U.S. Army Research Institute
for the Behavioral and Social Sciences



Research Report 1515

# Assessing the Impact of Mental Category on Simulated Tank Gunnery Performance



Scott E. Graham

March 1989

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

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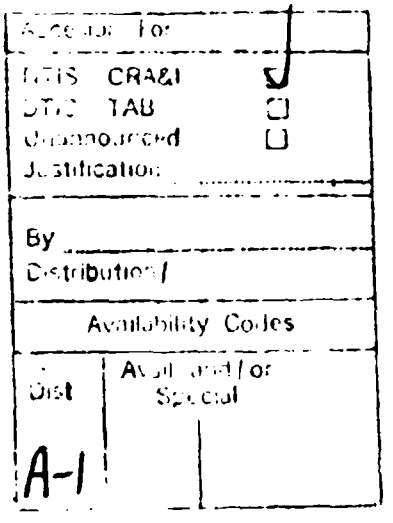


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The research evaluated the effects of mental ability on the gunnery performance of 19K One Station Unit Training (OSUT) soldiers. Five hundred forty-seven soldiers were given a 35-engagement tank gunnery test on the high-fidelity Institutional-Conduct of Fire Trainer (I-COFT). The I-COFT test included offensive and defensive engagements fired in normal and degraded operational modes. The primary analysis compared speed and accuracy performance as a function of mental category as derived from General Technical (GT) scores. The test scores were also used as parameter estimates in a soldier performance model based on Lanchester-type combat attrition models. OSUT soldiers with higher mental ability were faster and more accurate on the I-COFT test than were soldiers with lower mental ability. Mental category I & II soldiers hit 14% more targets than category IV soldiers and were 2 seconds faster. The effects of mental ability were relatively the same for both normal and degraded mode exercises. Analyses based on the soldier performance model indicated that category IV soldiers performed at 73% of category I & II soldiers.

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Research Report 1515

# Assessing the Impact of Mental Category on Simulated Tank Gunnery Performance

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## FOREWORD

The Commanding General, U.S. Army Armor Center (USAARMC), wants to ensure that armor crewmen possess the necessary skills to maximize the effectiveness of their high-tech tank weapon systems. To do so, USAARMC must identify those skills and abilities that lead to success on the modern battlefield. The results reported here help provide another link between specific soldier skill requirements and combat proficiency. This information was developed through a reanalysis of performance data recently collected as part of the Skills Selection and Sustainment ($S^3$) program. Taken together, the $S^3$ and the results of this research show that psychomotor, spatial, and mental ability are strong predictors of armor gunnery performance.

The research was conducted by the Fort Knox Field Unit of the U.S. Army Research Institute (ARI) as Technical Advisory Service to USAARMC; the results were briefed to the Commanding General in September 1988. This report demonstrates the Fort Knox Field Unit's ongoing assistance to the Armor Center, and it represents well the expertise and domain of the ARI Training Research Laboratory's efforts to identify the determinants of combat performance.

Edgar M. Johnson

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Technical Director

ASSESSING THE IMPACT OF MENTAL CATEGORY ON SIMULATED TANK GUNNERY PERFORMANCE

## EXECUTIVE SUMMARY


Requirement:

The research evaluated the effects of mental ability on the gunnery performance of 19K soldiers enrolled in One Station Unit Training (OSUT) and assessed the relative effects of mental ability on normal and degraded mode gunnery performance.

Procedure:

Five hundred forty-seven OSUT soldiers were given a 35-engagement tank gunnery test on the high-fidelity Institutional-Conduct of Fire Trainer (I-COFT). The I-COFT test included offensive and defensive engagements fired in normal and degraded operational modes. The primary analysis compared speed and accuracy as a function of mental category as derived from General Technical (GT) scores. The test scores were also used as parameter estimates in a soldier performance model based on Lanchester-type combat attrition models.

Findings:

OSUT soldiers with higher mental ability were faster and more accurate on the I-COFT test than soldiers with lower mental ability. Mental category I & II soldiers hit 14% more targets than category IV soldiers and were 2 seconds faster. The effects of mental ability were relatively the same for both normal and degraded mode exercises, suggesting that the same basic skills underlie normal and degraded mode performance. Analyses based on a soldier performance model indicated that category IV soldiers performed at 73% of the level of category I & II soldiers.

Utilization of Findings:

The results have been given to the U.S. Army Armor Center and are being used to document the skill requirements of successful armor combat performance.

ASSESSING THE IMPACT OF MENTAL CATEGORY ON SIMULATED TANK GUNNERY PERFORMANCE

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# ASSESSING THE IMPACT OF MENTAL CATEGORY ON SIMULATED TANK GUNNERY PERFORMANCE

## Introduction

The M1 Abrams tank may well be the best main battle tank in the world today. Its low-profile, advanced armor protection, shoot on the move capability, and high maneuverability allow the tank to deliver decisive combat power on the modern battlefield. Despite the advanced hardware, the M1 tank is fundamentally a manned weapon system, which means the tank's effectiveness is determined by crew performance. To maximize the effectiveness of the M1 tank, the Army must maximize the appropriate skills of its Armor crewmen.

The U.S. Army Armor Center (USAARMC) is therefore looking to identify the full array of soldier skills and abilities that lead to successful armor combat performance. Recent research by Graham (in prep) conducted as part of the Skills Selection and Sustainment ($S^3$) program found spatial and psychomotor skills to be strong determinants of simulated tank gunnery performance. The Commanding General, USAARMC, has requested that additional analyses be conducted on the $S^3$ data specifically to determine armor crewman performance levels as a function of mental category. The results of the $S^3$ reanalysis are presented here and examine the impact of mental ability on the gunnery performance of soldiers enrolled in Armor One Station Unit Training (OSUT).

## Assessing Mental Ability

The Armed Services administers to all soldiers entering the enlisted ranks a standardized paper-and-pencil test, the Armed Services Vocational Aptitude Battery (ASVAB). The ASVAB contains ten cognitive subtests which are combined to form a number of composites. One composite, the Armed Forces Qualification Test (AFQT), is used by the Army to classify soldiers into mental categories. The General Technical (GT) composite score can also be used to determine mental category. The specific categories used in the present analyses are I & II combined, IIIA, IIIB, and IV. As a note, the Army cannot, by law, enlist category V's nor more than 20% category IV's in an accession year. Table 1 shows the breakdown of mental categories by AFQT percentiles, GT scores, and estimated reading levels.

## Mental Ability and Armor Performance

Efforts to link measures of mental ability to armor performance have yielded mix results. Eaton, Bessemer, and Kristiansen (1979) identified several ASVAB measures which correlated with driving and gunnery performance of OSUT soldiers. These relationships did not, however, cross-validate to soldiers in Table of Organization and Equipment (TO&E) units in Europe. In particular, none of their predictors correlated with live-fire Table VIII performance fired at Grafenwoehr, FRG.

Table 1

Mental Categories as Determined by ASVAB Composite Scores

| Mental Category | AFQT Percentile | GT Score | Reading Grade Level |
|---|---|---|---|
| I | 93-100 | 129-155 | 12.7-12.9 |
| II | 65-92 | 110-128 | 10.6-12.6 |
| IIIA | 50-64 | 100-109 | 9.3-10.5 |
| IIIB | 31-49 | 90-99 | 8.1-9.2 |
| IV | 10-30 | 75-89 | 6.6-8.0 |
| V | 1-9 | 52-74 | 3.4-6.5 |

Black and Mitchell (1986) found a strong relationship between AFQT and performance on an M1 computer panel test. They constructed a general abilities composite from scores on three tests: entering data into a simulated M1 computer panel, executing the M1 computer self-test, and tracking. The general abilities composite correlated .49 with AFQT for the 123 M1 gunners drawn from five battalions. Their data also showed that while mental category I to IIIA personnel comprised only 66% of the total sample, those soldiers accounted for about 90% of the scoring on each of the three tests. Furthermore, while the category IV personnel made up 20% of the sample, they contributed less than 4% scoring on each of the three tests. Similar to the results of Eaton, et al. (1979), AFQT did not correlate with Table VIII performance.

A report by Scribner, Smith, Baldwin, and Phillips (1984) from the U.S. Military Academy (USMA) showed mental category to be highly related to live-fire gunnery performance on Table VIII fired at Grafenwoehr. Based on their analysis of 1131 M1 and M60 series crews, they estimated that category I TCs and gunners perform approximately 20% above category IV pairs with the M1 tank and 75% above category IV pairs with the M60 series tank. They interpreted these data as showing that the operation of the M1 fire control system in a fully operational mode helped to equalize the negative effects of lower mental abilities. They suggested, however, that when the M1 was required to fight in a degraded operational mode, the effects of AFQT would likely be even greater than the difference between the M1 and M60 series tanks.

The Scribner, et al. (1984) paper has stirred some controversy, largely because other researchers have failed to find such a relationship between mental ability and live-fire tank gunnery performance. Subsequent to the USMA

report, for example, the Office of the Chief of Armor (OCOA) analyzed the FY85 and FY87 Table VIII firing data from Grafenwoehr and found no correlation between performance and AFQT (Cisco, 1985; Leet, 1987). In the latter case, the data were sent to the USMA for assistance in analysis.

Another issue with the report concerns the presentation of data. The primary table shows "Tank Equivalent Kills" which are regression coefficients derived from a combat model algorithm. While the modeling analysis is perfectly acceptable, the table has too easily been misinterpreted as actual performance scores, which indicates a perfect relationship between AFQT and gunnery performance.

Research with the Israeli Army has also found a relationship between mental ability and armor performance. Tziner and Eden (1985) manipulated the composition of three-man tank crews by high and low mental ability and motivation. Following two months of intensive activity, unit commanders completed subjective performance rankings of eight subordinate crews. The results showed an additive effect of mental ability, i.e., the more high ability soldiers in the crew, the better the performance.

Perhaps more interesting was the interaction among the ability levels of the three crew positions. Crews composed of three high ability soldiers were ranked more effective than expected, while crews composed of three low ability soldiers were ranked less effective than expected. Based on this result, Tziner and Eden suggested the most effective crew combinations would be a majority of high-low-low crews with the rest being high-high-high. This allocation strategy avoids the disproportionate low productivity of the low-low-low ability condition, while leaving some of the highs for the most productive high-high-high ability crews.

Graham (1987) also found mental ability to be related to the command, control, and communication ($C^3$) performance of M1 TCs during single tank tactical exercises on the Simulation and Combined Arms Trainer (SIMCAT). The TCs were split into high and low ability groups based on their General Technical (GT) score. Significant differences in performance as a function of GT were found on numerous task measures including: accuracy of combat reports, number and accuracy of fire commands, decoding and plotting minefield coordinates, and the calling and adjusting of indirect fire. Regression analyses showed that the effects of mental ability greatly outweighed the effects of experience. This latter finding is consistent with the results of similar analyses reported in Scribner et al. (1984).

## Criterion Issues

Given the Armor credo to put "steel on target," it is not surprising that live-fire gunnery performance is the preferred measure of tank gunnery. In particular, the tendency has been to use scores from Tank Table VIII. Live-fire scores may not, however, always be most appropriate. Problems affecting reliability, e.g., varying weather and equipment conditions, make questionable the comparison of live-fire scores across days, ranges, and units.

Eaton and Whalen (1980) have documented one source of live-fire error, the difficulty in obtaining accurate scoring. Under relatively good field conditions, their best experimental group (soldiers with tripod-mounted periscopes) correctly sensed rounds hit or miss 87% of the time. TCs observing rounds from their own firing tank with a 10X rangefinder correctly sensed only 64% of the rounds, which is exceedingly low considering that 50% is chance. The computerization of ranges in the past decade may have improved the scoring of live-fire tests, but other sources of unreliability remain largely unimproved.

Tank table exercises, in addition, provide performance information at the crew-level which is inappropriate when one is interested in the performance of individual crewmen. The use of Table VIII as a valid measure of individual performance is also suspect in that the overwhelming goal of the exercise is to qualify as many tanks as possible. Every effort is therefore made by the unit to minimize the effects of individual crew deficiencies. While some live-fire criterion problems can be reduced by running well-controlled gunnery exercises specifically for research, ammunition costs and support requirements usually prohibit such efforts.

The inconsistent findings linking mental ability and armor performance are likely due to the unreliability of most live-fire gunnery measures. The positive relationship reported by Scribner et al. (1984) probably reflects a special testing situation. The live-fire scores were obtained from a newly built range on which none of the crews had previously fired. The new Table VIII also included revised scoring procedures and tougher standards which were largely unfamiliar to the firing units. These conditions undoubtedly resulted in a more reliable test than with most other live-fire tests for at least two reasons. Less advanced information was available about the range, i.e., crews had a tougher time "G-2ing" the range. The new standards and procedures also produced greater variability in the scoring.

Other researchers have likewise addressed live-fire criterion problems (Black & Mitchell, 1985; Eaton et al., 1979; Graham, 1985). In addition, Leet (1987) cites the response of the USMA group following their analysis of FY87 Table VIII data in which they were unable to replicate the positive linear regressions reported in 1984. The USMA group attributed the FY87 results to changes in the execution of Tank Table VIII, namely a decrease in the number of engagements from 13 to 10, crew familiarity with the range, and the ability of crews to refire for qualification. Each of these factors negatively affects reliability.

## Device-mediated Testing

High-fidelity tank gunnery simulators such as the Institutional-Conduct of Fire Trainer (I-COFT) are now being used as alternatives to live-fire testing. TC and gunner controls on the M1 I-COFT are virtually identical to those in the actual tank, making the I-COFT analogous to flight simulators used in military and commercial training. The I-COFT simulates tank optics with computer-generated imagery and can be used as either a whole-task or part-task trainer. In addition, I-COFT tests can be constructed to measure a full range of target engagement tasks, including target acquisition, laying the main gun, and issuing fire commands.

Device-mediated tests with the I-COFT offer certain advantages over other hands-on performance tests. These pluses include standardized administration and scoring, and the capability of inexpensively building longer tests with varied target conditions. Research evaluating the reliability of testing on the Unit-Conduct of Fire Trainer (U-COFT) has found test-retest reliability coefficients which exceed .80 (Graham, 1986). The I-COFT and U-COFT are essentially identical with the exception that the I-COFT includes software options which can present part-task training. I-COFT tests can also be used to separate the contributions on individual crewmen in tank gunnery engagements and can be safely administered to novice crewmen.

## Purpose of Research

The purpose of the research is to:

1. Evaluate the effects of mental ability on the gunnery performance of 19K OSUT soldiers.

2. Assess the relative effects of mental ability on normal and degraded mode gunnery performance.

# Method

## Participants

The project tested 547 19K (M1 tank crewman) OSUT soldiers from five training companies of the 1st Armored Training Brigade, Fort Knox, KY.

## I-COFT Test Construction

The I-COFT gunner's test developed specifically for this research contained four exercises taken from the I-COFT's Target Engagement Practice Exercises (TEPE). The exercises were selected with the assistance of the Armor Simulator Division, Weapons Department, U.S. Army Armor School (USAARMS). The selected exercises included offensive and defensive engagements fired with daylight and thermal sights under normal and degraded operational conditions. The selection of the exercises was constrained such that the OSUT soldiers had to have previously been trained on the tested conditions. Table 2 lists the exercises included in the test in the order of test presentation. Appendix A provides a complete description of the selected exercises taken from the Instructor's Utilization Handbook for the M1 Unit-Conduct of Fire Trainer (1985).

The one hour test required all targets to be engaged with the main gun. The test also employed the I-COFT's synthetic TC, an instructional feature whereby the software automatically acquires targets, lays the main gun, and gives fire commands. The synthetic TC, in effect, simulates a perfect TC in that it always gives correct fire commands and consistent target acquisition. All OSUT I-COFT gunnery training uses the synthetic TC, in part, because it eliminates the support requirement for a TC. For tank gunner testing purposes, the synthetic TC is ideal in that it helps ensure standardized testing.

Table 2

I-COFT Test Engagement Conditions

| I-COFT Exercise Number | Number of Targets | Own Vehicle | Targets | Fire Control Malfunctions |
|---|---|---|---|---|
| 31271 | 10 | Stationary | Short Range Stationary Handles | Primary Sight, Power Control |
| 32511 | 5 | Moving | Long Range Moving | None |
| 32241 | 10 | Stationary | Long Range Stationary | Stabilization System |
| 32321 | 10 | Stationary | Long Range Moving | None |

Performance Measures

Two performance measures were obtained from each exercise: percent hits and opening time. Percent hits was simply the number of targets hit divided by the number of targets presented. Opening time measured the amount of time from when a target appeared until the first round was fired. For engagements in which no rounds were fired, an opening time of 30 seconds was assigned, the maximum I-COFT opening time possible for the selected exercises. While there are situations in battle where it is advantageous not to fire, failure to fire at I-COFT targets was, by definition, an error. Assigning the maximum opening time when the gunner did not fire gave a poor score for poor performance.

A total percent hits and mean opening time were computed by taking the mean of the means for each of the exercises. This procedure resulted in an equal weighing of the exercises, even though the offensive exercise (own tank moving) had fewer targets. A speed/accuracy composite score was also computed by subtracting the standardized opening time from the standardized percent hits. The opening times were subtracted because lower times, i.e., faster opening times, represent better performance. The speed/accuracy composites were then transformed into t-scores, giving the speed/accuracy scores a mean of 50 and a standard deviation of 10.

Procedure

The I-COFT tests were administered by the I-COFT Instructor/Operators (I/O) during the last (or 20th) hour of OSUT I-COFT training; this fell in the tenth week of OSUT training. Because the test was given the second hour of a two-hour block, no warm-up was deemed necessary. Prior to the initial testing

session, the purpose of the project was explained to the I/O's. They were also told not to provide assistance to the soldiers once the test exercises began. The I-COFT tests were administered between April and August 1988.

Soldiers' GT scores were obtained from personnel records in the training brigade headquarters. The soldiers were classified into mental categories by their GT score as indicated in Table 1.

## Results and Discussion

### Results by Mental Category

The results show that soldiers in higher mental categories performed markedly better on the I-COFT gunnery test than did soldiers in lower mental categories. Table 3 shows I-COFT percent hits, opening times, and speed/accuracy composite as a function of mental category.

Table 3

Mean Percent Hits, Opening Times, and Speed/Accuracy Composite by Mental Category

| Mental Category | Percent Hits | Opening Time (Secs) | Speed/ Accuracy |
|---|---|---|---|
| I & II (n=220) | 67.1 | 17.7 | 53.0 |
| IIIA (n=126) | 64.1 | 18.3 | 50.9 |
| IIIB (n=130) | 59.1 | 18.9 | 47.6 |
| IV (n= 71) | 53.3 | 19.7 | 43.9 |
| Standard Deviation | 15.3 | 2.5 | 10.0 |

Oneway Analyses of Variance (ANOVA) substantiated the differences between mental categories for all three performance measures. Category I & II soldiers hit nearly 14% more targets than did category IV soldiers, $F(3,543) = 19.4$, $p < .0001$. A Tukey Honestly Significant Difference (HSD) post-hoc test found all of the means to be different from each other at the .05 level with the exception of I & II and IIIA.

Category I & II soldiers were also fastest, taking two seconds less to fire the first round than category IV soldiers, $F(3,543) = 14.6$, $p < .0001$. A Tukey HSD post-hoc test found category I & II soldiers to have faster opening

times than categories IIIB or IV, and category IIIA to have faster opening times than category IV ($p < .05$).

The ANOVA on the speed/accuracy composite yielded the same pattern, $F(3,543) = 20.6$, $p < .0001$. As with percent hits, the post-hoc test showed each of the means to be different from each of the others with the exception of categories I & II and IIIA.

These data further corroborate the findings of previous research (e.g., Scribner et al., 1984) that found mental ability to be related to gunnery performance, at least as measured on the high-fidelity I-COFT. Not unlike the Scribner, et al. (1984) research, the I-COFT gunnery test was conducted under conditions that were likely highly reliable.

Another similarity between the present I-COFT test and the Scribner et al. (1984) research was that the gunners in both projects had limited expectations about what they were going to be required to do. The OSUT soldiers were relatively inexperienced gunners and the test predominantly included conditions from the limits of their training. As discussed, the Scribner et al. (1984) data were obtained from live-fire tests on a new range with new standards.

Given a basic definition of intelligence (or mental ability) as the ability to quickly adapt to new situations, it is to be expected that higher mental ability soldiers would perform better under both the present and Scribner's (1984) conditions. Even more so, the modern battlefield will be rife with uncertainty, particularly in comparison to the well-predicted and controlled tank tables. It follows then that the effects of mental ability will be amplified in the ever-changing combat environment.

Normal and Degraded Operational Modes

An oft proposed position is that mental ability will have a larger impact on degraded mode performance than normal mode performance. The rationale is that in the confusion of battle, the high ability soldier will more quickly be able to diagnose the failure of a particular fire control component and implement the correct alternate procedure. Degraded mode procedures are difficult, in part, because of limited training opportunities. The introduction of the COFT trainers into the Armor training base has, however, greatly improved degraded mode training, as the majority of the COFT exercises train degraded mode procedures.

The I-COFT test included two exercises fired in normal mode (32511 and 32321) and two fired in degraded modes (31271 and 32241). Table 4 shows the mean percent hits and the correlation of percent hits with GT scores for the separate I-COFT exercises. Because of the large n, all of the correlations are significant.

Table 4

Mean Percent Hits and Correlations With GT Scores for Separate Exercises

| I-COFT Exercise Number | Salient Features | Mean Percent Hits | Correlation of GT with Percent Hits |
|---|---|---|---|
| 31271 | Degraded Mode - Gunner's Auxiliary Sight (GAS) | 54% | .22 |
| 32511 | Normal Mode - Offensive engagement, moving targets | 73% | .22 |
| 32241 | Degraded Mode - Stabilization Failure | 81% | .24 |
| 32321 | Normal Mode - Defensive engagement, moving targets | 43% | .27 |
| Total Test | | 63% | .31 |

Table 5 shows the mean speed/accuracy composite for the separate exercises as a function mental category. The composite scores for each exercise were converted to t-scores with a mean of 50 and a standard deviation of 10. Oneway ANOVAs computed on the composites found mental category to be a significant factor in each of the four exercises.

The results indicate no difference in the relative performance of normal and degraded mode I-COFT exercises as a function of mental ability. As a caveat, the I-COFT test did not represent the full range of degraded mode conditions, in part, because the degraded mode test conditions were limited to those that had already been trained in OSUT. That no interaction was found between mental ability and normal/degraded conditions is, however, consistent with the results of Mendel and Erffmeyer (1988). Their research assessed the impact of the Excellence in Armor (EIA) program on OSUT performance. Perhaps the best interpretation of these findings is that the same basic skills underlie the performance of normal and degraded mode performance. This is particularly true in situations similar to the I-COFT test and Table VIII, where the gunner knows what degraded mode procedures will be required.

Table 5

Speed/Accuracy Composites for the Separate Exercises by Mental Category

| I-COFT Exercise Number | Salient Features | Mental Category I&II | IIIA | IIIB | IV | F(3,536) |
|---|---|---|---|---|---|---|
| 31271 | Degraded Mode Fired from GAS | 52.1 | 50.8 | 48.4 | 45.6 | 8.86* |
| 32511 | Normal Mode Offensive | 52.3 | 51.4 | 48.2 | 46.3 | 8.54* |
| 32241 | Degraded Mode Stab Failure | 52.2 | 51.4 | 47.8 | 45.2 | 13.3* |
| 32321 | Normal Mode Defensive | 52.7 | 50.6 | 48.1 | 44.7 | 14.5* |

* $p < .0001$

As suggested, mental ability is likely to have a larger effect when the gunner (or TC) must quickly diagnose the problem and react. This hypothesis was not adequately tested in the research. While the I-COFT test contained degraded mode exercises, the gunners were instructed on the simulated fire control system failure before each exercise began. (Refer to Appendix A for the instructions). Discussions with I-COFT personnel indicate that minor hardware modifications could make it possible to randomly induce fire control system faults in the middle of I-COFT exercises. This modification would permit a much better test of performance under degraded modes.

Meaningfulness of Results

What is the practical significance of the findings that category I & II soldiers shot 67% of the targets while category IV soldiers shot 53% of the targets and took two seconds longer to fire? One approach is to examine the effect size as urged by proponents of meta-analysis, e.g., Glass (1977). Effect size reflects the magnitude of the difference between groups in terms of standard deviation units. Note that the difference between Category I & II and Category IV for percent hits and the speed/accuracy composite approached 1.0. An effect size of 1.0 is generally considered a large effect (Cohen, 1977).

Another approach is to interpret the value of the differences between groups in terms of potential hardware changes. In this context, consider the performance levels of the category IV soldiers as baseline performance. How

much would it cost to improve the fire control system of the M1 tank such that in situations where it is now 53% accurate, it would become 67% accurate? Likewise, what hardware modifications would be required and their associated costs to improve the system firing rate two seconds? A third approach is to input the obtained values into a soldier performance model and calculate the impact of group performance differences in terms of the model.

## Soldier Performance Modeling Analyses

Bessemer (1988) has developed a composite measure of tank gunnery effectiveness based on the Lanchester combat attrition model. Bessemer's work has, in part, simplified Bonder's (1970) Markov-dependent fire model to the extent that the I-COFT test data can be used as values in the composite equation for gunnery effectiveness. (Refer to Taylor (1980) for a thorough discussion of the Lanchester-type models.) The result is a composite gunnery performance measure which combines hit and time data into a single meaningful score.

From Bonder's (1970) Markov-dependent fire model, Bessemer (1988) derived the following equation for "Estimated time to hit target"

$$E(T) = t_a + t_1 + [(1 - p_1) / p_n] t_1$$

where:

$E(T)$ = Estimated time to hit target

$t_a$ = Time to acquire target

$t_1$ = Time to fire following acquisition

$p_1$ = Probability of first round hit

$p_n$ = Probability of subsequent round hit.

Based on the following assumptions, the derived equation is a special case of Bonder's (1970) general model of "Estimated time to kill." First, the conditional probability of a hit following a hit is assumed to equal the conditional probability of a hit following a miss. Second, the time to fire following acquisition is assumed to be constant for the first and subsequent rounds. Third, and as is true in Bonder's general case, the model assumes a target rich environment.

Given that the expression, $[(1 - p_1) / p_n]$, represents the expected number of rounds required to hit the target following the first round, the equation is fairly intuitive. The estimated time to hit the target is the sum of (a) the time to acquire the target plus, (b) the time to fire the first round (together equalling opening time) plus, (c) the expected number of additional rounds needed to hit the target multiplied by (d) the time to fire subsequent rounds. The equation estimates time to hit the target rather time to kill the target because range, ammunition, and target characteristics are ignored.

Several additional assumptions were made in the analysis of the I-COFT data. First, it was assumed that the probability of hits was constant across all rounds, i.e., the probability of a first round hit was equal to the probability of subsequent round hits. Second, it was assumed that the target acquisition time was a constant for all engagements, with the constant estimated at five seconds.

The five second constant was derived from the following information. In the three of four exercises which were defensive engagements, the synthetic TC took an average of nearly two seconds to lay the gun within three degrees of the target. A typical gunner then took one second to switch the sight to 10 power and say "identified." The synthetic TC then directed "driver move out," after which it took around three seconds for the tank to move from a turret-down to a hull-down position. In the one offensive engagement, the last step was not applicable. The five second estimate is the weighted mean of the four engagements.

Mean percent hits and opening times from the I-COFT tests for each of the mental categories were plugged into the above equation. The results represented the number of seconds to hit a target. A new measure, "estimated hits per minute," was then calculated by dividing the result into 60 seconds. Table 6 shows the estimated hits per minute in a target rich environment as a function of mental category.

Table 6

Estimated Hits Per Minute by Mental Category

| Mental Category | Hits per Minute |
|---|---|
| I & II | 2.5 |
| IIIA | 2.3 |
| IIIB | 2.1 |
| IV | 1.8 |

These data show that according to the model of tank gunnery effectiveness category I & II soldiers would hit 2.5 targets per minute in a target-rich environment, while category IV's would hit only 1.8 targets per minute. Assuming for a moment the performance of the category I & II soldiers to be 100%, Figure 1 shows the estimated hits per minute data as a percent of category I & II performance.

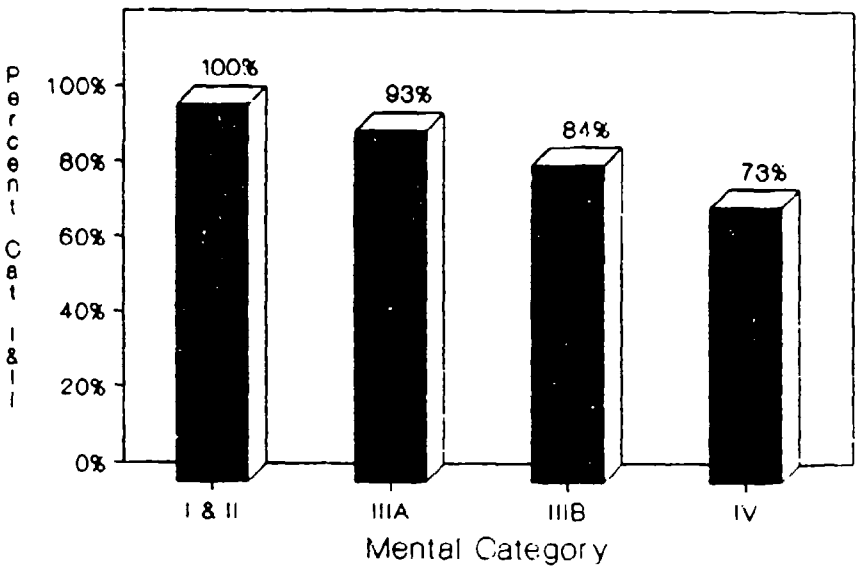


Figure 1. Estimated hits per minute as a percentage of mental category I & II performance.

A caveat is necessary. Incorporating the I-COFT data into the gunnery effectiveness combat model removes the results a considerable degree from actual soldier performance. The validity of the results now become additionally dependent on the quality of the assumptions. While each assumption independently appears to be reasonable, taken together it is less clear. Nevertheless, the gunnery effectiveness results do provide additional perspectives on the meaning of the data.

An alternative way to consider the hits per minute data is to look at how many M1 tanks it would take to hit ten opposing forces (OPFOR) tanks in a one minute battle in a target rich environment. Table 7 shows these data by mental category.

These data may even underestimate the number of additional tanks required for the poorer performers, i.e., lower mental categories. Consider a scenario where ten OPFOR vehicles are attacking a defensive position at 30 kilometers per hour. The longer it takes to kill the targets, either through misses or longer engagement times, the closer the OPFOR tanks come. While it may be possible to win a battle with a three to one numerical disadvantage when the OPFOR tanks are at 2000 meters, success is highly unlikely after the tanks close to 600 meters. This is to suggest that there will be situations where only the most accurate and fastest tank crews will be the ones to survive.

Table 7

Number of M1 Tanks Required to Hit 10 OPFOR Tanks
in a 1-Minute Battle by Mental Category

| Mental Category | Number of M1 tanks |
|---|---|
| I & II | 4.0 |
| IIIA | 4.3 |
| IIIB | 4.8 |
| IV | 5.5 |

Yet another way to consider the gunnery effectiveness data is to convert the numbers in Table 7 to dollar values based on the cost of the additional tanks. Table 8 shows the estimated dollar costs of additional tanks required to equate the performance levels of the different mental category. For example, it takes 1.375 category IV tanks to equal the performance of one category I & II tank (5.5/4.0). At $2.5M per M1 tank, category IV gunners require an additional $938,000 worth of tanks to make them equal in performance to category I & II.

Table 8

Estimated Dollar Costs of Additional Tanks Required
to Equate Performance of Mental Categories

| Mental Category | Cost above Category I & II |
|---|---|
| I & II | $0 |
| IIIA | $188K |
| IIIB | $500K |
| IV | $938K |

## Summary

The results indicate that OSUT soldiers with higher mental ability were faster and more accurate on the I-COFT gunnery test than soldiers with lower mental abilities. Analyses using a soldier performance model demonstrated that differences in performance levels would likely have a large impact on unit combat effectiveness. Furthermore, the model showed category IV soldiers performed at approximately 73% of category I & II soldiers.

The link between mental ability and gunnery performance was demonstrated with soldiers who were essentially novices in tank gunnery. Whether these results represent the relationship of mental ability and tank gunnery across all levels of proficiency is not addressed. Taken together with the Scribner et al. (1984) results, however, differences in tank gunnery performance have been demonstrated as a function of mental ability for both OSUT soldiers and soldiers from highly trained TO&E units.

Other factors besides mental ability also clearly contribute to differences in tank gunnery performance. Previous $S^3$ analyses of these same data show spatial and psychomotor test scores to be even more highly correlated with I-COFT speed and accuracy than mental ability (Graham, in prep). Success in combat, in addition, requires the performance of a number of tasks other than gunnery, in particular command, control and communication ($C^3$) and tactics. Other research will likely be conducted to determine the skills and abilities necessary for successful $C^3$ and tactical performance. Fortunately, recent developments in the simulation arena, e.g., the Simulation Networking (SIMNET) system and the Phantom Run Instrumented MILES - Extended (PRIME), should enhance the identification, training, and evaluation of critical $C^3$ and tactical gunnery skills.

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TRAINING EXERCISE NUMBER: 31271

TITLE: STATIONARY TANK - SHORT RANGE SINGLE STATIONARY TARGETS (GUNNER - BATTLESIGHT - GAS - MANUAL - DAY - MALF: LRF - STAB - GPS - COMP - PCH - MT)

SCOPE: The crew, occupying a stationary firing position, engages single stationary targets located from 640-1500 meters. Visibility is day unlimited and the tank is operational except for the GPS, stabilization, power control handles, manual elevation handle trigger, computer and rangefinder.

TIME: 10 minutes.

TASK: Engage stationary target from a stationary tank.

CONDITIONS:

a. Firing owntank is in a turret down position.

b. Owntank is fully operational except for the stabilization, GPS, power control handles, rangefinder, computer and manual elevation handle trigger.

c. Stationary targets vary in range from 640-1500 meters.

d. Visibility is daylight unlimited.

e. Battlesight ammo and range is SABOT-1200 meters (main gun SABOT).

STANDARDS:

From time of full target exposure, move into a hull-down firing position, open fire within 23 seconds, and kill the target within 25 seconds without exposing owntank more than 15 seconds. (See Note 1)

PERFORMANCE MEASURES: (All times are from target exposure)

a. Target Acquisition

1. Identify the target correctly.

2. Lay the weapon for direction so the gunner "identifies" the target within 10 seconds.

b. Reticle Aim

1. Point targets

(a) Main Gun

(1) Open fire within 18 seconds.

(2) Within 20 seconds, kill two targets with first round or kill the target with the second round with a reticle lay error of less than .67 mils. (See Note 1)

(b) COAX Machine Gun

(1) Open fire within 18 seconds.

(2) Obtain at least 3 hits within 20 seconds with no more than 100 rounds.

2. Area Targets

(a) COAX machine gun

(1) Open fire within 18 seconds.

(2) Obtain at least 50 percent target coverage within 25 seconds with no more than 100 rounds.

c. System Management

1. Perform no system management errors.

2. Errors will be assessed for the following:

(a) Firing the wrong weapon or ammunition at the target.

(b) Firing with GPS in low power.

(c) Exposing owntank longer than 15 seconds.

d. Crew Coordination

1. Perform no crew coordination errors.

2. Errors will be assessed for the following:

(a) Omitting elements of the initial and subsequent fire command.

(b) Including incorrect elements in the initial or subsequent fire command.

NOTE 1: Additional time, for time to fire and time to kill is provided for targets located beyond effective battlesight range, (SABOT - ~~0-1400~~, HEAT 0-1100). Additional time: 1 target - 5 seconds.

INSTRUCTOR NOTES:

a. Become familiar with the exercise.
b. Check that crew has correct setup for normal mode.
c. Read instructions to the crew.
d. Initiate exercise.
e. Monitor crew's performance.
f. Critique the exercise.

CREW INSTRUCTIONS:

"The purpose of this exercise is to develop the skills necessary to detect, identify, engage and hit a stationary target from a stationary tank using battlesight gunnery techniques. Assume you are in combat occupying a turret down stationary defensive firing position. Your tank is operational except for the GPS, stabilization, power control handles, manual elevation handle trigger, computer and rangefinder. Battlesight ammo and range is SABOT-1200 meters. It is daylight and visibility is unlimited. Ensure that all switches and controls are at their operating position. (Pause). Upon detecting a target, you must move to a hull down position, open fire within 23 seconds, kill the target within 25 seconds without exposing owntank more than 15 seconds. If the target is beyond effective battlesight range, you will receive an additional 5 seconds. You will be evaluated on proper fire commands and gunnery techniques. Upon completion of the exercise, you will receive a critique of your performance. Time begins when the target appears. Do you have any questions?"

TARGET SUMMARY:

| TARGET PRESENTATION SEQUENCE | TARGET | RANGE | SPEED | VIEW | GUN | SIGHT | AMMO |
|---|---|---|---|---|---|---|---|
| 1 | Tank | 1070 | stationary | full 45° right | main | GAS | SABOT |
| 2 | Tank | 1250 | stationary | full left | main | GAS | SABOT |
| 3 | APC | 1010 | stationary | full 45° right | main | GAS | HEAT |
| 4 | Truck | 910 | stationary | full left | main | GAS | HEAT |
| 5 | APC | 960 | stationary | full 45° right | main | GAS | HEAT |
| 6 | Tank | 1500 | stationary | full 45° right | main | GAS | SABOT |
| 7 | Heli-copter | 1260 | stationary | full 45° right | main | GAS | HEAT |
| 8 | Truck | 640 | stationary | full 45° left | coax | GAS | 7.62mm |
| 9 | APC | 920 | stationary | full 45° right | main | GAS | HEAT |
| 10 | Tank | 1390 | stationary | full 45° right | main | GAS | SABOT |

NOTE: There are four target presentation sequence replications. The computer will select the replication appropriate for the crew.

**TRAINING EXERCISE NUMBER:** 32511

**TITLE:** MOVING TANK - LONG RANGE SINGLE MOVING TARGETS (GUNNER - PRECISION - GPS - NORMAL - DAY)

**SCOPE:** The crew, operating a moving tank, engages single moving targets located from 1650-2050 meters. Visibility is day unlimited and the tank is fully operational.

**TIME:** 10 minutes.

**TASK:** Engage a moving target from a moving tank.

**CONDITIONS:**

a. Firing owntank is moving 20-35 miles per hour.

b. Owntank is fully operational with weapons loaded (main gun SABOT).

c. Moving targets vary in range from 1650-2050 meters.

d. Visibility is daylight unlimited.

**STANDARDS:**

From time of full target exposure, open fire within 18 seconds and kill the target within 20 seconds.

**PERFORMANCE MEASURES:** (All times are from target exposure)

a. Target Acquisition

1. Identify the target correctly.

2. Lay the weapon for direction so the gunner "identifies" the target within 10 seconds.

b. Reticle Aim

1. Point targets

(a) Main Gun

(1) Open fire within 18 seconds

(2) Within 20 seconds, kill the target with first round or kill the target with the second round with a reticle lay error of less than .67 mils.

c. System Management

1. Perform no system management errors.

2. Errors will be assessed for the following:

(a) Failing to range prior to firing.

(b) Firing the wrong weapon or ammunition at the target.

(c) Firing with GPS in low power.

(d) Firing ammo different than announced in the fire command.

d. Crew Coordination

1. Perform no crew coordination errors.

2. Errors will be assessed for the following:

(a) Omitting elements of the initial and subsequent fire command.

(b) Including incorrect elements in the initial or subsequent fire command.

(c) Using the elements of the initial and subsequent fire command in the incorrect sequence.

INSTRUCTOR NOTES:

a. Become familiar with the exercise.
b. Check that crew has correct setup for normal mode.
c. Read instructions to the crew.
d. Initiate exercise.
e. Monitor crew's performance.
f. Critique the exercise.

CREW INSTRUCTIONS:

"The purpose of this exercise is to develop the skills necessary to detect, identify, engage and hit a moving target from a moving tank. Assume you are in combat on the attack. Your tank is fully operational and weapons are loaded (main gun SABOT). It is daylight and visibility is unlimited. Ensure that all switches and controls are at their operating position. (Pause). Upon detecting a target, open fire within 18 seconds, kill the target within 20 seconds. You will be evaluated on proper fire commands and gunnery techniques. Upon completion of the exercise, you will receive a critique of your performance. Time begins when the target appears. Do you have any questions?"

TARGET SUMMARY A:

| TARGET PRESENTATION SEQUENCE | FIRING TANK SPEED | TARGET | RANGE | SPEED | VIEW | GUN | SIGHT | AMMO |
|---|---|---|---|---|---|---|---|---|
| 1 | 20 MPH | Tank | 1790 | Moving 20 MPH | full left | main | GPS | SABOT |
| 2 | 25 MPH | Tank | 1650 | Moving 25 MPH | full 45° right | main | GPS | SABOT |
| 3 | 20 MPH | APC | 1720 | Moving 20 MPH | full left | main | GPS | HEAT |
| 4 | 25 MPH | Helicopter | 1700 | Moving 25 MPH | full 45° left | main | GPS | SABOT |
| 5 | 30 MPH | Helicopter | 1750 | Moving 40 MPH | full 45° left | main | GPS | HEAT |

**TRAINING EXERCISE NUMBER: 32241**

TITLE: STATIONARY TANK - LONG RANGE SINGLE STATIONARY TARGETS (GUNNER - PRECISION - GPS - EMERGENCY - DAY - MALF: STAB - COAX)

SCOPE: The crew, occupying a stationary firing position, engages single stationary targets located from 620-2390 meters. Visibility is day unlimited and the tank is fully operational except for stabilization. The COAX fails during the exercise but can be corrected by immediate action.

TIME: 10 minutes.

TASK: Engage a stationary target from a stationary tank.

CONDITIONS:

a. Firing owntank is in a turret down position.

b. Owntank is fully operational except for stabilization. The COAX fails during the exercise, but can be corrected by immediate action.

c. Stationary targets vary in range from 620-2390 meters.

d. Visibility is daylight unlimited.

e. Weapons are loaded (main gun SABOT).

STANDARDS:

From time of full target exposure, move into a hull-down firing position, open fire within 18 seconds, and kill a point target within 20 seconds or obtain at least 50 percent coverage of an area target within 25 seconds without exposing owntank more than 15 seconds.

PERFORMANCE MEASURES: (All times are from target exposure)

a. Target Acquisition

1. Identify the target correctly.

2. Lay the weapon for direction so the gunner "identifies" the target within 10 seconds.

b. Reticle Aim

1. Point targets

(a) Main Gun

(1) Open fire within 18 seconds.

(2) Within 20 seconds, kill the target with first round or kill the target with the second round with a reticle lay error of less than .67 mils.

(b) COAX Machine Gun

(1) Open fire within 18 seconds.

(2) Obtain at least 3 hits within 20 seconds with no more than 100 rounds.

2. Area Targets

(a) COAX machine gun

(1) Open fire within 18 seconds.

(2) Obtain at least 50 percent target coverage within 25 seconds with no more than 100 rounds.

c. System Management

1. Perform no system management errors.

2. Errors will be assessed for the following:

(a) Failing to range prior to firing.

(b) Firing the wrong weapon or ammunition at the target.

(c) Firing with GPS in low power.

(d) Firing ammo different than announced in the fire command.

(e) Exposing owntank longer than 15 seconds.

d. Crew Coordination

1. Perform no crew coordination errors.

2. Errors will be assessed for the following:

(a) Omitting elements of the initial and subsequent fire command.

(b) Including incorrect elements in the initial or subsequent fire command.

(c) Using the elements of the initial and subsequent fire command in the incorrect sequence.

INSTRUCTOR NOTES:

a. Become familiar with the exercise.
b. Check that crew has correct setup for emergency mode.
c. Read instructions to the crew.
d. Initiate exercise.
e. Monitor crew's performance.
f. Critique the exercise.

CREW INSTRUCTIONS:

"The purpose of this exercise is to develop the skills necessary to detect, identify, engage and hit a stationary target from a stationary tank. Assume you are in combat occupying a turret down stationary defensive firing position. Your tank is fully operational except for stabilization and weapons are loaded (main gun SABOT). It is daylight and visibility is unlimited. Ensure that all switches and controls are at their operating position. (Pause). Upon detecting a target, you must move to a hull down position, open fire within 18 seconds, kill the target within 20 seconds or, if an area target, cover 50 percent of the target within 25 seconds without exposing owntank more than 15 seconds.You will be evaluated on proper fire commands and gunnery techniques. Upon completion of the exercise, you will receive a critique of your performance. Time begins when the target appears. Do you have any questions?"

**TARGET SUMMARY**

| TARGET PRESENTATION SEQUENCE | TARGET (1) | RANGE | MOTION SPEED DIRECTION | VIEW | GUN | SIGHT | AMMO |
|---|---|---|---|---|---|---|---|
| 1 | Tank | 1750 | stationary | full 45° right | main | GPS | SABOT |
| 2 | APC | 2010 | stationary | full 45° right | main | GPS | HEAT |
| 3 | Tank | 1740 | stationary | full 45 ° right | main | GPS | SABOT |
| 4 | Heli-copter | 2290 | stationary | full 45° right | main | GPS | HEAT |
| 5 | Tank | 2390 | stationary | full 45° right | main | GPS | SABOT |
| 6 | Troops | 620 | stationary | area | coax (1) | GPS | 7.62mm |
| 7 | Truck | 700 | stationary | full 45° right | main | GPS | HEAT |
| 8 | Tank | 2180 | stationary | full 45° right | main | GPS | SABOT |
| 9 | Heli-copter | 2110 | stationary | full 45° right | main | GPS | HEAT |
| 10 | Tank | 2340 | stationary | full 45° left | main | GPS | SABOT |

NOTE 1: Coax fail to fire. If crew applies immediate action the weapon will fire.

NOTE 2: There are four target presentation sequence replications. The computer will select the replication appropriate for the crew.

TRAINING EXERCISE NUMBER: 32321

TITLE: STATIONARY TANK - LONG RANGE SINGLE MOVING TARGETS (GUNNER - PRECISION - GPS - NORMAL - NIGHT)

SCOPE: The crew, occupying a stationary firing position, engages single moving targets located from 800-2130 meters. It is night and visibility is limited to TIS conditions.

TIME: 10 minutes.

TASK: Engage a moving target from a stationary tank.

CONDITIONS:

a. Firing owntank is in a turret down position.

b. Owntank is fully operational with weapons loaded (main gun SABOT).

c. Moving targets vary in range from 800-2130 meters.

d. Visibility is night limited to TIS conditions.

STANDARDS:

From time of full target exposure, move into a hull-down firing position, open fire within 18 seconds, and kill the target within 20 seconds without exposing owntank more than 15 seconds.

PERFORMANCE MEASURES: (All times are from target exposure)

a. Target Acquisition

1. Identify the target correctly.

2. Lay the weapon for direction so the gunner "identifies" the target within 10 seconds.

b. Reticle Aim

1. Point targets

(a) Main Gun

(1) Open fire within 18 seconds.

(2) Within 20 seconds, kill the target with first round or kill the target with the second round with a reticle lay error of less than .67 mils.

(b) COAX Machine Gun

(1) Open fire within 18 seconds.

(2) Obtain at least 3 hits within 20 seconds with no more than 100 rounds.

c. System Management

1. Perform no system management errors.

2. Errors will be assessed for the following:

(a) Failing to range prior to firing.

(b) Firing the wrong weapon or ammunition at the target.

(c) Firing with GPS in low power.

(d) Firing ammo different than announced in the fire command.

(e) Exposing owntank longer than 15 seconds.

d. Crew Coordination

1. Perform no crew coordination errors.

2. Errors will be assessed for the following:

(a) Omitting elements of the initial and subsequent fire command.

(b) Including incorrect elements in the initial or subsequent fire command.

(c) Using the elements of the initial and subsequent fire command in the incorrect sequence.

INSTRUCTOR NOTES:

a. Become familiar with the exercise.
b. Check that crew has correct setup for normal mode.
c. Read instructions to the crew.
d. Initiate exercise.
e. Monitor crew's performance.
f. Critique the exercise.

CREW INSTRUCTIONS:

"The purpose of this exercise is to develop the skills necessary to detect, identify, engage and hit a moving target from a stationary tank. Assume you are in combat occupying a turret down stationary defensive position. Your tank is fully operational and weapons are loaded (main gun SABOT). It is night and visibility is limited to TIS conditions. Ensure that all switches and controls are at their operating position. (Pause). Upon detecting a target, you must move to a hull down position, open fire within 18 seconds, kill the target within 20 seconds without exposing owntank more than 15

seconds. You will be evaluated on proper fire commands and gunnery techniques. Upon completion of the exercise, you will receive a critique of your performance. Time begins when the target appears. Do you have any questions?"

TARGET SUMMARY

| TARGET PRESENTATION SEQUENCE | TARGET | RANGE | MOTION SPEED | VIEW | GUN | SIGHT | AMMO |
|---|---|---|---|---|---|---|---|
| 1 | Tank | 1870 | moving 20 MPH | full right | main | GPS (TIS) | SABOT |
| 2 | Heli-copter | 2120 | moving 35 MPH | full left | main | GPS (TIS) | HEAT |
| 3 | APC | 1700 | moving 25 MPH | full right | main | GPS (TIS) | HEAT |
| 4 | Tank | 2030 | moving 25 MPH | full 45° right (variable) | main | GPS (TIS) | SABOT |
| 5 | APC | 2010 | moving 23 MPH | full left | main | GPS (TIS) | HEAT |
| 6 | Tank | 2000 | moving 18 MPH | full 45° right | main | GPS (TIS) | SABOT |
| 7 | Truck | 2040 | moving 20 MPH | full front | main | GPS (TIS) | HEAT |
| 8 | Truck | 800 | moving 19 MPH | full Front | coax | GPS (TIS) | 7.62mm |
| 9 | Heli-copter | 2130 | moving 30 MPH | full right | main | GPS (TIS) | HEAT |
| 10 | Tank | 2040 | moving 25 MPH | full 45° left (variable) | main | GPS (TIS) | SABOT |

NOTE: There are four target presentation sequence replications. The comr will select a replication appropriate for the crew.