the dactylion of the middle finger (digit III) measured along the long axis of the hand.

g) palm length - the distance from the distal wrist crease to furrow where the middle finger (digit III) folds upon the palm.

h) hand breadth - the breadth of the hand between metacarpal-phalangeal joints II and V.

I) hand circumference - the circumference of the hand measured over the metacarpal-phalangeal joints.

j) forefinger length - the distance from the crotch of the thumb to the tip of the forefinger (digit II).

k) fist circumference - the circumference of the clenched fist (with the thumb lying across the end of the fist) measured with the tape passing over the thumb and the knuckles.

l) grip diameter, inside - the diameter of the widest level of a cone which the volunteer can grasp with his thumb and middle finger touching.

BODY COMPOSITION

The body composition of volunteers was assessed using dual energy X-ray absorptiometry (DEXA) in order to provide information concerning body composition and muscle mass for body regions. Women were screened for pregnancy using a blood test within 48 hours prior to this test.

MAXIMAL STRENGTH TESTS

The maximal capacity strength (1 RM) for grip strength, bench press, overhead press, left and right arm curl, tip-to-tip finger pinch, lateral finger pinch, 3-jaw chuck finger pinch, trigger pull with index finger, and supporting arm maximal lift strength (arm raise strength) and supporting arm fatigue were measured. For all strength tests, volunteers were instructed to use proper lifting technique, and adequate rest was provided between maximal strength attempts.

For bench press and overhead press, following a warm-up set, weight was added with each successive 1 RM attempt, until the volunteer could not safely complete the lift (according to USARIEM Type Protocol, 8 November 1993). The warm-up consisted of three to six lifts at 30% or less of the volunteer's subjective predicted maximum for the first two or three trials of the test (less than 50% of the subjective predicted maximum), as suggested by Semenick, 1994. Weight was added according to each volunteer's subjective assessment of his or her ability and was in 1-10 kg increments. A minimum of three minutes rest was given after each attempt. After a failed attempt, weight was removed to yield an intermediate load to assess 1RM as accurately as possible (to the nearest 1.0 kg). Arm-curl strength was assessed using dumbbells for each arm individually.

To measure handgrip, pinch strength and isometric trigger strength, the volunteers were seated at a table, with the shoulder at 0°, elbow at 90°, and wrist neutral, and instructed to squeeze a molded handgrip, pinch dynamometer, or to squeeze a trigger. To measure arm raise strength, subjects stood as if firing a rifle, their shoulder and elbow held at the angles they used during M16 weapon firing (as determined by prior goniometric measurement), while gripping a round, taped aluminum handle. The handle was attached by cable to a load cell mounted on a wooden slip free platform. The subject was instructed to lift up on the handle as hard as they could. The maximum force produced, in all cases, was measured with a load cell and registered on a digital readout. The highest two of the three trials (within 10% of one another) was averaged.

QUESTIONNAIRES

A pain, soreness and discomfort scale (PS&DS) was given before and after each marksmanship testing session to provide information on any muscular symptoms that might have resulted from the sustained contractions during the session. The PS&DS required volunteers to rate their level of pain, soreness and discomfort on 22 body sections using a modified Corlett and Bishop scale (Corlett and Bishop, 1976; Appendix A). A rating of perceived exertion (RPE; Appendix B) on a 15-point Likert-type scale provided information on how hard volunteers felt they were working (Borg, 1962; Borg, 1982) and the level of fatigue in their supporting arm. Subjects were also asked to rate the weapon configuration they had just tested for comfort and ease-of-use on a 15-point scale. The subjects were also asked to subjectively rate their preference for each weapon they had tested with. They were simply shown a picture of the weapons and asked to rate them in order of preference from 1 (best liked) to 8 (least liked).

RESULTS

MARKSMANSHIP

Data from marksmanship testing (total points, DCM, SGT) were analyzed with an overall 2 X 2 X 4 (gender X weapon X stock length) repeated measures analysis of variance. No significant main effect was found for gender, weapon, or stock length. Marksmanship data from the M16A2 configurations (Figures 5, 6, & 7) tended to be similar for both males and females; whereas, marksmanship data from the M4 carbine configurations tended to show a slight gender bias (Figures 8, 9, & 10). However, none of these comparisons was statistically significant. The means and standard deviations for marksmanship data are presented in Table 2.

FIGURE 5

Marksmanship Results with the M16A2: Total Points Scored

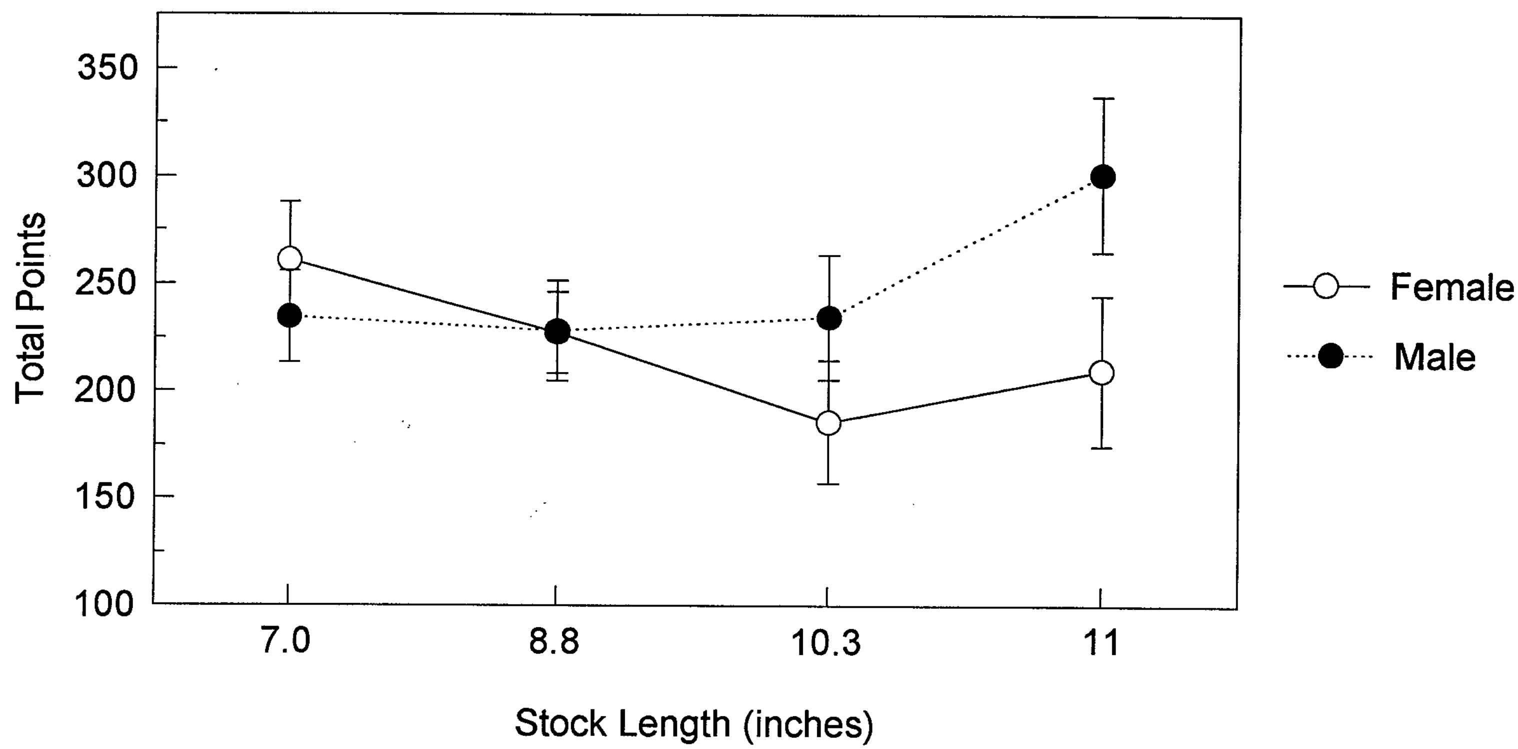


FIGURE 6

Marksmanship Results with the M16A2: Distance from Center Mass

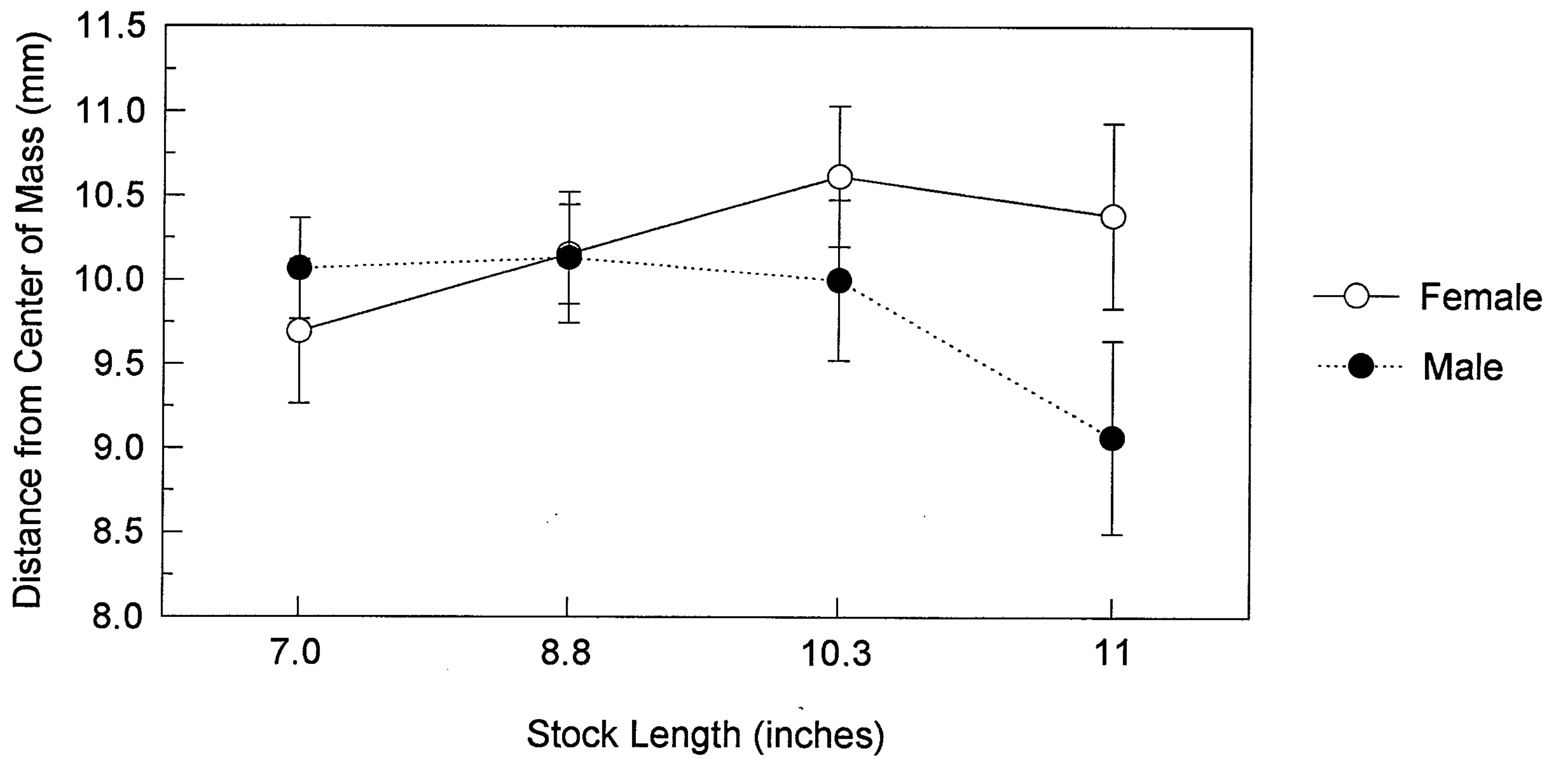


FIGURE 7

Marksmanship Results with the M16A2: Shot Group Tightness

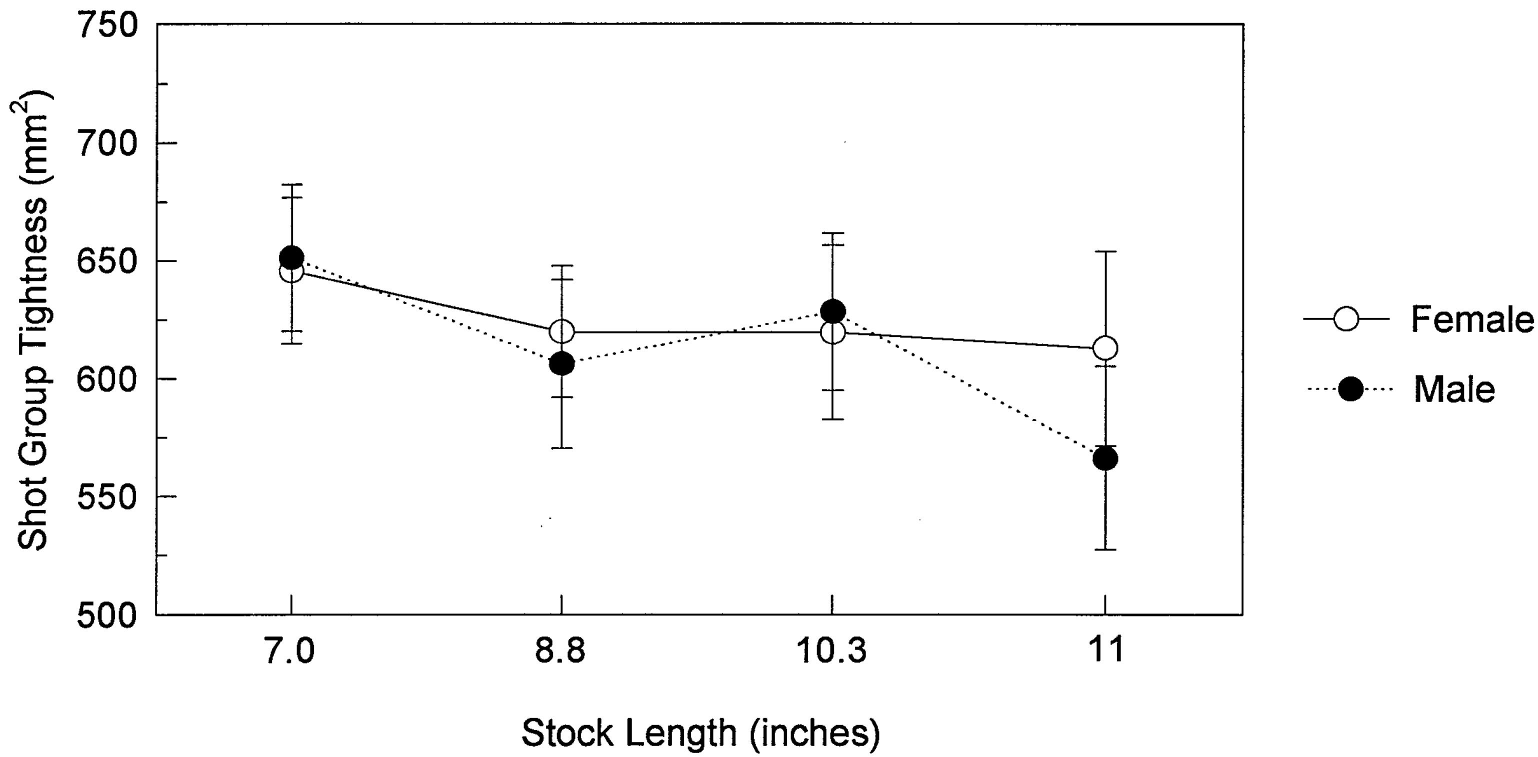


FIGURE 8

Marksmanship Results with the M4 Carbine: Total Points Scored

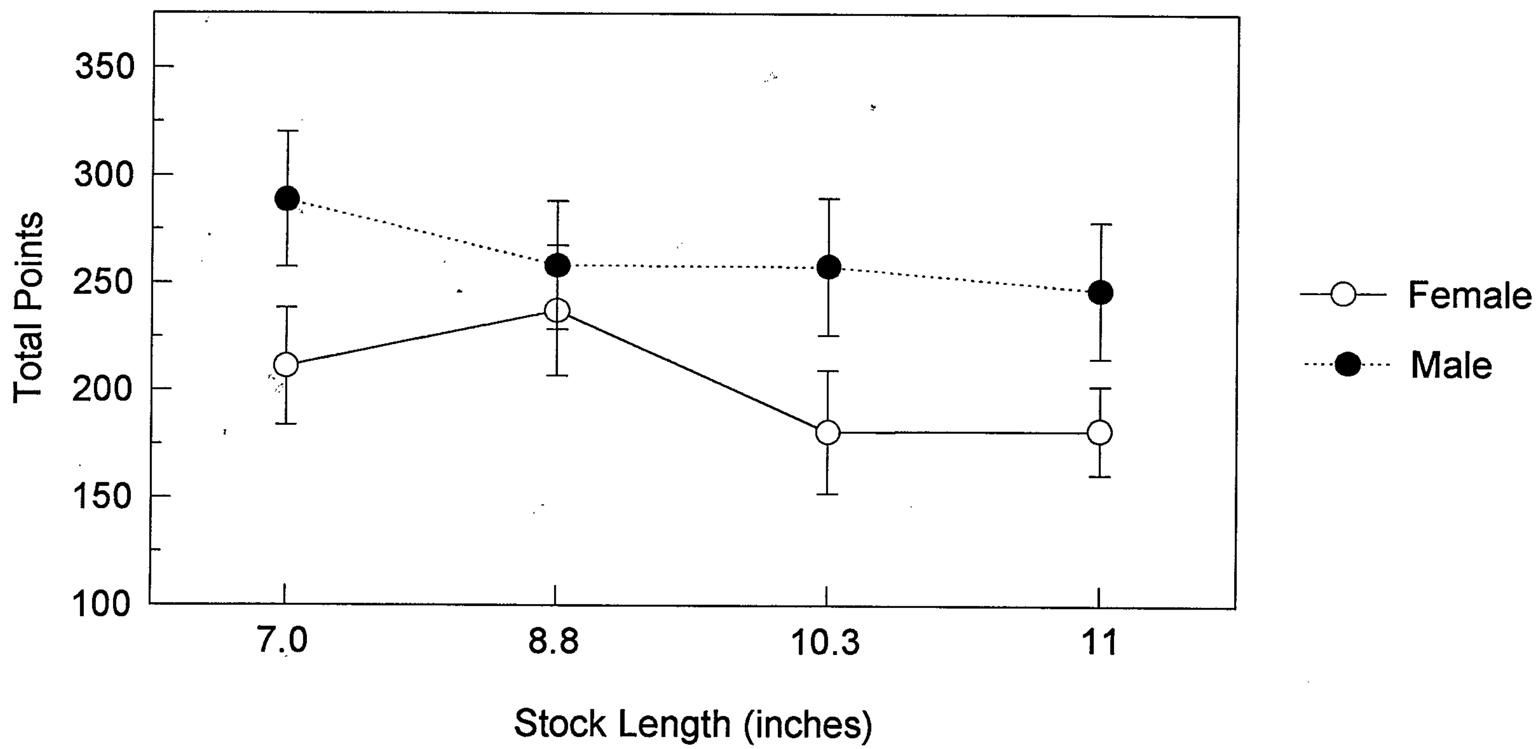


FIGURE 9

Marksmanship Results with the M4 Carbine: Distance from Center Mass

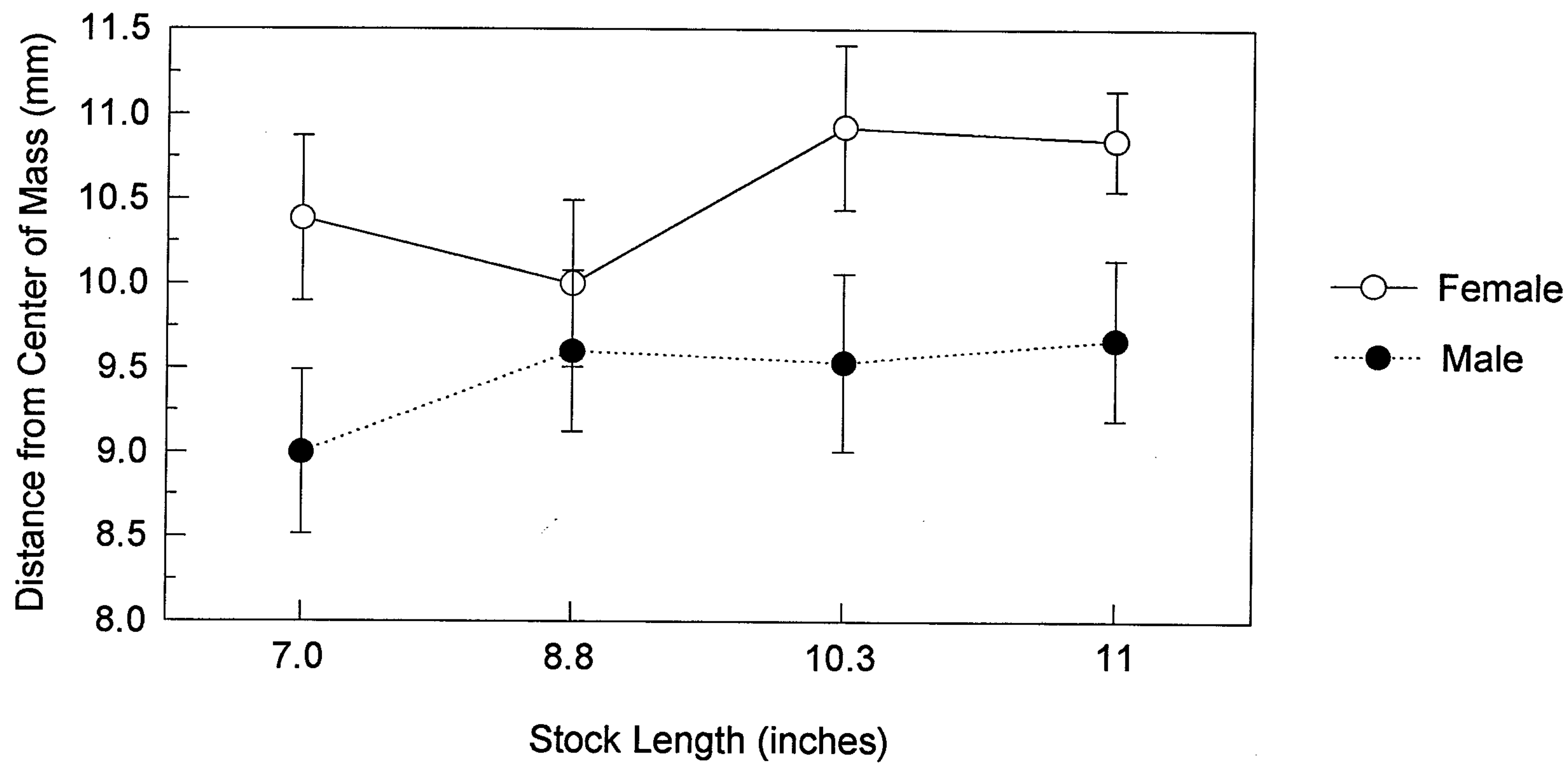


FIGURE 10

Marksmanship Results with the M4 Carbine: Shot Group Tightness

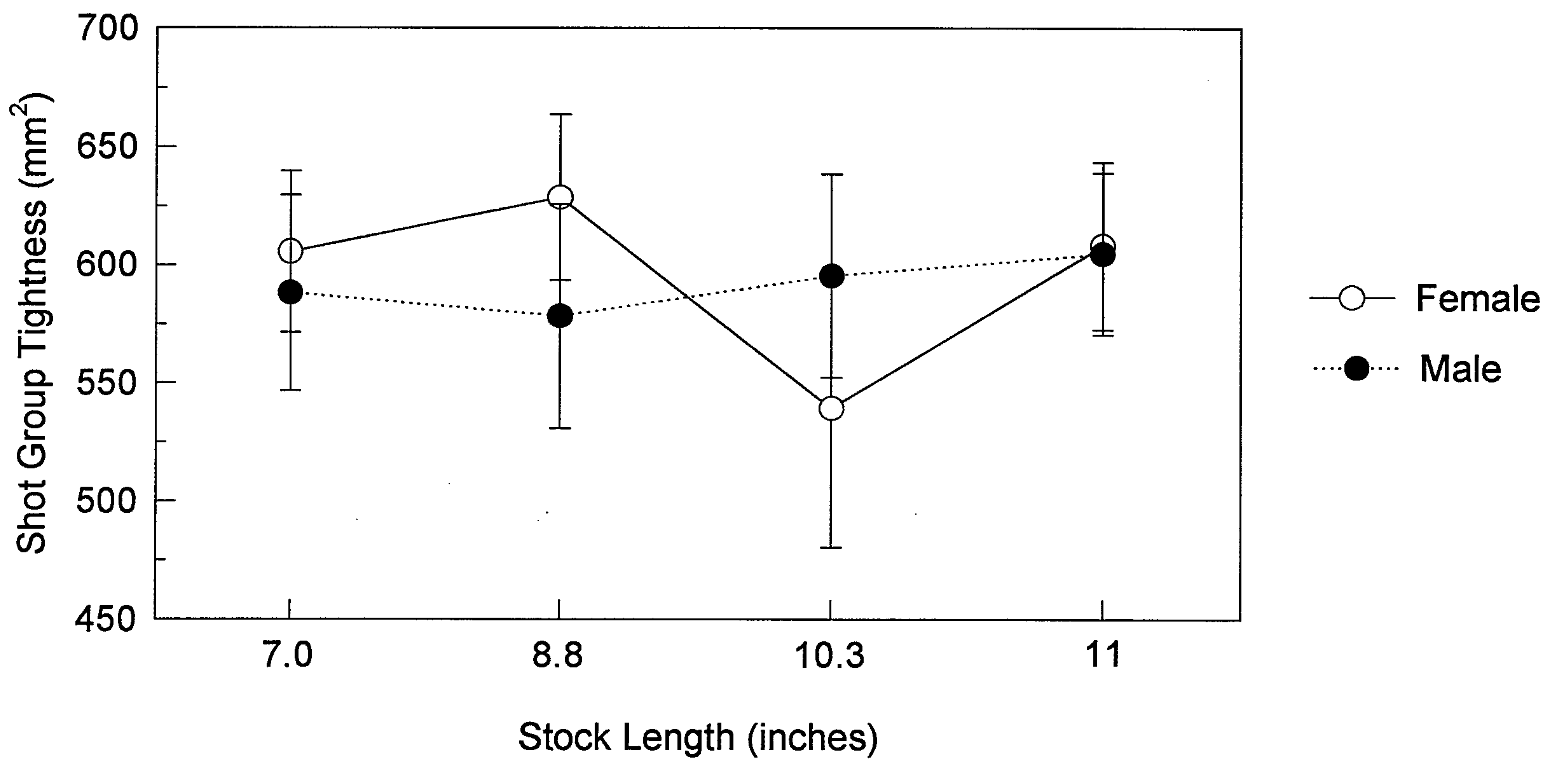


TABLE 2

DESCRIPTIVE STATISTICS FOR NOPTEL MARKSMANSHIP, MEANS AND STANDARD DEVIATIONS FOR TOTAL POINTS, DISTANCE FROM CENTER OF MASS AND SHOT GROUP TIGHTNESS.

TOTAL POINTS								
	M16A2 7"Stock	M16A2 8.8"Stock	M16A2 10.3"Stock	M16A2 11"Stock	M4 7"Stock	M4 8.8"Stock	M4 10.3"Stock	M4 11"Stock
Female	260.7±97.8	227.2±68.4	185.6±103.8	209.4±126.4	211.0±98.4	237.0±109.8	180.6±103.2	181.4±73.7
Male	234.4±83.0	227.9±91.3	234.4±112.9	301.2±140.8	288.8±121.9	258.2±115.9	257.7±123.7	246.9±124.0
All Groups	246.6±89.4	227.5±80.0	211.7±109.6	258.6±139.9	252.7±116.5	248.4±111.6	221.9±119.2	216.5±107.2

DISTANCE FROM CENTER OF MASS								
	M16A2 7"Stock	M16A2 8.8"Stock	M16A2 10.3"Stock	M16A2 11"Stock	M4 7"Stock	M4 8.8"Stock	M4 10.3"Stock	M4 11"Stock
Female	9.6±1.5	10.1±1.1	10.7±1.6	10.4±2.0	10.3±1.5	9.9±1.7	10.8±1.6	10.8±1.1
Male	10.0±1.3	10.1±1.4	10.0±1.7	8.9±1.2	9.1±1.9	9.6±1.8	9.6±1.9	9.8±1.9
All Groups	9.8±1.4	10.1±1.2	10.3±1.7	9.6±2.2	9.7±1.8	9.8±1.7	10.2±1.8	10.3±1.7

SHOT GROUP TIGHTNESS								
	M16A2 7"Stock	M16A2 8.8"Stock	M16A2 10.3"Stock	M16A2 11"Stock	M4 7"Stock	M4 8.8"Stock	M4 10.3"Stock	M4 11"Stock
Female	645.8±112.1	620.1±100.7	619.8±133.4	612.8±148.9	605.7±123.4	628.9±126.3	539.5±213.2	608.0±128.4
Male	651.3±120.8	606.3±138.7	628.3±129.2	566.2±150.9	588.4±160.7	578.3±183.9	595.4±167.2	604.7±132.8
All Groups	648.8±114.7	612.7±120.5	624.4±128.8	587.9±149.0	596.4±142.3	601.8±159.0	569.4±188.4	606.2±128.4

Review of the raw data showed that subjects shot rather poorly with all weapons (ca. 30% of total possible score), although they performed slightly better with the M16A2 with 11 inch stock (standard M16A2). All subjects practiced with each weapon configuration but due to time constraints were not trained to asymptotic performance levels. Since all had extensive practice firing the standard M16A2 during basic training, subjects were much more familiar with this weapon. During prior experience, some subjects may have devised strategies to help them shoot better, which they were able to apply to the standard M16A2 but had not tested on the experimental weapon configurations. Since there was difference in weapon weight due to the differing weights of the fixed versus collapsible stock (Table 1), weapon weight must be considered in the interpretation of the data. Therefore, the data were reanalyzed using only the collapsible stock configurations in a 2 x 2 x 3 (gender x weapon x stock length) repeated measures ANOVA. The standard M16A2 and the M4 carbine with fixed 11 inch stock were not used in the analysis. This alternative data analysis eliminates the possible confounding effects caused by additional familiarity with the standard M16A2, and varying weapon weights. This procedure provides two stable weight categories: 8.4 lbs for all M16A2 configurations and 6.4 lbs for all M4 carbine configurations.

When collapsible stock M16 and M4 configurations were reanalyzed, stock length and weapon type were found to significantly affect marksmanship. Post-hoc analysis revealed mean total points scored with weapons having the 7" stock were significantly better than with the 10.3 " stock ($P<.04$; Figure 11). The mean DCM was significantly less for weapons with the 7" stock versus the 10.3" stock ($P<.04$; Figure 12). Overall SGT was significantly better for the M4 carbine versus the M16A2 ($P<.04$; Figure 13).

ARM-HAND STEADINESS

Data from arm-hand steadiness tests were analyzed with an overall 2 X 2 X 4 (gender X weapon X stock length) and also a 2 X 2 X 3 (gender x weapon x stock length) repeated measures ANOVA (again, excluding the fixed stock configurations). No significant gender effect was found (Figures 14, 15, 16, 17). However, significant main effects were found for both stock length and weapon type in both analyses. The arm-hand steadiness data did not show any bias toward the M16A2. This is likely due to the fact that this was a novel task.

The amount of time spent "off target" was significantly reduced at stock lengths of 7 and 8.8 versus the 10.3 inch stock length ($P<.01$; Figure 18). Time off target was significantly less for the M4 carbine versus the M16A2 configurations ($P<.0001$; Figure 19).

The number of errors (number of times the stylus touched the metal plate) was significantly reduced at the 7 inch stock length versus both the 8.8 and 10.3 inch stock lengths ($P<.01$; Figure 20). The number of errors was significantly less for the M4 carbine overall versus M16A2 configurations ($P<.0003$; Figure 21).

Post-hoc analysis of the 2 X 2 X 4 ANOVA showed time off target was significantly less for the M4 carbine with the 7.0 inch stock versus the M4 with the 10.3 inch stock length ($P<.05$; Figure 22). Time off target was significantly less for M4 carbine configurations with the 7 and 8.8 inch stocks versus all configurations of the M16 and both the 10.3 and 11 inch fixed stock M4 carbine configurations($P<.05$; Figure 22). No significant difference between M16A2 configurations was found ($P>.05$; Figure 22). Errors were significantly less for all M4 configurations versus all M16A2 configurations except for the M16A2 with the 7 inch stock ($P<.05$; Figure 23).

FIGURE 11

Plot of Mean Total Points: Main Effect for Stock Length

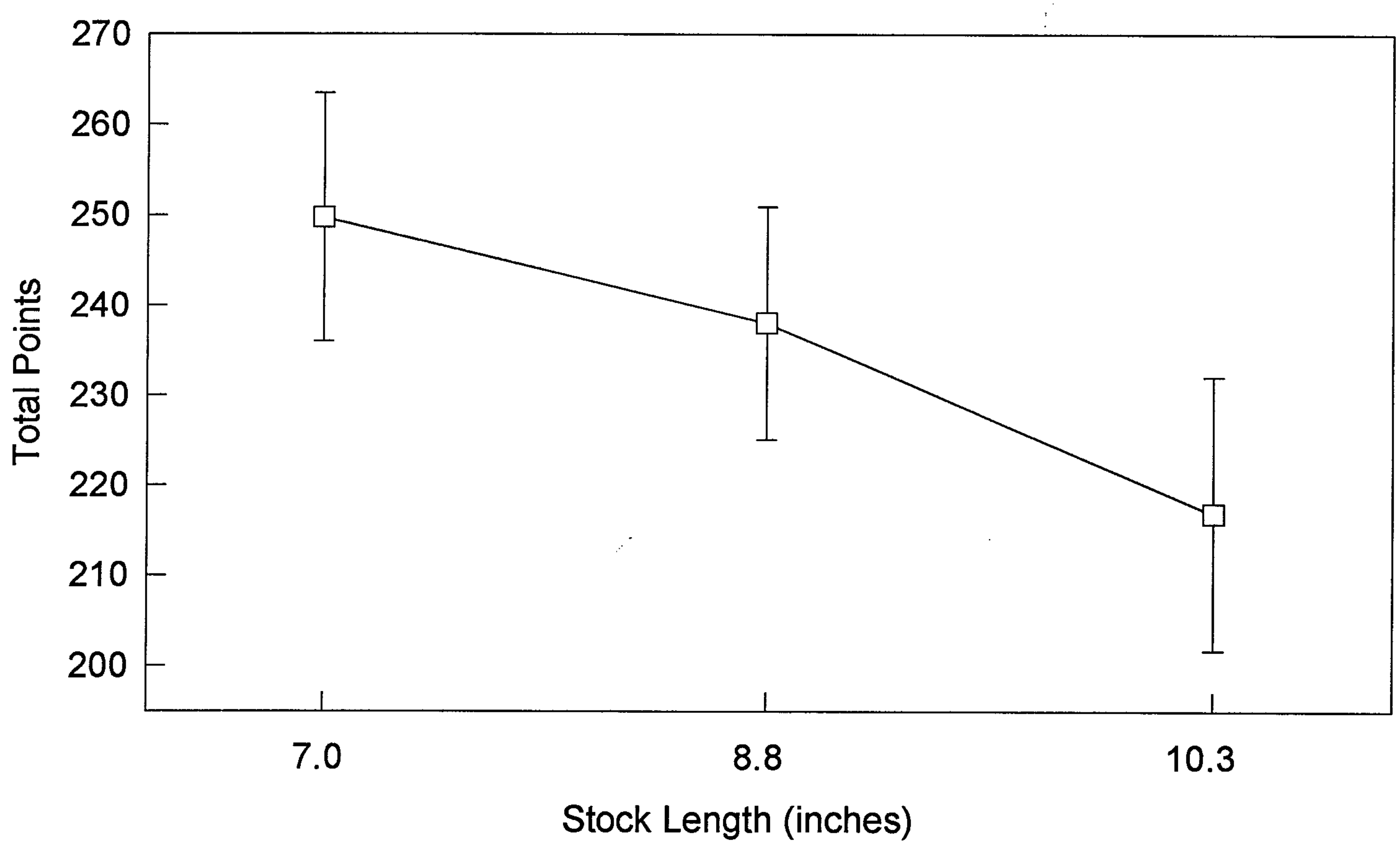


FIGURE 12

Plot of Mean Distance from Center of Mass: Main Effect for Stock Length

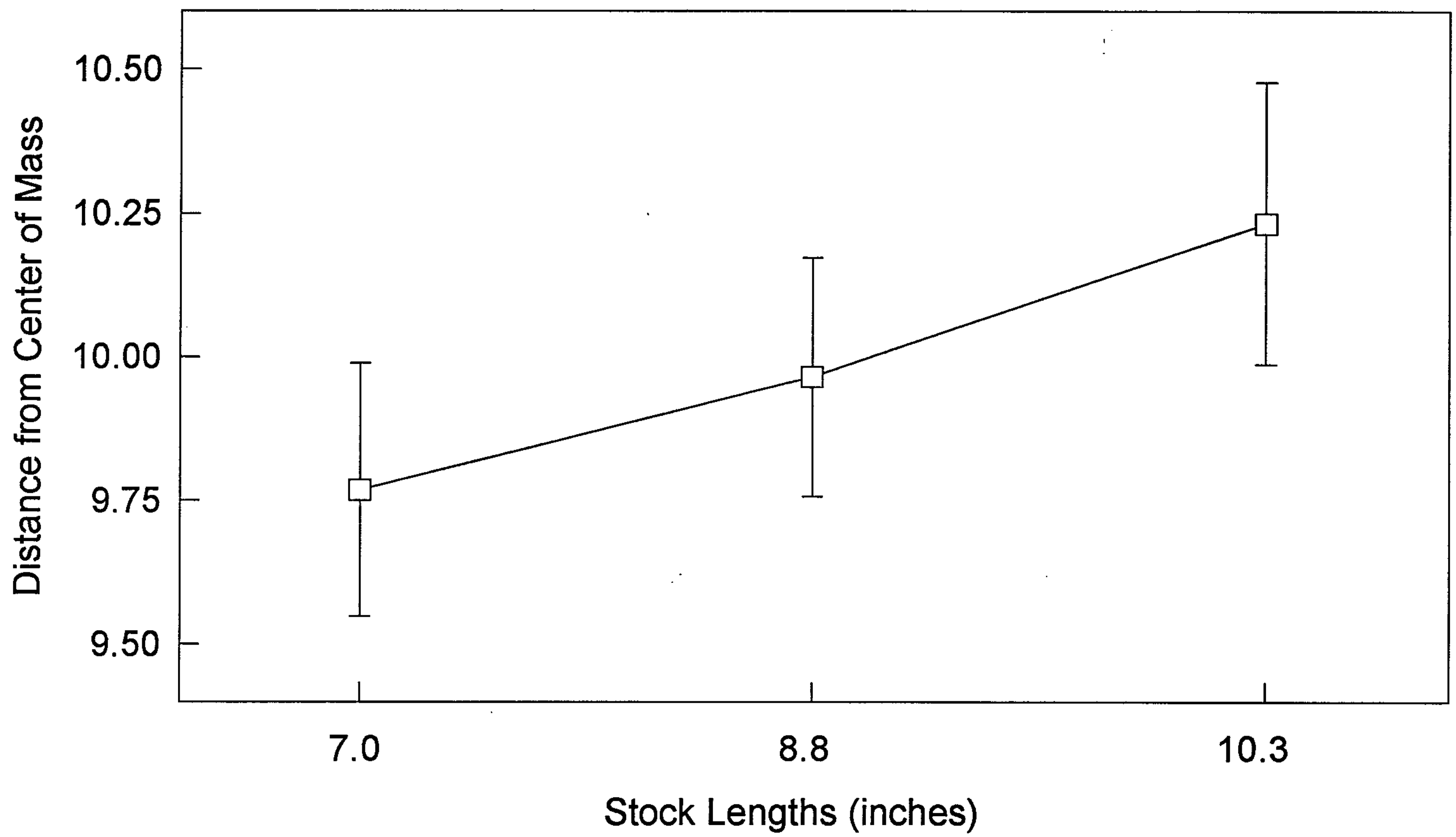


FIGURE 13

Plot of Mean Shot Group Tightness: Main Effect for Weapon

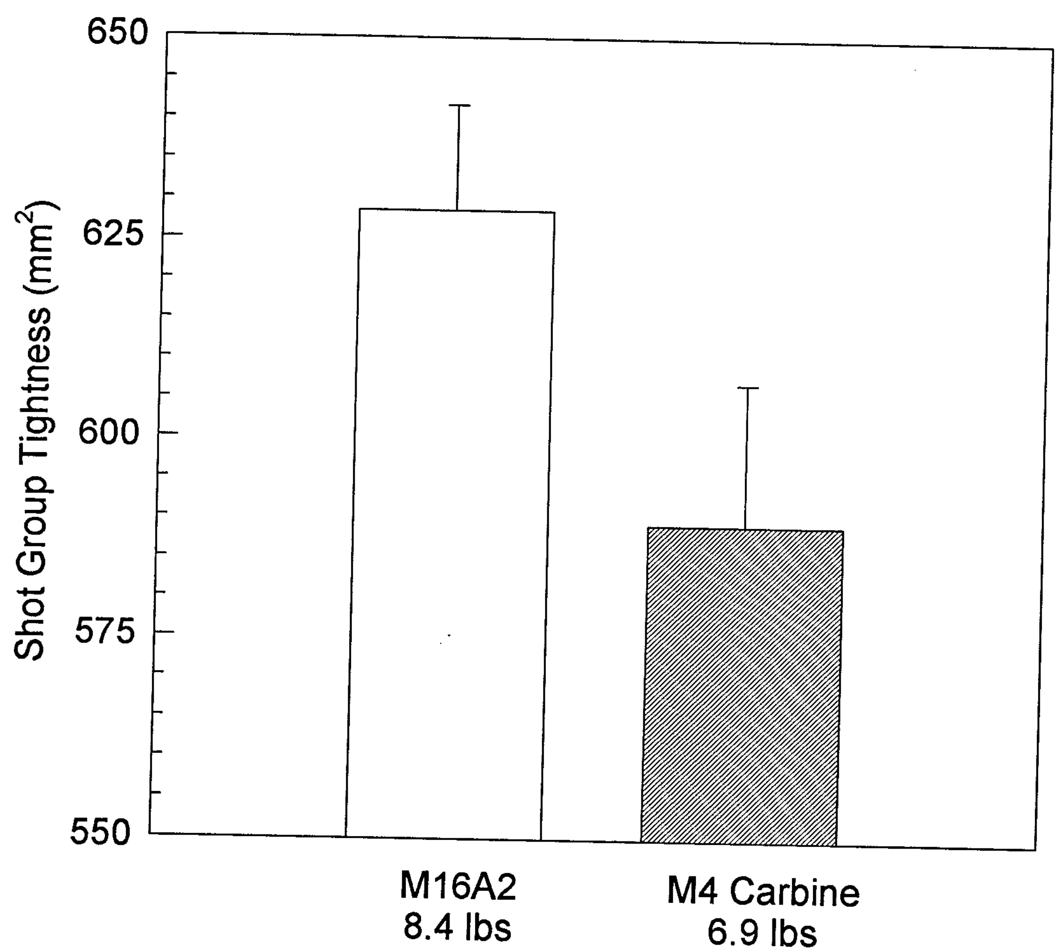


FIGURE 14

Arm-Hand Steadiness Results with M16A2: Time off Target

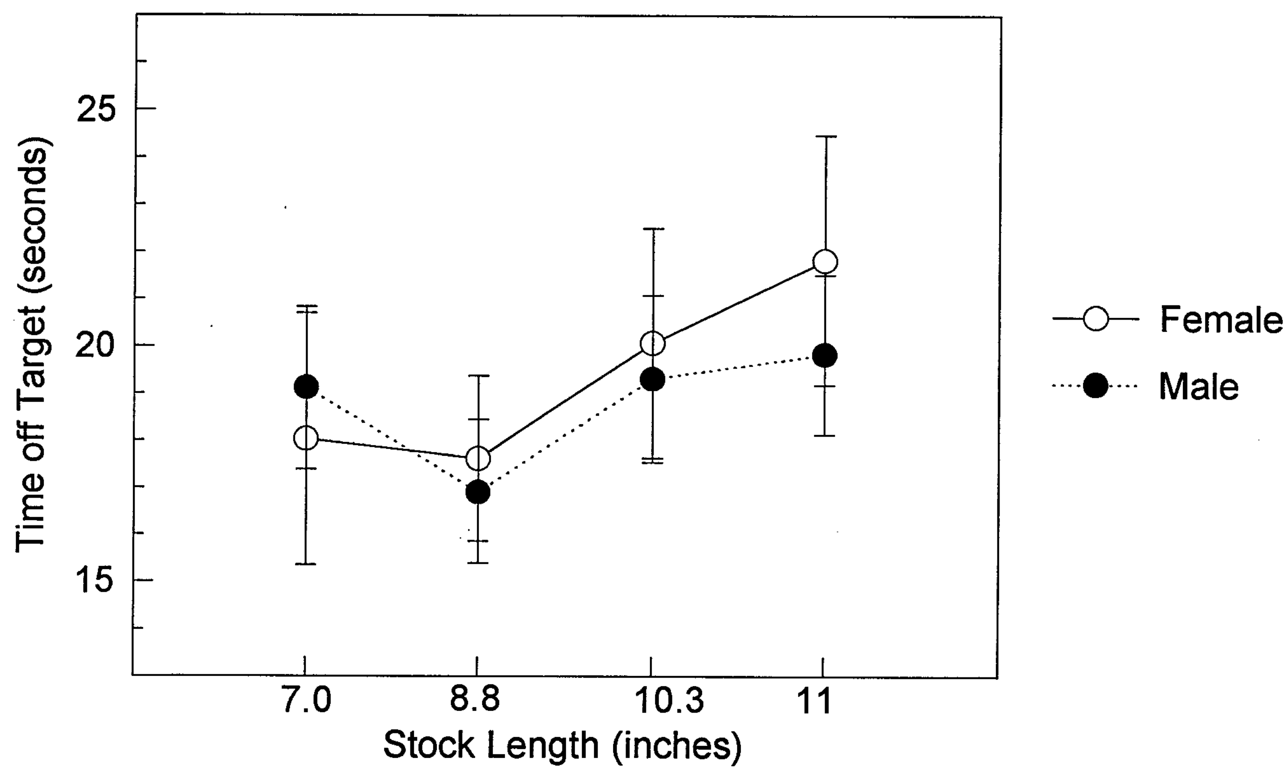


FIGURE 15

Arm-Hand Steadiness Results with M4 Carbine: Time off Target

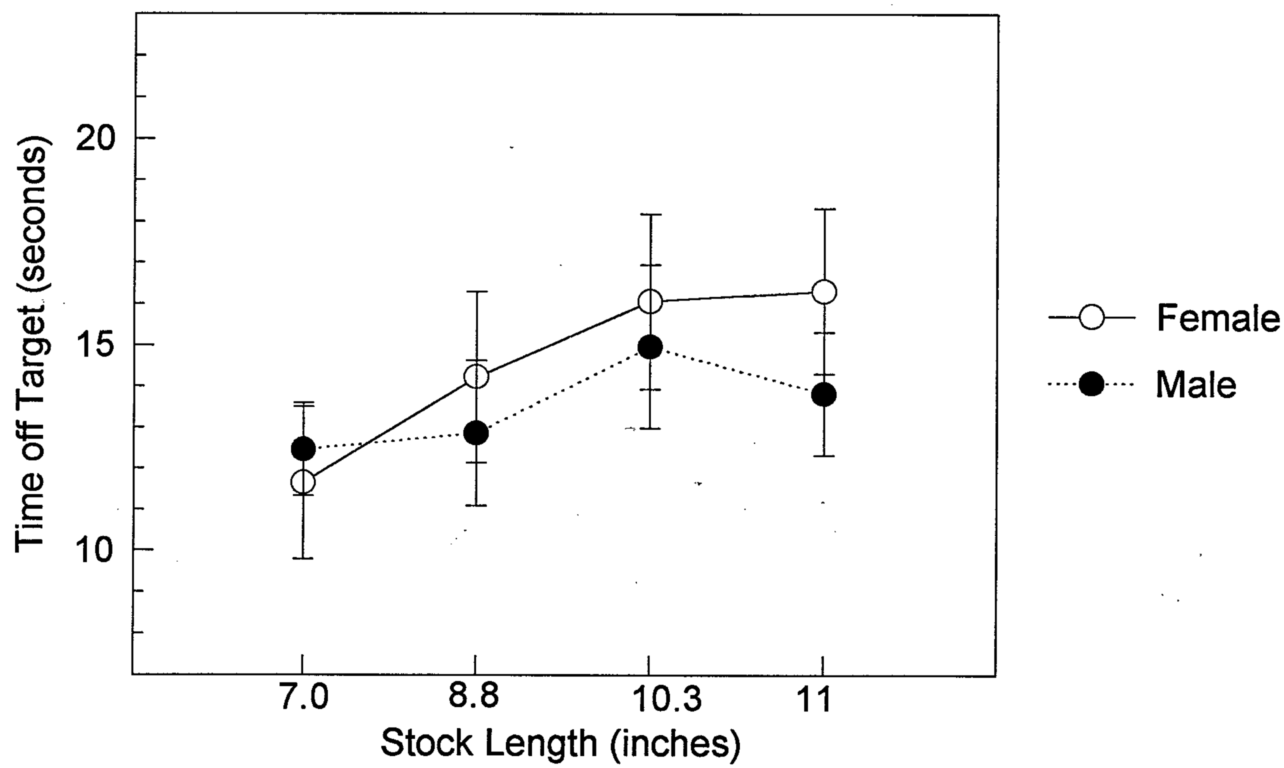


FIGURE 16

Arm-Hand Steadiness Results with the M16A2: Errors

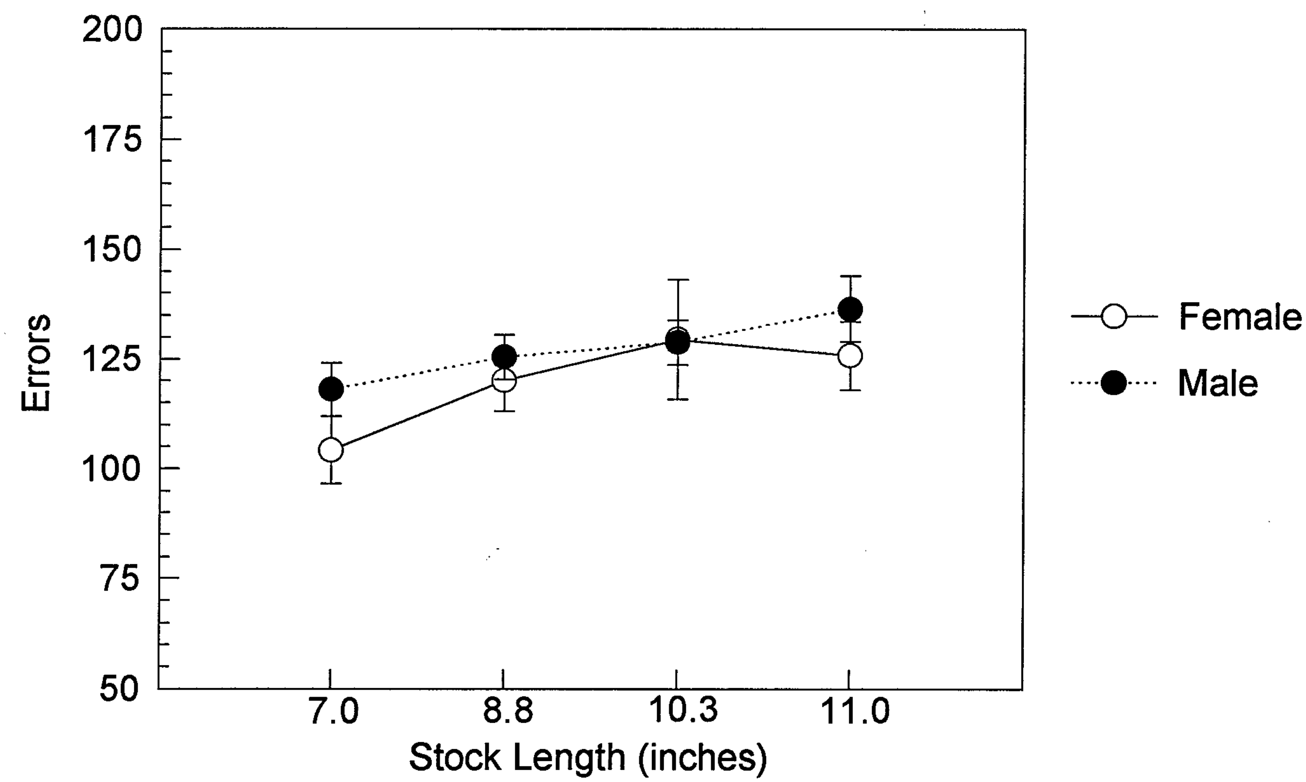


FIGURE 17

Arm-Hand Steadiness Results with the M4 Carbine: Errors

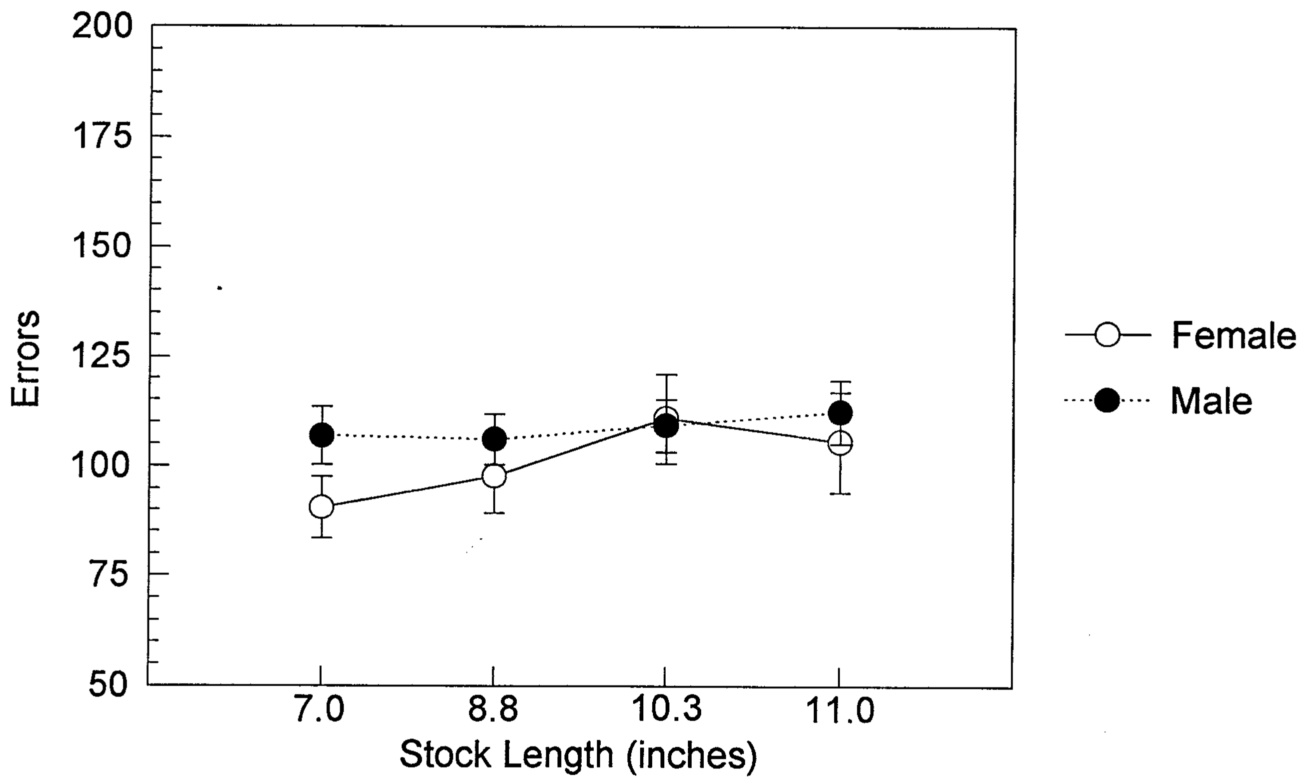


FIGURE 18

Plot of Mean Time off Target: Main Effect for Stock Length

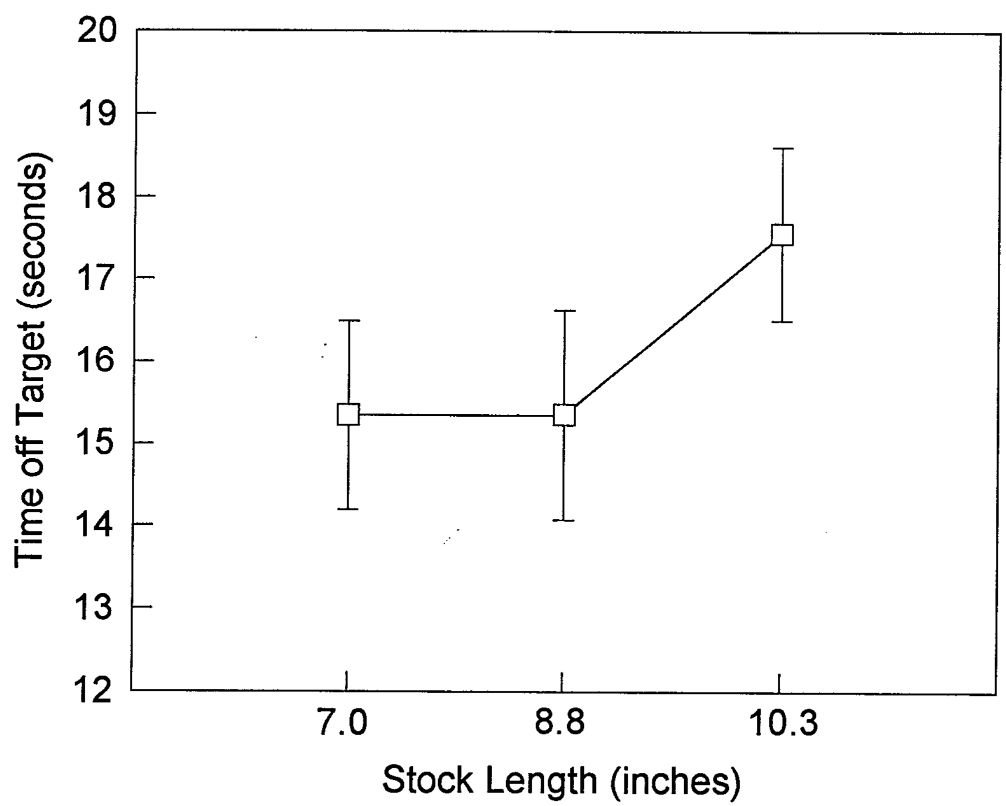


FIGURE 19

Plot of Mean Time off Target: Main Effect for Weapon

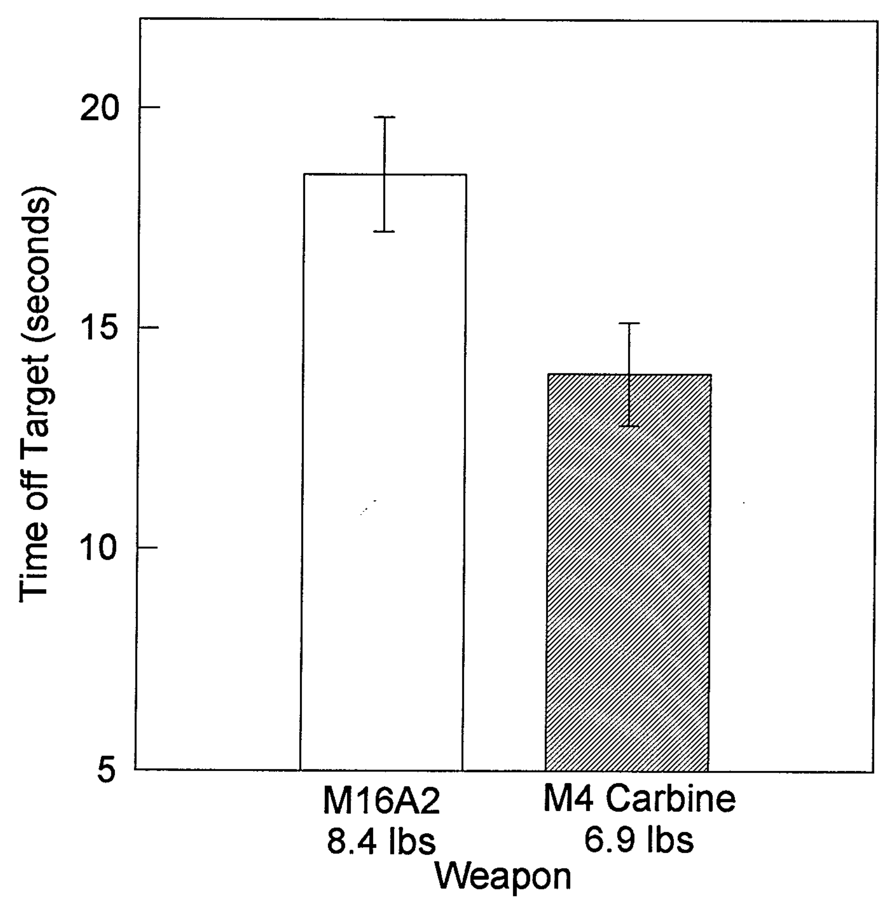


FIGURE 20

Plot of Mean Errors: Main Effect for Stock Length

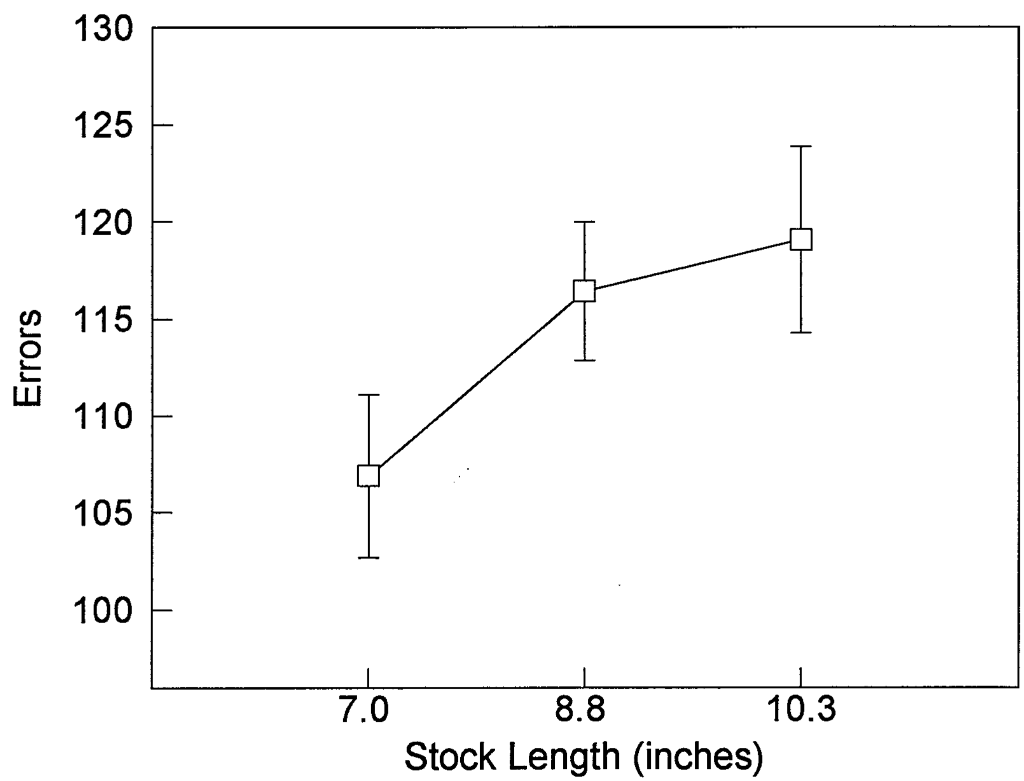


FIGURE 21

Plot of Mean Errors: Main Effect for Weapon

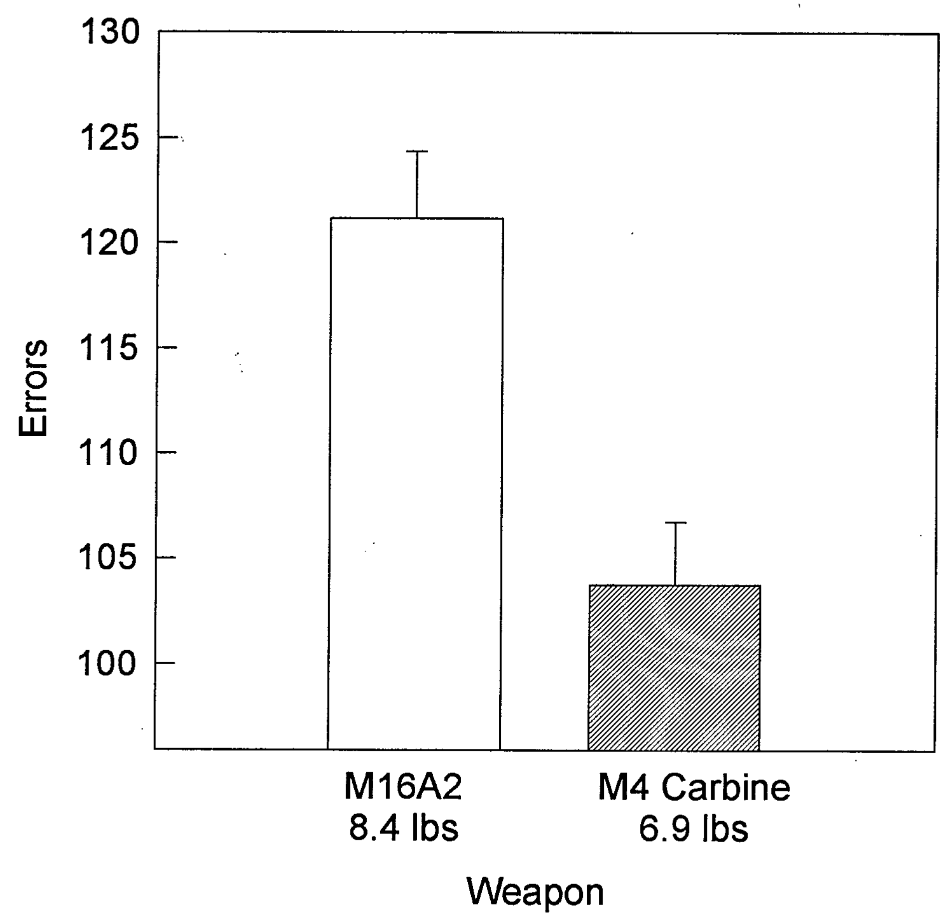


FIGURE 22

Plot of Mean Time off Target for all Groups and Stock Lengths

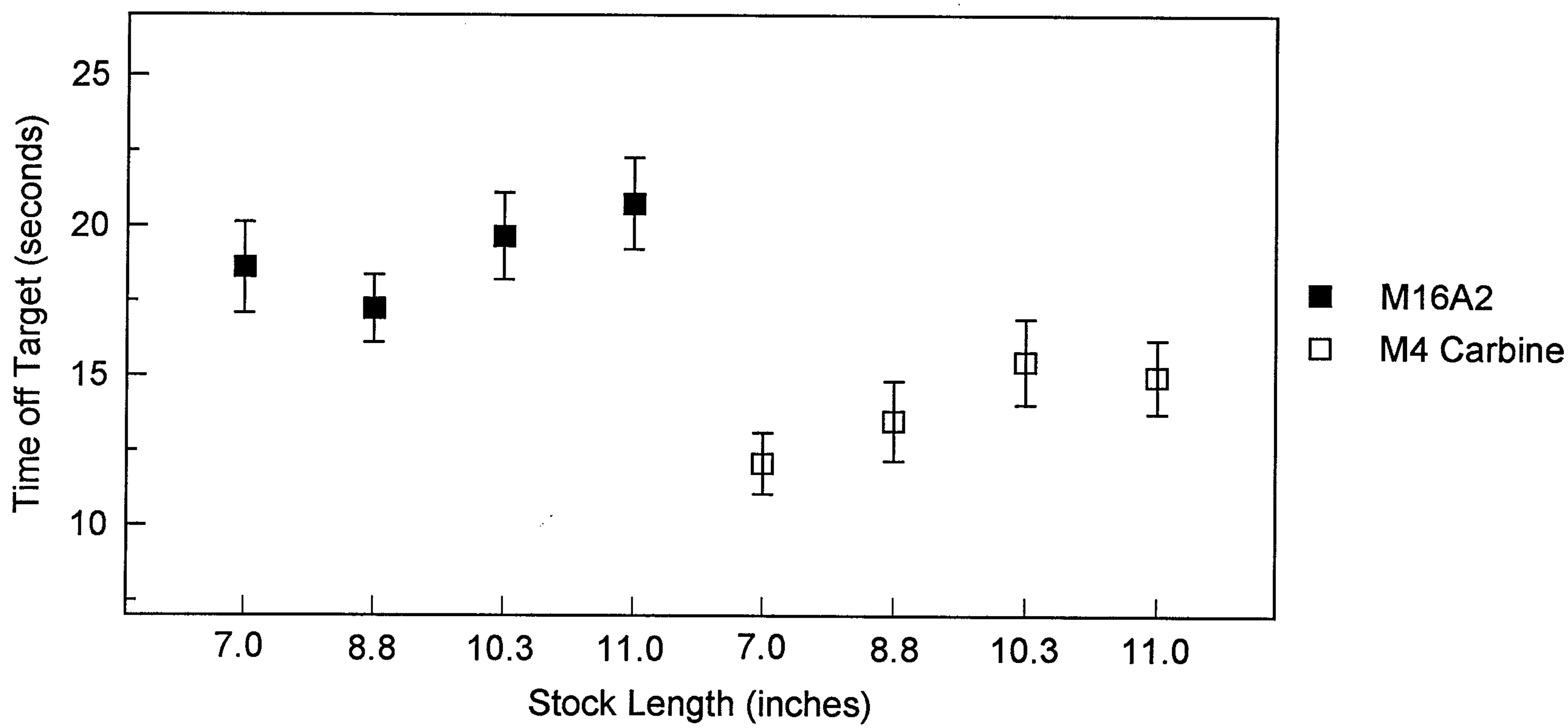
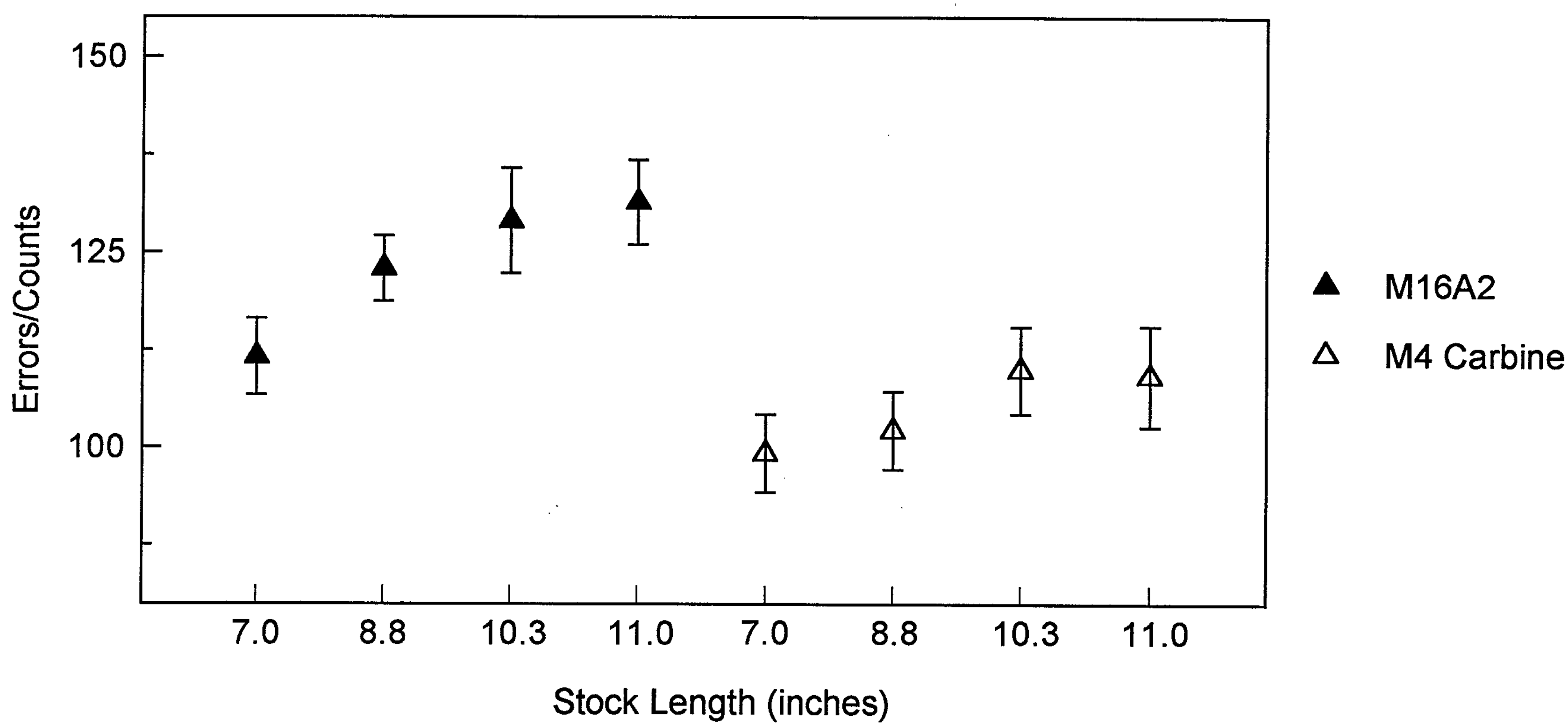


FIGURE 23

Plot of Overall Mean Errors for all Groups and Stock Lengths



ANTHROPOMETRY

Anthropometric measurements are presented in Table 3. The means for the anthropometric measurements made upon the subjects in this study fell within one standard deviation of the mean anthropometric measurements of U.S. Army personnel (Gordon et al., 1989).

The elbow joint angle of each subject was measured with a goniometer while they subsequently held each weapon at each stock length. Values for elbow joint angle varied widely among subjects and were not found to differ significantly. However, the mean values for each weapon at each stock length are shown in Figures 24 and 25 for completeness. The increase in joint angle seen with increasing stock lengths was not significant, but does suggest that joint angle increases with increase stock length.

STRENGTH MEASURES AND BODY COMPOSITION

The male subjects were significantly stronger in all strength measures versus the females in this study (Table 4; Student's T-test, unpaired; $P<.05$). The means and standard deviations for strength measures are presented in Table 4. Overall, females performed at about 56% of the males strength level for all strength tests combined. Females also fatigued earlier on the arm-raise to fatigue task (Table 4). Male subjects had significantly less body fat and leaner arms versus the females (Table 5; Student's T-test unpaired, $P<.05$).

TABLE 3

Anthropometry			
	Male	Female	% of Male
Height (cm)	176.0±7.8	164.3±6.4	94
Weight (kg)	79.5±10.8	67.5±9.2	85
Sleeve Outseam (cm)	59.3±3.4	54.4±3.6	92
Arm Length (cm)	79.2±4.2	73.1±4.8	92
Shoulder to Elbow (cm)	36.6±2.1	32.9±5.2	90
Radiale to Stylion (cm)	28.5±1.8	26.2±2.1	92
Elbow to Grip (cm)	34.7±1.8	31.5±2.0	91
Hand Length (cm)	19.0±1.3	17.2±1.0	91
Palm Length (cm)	10.7±0.7	9.8±0.6	92
Hand Breadth (cm)	8.7±0.4	7.5±0.38	86
Hand Circumference (cm)	21.0±1.0	18.2±1.1	87
Forefinger Length (cm)	12.2±0.8	11.0±0.6	90
Fist Circumference (cm)	27.6±1.2	24.0±1.2	87
Grip Diameter (cm)	2.0±0.1	1.9±0.1	95

TABLE 4

Strength Measures			
	Male (Mean ± SD)	Female (Mean ± SD)	% of Male Strength
Grip Strength (lbs)	96.1 ±25.5	53.2 ±17.0	55
Bench Press (lbs)	188.0 ±26.8	85.7 ±17.6	46
Overhead Press (lbs)	125.3 ±20.7	64.3 ±7.9	51
Left Arm Curl (lbs)	34.0 ±4.7	15.8 ±4.2	47
Right Arm Curl (lbs)	35.3 ±4.8	17.5 ±4.0	50
Tip to Tip Pinch (lbs)	18.9 ±3.2	11.7 ±2.1	62
Lateral Pinch (lbs)	22.3 ±3.3	15.1 ±3.5	68
3-Jaw Chuck Pinch (lbs)	22.2 ±2.7	16.6 ±3.7	75
Trigger Pull (lbs)	30.7 ±9.5	18.0 ±5.3	59
Arm Raise (lbs)	38.0 ±9.8	17.3 ±4.6	46
Arm Raise Fatigue (sec.)*	28.1 ±15.9	23.4 ±11.7	83

* Mean and SD values for arm raise fatigue are in seconds.

TABLE 5

Body Composition and Lean Mass Results			
	Mean % Body Fat	Mean % Lean Mass Right Arm	Mean % Lean Mass Left Arm
Male	18.8±6.9	81.1±8.9	80.1±8.5
Female	34.2±6.3	55.5±7.4	56.1±8.2

FIGURE 24

Plot of Mean Joint Angles for M16A2

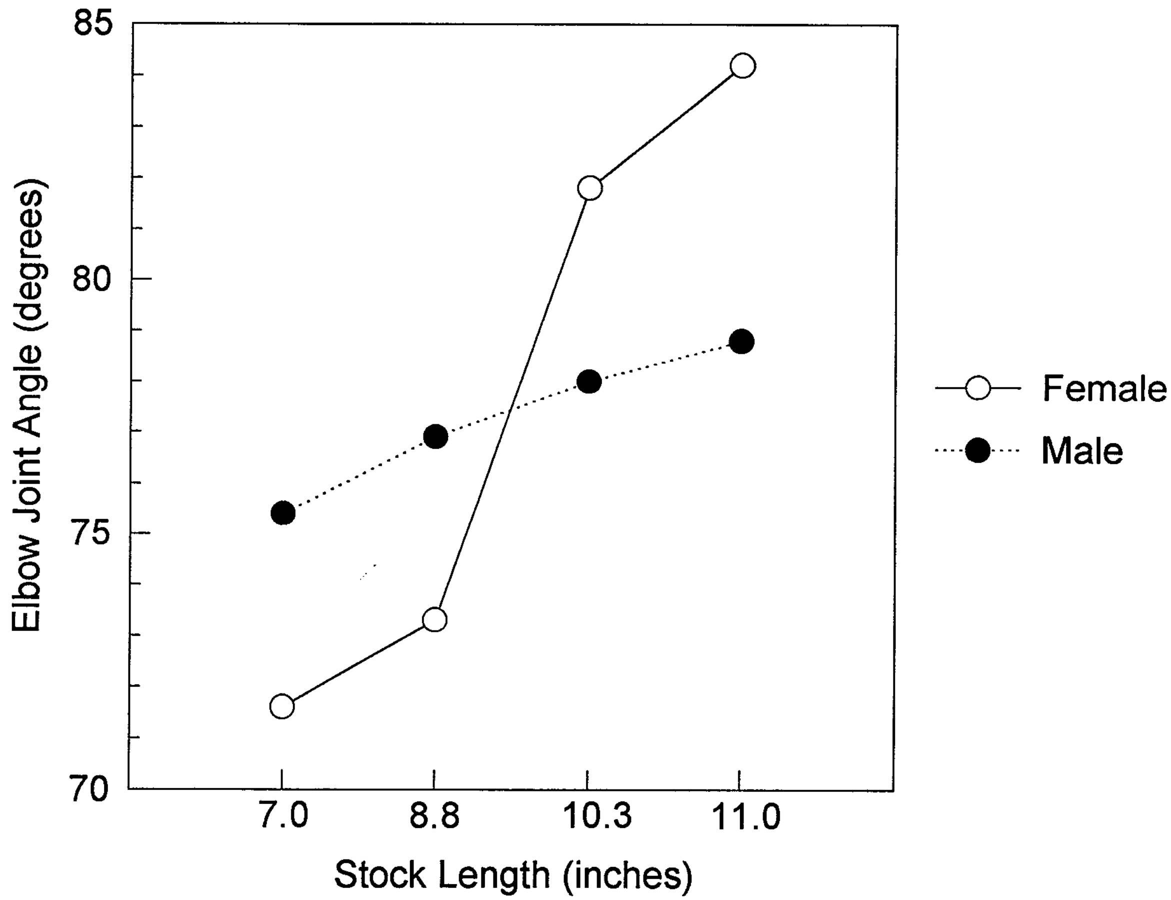
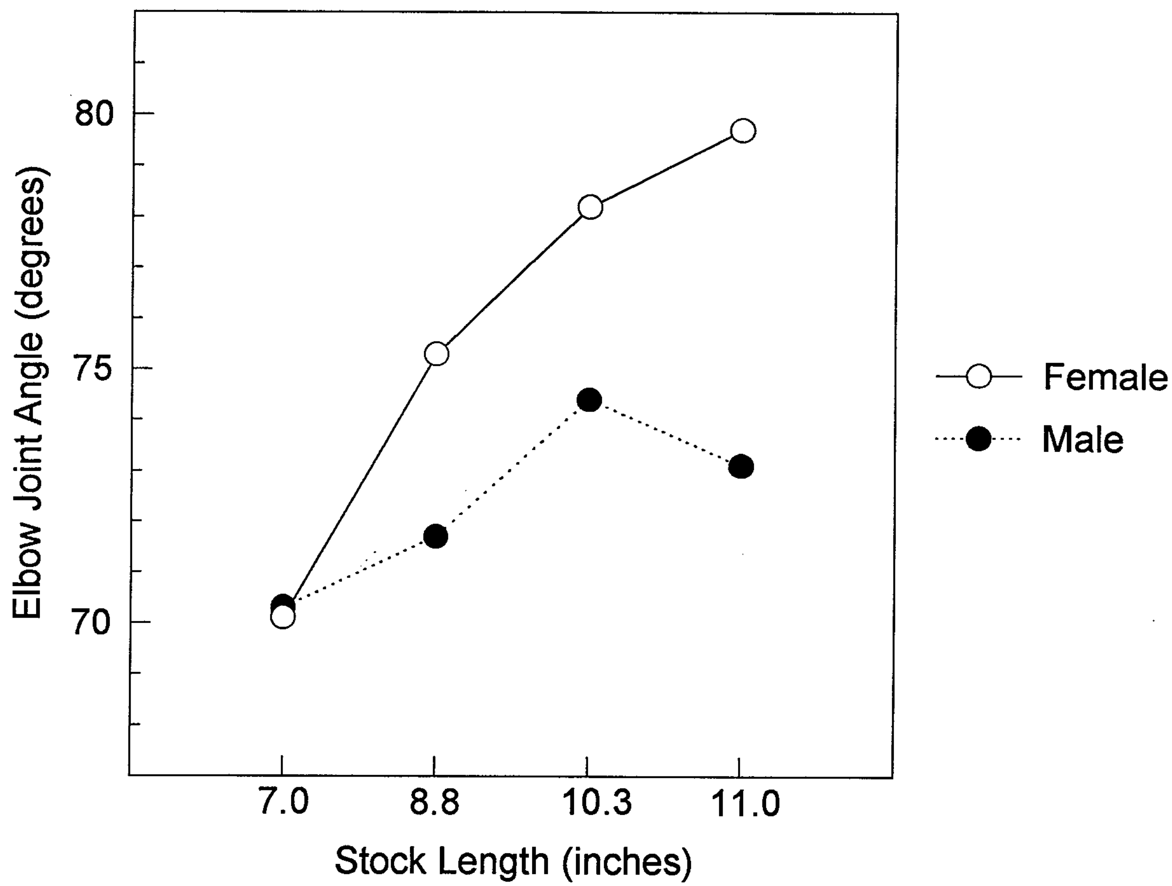


FIGURE 25

Plot of Mean Joint Angles for M4



RATING OF PERCEIVED EXERTION, FATIGUE, COMFORT AND EASE OF USE

Means and standard deviations for subjective ratings of perceived exertion, fatigue, comfort and ease of use are reported in Table 6. Significant main effects were found for gender, weapon, and stock length and are indicated in Table 7 ($P<.001$; Figure 26 & 27).

PAIN SORENESS AND DISCOMFORT SCALE

The probabilities for significant increase in pain soreness and discomfort for ten body regions are presented in Table 8. The shaded boxes indicate significant pre- versus post-shooting PS&DS for that body region. No significant pre- versus post-testing PS&DS was found for any other any other body region, including the lower back and legs.

WEAPON AND STOCK LENGTH PREFERENCE

Both male and female subjects preferred the M4 carbine over the M16A2 in all configurations of stock length tested. The mean rank scores are presented in Figure 28.

TABLE 6

Ratings of Self-Perceived Exertion, Fatigue, Comfort and Ease of Use						
Gender	Weapon	Stock Length	Exertion	Fatigue	Comfort	Ease
Male	M16A2	7.0	11.6±1.8	12.2±1.9	11.3±2.2	11.1±2.3
Female	M16A2	7.0	13.0±2.3	13.6±2.7	12.2±2.6	11.3±2.3
Male	M16A2	8.8	11.4±1.7	12.1±2.2	11.7±2.5	10.8±1.9
Female	M16A2	8.8	14.2±2.6	14.3±2.6	13.2±2.6	13.0±3.0
Male	M16A2	10.3	12.7±1.4	13.4±2.0	12.4±1.6	12.1±1.8
Female	M16A2	10.3	14.6± 2.7	15.5±2.2	14.8±3.6	14.9±3.1
Male	M16A2	11.0	12.8±1.7	12.9±2.1	12.2±2.4	11.1±2.4
Female	M16A2	11.0	16.6±2.1	16.5±2.5	16.1±2.6	15.1±3.6
Male	M4	7.0	14.6± 2.7	15.5±2.2	14.8±3.6	14.9±3.1
Female	M4	7.0	8.3±1.3	9.5±2.2	9.5±3.3	9.3±2.5
Male	M4	8.8	10.3±2.8	10.3±1.8	9.2±2.9	9.0±1.9
Female	M4	8.8	8.5±1.7	9.0±2.0	8.7±2.2	8.7±2.0
Male	M4	10.3	10.2±2.2	10.7±2.5	9.4±2.1	9.8±2.1
Female	M4	10.3	9.7±1.8	9.9±1.9	10.2±2.7	9.7±2.1
Male	M4	11.0	11.1±2.2	11.5±3.3	11.4±3.9	11.6±3.7
Female	M4	11.0	10.1±1.5	10.8±1.6	9.7±1.9	9.7±1.8

TABLE 7

ANOVA Probabilities for Main Effects and Interactions for Ratings of Perceived Exertion, Fatigue, Comfort and Ease				
	Exertion	Fatigue	Comfort	Ease of Use
Gender	.00	.00	.00	.00
Weapon	.00	.00	.00	.00
Stock	.00	.00	.00	.00
Gender X Weapon	.50	.45	.05	.08
Gender X Stock	.31	.13	.05	.02
Stock X Weapon	.84	.91	.46	.95
Gender X Weapon X Stock	.39	.60	.69	.70

TABLE 8

Probabilities for Significant Effect for Self-Rated Pain and Soreness (Pre vs. Post)												
Weapon	Stock Length	Gender	Shoulder Joint	Elbow Joint	Wrist Joint	Front Shoulder	Biceps	Front Forearm	Front Hand	Back Shoulder	Triceps	Back Forearm
M16A2	7.0	Male	P>.05	P>.05	P<.03	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M16A2	7.0	Female	P<.01	P<.02	P<.01	P<.01	P<.05	P>.05	P<.03	P<.02	P>.05	P>.05
M16A2	8.8	Male	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M16A2	8.8	Female	P>.05	P>.05	P<.02	P>.05	P>.05	P<.03	P>.05	P>.05	P>.05	P>.05
M16A2	10.3	Male	P>.05	P>.05	P<.01	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M16A2	10.3	Female	P<.02	P<.02	P<.01	P>.05	P>.05	P<.03	P>.05	P>.05	P>.05	P>.05
M16A2	11.0	Male	P>.05	P>.05	P<.02	P<.03	P<.04	P>.05	P>.05	P>.05	P>.05	P>.05
M16A2	11.0	Female	P<.02	P<.01	P<.01	P>.05	P<.01	P<.02	P<.04	P<.03	P<.02	P<.03
M4	7.0	Male	P>.05	P>.05	P>.05	P>.05	P>.05	P<.03	P>.05	P>.05	P>.05	P>.05
M4	7.0	Female	P>.05	P>.05	P>.05	P<.03	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M4	8.8	Male	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M4	8.8	Female	P>.05	P>.05	P<.01	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M4	10.3	Male	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M4	10.3	Female	P>.05	P>.05	P<.02	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M4	11.0	Male	P>.05	P>.05	P>.05	P<.02	P>.05	P>.05	P>.05	P>.05	P>.05	P>.05
M4	11.0	Female	P>.05	P>.05	P>.05	P>.05	P>.05	P<.03	P>.05	P>.05	P>.05	P<.03

FIGURE 26

Ratings of Self-Perceived Exertion and Fatigue

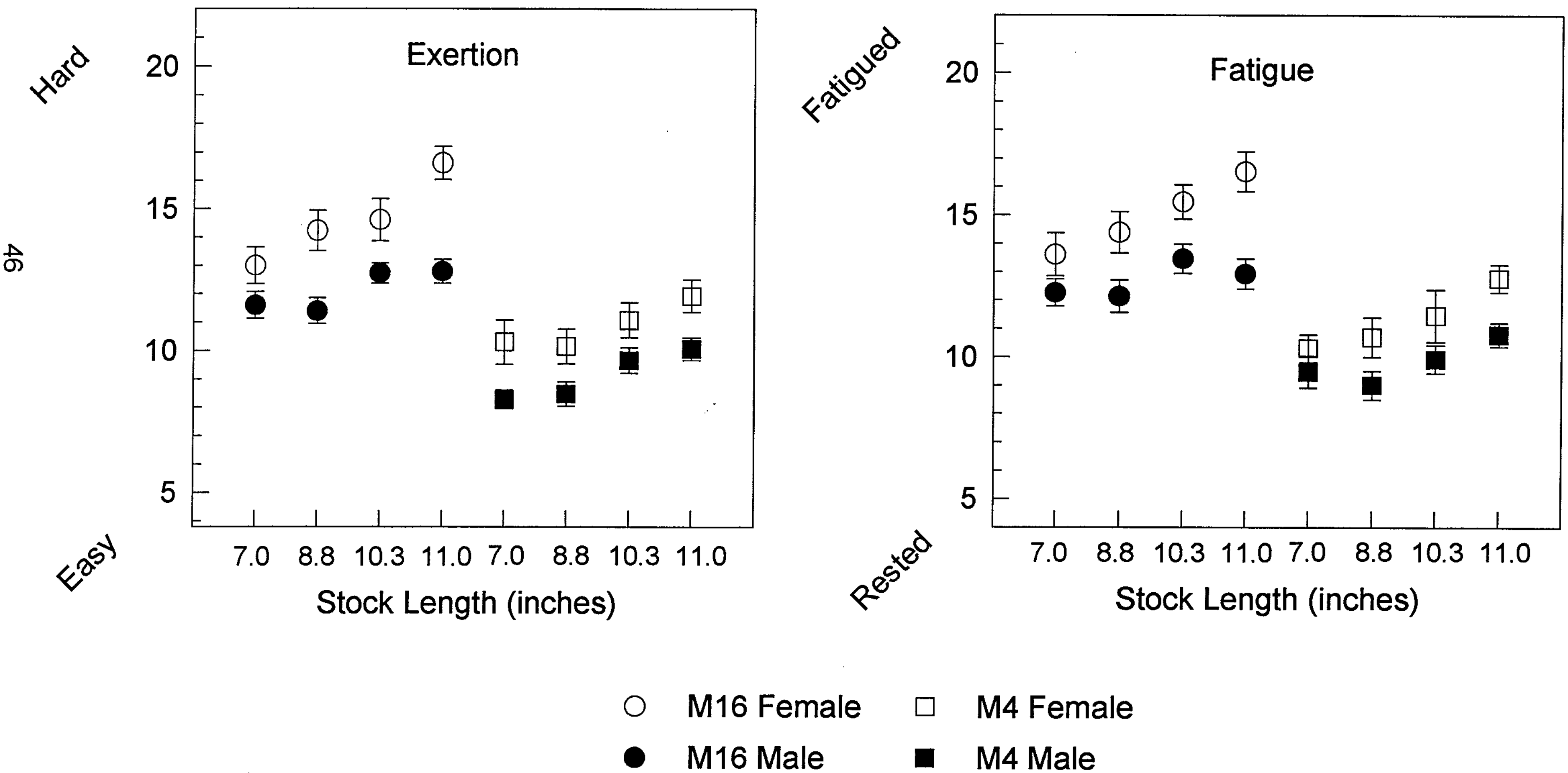


FIGURE 27

Ratings of Self-Perceived Comfort and Ease of Use

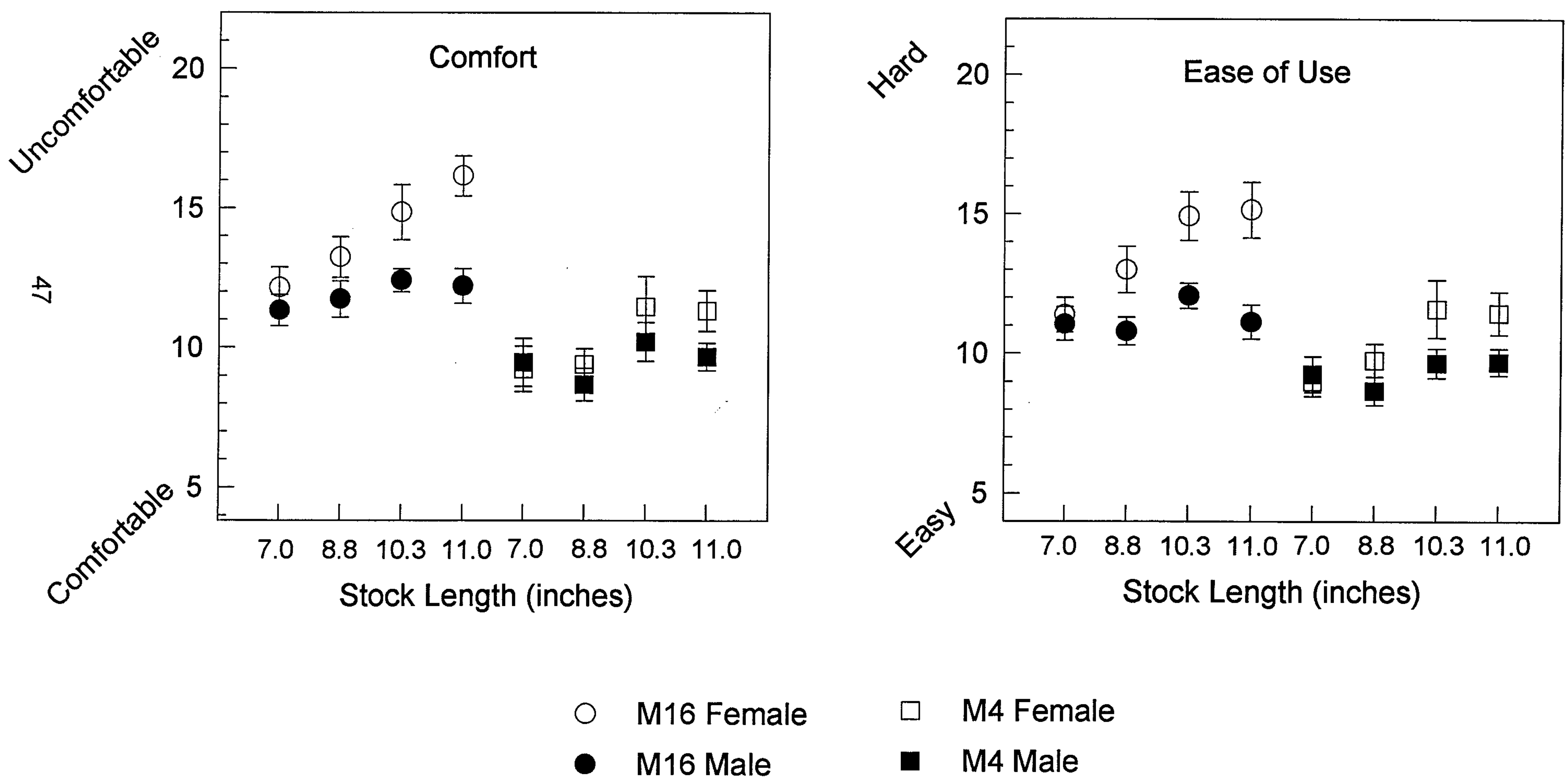
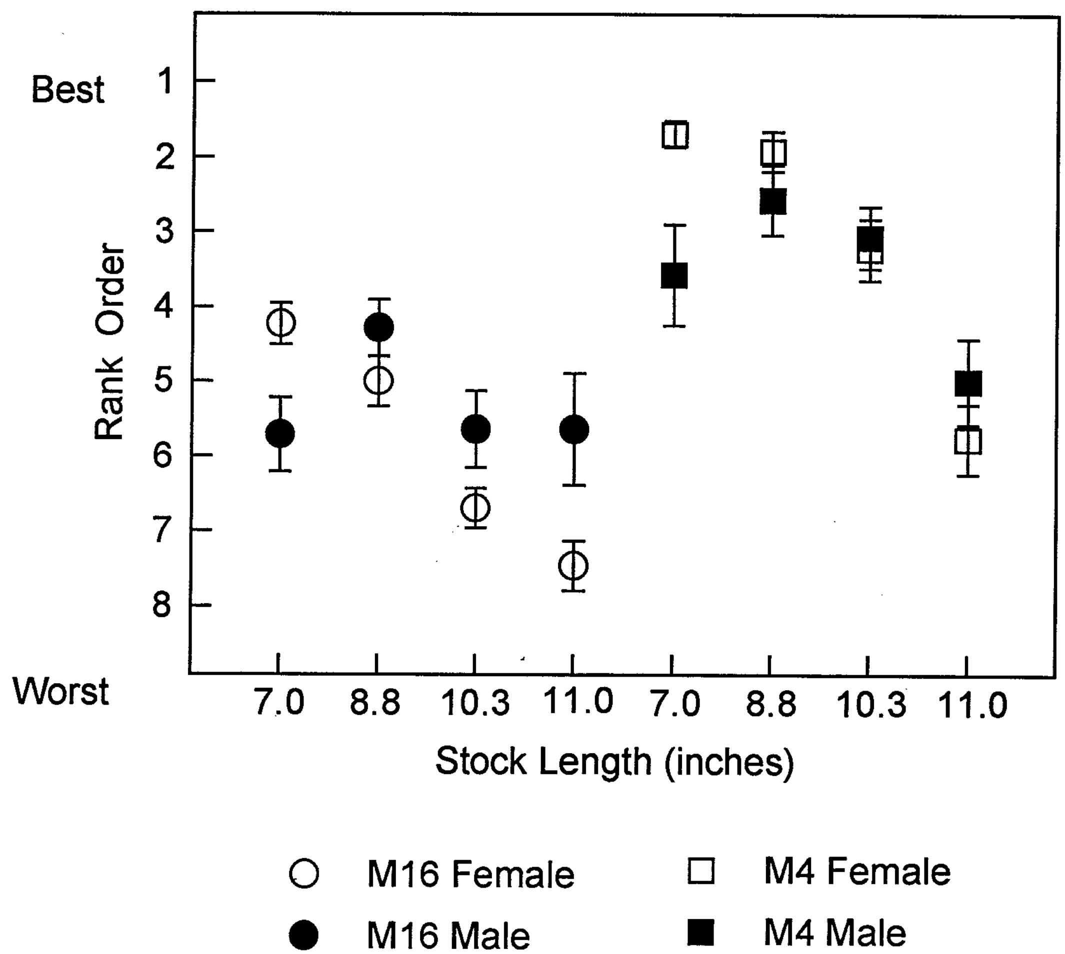


FIGURE 28

Subjective Preference for Weapon and Stock Length



DISCUSSION

The major findings of this study can be summarized as follows: 1) No significant gender difference was observed in marksmanship performance with either the M16A2 rifle or M4 carbine, using the Noptel marksmanship simulator. 2) Reduction of stock length improved marksmanship performance and arm-hand steadiness for both male and female soldiers. 3) Reduction of weapon weight improved marksmanship performance and arm-hand steadiness, again for both male and female soldiers. 4) Soldiers preferred a lighter weapon when given a choice; they experienced less discomfort when using the M4 carbine versus the M16A2, and they reported the M4 carbine was easier to use.

Both the female and male subjects in this study were well within the average anthropometric size and strength of previously reported U.S. Army populations (Tables 3 & 4; Gordon et al., 1989; Vogel, 1989). In spite of the difference in size and strength, the female subjects did not perform significantly worse (or better) on the marksmanship task. The most noticeable difference between this study and previous reports is that in this study live ammunition was not used. With the Noptel system, the weapons are dry-fired and no recoil, smoke, or noise (other than the click of the hammer falling) is present. Subjects shot in a standing position for a total of 20 minutes. Johnson and Merullo (1996) using a Weaponeer Rifle Marksmanship Simulator found that during simulated sentry duty, women tended to hit significantly fewer targets after 1.5 hours of a 3-hour sentry duty period versus male subjects. The Weaponeer simulates both recoil and the loud retort of an actual M16A2. It may be that the time period of testing in the study presented here was not of a sufficient length to induce a decrement in female marksmanship performance due to fatigue or upper body strength differences.

The improvement in marksmanship points and distance from center of mass with reduction in stock length (Figure 11 and 12) are in agreement with previous reports (Lee and Yuan, 1995). The shortest stock length used here is associated with a decrease in the DCM of the weapon measured from the butt-end of the rifles (Table 1). Additionally the angle of the elbow joint of the supporting arm is reduced when using the shorter stock (Figures 24 and 25).

The lack of a gender difference in the arm-hand steadiness task would seem to correspond somewhat to the lack of gender difference in marksmanship. It has previously been reported that women have greater arm-hand steadiness than men (Hudgens et al., 1988). The lack of a gender difference here may be due to the novel nature of the arm-hand steadiness task devised for this study versus previously reported results (2-handed versus 1-handed, standing versus sitting, and increased weight of the object being held; Hudgens et al., 1988;). It may be that for the short duration used here (1 minute), a significant difference between genders was not detectable.

Significant main effects were found for stock length and weapon weight for the arm-hand steadiness task (Figures 18, 19, 21). Reducing stock length significantly decreased the time off target and reduced errors, suggesting that decreasing stock length and weapon weight improves overall arm-hand steadiness and thus may improve marksmanship (Figure 23 and 24).

The females were found to report a significantly greater feeling of exertion and fatigue versus the male subjects. These self-reported feelings of exertion and fatigue were significantly greater at the longer stock lengths and with the M16A2 configurations versus the M4 carbine configurations (Table 6; Figure 26). It is interesting to note that although no performance decrement was detected, the females thought they were working harder and did report being more fatigued than the males. Women also reported the M16A2 configurations to be significantly more uncomfortable and harder to use than the M4 carbine configurations. Both men and women found the shorter stock lengths and lighter M4 carbine more comfortable and easier to use. The preference of the male and female soldiers as shown in Figure 28 shows that the M4 carbine was preferred overall and that the shorter stock lengths were liked better than the longer stock lengths.

The interpretation of these results must be regarded with care for several reasons. First, the study here used the Noptel Marksmanship system which utilizes weapons which are dry-fired only. The lack of recoil, noise, smoke, etc., is a substantial factor in marksmanship. Indeed, in live-fire tests of the M4 carbine and M16A2 (not part of this study), soldiers reported the M16A2 was better than the M4 carbine because of its increased weight which reduced the recoil of the weapon (Kemnitz, C.P. personal observation). Also, the collapsible stock of the M4 carbine was found to slip off the shoulder of some soldiers during firing with live ammunition and the recoil of the weapon caused some facial injuries (Kemnitz, C.P. personal observation). Any beneficial effects of improved arm-hand steadiness and marksmanship due to reduction of weight or stock length need to be confirmed on a live-fire range with live ammunition.

CONCLUSIONS

1. No gender difference in marksmanship performance was observed with either the M16A2 rifle or the M4 carbine.

2. Reducing stock length from 10.3" to 7.0" significantly improved marksmanship scores, and reduced the distance of shot groups from the center mass of the target.

3. Shot group tightness was significantly better with the M4 carbine (6.9 lbs) versus the M16A2 rifle (8.4 lbs).

4. No significant gender difference was observed in arm-hand steadiness between male and female soldiers.

5. Shorter stock lengths (7.0 and 8.8") significantly reduced mean time off target in the arm-hand steadiness task.

6. Time off target was significantly reduced with the M4 carbine overall versus the M16A2 rifle.

7. The number of errors counted was significantly less with the 7.0 inch stock versus both the 8.8 and 10.3 inch stock lengths.

8. Errors were significantly reduced overall with the M4 carbine versus the M16A2 rifle.

9. Subjects rated the M16A2 weapon configurations (stock lengths 7.0, 8.8, 10.3, and 11.0") harder to use and reported feeling more fatigued following testing with these weapons versus the M4 carbine.

10. The M4 carbine was rated easier to use and more comfortable than the heavier M16A2.

11. Significantly more pain and discomfort was reported by subjects following testing with the M16A2 configurations versus the M4 carbine.

RECOMMENDATIONS

1. The results of this study should be confirmed in a controlled live-fire experiment.

2. Consideration should be given to reducing stock length or providing adjustable stock length weapons to soldiers who prefer them.

3. Consideration should be given to reducing overall rifle weight to improve soldier performance.

4. Further study is recommended of the relationship of weapon weight, stock length, weapon center of mass and shooter stability, especially in relation to the wearing of protective body armor and chemical/biological protective suits, as stock length reduction may improve overall marksmanship performance.

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