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The UCLA National Center for Research on Evaluation, Standards, and Student Testing (CRESST) conducted research on assessment models and tools designed to support Naval distance learning (DL), with application to USMC marksmanship training. CRESST examined the role of cognitive and non-cognitive variables in the prediction of rifle marksmanship performance in a series of studies. The evidence suggests a knowledge component to shooting performance, and differences in knowledge of rifle marksmanship between participants' pre-classroom training and post-classroom training, between more experienced participants and less experienced participants, between high performers and low performers, and between higher aptitude and lower aptitude participants. Knowledge measures can predict record-fire scores moderately in less experienced samples, and when combined with other variables within the stages-of-skill-processing framework, can predict record-fire scores as well as scores from a rifle simulator.

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Determinants of Rifle Marksmanship Performance: Predicting Shooting Performance With Advanced Distributed Learning Assessments

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Knowledge, Models and Tools to Improve
the Effectiveness of Naval Distance Learning

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Office of Naval Research
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ACRONYMS AND TERMS

Acronym or Term	Definition
ADL	Advanced distributed learning. Training, instruction, and assessment delivered over the Web.
BMK	Basic marksmanship knowledge. Selected-response measure intended to sample basic knowledge about USMC rifle marksmanship.
CTSR	Classroom Test of Scientific Reasoning.
CWO	Chief warrant officer.
DL	Distributed learning, distance learning. Used synonymously to refer to Web-based learning.
ELR	Entry-level rifle marksmanship.
ESP	Evaluation of shooter positions. Online task intended to measure a participant's knowledge of proper and improper shooting positions.
GCT	General Classification Test.
KSA	Knowledge, skills, and abilities.
KD	Known distance. Course of fire at specified distances (e.g., 200 yards).
LT	Lieutenant.
Phase I	Rifle marksmanship classroom training period, Wednesday and Thursday of Week 1.
Phase II	Rifle marksmanship live-fire period, Monday through Thursday of Week 2.
SLR	Sustainment-level rifle marksmanship.

DETERMINANTS OF RIFLE MARKSMANSHIP PERFORMANCE: PREDICTING SHOOTING PERFORMANCE WITH ADVANCED DISTRIBUTED LEARNING ASSESSMENTS[1]

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March 31, 2004

ABSTRACT

The UCLA National Center for Research on Evaluation, Standards, and Student Testing (CRESST) is under contract to the Office of Naval Research (ONR) to conduct research on assessment models and tools designed to support Navy and Marine Corps distance learning (DL). The first such application is in support of USMC marksmanship training. In a series of studies we examined the role of cognitive and non-cognitive variables in the prediction of rifle marksmanship performance. Prior research on predicting shooting performance suggests a deceptively complex task sensitive to a variety of variables. The stages-of-skill-development model (Ackerman, 1987, 1992; Fitts & Posner, 1967) suggests cognitive measures will be most sensitive to individuals in the learning phase, and perceptual-motor measures most sensitive to individuals past the learning phase. The role of cognitive variables (knowledge of shooting in particular) is largely unexplored

[1] We would like to thank the staff at Stone Bay WTBN, especially Col. Sheldon, LtCol. Harrelson, CWO Conrad, CWO Bennett, SSgt. Armistead, Sgt. Butterbaugh, Sgt. Burke, Sgt. Behan, Capt. Athanasiadis, MSgt. Race, and Cpl. Cabe. We would also like to thank the staff at Quantico WTBN, especially MGen. Jones, BGen. Flynn, Major Thomas, Col. Bourgeois, Col. Kerrigan, CWO Pipenhagen, Major Bourne, Capt. Hasseltine, SSgt. Jones, Sgt. Greene, Sgt. Pritt, GySgt. Kyle, GySgt. Witherspoon, and SSgt. Pinheiro. We also thank all the Marines from Stone Bay and Quantico who participated in these studies. Special thanks to Steve Jones of Mitre Corp. for facilitating the process. We also wish to thank the following people from UCLA/CRESST: Joanne Michiuye for her help with the preparation of this manuscript and with data collection, Nicole Kersting and Gale Stuart for their help with data analysis, Cecile Phan and Gary Dionne for their help with data collection, and David Brill, Farzad Saadat, Ravi Sinha, and Matthew Zhang for programming and technical support.

beyond examination of shooting performance across groups receiving different training and instruction.

In a series of studies we were able to predict record-fire performance between .52 to .86, depending on the sample. Bivariate correlations between various measures and record-fire scores were obtained in the .2 to .8 range. Perceptual-motor measures—intended to reflect experience—were consistently a good predictor of performance. The most recent record-fire score predicted record-fire score at the .3 to .4 range. The best single predictor of record-fire score was the firing line experience survey, which yielded correlation coefficients from .6 to .8. Cognitive measures (aptitude and knowledge related to marksmanship) in less experienced samples related to record-fire score in the .2 to .4 range. No relationships between record-fire score and knowledge measures were found in the more experienced sample. Affective measures (worry, anxiety) predicted record-fire scores in the -.3 to -.6 range and in general, for the affective and firing line experience measures, state measures had coefficients of higher magnitude than the trait versions.

Overall, we have gathered evidence that in general suggests a knowledge component to shooting performance. The results of our studies point to differences in knowledge of rifle marksmanship between participants' pre-classroom training and post-classroom training, between more experienced participants and less experienced participants, between high performers and low performers, and between higher aptitude and lower aptitude participants. Knowledge measures can predict record-fire scores moderately in less experienced samples, and when combined with other variables within the stages-of-skill-processing framework, can predict record-fire scores as well as scores from a rifle simulator.

Rifle marksmanship is a complex psychomotor skill sensitive to variations in the individual, equipment, and environment. It is unlikely that variation in the equipment and environment can be reduced much, thus leaving the individual as the only area for improvement. Given that we have found a cognitive component to rifle marksmanship performance, it may be that improving a Marine's knowledge of rifle marksmanship will have the most cost-effective payoff. Early identification and remediation could lead to increased cost savings in travel, decreased time away from the Marine's home unit, increased throughput on the firing line, increased time coaches spend providing feedback to shooters on the firing line, and lower ammunition and target costs. In addition to cost savings, early identification and remediation could lead to higher scores overall and fewer unqualified Marines.

SECTION I: OVERVIEW

Background

Rifle marksmanship is a core value of the Marine Corps. The creed "Every Marine is a Rifleman" embodies the value Marines place on marksmanship. Marines are recognized as having the best marksmanship training and riflemen of the uniformed services and the Marines' competitive marksmanship program has consistently generated world-class shooters since its inception. Marines have to undergo annual qualification and their performance accounts for part of a promotional decision. Regardless of occupation, whether their job is infantry, air combat, or support, and regardless of weapons specialty, every Marine[2] must qualify on an M16A2 rifle at least as a marksman or it is unlikely he or she will be promoted.

The UCLA National Center for Research on Evaluation, Standards, and Student Testing (CRESST) is under contract to the Office of Naval Research (ONR) to conduct research on assessment models and tools designed to support Navy and Marine Corps distance learning (DL). The project is called Knowledge, Models and Tools to Improve the Effectiveness of Naval Distance Learning, or KMT. The approach to conducting KMT research has been to develop and test tools designed to address the assessment and training requirements posed by real Navy and Marine Corps training applications. The first such application is USMC marksmanship training.

USMC Context of the Work

Ensuring that every Marine qualifies, as well as improving sustainment-level training such that every Marine qualifies as expert, is the concept behind program HUEY (Unqualified [UNQ] to Expert), developed by Lt. Col. Carl Shelton of the Stone Bay Weapons Training Battalion (WTBN). Initially, the idea was that assessment tools and simulations could be used to provide remedial training to Marines *after* they failed to qualify. Later conceptualizations evolved to the idea of the potential of using distributed learning technology—online assessments and instruction—to assess Marines and if needed, provide instruction *before* Marines

[2] Some exemptions apply based on experience or rank, such as Marines with 20 years or more of active duty, Colonels and above, Sergeants Major or Master Gunnery Sergeants, and CWO 4 and 5.

reached the firing line—and ideally, before they reached Stone Bay. Bewley et al. (2003) describe the current marksmanship training process in more detail.

The potential for time and cost savings is there: Early identification and remediation could lead to increased cost savings in travel, decreased time away from the Marine's home unit, increased throughput on the firing line, increased time coaches spend providing feedback to shooters on the firing line, and lower ammunition and target costs. In addition to cost savings, early identification and remediation could lead to higher scores overall, fewer UNQs, and more experts. However, the potential for cost savings and enhanced shooting performance is contingent on the ability to first identify potential UNQs and potential low shooters.

This document reports on a series of studies conducted to examine the role of cognitive and non-cognitive variables in the prediction of rifle marksmanship performance. We begin with an introduction to rifle marksmanship, then review the literature on predicting shooting performance, and end the section with our validation strategy and research questions. The next major section reports on the domain sampled and presents an overview of all of the study findings. The third major section reports on the pilot studies, and the fourth major section reports on the main studies.

Introduction to Rifle Marksmanship

In this section we describe our conceptualization of rifle marksmanship as a kind of skilled sport. We first briefly describe what makes shooting difficult, and then discuss five variables, based on the literature, that affect shooting performance.

Why Is Consistently Hitting a Target Difficult?

One of the most remarkable achievements in USMC marksmanship training and weaponry is in developing a shooter's skill to routinely hit a 19-inch circular area at 500 yards in the prone position. Five hundred yards is about 1.5 times farther than the distance between two people at opposite ends (lengthwise) of the Los Angeles Coliseum (see Figure 1). What makes this achievement even more remarkable is that virtually any deviation of the rifle from the center line will result in a miss. A rifle muzzle deflection of 1/16 inch (about the thickness of a quarter) from the center line will result in the bullet strike being off by about five inches at 100 yards and over 2 feet at 500 yards.

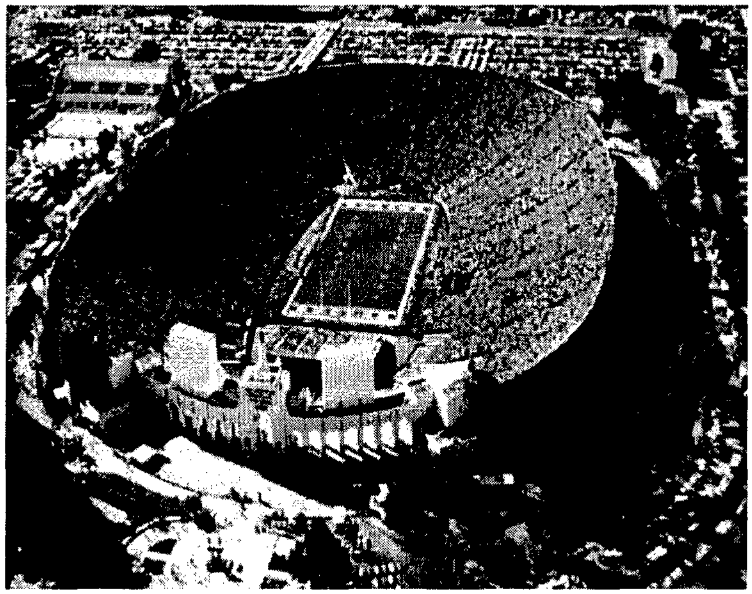

Figure 1. Example of the USMC qualification distance in the slow-fire prone position: approximately 1.5 stadium lengths of the Los Angeles Coliseum.

Adding to this complexity are uncontrollable factors such as wind velocity, gravity, and ammunition ballistics. For example, a 10-mph breeze (enough to raise dust and loose paper) displaces a round about 2 feet over 500 yards. Gravity alone results in the round dropping 20 inches over 300 yards. Variations in the amount of propellant across bullets result in 10-inch shot groups at 300 yards for skilled shooters (U.S. Army, 1989).

These examples do not take into account factors associated with the shooter—perhaps the most variable component. Normal breathing in the standing position can displace the rifle muzzle 1/2 inch from inhale to exhale, while changes due to the heart pulse can also displace the muzzle a fraction of an inch. If a shooter's sight alignment is off by a fraction of an inch, the shooter is unlikely to hit the target. Fatigue decreases results by causing shaking, wobble, or other instabilities; flinching or bucking due to recoil or reaction to the report causes the shooter to jerk the rifle, as does pulling or yanking the trigger. Exacerbating position instability is the emotional state of the shooter—anxiety and other factors increase the heart and breathing rates. Finally, the recoil from the rifle can cause the muzzle to rise about 20 milliradians (Torre, Maxey, & Piper, 1987). Figure 2 shows how minute changes of the rifle affect the bullet strike under ideal conditions. For example, moving the muzzle 1/8 of an inch results in the bullet strike being off-center by nearly 2 feet at 200 yards.

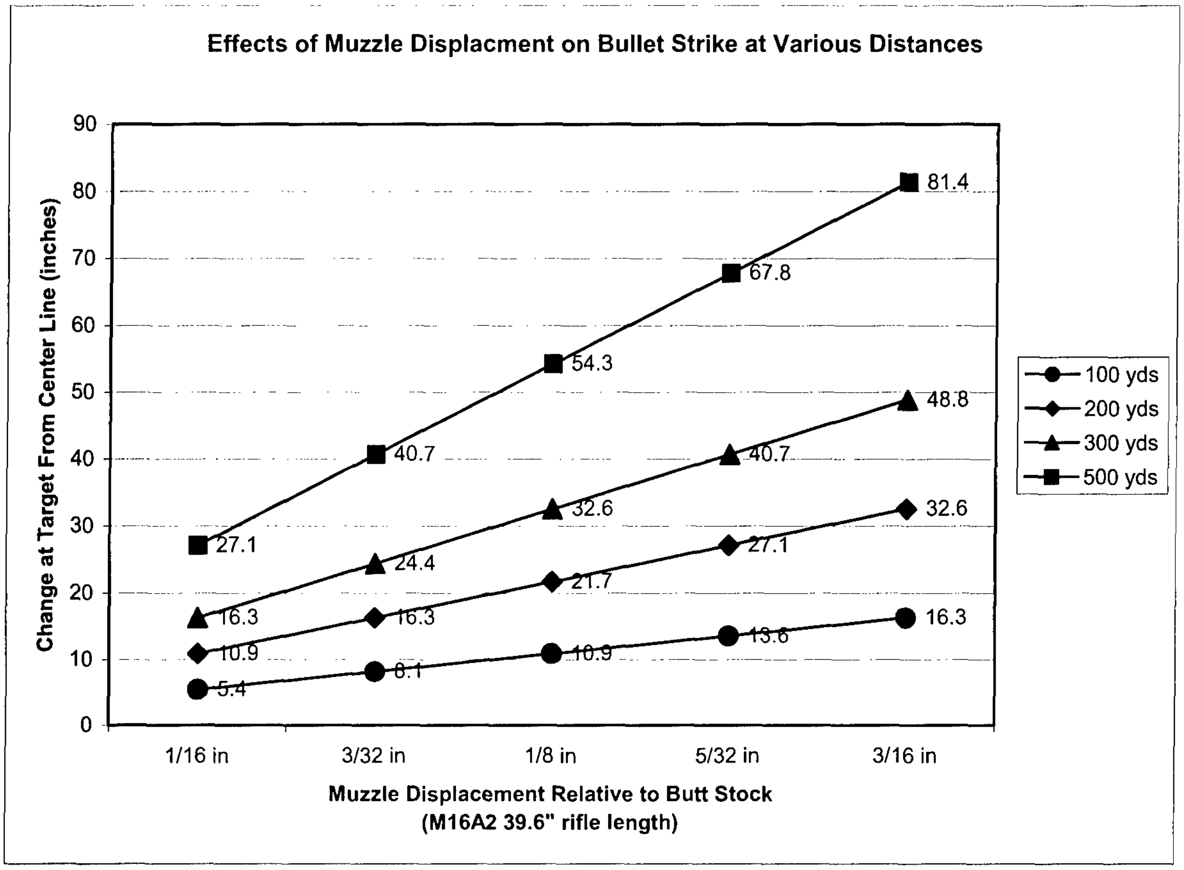

Figure 2. Estimated effects of muzzle displacement on bullet strike at different distances under ideal conditions. Actual displacement is greater.

Thus, accurately and consistently hitting a target is a complex interaction of factors immediately before, during, and immediately after the round goes off: establishing and maintaining sight alignment on the target, maintaining postural steadiness, not disturbing the rifle while squeezing the trigger, and adjusting for environmental effects. Virtually any deviation from a motionless position will result in a miss, virtually any deviation from a perfectly aligned and sighted rifle will result in a miss, and lack of compensation for wind, distance, and other environmental factors will result in a miss.

Further, accurately predicting shooting performance may be difficult given the low reliability of record-fire scores (Schendel, Morey, Granier, & Hall, 1983). The relationships between successive trials have been found to range from no relationship (Marcus & Hughes, 1979) to moderate correlations in the .5 range (Vielhaber & Lauterbach, 1966), to high correlations (MacCaslin & McGuigan, 1956) in the mid- to high .80s.

Prior Rifle Marksmanship Research

There has been little effort to understand rifle shooting as a complex skill as opposed to other sports (c.f., baseball [French, Nevett, Spurgeon, Graham, & Rink, 1996; French, Spurgeon, & Nevett, 1995; Nevett & French, 1997], tennis [McPherson & French, 1991; McPherson, 1999a, 1999b; McPherson & Thomas, 1989; Nielsen & McPherson, 2001]). In general, the conceptual framework behind marksmanship research has been driven by improving training on the "fundamentals of rifle marksmanship"—the physical and mental factors believed to underlie skilled shooting performance. The basic set of relationships among postural stability, rifle handling, distance, and weather were established by World War I. For example, the 1916 Marine Corps Score Book (Harllee, 1916) describes the set of marksmanship fundamentals that are also covered in the current Marine Corps Rifle Marksmanship Manual (U.S. Marine Corps, 2001b). The basic procedures for aligning sights, maximizing position stability, and establishing and maintaining breath and trigger control remain essentially unchanged. Most of the research on rifle marksmanship has been conducted by the U.S. Army where the focus has traditionally been on developing and evaluating different training programs (e.g., Evans, Dyer, & Hagman, 2000; Evans & Osborne, 1998; Evans & Schendel, 1984; Hagman, 1998, 2000; Hagman, Moore, Eisley, & Viner, 1987; Hagman & Smith, 1999; McGuigan, 1953).

Studies that have explicitly attempted to predict rifle performance have been conducted in the context of evaluating how well performance on a rifle simulator relates to actual record-fire performance on the firing range (e.g., Hagman, 1998; Marcus & Hughes, 1979; Schendel, Heller, Finley, & Hawley, 1985; Smith & Hagman, 2000; Torre et al., 1987). Another body of research has used shooting as a platform to study skilled behavior in relation to psychophysiological constructs and measurements (e.g., Bird, 1987; Hatfield, Landers, & Ray, 1987; Janelle et al., 2000; Kerick, Iso-Ahola, & Hatfield, 2000; Konttinen & Lyytinen, 1992, 1993; Konttinen, Lyytinen, & Konttinen, 1995).

A complementary approach that we have adopted is to conceptualize the domain of rifle marksmanship performance as a function of skill and environment. We have conceptualized the skill component as being composed of three interrelated dimensions: perceptual-motor, cognitive, and affective. The environment component is composed of two factors that are uncontrollable, equipment and environment.

Unfortunately, shooting has not been conceptualized as a skilled sport and there has been little in the way of theoretical development to point to the set of important variables or processes underlying skilled shooting performance. By extension, prior research provides little specific guidance on which variables to measure. However, one conclusion that is clear from prior research is that consistently hitting the same area of a target is difficult. This difficulty is presumably due to the requirement to simultaneously coordinate gross-motor control of body positioning with fine-motor control of the trigger finger, minute movements of the hands, elbows, legs, feet, and cheek, and perceptual cues related to the target, front and rear sights, rifle movement, and body movement, while under stressful conditions.

Thus, from a theoretical stance, little is known about which variables differentiate shooters of different skill levels; how perceptual-motor, cognitive, and affective variables relate to each other over time; how fast shooting skill decays over time; how sensitive shooting performance is to shooting conditions; or the relative importance of different shooting position variables.

Rifle Marksmanship as a Complex Skill

To better understand rifle marksmanship performance, we have adopted the stages-of-processing framework of skilled learning (Ackerman, 1987, 1992; Fitts & Posner, 1967; Wrisberg, 2003). The general notion is that skilled performance evolves over three stages of development: an early cognitive phase, an intermediate associative phase, and a final autonomous phase (Fitts & Posner, 1967). During the cognitive stage, trainees are in the process of learning what the task entails—the procedures, relevant perceptual cues, different shooting positions, how to coordinate breathing and squeezing the trigger, and how to use results (i.e., where the round hit) as feedback. Thus, there is high cognitive demand for performers to attend to multiple stimuli and procedures. During the cognitive stage, trainees typically learn about the task through individual or whole-group instruction or other training vehicles (e.g., CD-ROM instruction, rifle simulators). Training involves weapon handling and the fundamentals of marksmanship—what aiming, breath control, trigger control, and the different positions are, and how they affect shot placement. During live-fire practice, trainees commit much of their cognitive resources on learning and understanding the task with respect to performance.

Some examples of the kinds of learning activities during the cognitive phase for rifle marksmanship would be learning the terminology, learning how to handle the weapon, and learning the fundamentals of rifle marksmanship. Performance during the cognitive phase is low, error-prone, and inconsistent, and requires conscious thought. The high cognitive-processing demands imposed by the task also make performance sensitive to distractions and other ongoing activities. Novice shooters would be expected to have a poor grasp of the fundamentals, score low, exhibit poor coordination and integration of the different elements of the fundamentals, and not be able to recognize correct from incorrect positions. Novice shooters would also be expected to be more sensitive to changes in the environment (e.g., weather, equipment malfunction, anxiety) than more advanced shooters.

The intermediate stage is characterized by performers knowing what is expected of the task. During this stage, the attentional demands of the task are reduced and thus trainees can focus on refining the motor responses to the task and develop and test techniques to improve performance. Practice on the task becomes more refined and consistent and the gross errors of the cognitive phase diminish. Speed and accuracy on the task improve over the practice period as coordination between cognitive and motor responses improves. During this stage and the more advanced automaticity stage, knowledge becomes increasingly compiled and broad ability measures and content-specific abilities become less influential on performance for closed-ended skills such as marksmanship.

Characteristics of the associative phase for rifle marksmanship would include a basic knowledge of weapons handling, terminology, and the fundamentals of rifle marksmanship. Performance during the associative phase would show rapid improvement over the course of fire.

In the final stage, the performer executes the skill automatically. Performance is consistent and seemingly effortless. The cognitive load on performers with respect to executing the task is lowered (compared to other stages), thus freeing up resources. Shooters who have reached the autonomous phase could be expected to be true experts—snipers or members of the rifle team, for example. Performance is consistent and robust against distractions. There may be increases in performance but the rate of improvement slows over time. Very few individuals are expected to reach this stage without deliberate, effortful, and consistent practice.

Thus, the stages-of-processing conception provides an interpretive framework to understand (a) how overall rifle marksmanship performance evolves over time, and (b) that different classes of variables differentially relate to performance at each stage of development.

Understanding Rifle Marksmanship Within the Stages-of-Processing Framework

In this section we first review the past research on predicting shooting performance and interpret the findings within this framework. Figure 3 shows the broad categories and the variables from prior research that have been examined within each category. This broad framework was used to guide our development of assessments of rifle marksmanship, conditioned by feasibility and delivery constraints. Table 1 and Table 2 summarize the findings of studies that have explicitly examined predictors of record-fire performance.

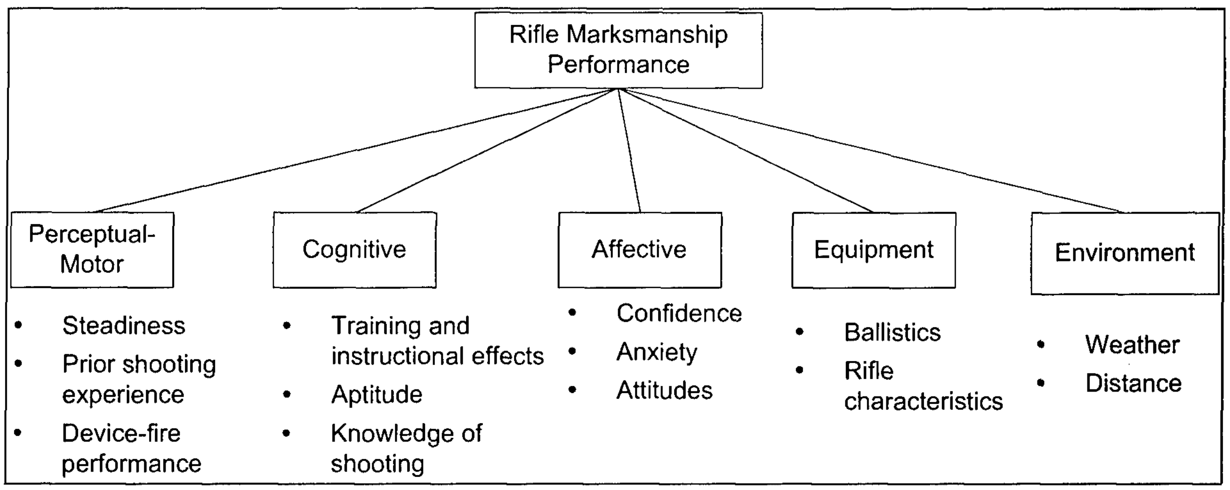

Figure 3. Overview of rifle marksmanship variables examined in marksmanship research.

Table 1

Summary of Perceptual-Motor Variables Related to Record-Fire Performance ($p < .05$)

Predictor variables	r	n
Rifle steadiness (Humphreys, Buxton, & Taylor, 1936)	.72	43
Rifle steadiness (McGuigan & MacCaslin, 1955)	.22	148
Rifle steadiness (Spaeth & Dunham, 1921)	.61	73
Prior shooting experience and aptitude (MacCaslin & McGuigan, 1956)	R = .67 to .72	
Prior shooting experience (Tierney, Cartner, & Thompson, 1979), males	.24	
Prior shooting experience (Tierney et al., 1979), females	.19	
Prior hunting experience (Tierney et al., 1979), males	.21	
Prior experience with a .22 rifle (Thompson, Smith, Morey, & Osborne, 1980), males	.21 to .25	
Prior record-fire performance (McGuigan & MacCaslin, 1955). Repeated qualification course 3 times.	.88 and .84	
Self-reported prior record-fire performance (Schendel et al., 1983)	.29	121
Prior record-fire performance (Smith, 2000, Experiment 2)	.37	50
Prior record-fire performance (Thompson, Morey, Smith, & Osborne, 1981)		388
Weaponeer device-fire (Schendel et al., 1985, Experiment 1)	.37–.74	102
Weaponeer device-fire (Schendel et al., 1985, Experiment 2)	.17–.55	244
Combat Training Theater device-fire (Marcus & Hughes, 1979)	low	
Laser Marksmanship Training System device-fire (Smith & Hagman, 2000)	.55	95
Engagement Skills Trainer device-fire (Hagman, 1998)	.68	102
Other device-fire (Torre et al., 1987)	.54	29

Table 2

Summary of Cognitive and Affective Variables Related to Record-Fire Performance ($p < .05$ unless otherwise noted)

Predictor variables	r	n
Cognitive		
ASVAB clerical/administrative (Carey, 1990)	.26§	
ASVAB general technician (Carey, 1990)	.35§	
ASVAB electrical repair (Carey, 1990)	.32§	
ASVAB mechanical maintenance (Carey, 1990)	.38§	
ASVAB composite (Carey, 1990)	.32§	
Infantry training GPA (Carey, 1990)	.25§	
Core job knowledge (Carey, 1990)	.31§	
Supervisor ratings (Carey, 1990)	.16§	
Skill Qualification Test, a measure of a soldier's skill achievement (Wisher, Sabol, Sukenik, & Kern, 1991)	.24	439
Armed Forces Qualification Test (Wisher et al., 1991)	n.s.	
Knowledge of zeroing (Thompson et al., 1980)	.50	144
Knowledge of bullet strikes at greater ranges than the 25m target trainees were practicing on (Thompson et al., 1980)	.33	144
Knowledge of distance effects and appropriate sight adjustments (Thompson et al., 1980)	.31	144
Anxiety		
Self-reported nervousness (Tierney et al., 1979)	-.19	
Predicted record-fire score for soldiers whose confidence estimates in their prediction were > 90% (Schendel et al., 1983)	.50	41

§Significance level not reported.

Perceptual-motor variables. The perceptual-motor variables under consideration relate to the physical aspects of shooting such as carrying out the different shooting positions, establishing proper sight alignment and sight picture, and maintaining rifle steadiness. Skilled shooters are able to position various body parts to achieve maximum rifle support with minimal fatigue in different positions (prone, sitting, kneeling, standing), and establish and maintain sight alignment (centering the front sight post within the rear sight aperture) and correct sight picture (centering the sights on the target). A shooter's skill in consistently hitting the same spot on a target is determined largely by the extent to which he or she can maintain these factors before, during, and after firing a round.

Steadiness. For example, skilled shooters have been found to be able to hold a rifle steadier than unskilled shooters and this steadiness relates positively to shooting performance (Humphreys et al., 1936; McGuigan & MacCaslin, 1955; Spaeth & Dunham, 1921). In general, being able to maintain a steady body position has consistently been found to be related to shooting performance. Expert shooters have been found to perform higher on measures of whole-body stability (e.g., Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996; Gates, 1918). While an obvious finding, what is less obvious is that experts have been found to increase their stability during the aiming period preceding the shot (Era et al., 1996).

Experience with weapons. Another important variable that has been found related to shooting performance is experience with weapons and prior record-fire performance. MacCaslin and McGuigan (1956) found self-reported shooting experience combined with aptitude scores contributed substantially to record-fire score prediction, with multiple R between .67 and .72, $p < .01$. Similarly, Tierney et al. (1979) found low, positive relationships between self-reported prior rifle experience and record-fire scores for males and females ($r = .24$, $p < .05$; $r = .19$, $p < .05$). In addition, hunting experience also correlated significantly with record-fire scores for males ($r = .21$, $p < .05$). Similarly, significant relations were found between self-reported experience with a .22 caliber rifle and record-fire scores for male entry-level Army trainees (r ranged from .21 to .25, depending on the experimental condition, Thompson et al., 1980).

Previous record-fire performance. In addition to experience with weapons, one of the best predictors of a record-fire score is the shooter's previous record-fire score. McGuigan and MacCaslin (1955) reported test-retest reliabilities of unskilled Army trainees on three trials of a slow-fire qualification course. The average reliability of the slow-fire course for samples drawn from two Army bases was .88 and .84. Schendel et al. (1983) report a significant correlation between Army soldiers' self-reported prior record-fire score and actual record-fire score ($r = .29$, $n = 121$, $p < .01$). Smith (2000, Experiment 2) found a correlation of .37 ($p < .05$, $N = 50$) between the prior year's record-fire score and the current year's record-fire score for U.S. Army Reserve soldiers. As part of a study of skill retention, soldiers were retested 6 weeks after completing the basic rifle marksmanship course (Thompson et al., 1981). Soldiers ($N = 388$) repeated the same qualification course six weeks after record qualification. No correlations between record-fire and retest scores were reported;

however, compared to the record-fire score, 33% of soldiers scored lower and 60% of soldiers scored higher.

Device-fire performance. Device-fire performance, or shooting performance on a rifle simulator, has been one of the strongest predictors of record-fire performance. The use of rifle simulators has received much attention because of the cost-savings potential for sustainment-level training and remediation.

One of the earliest rifle simulator systems was Weaponeer. Schendel et al. (1985, Experiment 1) examined the relationship between device-fire scores on Weaponeer and record-fire scores 1 to 2 days later (foxhole supported position only). Schendel et al. (1985) found correlations between .37 and .74, depending on the experimental condition. However, in a follow-up study, the authors found lower correlations, between .17 and .55. Similar results were found for the Laser Marksmanship Training System (LMTS). Smith and Hagman (2000) found a moderate correlation between LMTS device-fire scores and range record-fire scores (r = .55, p < .05, N = 95). Likewise, Hagman (1998) found a strong correlation between record-fire scores and device-fire scores using the Engagement Skills Trainer (r = .68, p < .05, N = 102). Finally, a moderate correlation was found by Torre et al. (1987) in their investigation (r = .54, p < .05, n = 29). Other systems have been investigated (e.g., Combat Training Theater, Marcus & Hughes, 1979), but low correlations between device-fire and record-fire scores have been found, possibly owing to poor live-fire range conditions.

Summary. Some of the strongest predictors of shooting performance are experience-related variables. Surprisingly, the magnitude of the relationship is lower than might be expected and the correlation between the experience-related variables and shooting score varies considerably across studies. For example, the test-retest reliability of previous shooting experience is at best in the .80s (McGuigan & MacCaslin, 1955) across the span of a few days. As the time interval increases (e.g., across annual qualifications), the correlation drops to the .30s. Just as surprising are the range of correlations between device-fire and record-fire scores (r ranges from .2 to .7) over one or two days. Our interpretation of these results is that in general, shooting performance is very sensitive to many variables. While perceptual-motor variables may be the strongest predictor of shooting performance, cognitive and affective variables may help explain the variation.

Cognitive variables. Presumably underlying shooting performance is the knowledge of marksmanship—(a) knowing position-related factors (e.g., what the different positions are, how to properly position limbs, how to control breathing and trigger, how to align the sights on the target), and (b) knowing cause-effect relations (e.g., knowing how yanking the trigger affects the muzzle, knowing why the rifle should be supported by bone instead of muscle, understanding the concept that everything a shooter does position-wise should minimize body movement [and thus rifle movement]).

The importance of knowledge of marksmanship was recognized by early authors on shooting. For example, Whelen (1918, p. 455) asserted that "Rifle shooting is almost entirely a matter of *intelligent* practice. Practice alone, without head work, will not get one very far." Similarly, the 1916 Marine Corps Score Book emphatically stated that Marines should not even be allowed to handle a weapon if they did not know the fundamentals of marksmanship (Harllee, 1916). However, rifle marksmanship research has virtually ignored the simple questions of how much do shooters know about marksmanship and how does their knowledge of marksmanship relate to their shooting performance?

Training effects. The available evidence suggests that shooting performance is sensitive to knowledge. Studies of different training programs clearly show group differences in record-fire scores. For example, McGuigan (1953) compared part- and whole-task training methods with Army basic trainees. Those soldiers in the whole-task training condition outperformed soldiers in the part-task training condition on record-fire performance. Further, regardless of training condition, soldiers in general shot higher after receiving training.

Additional evidence of the sensitivity of shooting to instruction is seen in an instructional study by Boyce (1987). In her study, Boyce compared the performance of unskilled (novice) shooters in the prone position across three instructional conditions and a control condition over five days (trials). The experimental conditions received different forms of instruction on marksmanship. The control condition received the minimal instruction required to safely shoot the weapon. In general, conditions with instruction on marksmanship significantly outperformed the control group. In addition, a main effect for trial was found, with the mean score across conditions on the first trial significantly lower than the mean score on subsequent trials. Similarly, higher rifle marksmanship performance was observed in normal versus accelerated training cycles, again suggesting sensitivity to instruction and thus a cognitive component (Cline, Beals, & Seidman, 1960).

Knowledge of shooting. In a study comparing different marksmanship training techniques, Thompson et al. (1980) found that for entry-level male Army trainees, record-fire scores correlated with knowledge of zeroing (r = .50, p < .001, n = 144), knowledge of bullet strikes at greater ranges than the 25m target trainees were trained on (r = .33, p < .001, n = 144), and knowledge of range effects and appropriate sight adjustments (r = .31, p < .001, n = 144). However, this finding was only for the experimental treatment receiving the most training support. A similar pattern of correlations but lower in magnitude (r in the low .20s) was found for another experimental condition. However, no such relations were found for the normal training condition or for a third training condition.

Aptitude and achievement. Other studies have examined the relationship between aptitude and achievement measures with record-fire performance. While not measures of marksmanship knowledge, these variables suggest the potential for shooters to acquire the knowledge.

Carey (1990) examined the relationship between a variety of background variables and first-term enlisted Marines' known distance (KD) record-fire performance. Moderate correlations between various subscales of the ASVAB and record-fire scores were found, ranging from .26 for the clerical/administrative subscale to .38 on the mechanical maintenance. The relationship to the overall ASVAB composite was .32. Infantry training GPA was weakly related to record-fire scores (r = .25), as was performance on a core job knowledge test (r = .31) and supervisor ratings (r = .16). Unfortunately, Carey does not report significance levels of these correlations.

Similarly, a significant correlation was found between record-fire score and score (r = .24, p < .01, n = 439) on the Skill Qualification Test, a measure of a soldier's skill achievement (Wisher et al., 1991). However, Wisher et al. found no relationship between soldiers' scores on the Armed Forces Qualification Test (AFQT), a measure of aptitude, and their record-fire scores. As mentioned earlier, MacCaslin and McGuigan (1956) combined aptitude (Aptitude Area I on the Army Classification Battery) and self-reported shooting experience to predict record-fire score with a multiple R in the .70 range.

Summary. While knowledge of rifle marksmanship has been recognized as important for nearly a century, there has been virtually no research examining the relationship between knowledge of rifle marksmanship and shooting performance. The only study that did examine what was learned from training found moderate relationships between knowledge and shooting performance. Training clearly has an impact on shooting performance, and proxy variables for the potential to learn such knowledge are suggestive of a relationship. These findings point to a possible knowledge component to shooting performance.

Affective variables. As with knowledge variables, the relationship between affective variables and shooting performance has been largely unexplored. In general, the amount and type of mental thoughts preceding the moment of firing are believed to have an influence on shot quality. For example, EEG frequencies preceding low-scoring shots in an expert shooter were interpreted as resulting from distracting thoughts and increased mental activity (Bird, 1987; Konttinen & Lyytinen, 1992). This interpretation is consistent with an early examination of expert and novice shooters (Gates, 1918), where novice shooters' performance was affected severely by dwelling on steadiness factors (e.g., "I can't seem to control myself" or "There, I moved again"; p. 3). Tierney et al. (1979) found low, negative relationships between self-reported nervousness about firing and record-fire scores for females but not males ($r = -.19$, $p < .05$). Sade, Bar-Eli, Bresler, & Tenenbaum (1990) found that highly skilled shooters reported significantly lower (state) anxiety than moderately skilled shooters when measured 10 minutes prior to competition (seven occasions). Further, shooting performance was negatively related with state anxiety in six of seven competitions.

Equipment and environmental variables. Finally, a third area that has received attention is in investigating equipment aspects. For example, Kemnitz, Rice, Irwin, Merullo, and Johnson (1997) found that shooting performance on an M16A2 (as measured using a rifle simulator) increased with a shorter stock and reduced rifle weight. Early studies of the M16A1 rifle examined performance variables such as accuracy of the rifle, zeroing, shooter error, barrel stress, and ballistics. Osborne, Morey, and Smith (1980) and later studies compared firing and serviceability characteristics of the M16A1 to M16A2 (Osborne & Smith, 1986).

Summary and discussion. In general, the highest correlations with record-fire scores were with steadiness scores and live-fire and device-fire scores. Prior record-fire scores correlated lower with current record-fire scores, possibly owing to skill decay over time periods of 12 months. Prior shooting experience related with record-fire scores, but the correlations were low in magnitude. Knowledge-related variables correlated moderately with record-fire scores, and prior shooting experience scores correlated even lower.

When the data are interpreted within the stages-of-skill-processing framework, several trends appear that are consistent with the framework. First, the overall variability in shooting performance across studies can be interpreted as sensitivity of the act of shooting to different conditions. The strongest evidence that shooting can be consistent is in the test-retest study by McGuigan and MacCaslin (1955). In their studies, the shooters fired the same qualification course three times across three days. The test-retest coefficient was .84 and .88 depending on the sample.

One of the most interesting findings is the low predictability of the most recent record-fire score (r in the .3–.4 range). Again, when interpreted in terms of the stages-of-skill-processing framework, the data are consistent with the idea that shooters were still in the cognitive phase. The sample was young soldiers or Marines who were undergoing sustainment-level training and requalification. The typical time in service was 1-2 years. Performance was varied and inconsistent.

The low to moderate correlations between device-fire and record-fire scores observed across different rifle simulators may reflect a possible effect due to fidelity of the shooting context. That is, the simulator system only approximates shooting conditions. The simulators in the studies reviewed in this report are all intended to be used indoors. Indoor conditions remain stable compared to the outdoors, which can vary considerably over time (e.g., cloud cover, intensity of sunlight [time of day], temperature, and humidity). The act of firing differs as well. Recoil and report are not simulated except for the Engagement Skills Trainer (EST) system, which also found the highest correlations with record-fire scores. Finally, the consequences of poor performance were low for device-fire and relatively high for record-fire. The studies were conducted with volunteers and device-fire scores were not part of the participant's permanent record. One effect of this difference was that the shooters probably did not experience as much "match pressure" during device-fire as they did during record-fire.

Consistent with the idea of more varied performance in the early stages of skill learning compared to later stages, higher correlations between device-fire and record-fire were found for the presumably more experienced sample. The sample in

Smith and Hagman (2000) were U.S. Army Reservists whereas other studies used entry-level trainees. In this case, the entry-level trainees would be expected to show inconsistent performance on both the rifle simulator and for record-fire, which may explain the lower correlations.

Overall, the research reviewed on predicting shooting performance suggests a deceptively complex task sensitive to a variety of variables. There appears to be a strong perceptual-motor component that includes motor control and experience variables. Further, shooting performance also appears to be sensitive to affective variables via the influence of anxiety on motor control. There also appears to be an aptitude and knowledge component associated with shooting performance; however, this area appears to be largely unexplored beyond examination of shooting performance across groups receiving different training and instruction.

Validation Strategy

Prior rifle marksmanship research has examined tangentially the role of knowledge in shooting performance. However, while there exists no research examining the relationships among perceptual-motor, cognitive, and affective variables for Marines in the learning phase and past the learning phase, research in other sports suggests the existence of a relationship between cognitive and motor skills (McPherson & French, 1991; Thomas, French, & Humphries, 1986). Thus, much of the work reported herein is an attempt to gather validity evidence to address these issues.

Our validation approach was to gather a range of evidence that would provide information about the suitability of our assessments for the purpose of identifying Marines who would be at risk of failing qualification. However, because very few Marines fail qualification (and the sample used in our data collection reflected this), we instead addressed the broader question of predicting record-fire score. In addition, given that the measures we developed were novel and their application to rifle marksmanship the first we knew of, we gathered a wide range of validity evidence that would provide information about the quality of our measures. Each type of evidence is described below.

Evidence of knowledge and skill performance consistent with the skill acquisition model. An important piece of evidence of the suitability of our assessment approach would be in findings that are consistent with the skill-acquisition model. In particular, perceptual-motor variables should matter more for prediction for more experienced participants (vs. less experienced), and aptitude and domain-related variables should matter more for less experienced participants (vs. more experienced).

Evidence of the predictability of record-fire scores. Another important piece of evidence would be in achieving high predictability of record-fire scores using our set of measures as dependent variables. If the set of perceptual-motor, cognitive, and affective measures—all ADL compatible—could predict Marines' record-fire scores reasonably well, then that finding would be compelling evidence for our approach.

Evidence of a relationship among knowledge measures. In addition to construct and predictive validity of our measures, there should also be evidence that our knowledge measures relate to each other; however, because the measures target different areas of marksmanship knowledge, we expected the measures to be differentially sensitive to Marines with different levels of experience.

Evidence of the sensitivity of knowledge measures. Another important body of evidence that would provide information on the quality of our measures is the sensitivity of our measures to (a) instructional effects and (b) knowledge differences. With respect to instructional sensitivity, one criterion of a sensitive instrument is its capability to detect changes in knowledge when learning occurs; that is, the measure should yield lower scores on a pretest and higher scores on a posttest, where the intervening event is instruction. Related to this is the idea that the measure should yield higher scores for those who have more knowledge than for those with less knowledge.

Research Questions

As suggested by the review on rifle marksmanship research, a variety of variables have been found to relate to shooting performance, including perceptual-motor, cognitive, and affective variables. The skill-acquisition model suggests poorest performance during the learning phase (i.e., when trainees are least likely to have acquired and internalized the knowledge required to shoot well). This framework guided our measurement strategy in the following way. First, we assumed that shooting skill, as measured by record-fire scores, followed the skill-acquisition model; thus, we expected that consistently lower shooting scores would be an indication that Marines were in the learning phase and consistently higher shooting scores would be an indication Marines were past the learning phase. Second, because we assumed a relationship between low performance and learning, we focused on developing or adopting measures that would differentiate Marines in the learning phase from Marines past the learning phase. We briefly describe next how we operationalized each type of variable and then present the research questions.

Perceptual-motor. We defined the perceptual-motor construct for rifle marksmanship as the combination of perceptual, gross-motor, and fine-motor skills related to successfully shooting a rifle. While measures of steadiness have been used in prior research and have shown a relationship with record-fire scores, our assumption was that such measures would not be feasible in a fielded setting and thus were ruled out. Instead, we developed survey questions that would serve as indirect measures of perceptual-motor development.

We expected the perceptual-motor component to function differently depending on where the Marine was in the skill-acquisition phase. For the current studies, we measured the perceptual-motor construct via proxy variables such as prior record-fire scores, prior shooting experience, shooting frequency, and competitive shooting experience.

Cognitive. We operationalized the cognitive construct as (a) aptitude and (b) knowledge of rifle marksmanship. Given the ADL environment, we targeted the knowledge component for measurement as knowledge was expected to be the most variable for Marines in the learning phase of the skill-acquisition model. In addition, we expected that measuring the knowledge component would be a tractable problem in an ADL context.

We used the CRESST development model to focus on the cognitive demands underlying rifle marksmanship. Cognitive demands refers to the set of skills, knowledge, and abilities (KSA) underlying successful rifle marksmanship. In the current study, the KSAs were the targets of assessment, particularly knowledge. Within that context, we developed assessments that we expected to be differentially sensitive to shooters in the learning phase compared to shooters past the learning phase. That is, we expected that higher performing shooters would have a deeper understanding and a broader knowledge base about rifle marksmanship compared to lower performing shooters.

Affective. We defined the affective construct for rifle marksmanship as the set of worry and anxiety constructs related to successful rifle marksmanship. Prior research suggests a relationship between affective variables and record-fire scores. Anecdotal evidence (i.e., discussion with marksmanship coaches) also suggests that anxiety and worry are negatively related to shooting performance, possibly owing to their effect on physiological processes (e.g., increased heart rate, breathing) and subsequently on maintaining a steady rifle.

Thus, our research was organized around questions related to predicting record-fire scores and questions related to the quality of our measures. The first two research questions bear directly on rifle marksmanship. The last research question focuses on the quality of assessments.

To what extent can record-fire performance be predicted from knowledge, perceptual-motor, and affective variables?

- Given the skill-acquisition framework, we expected that in general, higher shooting performance would be associated with (a) a deeper understanding and a broader knowledge of rifle marksmanship, (b) more shooting experience, and (c) consistent shooting performance.
- For shooters in the learning phase, we expected higher shooting performance to be associated with (a) higher aptitude, (b) more knowledge about rifle marksmanship, and (c) inconsistent performance.
- Given prior research, we expected negative affect to be negatively associated with shooting performance.

What combination of perceptual-motor, cognitive, and affective measures yield the best predictors of record-fire performance?

- Given prior research, we expected in general that perceptual-motor variables would contribute the most to the overall prediction of shooting performance.
- Given the skill-acquisition framework, we expected (a) the perceptual-motor component to contribute more to the prediction of shooting performance for Marines past the learning phase than for Marines in the learning phase; and (b) the knowledge component to contribute more to the prediction of shooting performance for Marines in the learning phase than for Marines past the learning phase.

- Given the skill-acquisition framework, which does not address affect, we had no expectations of the degree to which affective variables would contribute to the prediction of shooting performance.

What is the quality of the validity evidence for our measures of rifle marksmanship knowledge?

- An important criterion for judging the quality of an assessment is the extent to which the expectations listed in the prior two research questions are borne out. Because these expectations are derived directly from a theoretical model and prior research, results consistent with a theoretical framework would be evidence that our assessments are operating as expected.
- Other criteria for judging the quality of our assessments are (a) the extent to which the knowledge measures relate to each other; and (b) the degree to which the assessments are able to detect differences due to instruction and differences due to presumed differences in knowledge.

SECTION II: MEASUREMENT APPROACH AND OVERVIEW OF STUDIES

Section II provides our general approach to developing measures, a brief listing of the studies conducted, and a brief summary of the findings of the different studies with respect to the research questions posed earlier.

Our general measurement approach was to develop a range of measures to assess the different kinds of knowledge expected of Marines at different competency levels. Before we could develop the measures however, we first had to understand the terminology, concepts, and causal relations within the domain of rifle marksmanship.

Domain Sampling

Our analysis of the domain resulted in identifying 119 key knowledge components culled from the USMC rifle marksmanship doctrine manual (USMC, 2001b). The knowledge components are given in Appendix A. The knowledge was separated into 37 factual and 38 causal knowledge components. Further refinement of the knowledge components resulted in identifying key factual knowledge (Appendix B) and key causal knowledge. Factual knowledge covered basic definitions and procedures and in general, could be acquired via rote memorization. Causal knowledge covered cause-effect relations (Appendix C) and was considered more conceptual. To determine which knowledge components to sample in our assessments, we asked the marksmanship coaches at Stone Bay to identify the topics most relevant to shooting performance. As a result of this consultation, we eliminated topics related to weather or the environment (e.g., effects of overcast), uniform (e.g., effects on placement of the rifle butt in the shoulder), ammunition, physiology (e.g., perspiration, rapid fatigue), and equipment (e.g., effects of rifle chamber temperature). The remaining knowledge elements were the major elements presumed to be most directly related to placing a round on target. Table 3 shows the topics and subtopics that were sampled across the assessments.

Table 3

Topics Sampled in Assessments

Topic	Subtopics
Breath control	Breath control, Natural Respiratory Pause, Natural point of aim
Trigger control	Bucking, Finger placement, Firm grip, Flinching, Grip of firing hand, Trigger control Trigger squeeze
Aiming	Accuracy, Aiming process, Follow-through, Eye on front sight post, Sight adjustment, Sight alignment/picture
Position	7 factors common to all shooting positions, Body placement, Bone support, Eye relief, Feet placement, Finger placement, Firm grip, Forward elbow placement, Forward hand placement, Leg placement, Muscular relaxation, Muscular tension, Rifle butt placement, Stable firing position, Stock weld placement
Other	Consistency, Distance effects, Weapons safety, BZO setting

Given the domain, our general measurement strategy was to develop a range of measures for different kinds of knowledge that we expected Marines of different competency levels to have. Over the course of the studies, we adopted, developed, and refined the following types of measures:

- Selected-response, basic rifle marksmanship knowledge measure to broadly sample the domain at a surface level (i.e., at the recognition and recall level).

- Constructed-response, conceptual understanding (knowledge map) instrument that was intended to measure Marines' understanding of cause-effect relations among different factors of shooting.

- Constructed-response, shot-group-knowledge instrument that was intended to measure Marines' knowledge of prototypical shot groups associated with different shooter errors.
- Constructed-response, knowledge-of-proper-shooting-position instrument that was intended to measure Marines' knowledge of proper or improper body elements of different shooter positions.
- Surveys of worry and anxiety.
- Survey items covering prior record-fire scores, prior training experience, perceived level of rifle marksmanship knowledge, perceived utility of marksmanship knowledge, firing line experience, and prior shooting experience.

Overview of Studies and Findings

Over one year, five data collections were conducted to test our measures on Marines at two sites that conducted rifle marksmanship training (Stone Bay, NC, and Quantico, VA). The data were from sustainment-level (SLR) Marines and entry-level (ELR) 2nd Lieutenants. Table 4 presents an overview of the studies and Table 5 presents an overview of the evidence with respect to each of the types of validity evidence.

Table 4

Overview of Studies

Date and study	Location	Sample	Purpose
June 2002, Pilot 1	Stone Bay, NC	SLR	Pilot test measures (on paper), gather feedback from instructors.
Nov. 2002, Pilot 2	Stone Bay, NC	SLR	Pilot test online system in an operational environment.
Dec. 2002, Study 1	Stone Bay, NC	SLR	Test assessments of marksmanship knowledge and evaluate prediction of qualification score.
Mar. 2003, Study 2	Quantico, VA	SLR	Replicate study on 2nd sample.
May 2003, Study 3	Quantico, VA	ELR	Replicate study on 2nd LTs undergoing entry-level training.

Table 5

Overview of Findings

Research question	Supporting evidence
To what extent can record-fire performance be predicted from knowledge, perceptual-motor, and affective variables?	
• Given the skill-acquisition framework, we expected that in general, higher shooting performance would be associated with	
A deeper understanding and a broader knowledge of rifle marksmanship	• In Study 2, low performers scored significantly lower on the knowledge map and basic marksmanship knowledge tasks, and perceived their level of knowledge as lower than others. • In Study 2, participants who had just completed the Marksmanship Coaches Course scored significantly higher than the SLR sample on the knowledge map and shot group depiction tasks.
More shooting experience	• In Study 2, coaches reported significantly higher record-fire scores in the past than the SLR sample. • In Study 2, record-fire score was significantly related to frequency of shooting outside of job, and years of shooting experience prior to joining the USMC.
Consistent shooting performance	• Unable to test due to inadequate sample size.
• For shooters in the learning phase, we expected higher shooting performance to be associated with	
Higher aptitude	• In Study 3 (entry-level 2nd LT shooters), aptitude was a significant and moderate predictor of record-fire score.
More knowledge about rifle marksmanship	• In Study 1, for participants classified as learners, record-fire scores were significantly and moderately related to basic marksmanship knowledge scores and shot group depiction scores. • In Study 1, for participants classified as low performers, record-fire scores were significantly and moderately related to shot group depiction scores and perceived utility of marksmanship knowledge. • In Study 3 (entry-level 2nd LT shooters), expert-qualified shooters scored significantly higher on basic marksmanship knowledge and perceived level of marksmanship knowledge.

• For shooters in the learning phase, we expected to find	
Inconsistent shooting performance	• Unable to test due to inadequate sample size.
• Given prior research, we expected negative affect to be	
Negatively associated with shooting performance	• In Study 2, trait worry, state worry, and state anxiety were negatively and significantly related to record-fire scores. • In Study 3, trait worry, state worry, and state anxiety were negatively and significantly related to record-fire scores.
What combination of cognitive, perceptual-motor, and affective measures yield the best predictors of record-fire performance?	
• Given prior research, we expected in general that	
Perceptual-motor variables would contribute the most to the overall prediction of shooting performance	• In Pilot Study 1, frequency of shooting outside of job contributed substantially to the prediction of record-fire score. • In Pilot Study 2, Study 1, and Study 2, most recent record-fire score contributed substantially to the prediction of record-fire score. • In Study 2, self-reported firing line experience contributed substantially to the prediction of record-fire score.
• *Given the skill-acquisition framework, we expected*	
Perceptual-motor component to contribute more to the prediction of shooting performance for Marines past the learning phase than for Marines in the learning phase	• In Study 1, this relationship was not found for high performers (there were no good predictors of record-fire score for high performers).
Knowledge component to contribute more to the prediction of shooting performance for Marines in the learning phase than for Marines past the learning phase	• In Study 1, this relationship was not found for medium performers on the basic marksmanship knowledge measure ($p = .09$) and on whether they took the coaches course. • In Study 3, aptitude, basic marksmanship knowledge, and perceived level of marksmanship knowledge related significantly to record-fire score.
• Given the skill-acquisition framework, which does not address affect	
We had no expectations of the degree to which affective variables would contribute to the prediction of shooting performance	• In Study 2, trait worry did not contribute to the prediction of record-fire score, after taking into account most recent record-fire score, firing line experience, and marksmanship basic knowledge. • In Study 3, state worry contributed to the prediction of record-fire scores ($p = .07$), above and beyond firing line experience and aptitude.

• What is the quality of the validity evidence for our measures of rifle marksmanship knowledge?	
Extent to which the knowledge measures relate to each other	• In Pilot Study 2, basic marksmanship knowledge was related low but significantly to whether participants had Phase I training and the more recently they had Phase I training. • In Study 1, low to moderate correlations were found between all measures of knowledge (basic marksmanship knowledge, knowledge map, shot group depiction, and evaluation of shooter positions) except between knowledge map and shot group depiction. • In Study 2, basic marksmanship knowledge related low but significantly with knowledge map, shot group depiction, and perceived level of knowledge of marksmanship. • In Study 3, aptitude related moderately significantly to the basic marksmanship knowledge test and pre-classroom training knowledge map, and shot group depiction related to pre- and post-classroom training knowledge map scores. • In Study 3, pre-classroom training knowledge map scores related significantly to the post-qualification knowledge map posttest. • In Study 3, the previous occasion's knowledge map score related significantly to the following occasion's knowledge map score.
Degree to which the assessments are able to detect differences due to instruction	• In Study 2, significant differences were found between pre-classroom training and post-qualification scores on the basic marksmanship knowledge and knowledge map measures. • In Study 3, significant differences were found between pre-classroom training and post-qualification scores on the basic marksmanship knowledge, shot group depiction, and knowledge map.
Differences due to presumed differences in knowledge	• In Study 2, participants who had just completed the Marksmanship Coaches Course scored significantly higher than the SLR sample on the knowledge map and shot group depiction tasks.

SECTION III: PILOT STUDIES

Section III describes two pilot studies conducted to gather information about the quality of our assessments. We conducted two pilot studies and three studies on different samples. The purpose of the first pilot study was to gather preliminary data on the relationships between knowledge of rifle marksmanship and shooting performance. The purpose of the second pilot study was to test the online versions of our software in the target environment. We wanted to identify, prior to the main study, any technical issues as well as gather information on the usability of our assessments.

Pilot Study 1—Method

A pilot study was conducted to test paper-based versions of our measures and administration procedures. The pilot study was conducted on the final day of the Marines' annual qualification week. Our focus was to gather information on the predictive validity of our measures by collecting preliminary data on the relationships between knowledge of rifle marksmanship and shooting performance.

Participants

Sixty Marines of various shooting ability participated in the study. In general, the Marines were between the ages of 18-30.

Design

The measures were administered to two groups of Marines. The first group was Marines who had been classified as "unqualified" at least once during qualification week. The second group was Marines who had qualified at either the sharpshooter or expert level. The tasks were timed to get a sense of the amount of time needed to complete the task. The Marines were instructed to wait for further instructions after each task was completed.

Measures

Record-fire score. The main outcome measure was a Marine's record-fire score. These scores were self-reported by Marines.

Knowledge mapping. Knowledge mapping was intended to measure in general, Marine's knowledge of rifle marksmanship and in particular, cause-effect relations among different aspects of marksmanship. The task required Marines to graphically depict their understanding of rifle marksmanship in terms of a network. The nodes in the network represented concepts, and labeled links among concepts represented the relationships among concepts. The sets of concepts and link labels were provided to Marines. The concepts provided were *Accuracy of aim (AOA), Battlesight zero (BZO), Bone support (BS), Center of mass (COM), Eye focus on front sight post (Eye on FSP), Eye relief (ER), Firm hand grip on trigger (FHG), Increased target distance (ITD), Muscular relaxation (MR), Rapid fatigue (RF), Rifle recoil recovery (RRR), Sight alignment (SA), Sight picture (SP), Sling tension (ST), Stable firing position (SFP), Stock weld placement (SWP), Trigger control (TC),* and *Weapon movement (WM).* The link labels provided were *causes, decreases, distorts, helps, increases, influences, leads to,* and *requires.*

Basic marksmanship knowledge. This task was intended to serve as a measure of participants' prior knowledge of rifle marksmanship. Marines were given 20 terms and asked to provide a short written response that could be a definition of the term or the significance of the term. The terms were *Weapon conditions, Weapons handling safety rules, Remedial action, Aiming, Breath control, Trigger control, Four shooting positions, Sight alignment, Sight picture, Zeroing, BZO, Natural point of aim, Natural respiratory pause, Muscling the rifle, Bone support, Muscular relaxation, Front sight post, Rear sight elevation knob, Rear sight windage knob,* and *Effects of weather.*

Shot-to-shot explanation. The intent of this task was to measure a Marine's reasoning from shot to shot. This measure was an attempt to mimic the cognitive demands of what a Marine would experience on the firing line under slow-fire conditions (i.e., fire a round, observe strike, evaluate possible causes of the observed strike). Five frames were shown to the Marine. Each successive frame showed successive bullet strikes. The Marine was required to check off possible causes that could give rise to the observed shot pattern from a list of 18 possible reasons. An example of the measure and hypothetical response are contained in Appendix D.

Shot group pattern analysis task. The intent of this task was to measure the extent to which a Marine could look at two shot patterns and posit adjustments made to the shooter (position or rifle) that could explain the difference between the two shot groups. A copy of the measure is contained in Appendix E.

Shot group depiction task. The intent of this task was to measure Marines' knowledge of shot groups associated with common shooter problems. Marines were required to draw a 5-shot group for problems with breathing, sight adjustment, trigger control, flinching, bucking, and focusing on the target. A sample showing the general format is contained in Appendix F.

Background survey. The intent of this task was to be able to characterize the sample and identify background characteristics that could differentiate high from low shooters. The kind of information gathered included unit information, prior shooting experience, combat status of unit, marksmanship training experience, and prior qualification scores.

Procedure

Our original intent was to have only coaches and staff review our measures; however, an opportunity arose to have Marines undergoing SLR qualification take our measures, although it was outdoors and under poor conditions. We reasoned that data under poor conditions could still provide useful information.

Data were collected across two groups on the same day. The first group of participants had shot poorly (i.e., unqualified or marksman). The second group was composed of participants who qualified as sharpshooter or expert. Participants were administered the knowledge and background measures as shown in Table 6. Participants were instructed to take as much time needed for the tasks. In general, participants finished all the tasks within the allotted time. The only exception was the knowledge map task, with some participants taking slightly longer.

Table 6

Administration Schedule

Task	Time allotted
Introduction to study	5
Basic marksmanship knowledge task	15
Shot group depiction task instructions and task	15
Shot-to-shot explanation task instructions and task	15
Shot group pattern analysis task	10
Background survey	10
Knowledge mapping instructions and task	20

Pilot Study 1—Results

Analyses of our preliminary measures suggested a relationship between Marines' self-reported qualification scores and knowledge of marksmanship. Based on this particular sample of Marines, we found that Marines' self-reported qualification score was related to the quality of their knowledge map. Self-reported qualification scores were best predicted by whether the Marine took the coaches course and the frequency of shooting outside of their USMC duties ($R = .62, p < .05$), followed by the extent to which they were able to depict shot groups associated with common shooter errors ($R = .55, p < .05$). Quality of the knowledge map was also related to qualification scores, although marginally statistically significant ($r = .36$, $p = .08$, $n = 24$). Marines' self-reported *previous* year's qualification score was also related to self-reported qualification score ($r = .38, p < .05$).

Discussion of Pilot Study 1

Note that these results were based on a sample of Marines who were administered paper measures under very poor administration conditions. Marines were sitting on bleachers on the firing range, under windy conditions. Also, the measures were exploratory and our first attempt at measuring knowledge of rifle marksmanship. Thus, these results are at best only suggestive of a relationship between shooting skill and knowledge.

Pilot Study 2— Method

The main objective of this pilot study was to carry out a technical dry run of the main study with Marines in the target environment. We wanted to identify any technical issues and gather information on the usability of our assessments. We dropped measures from Pilot Study 1 that did not appear promising, revised promising measures, and converted the paper measures to an online format. During the administration of our measures, numerous technical issues arose. The most serious issue was the severe network security restrictions, which prevented the administration of our QuickTime-based assessments.

Participants

Ninety-five Marines of various shooting ability participated in the study. In general, the Marines were between the ages of 18-30. Ninety-three of the participants were men and 2 were women. Sixty-six point seven percent of the participants were White, non-Hispanic; 11.1% were Latino/a; 9.1% were African-American; and 4.0% were Native American. Participants had completed the final week (Phase II) of their annual marksmanship qualification.

Measures

Record-fire score. The main outcome measure was participants' record-fire score. This score is the official score on record and is the sum of subscores on different positions at different distances. The various positions and distances, and score ranges are shown in Table 7. Cronbach's alpha for the record-fire score was .67. Qualification classifications are shown in Table 8. Note that the scale differs for scores on the entry-level and sustainment-level courses of fire. A conversion table developed by the USMC is given in Appendix G.

Table 7

Known-Distance Course Position and Scoring

Position	Distance (yards)	Maximum possible score
Slow-Fire Course		
Sitting	200	10
Kneeling	200	10
Kneeling	300	5
Standing	200	10
Prone	500	10
Rapid-Fire Course		
Kneeling	200	10
Prone	300	10

Table 8

Qualification Categories and Associated Score Ranges

Classification	SLR score range
Expert	40-65
Sharpshooter	35-39
Marksman	25-34
Unqualified	< 25

Knowledge mapping. We refined the knowledge map sets of terms and links and developed an online version that Marines could use to draw their maps. The terms were *7 factors common to all shooting positions (7F), accuracy (ACC), aiming process (AP), bone support (BS), breath control (BC), elbow placement (EP), eye on front sight post, (EFSP), eye relief (ER), finger placement (FP), follow-through (FT), forward hand placement (FHP), fundamentals of marksmanship (FM), grip of firing hand (GFH), muscular relaxation (MR), muscular tension (MT), natural respiratory pause (NRP), placement of buttstock in shoulder (PBS), sight adjustment (SADJ), sight alignment (SALGN), sight picture (SP), stable firing position (SFP), stock weld placement (SWP), trigger control (TC),* and *trigger squeeze (TSQ)*. The links were *affects, causes, decreases,* *during, follows, helps, improves, increases, leads to, part of, prevents, requires, type of, uses,* and *worsens.*

The directions for the task were given orally and on a job aid. The directions were:

> Make a knowledge map with the given concepts and links. The concepts are related to Rifle Marksmanship. Drag the concepts to the screen. Then create links between concepts to show how the concepts are related to each other. Make as many relationships you can think of that seem important. You do not have to use all the concepts and links.

The job aid also included the lists of terms and links.

A screen shot of the computer interface of the Knowledge Mapping Tool is shown in Figure 4. The task required Marines to create a knowledge map of their understanding of rifle marksmanship. Participants dragged the icon labeled "concept" onto the drawing space. When the mouse was released, a fixed set of terms appeared in a pop-up menu and the Marine selected the term. To connect terms, the Marine would select the first term, hold the mouse down and drag to the destination term. Upon releasing the mouse, a fixed set of links would appear in a pop-up menu and the Marine would select the desired link.

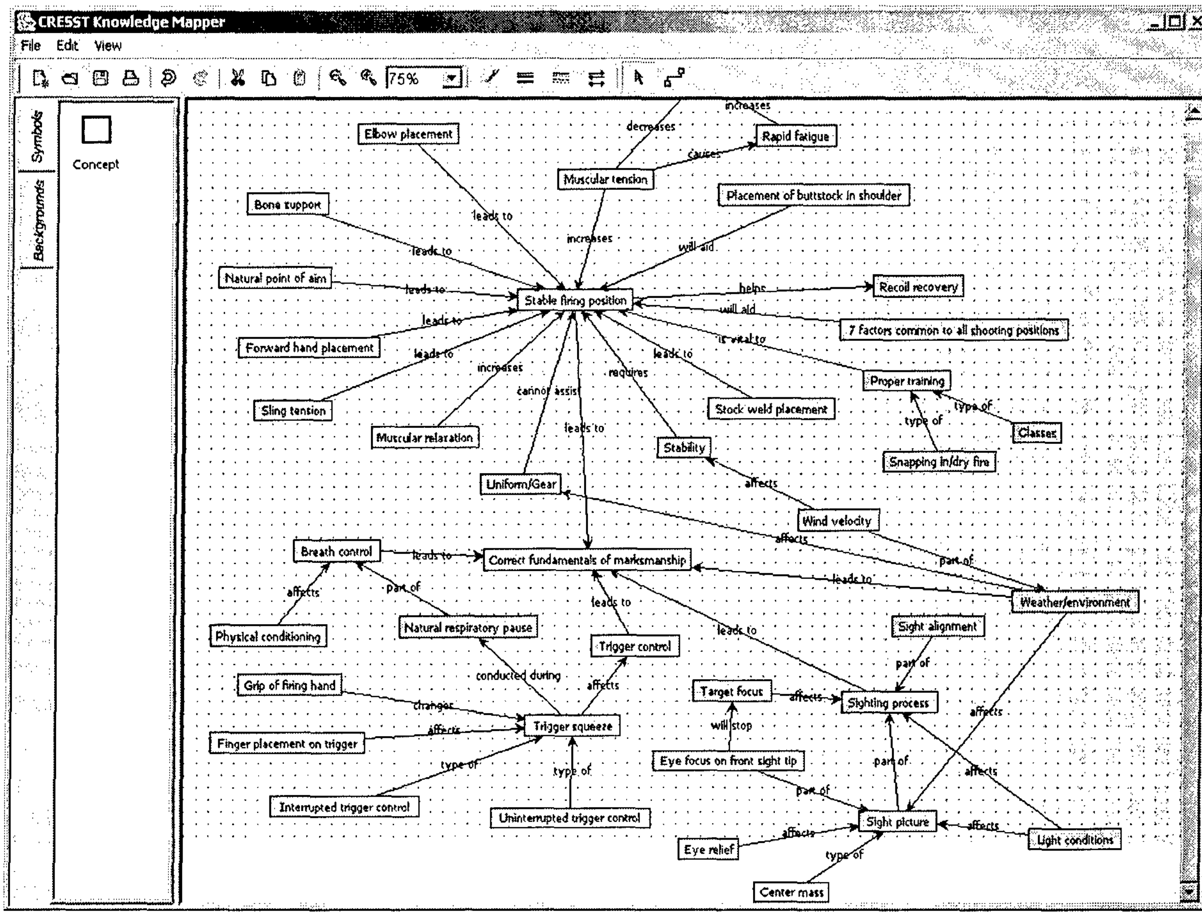

Figure 4. Sample screen shot of the knowledge map task computer interface.

Basic marksmanship knowledge. We converted the basic marksmanship knowledge measure from a short-answer format to a selected-response format. We developed items for the areas below and adopted several items from a Stone Bay/Force Service Support Group instructor-developed test. The measure contained 41 items and covered sight picture, sight adjustment, sight alignment, weapons safety, breathing, trigger control, stock weld, eye relief, bone support, firing hand placement, follow-through, muscle relaxation, forward hand placement, grip of firing hand, and muscular tension. Cronbach's alpha for the measure was .85.

Shot group depiction task. Similar to Pilot Test 1, we administered a slightly revised version of this measure. The task was designed to measure Marines' knowledge of shot groups associated with common shooter problems. Marines were required to draw a 5-shot group for problems with breathing, sight adjustment, flinching, bucking, and focusing on the target. Cronbach's alpha for the measure was .26.

The directions for the task were given orally and via a job aid. The directions were:

> Each icon represents a particular shooter error. For each type of error, **plot five bullet strikes** that reflect the conditions at 300 yards of a right-handed shooter in the kneeling position. Unless otherwise stated, assume no wind/weather effects.
>
> Note:
>
> 1. Use exactly 5 shots per error type.
> 2. Plot all shots **on the same target**. There is only one target. Each error type is indicated with a different color.
> 3. The table below provides a more detailed description of the type of problem.

A screen shot of the computer interface is shown in Figure 5. The task required Marines to drag exactly 5 icons of each color from the left column onto the target to show the shot pattern. Each icon was colored and represented a different kind of shooter error. The types of errors are shown in Table 9.

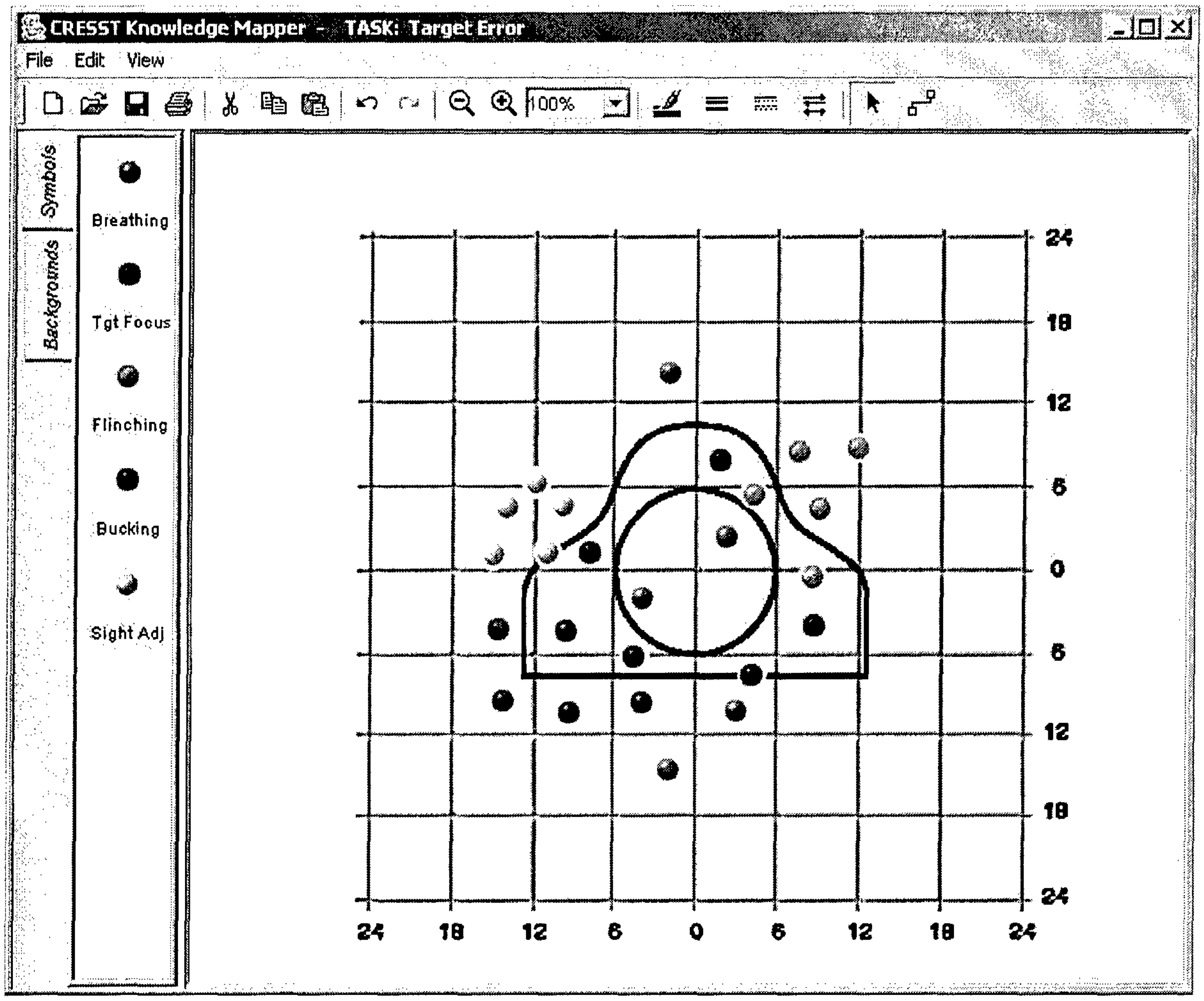

Figure 5. Sample screen shot of the shot group depiction task computer interface.

Table 9

Types of Errors for the Shot Group Depiction Task

Icon color	Type of problem
Gray	Breathing while firing
Blue	Aiming eye focused on the target instead of the front sight post while firing
Green	Flinching the body while firing (sudden small backward movement of body)
Red	Bucking the shoulder into the rifle stock while firing
Yellow	Sight adjustment problem (inadequate compensation) with wind blowing from the right

Participants' shot group depictions were scored automatically using an algorithm that was based on an expert's representation (see Appendix H). Each type of shot group was scored as correct or incorrect. To verify the automated scoring performance, shot group scores produced by the automated scoring algorithm were compared to scores assigned by a rater following a rubric (Appendix I). The rubric was developed from descriptions provided by USMC marksmanship coaches and from reviews of shot group analyses in U.S. Army and USMC field manuals (U.S. Army, 1989; USMC, 1992).

Agreement between the automated scoring routine and the human rater ranged from a low of 88.5% for the problems of target focus and sight adjustment, and a high of 96.5% for flinching.

Table 10

Percent Agreement Between Human Rater and Automated Scoring System (N = 113)

Type	Percent
Breathing	91.2
Target focus	88.5
Flinching	96.5
Bucking	94.7
Sight adjustment	88.5

Note. Sample included data from Pilot Study 1.

Evaluation of shooter positions (ESP). This task was intended to measure a Marine's skill at identifying proper and improper firing positions of a shooter posing in proper and improper positions. The shooter was shown in QuickTime VR, and Marines could rotate the image to view the shooter from different angles. Marines were asked to judge whether the shooter's position was proper or improper on the following elements: placement of firing hand, placement of forward hand, elbow placement, stock weld, breath control, rifle butt in pocket of shoulder, leg placement, feet placement, body placement, and overall position.

The directions for the task were:

Please evaluate the Marine's application of rifle marksmanship skills. You can examine the Marine in the following ways—

1. Rotating the picture to allow you to examine the Marine from all directions.
2. Clicking on "hotspots" on the picture—close-up pictures are available for certain areas of the Marine.
3. Viewing a 5-second animation of the sight picture preceding the firing of the shot.
4. Viewing the strike of the round on the target.

You will be asked to evaluate how proper the Marine's position is on the following:

Placement of firing hand
Placement of forward hand
Elbow placement
Stock weld
Breath control
Rifle butt in pocket of shoulder
Leg placement
Feet placement
Body placement

In addition, you will be asked for an overall judgment of the Marine's application of the fundamentals.

You are to use a 4-point scale ranging from "**proper**" to "**improper**."

A screen shot of the computer interface is shown in Figure 6. The task required participants to diagnose possible problems with a shooter's firing position. The participant was presented with a shooter (upper left quadrant of Figure 6). The figure was a QuickTime VR image, so the participant could rotate the image and have a 360-degree view, as well as view the shooter from different angles (i.e., as if viewing from ground level or slightly above). The participant could also view 5 seconds of the sight picture immediately prior to firing the round (upper right quadrant of Figure 6). In addition, there were "hotspots" on the shooter that could be viewed close up. The available hotspots were of the different body elements important to shooting (e.g., feet, elbows, stock weld, firing hand, grip—shown as ovals in the upper left pane in Figure 6). If the participant clicked on a hotspot area of the shooter, a close-up image would appear (lower left quadrant of Figure 6). Finally, the participant was required to judge the extent to which each body element was in its proper position.

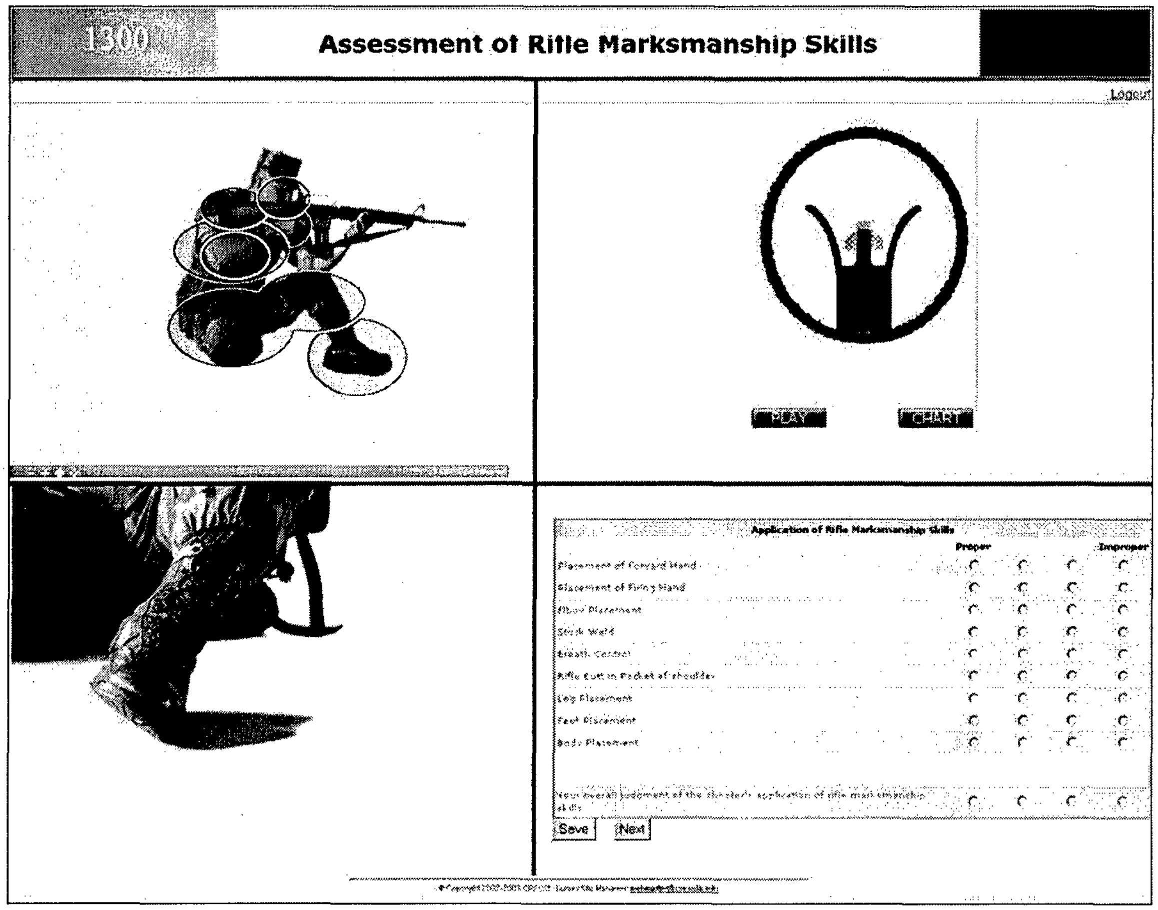

Figure 6. Sample screen shot of the ESP task computer interface.

Self-regulation survey. This measure was adopted from O'Neil and Herl (1998). The intent of this task was to measure Marines' use of self-regulation strategies with respect to classroom-based learning (i.e., planning, self-checking). Cronbach's alpha for the planning and self-checking scales were .85 and .83, respectively.

Background survey. We administered a revised background survey that was similar to Pilot Study 1. The revisions included improved terminology and more coverage in areas that looked promising from Pilot Study 1. In particular, we gathered more detailed information on Marines' unit, rank, marksmanship coaches course history, and shooting experience.

Procedure

Data collection was conducted across two sessions (morning and afternoon) on the same day. We administered the measures in two formats, paper and online. This allowed us to check for potential format differences. For the online versions of our measures, researchers from CRESST demonstrated the use of the software. The paper versions were self-explanatory. Because of firewall restrictions on MarineNet, the ESP measure could not be administered. We administered the measures in the order and allotted times shown in Table 11.

Table 11

Administration Schedule

Task	Time allotted
Introduction to study	5
Knowledge mapping instructions	10
Knowledge mapping task	20
Self-regulation survey	5
Shot group depiction task instructions and task	10
Basic marksmanship knowledge task	20
Background survey	5
Evaluation of shooter positions (planned but did not occur due to firewall restrictions)	45

Pilot Study 2—Results

Preliminary Analyses

During the morning session the system response was very sluggish and many Marines experienced "page not found" errors. We determined that these errors were primarily due to a very slow network connection. We fixed the problem prior to the afternoon session.

We conducted three 2(morning, afternoon) × 2(paper, online) ANOVAs on the knowledge mapping, shot group depiction, and basic marksmanship knowledge scores, to check for differences by session and format. Session was included as a factor given the technical problems in the morning. No significant effects were found for the knowledge mapping and shot group depiction; however, a session × format effect was found for the basic marksmanship knowledge measure, $F(1, 94)$ =

9.25, $MSE = 317.4$, $p < .05$. Follow-up pairwise comparisons showed that for the morning session, Marines administered the paper measure ($M = 27.0$, $SD = 4.5$, $n = 17$) performed significantly higher than those administered the online measure ($M = 20.3$, $SD = 6.7$, $n = 32$). No format differences were found for the afternoon session.

We concluded that the most likely cause for the format differences in the morning session was the computer problems. Given that there were no other format differences on our other measures (particularly the knowledge mapping scores), we concluded that format was not likely to have a large effect; thus, we pooled the sample across format.

Relationship of Measures to Record-Fire Score

In terms of relationships between our assessments and qualification score, we again found relationships that suggested a link between knowledge of rifle marksmanship and self-reported qualification score. For example, Marines' self-reported qualification score was related to their performance on our basic marksmanship knowledge measure ($r = .21$, $p < .05$), if they rated their job as non-ground combat ($r = .29$, $p < .01$), the number of months since their last Phase I training ($r = -.25$, $p < .05$), and their self-reported most recent qualification score ($r = .36$, $p < .01$).

With respect to performance on our assessments, we found that Marines scored higher on our basic marksmanship knowledge measure (a) if they had Phase I training ($r = .20$, $p < .05$); (b) the more recently (in months) they had Phase I training ($r = .24$, $p < .05$); and (c) the higher their self-reported most recent qualification score ($r = .23$, $p < .05$). Also, Marines tended to perform higher on the shot group depiction task (a) if they rated their job as non-ground combat ($r = .21$, $p < .05$); and (b) the more hours they reported shooting as part of their USMC duties ($r = .30$, $p < .05$).

Prediction of Qualification Score

The best predictor of self-reported qualification scores was from the following set of variables: (a) average of scores on the planning and checking scales, (b) number of months since the Marine's last Phase I training, (c) score on the basic marksmanship knowledge measure, (d) self-reported most recent qualification score, and (e) combat status of the Marine's job. The resulting multiple R for this sample was .53.

Discussion of Pilot Study 2

As with the first pilot study, the results related to our assessments need to be interpreted with caution. These data are from Marines who took our measures online and on paper. Further, about half of the sample who received the online assessments experienced technical problems with the software (e.g., slow-loading or non-loading Web pages; very slow system performance).

Given this caution, the results again suggest a knowledge component to shooting performance. As in the first pilot study, self-reported qualification scores were related significantly to measures of knowledge of the fundamentals, although the magnitude of the relationship was low. Evidence that our basic marksmanship knowledge measure was tapping knowledge of rifle marksmanship is seen in the relationship with the Phase I training variables (i.e., higher scores on the basic marksmanship knowledge measure if they had Phase I training and the more recent the Phase I training). Finally, the regression equation also supports the interpretation that there is a knowledge component to shooting performance. Basic marksmanship knowledge scores and recency of Phase I training improve the predictability of shooting performance above experience variables alone.

SECTION IV: MAIN STUDIES

Study 1—Method

The first study conducted in December 2002 was intended to examine the extent to which our online assessments could predict shooting performance among sustainment-level Marines. The full set of measures was administered online, and the current and most recent qualification scores were gathered from the Stone Bay database, not Marines' self-reports. UCLA researchers also observed the pit verification process and Stone Bay also provided verifiers to ensure the Marines' bullet strikes were accurately recorded on the score cards.

Participants

One-hundred fifty-nine Marines of various shooting skill participated in the study. A description of the sample is shown in Table 12 through Table 15. In general, the participants were male (94%), enlisted, with less than 2.5 years in service, and from a mix of support, base, and combat units.

Table 12

Descriptive Statistics on Background Variables

Variable	*n*	*M*	*SD*	Min.	Max.
Most recent qualification score	159	40.2	7.9	25	58
Second most recent qualification score	119	36.9	8.0	24	54
Third most recent qualification score	72	39.9	9.3	24	65
Age	159	21.9	3.2	19	45
Years in service	159	2.5	2.7	0	30
Frequency of shooting as part of duties[a]	159	2.1	1.0	1	5
Frequency of shooting outside of duties[a]	159	2.1	1.4	1	5
Years of shooting experience before Marines	159	3.2	4.7	0	19

[a]1 = *Never*; 2 = *Once or twice*; 3 = *A few times*; 4 = *Often*; 5 = *Very often*.

Table 13

Distribution of Participants by Combat Status

	Frequency	Percent
Division[a]	51	31.7
Force Service Support Group[b]	44	27.3
Support/Base[c]	39	24.2
Other[d]	27	16.8

[a]MEU, 2/10, 2/6, 2nd Marine Div, 2nd MEB, 3/2, 3/8, 3/6, 4 MEB, 8th Marine Regiment, II MEF. [b]FSSG. [c]Base and formal schools. [d]Aviation, division staff, Marine security guard.

Table 14

Distribution of Participants by Rank

	Frequency	Percent
Private (E-1)	2	1.3
Private First Class (E-2)	11	6.9
Lance Corporal (E-3)	105	66.0
Corporal (E-4)	34	21.4
Sergeant (E-5)	7	4.4

Table 15

Distribution of Participants by Marksmanship Instructor Training

Course	No. of participants who completed course
Marksmanship Coaches Course (MOS 8530)	11
Marksmanship Instructor (MOS 8531)	4
Small Arms Weapons Instructor (MOS 8532)	1
Range Officer (MOS 9925)	0

Design

The tasks were administered to six groups over three days during Phase I and Phase II. Seventy-nine participants had attempted qualification and 13 had not attempted qualification. The remaining number of participants did not respond. The online delivery problems were resolved and the online administration during the data collection was problem free. Training on the assessment tasks was standardized using an online video training task to ensure that each participant had the same training. Job aids were also provided to each participant.

Measures

The following measures were provided to us by the USMC or administered to Marines:

Record-fire score. The main outcome measure was Marines' record-fire score. These scores were the official score of record from the USMC database.

Most recent record-fire scores. These were self-reported qualification scores for the three most recent qualification trials.

Knowledge mapping. We used the same measure from Pilot Study 2.

Scoring of participant knowledge maps was conducted by comparing participants' knowledge maps against a criterion map. The criterion map was generated by our subject matter expert, who had completed the coaches course and the scout sniper program. A participant's score was the count of the number of propositions in his or her map that were also in the criterion map. The criterion map is given in Appendix J (Expert Nov./Dec., screen shots) and Appendix K (Expert Nov./Dec., propositions).

Basic marksmanship knowledge. We used the same measure from Pilot Study 2 with slight modifications to wording.

Shot group depiction task. We used the same measure from Pilot Study 2.

Self-regulation survey. We used the same measure from Pilot Study 2.

Background survey. We used the same measure from Pilot Study 2.

Evaluation of shooter positions (ESP). We used the same measure from Pilot Study 2.

Procedure

We administered the measures in two formats, paper and online. Most of the participants received the assessments online; however, because there were additional participants available (i.e., participants were provided at the company level, and we did not have enough computers; thus, these additional participants were administered paper versions of our measures). We followed the same administration schedule and procedure as Pilot Study 2, with the exception that the instructions for each online task were delivered via an online training demo.

Study 1—Results

We present the results of this study around two key issues: (a) the prediction of record-fire performance, and (b) the reliability and the validity evidence of cognitive measures used in this study. Our research questions around the two main issues are repeated below.

- To what extent can record-fire performance be predicted from knowledge, perceptual-motor, and affective variables?
- What combination of perceptual-motor, cognitive, and affective measures yield the best predictors of record-fire performance?
- What is the quality of the validity evidence for our measures of rifle marksmanship knowledge?

The first two questions address the first issue of prediction, and the last question addresses the strength of the validity evidence for our measures.

Prediction of Record-Fire Performance

To predict record-fire performance, we conducted a series of multiple regression analyses. Predictions were made for the whole group, which draws from the entire sample, and subgroups. In this section, we present the results of the whole-group prediction first, followed by four subgroup predictions, for the same set of questions.

Prediction of Record-Fire Performance Based on the Entire Sample

To predict the record-fire performance of Marines, we conducted multiple regression analyses for the entire sample ($N = 103$). Multiple regression analyses can be used to determine which combination of measures is the best predictor of performance and the quality of the prediction, when the ranges of important variables are naturally occurring and not restricted (this advantage will be clear when compared to the subsample prediction in the next section).

The outcome variable of multiple regression is record-fire score. Table 16 presents descriptive statistics and intercorrelations for the measures, and Table 17 presents the descriptive statistics for the measures included in the multiple regression analysis. Table 18 displays the results of the multiple regression analysis.

Table 16

Descriptive Statistics and Intercorrelations Among Main Variables

Measure	*n*	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. Record-fire score	156	39.92	9.41	--								
2. Most recent record-fire score	121	35.41	8.78	.41**	--							
3. Basic marksmanship knowledge	161	26.47	6.17	.29**	.24**	--						
4. Shot group depiction	154	1.53	1.13	.27**	.15	.42**	--					
5. Evaluation of shooter positions	160	59.88	8.32	.20*	-.02	.19*	.27**	--				
6. Knowledge map	151	2.28	2.27	.12	.14	.35**	.14	.23**	--			
7. Whether took coaches course	161	0.07	0.26	.15	.15	.07	-.05	.06	.02	--		
8. Mean of self-regulation planning and checking scales	156	3.18	0.52	.22**	.20*	.20*	.13	.05	.13	.05	--	
9. Perceived utility of marksmanship knowledge to shooting performance	157	4.43	0.90	.20*	-.02	.17*	.20*	.11	.09	.16*	.16*	--
10. No. of months since last Phase I training	152	4.45	7.07	-.26**	-.11	-.39**	-.27**	-.14	-.15	-.09	-.08	-.07

Table 17

Descriptive Statistics for Variables Used in the Multiple Regression Analysis

Variable	*n*	*M*	*SD*	Min.	Max.
Record-fire score	156	39.92	9.41	1	58
Most recent record-fire score	121	35.41	8.78	6	56
Basic marksmanship knowledge	161	26.47	6.17	0	40
Shot group depiction	154	1.53	1.13	0	4
Evaluation of shooter positions	160	59.88	8.32	34	79
Knowledge map	151	2.28	2.27	0	11
Whether took coaches course	161	0.07	0.26	0	1
Mean of self-regulation planning and checking scales	156	3.18	0.52	1.44	4.00
Perceived utility of marksmanship knowledge to shooting performance	157	4.43	0.90	1	5
No. of months since last Phase I training	152	4.45	7.07	0	26

Table 18

Regression Summary Predicting Record-Fire Performance

Variable	Coefficient	*SE*	*p* value
Most recent record-fire score	0.36	0.11	.00
Basic marksmanship knowledge	0.34	0.19	.08
Shot group depiction	0.34	0.83	.68
Evaluation of shooter positions	0.19	0.11	.09
Knowledge map	-0.08	0.44	.86
Whether took coaches course	3.57	2.85	.21
Mean of self-regulation planning and checking scales	1.72	1.75	.33
Perceived utility of marksmanship knowledge to shooting performance	0.36	1.06	.74
No. of months since last Phase I training	-0.24	0.13	.07

What combinations of perceptual-motor (proxies), cognitive, and affective measures yield the best (practical) predictors of record-fire performance? As shown in Table 18, basic marksmanship knowledge, shot group knowledge, proper position identification, knowledge map, self-regulation, and perceived value of knowledge to shooting performance showed up as good predictors among cognitive measures, while most recent record-fire score, shooting coach status, and the number of months since last sustainment-level training on marksmanship made a good set of predictors among copious background measures.

This combination of cognitive and background measures was chosen among all other possible combinations, based mainly on theoretical considerations, although it was modified based on empirical results. Specifically, sets of covariates were chosen first according to the theoretical framework, and those were modified by empirical results, such as bi-variate correlation between the possible predictor and record-fire performance, and the multiple correlation coefficient (R) of multiple regression analyses. For example, variables such as the number of months since last sustainment-level training on marksmanship were discovered empirically. In addition, some variables that were not statistically significant were retained in the regression out of theoretical considerations.

The best predictor of record-fire score was the most recent record-fire score, which was the single significant predictor in the regression ($p < .01$). Basic marksmanship knowledge, proper position identification, and the number of months since last sustainment-level training on marksmanship were also close to statistical significance with p values between .05 and .10. Participants tended to fire more accurately by 3.2 points when their most recent record-fire score was 1 standard deviation (8.7 points) higher, holding constant all the other variables in the equation. Again holding constant all the other variables, participants are expected to fire more accurately by 2.1 and 1.6 points when they are 1 standard deviation higher in the basic marksmanship knowledge and proper position identification measures, respectively (6.2 points and 1.1 points); a participant tended to fire more accurately by 1.7 points when the last sustainment-level training on marksmanship was within the last 7 months (which is 1 standard deviation of the variable).

To what extent can record-fire performance be predicted from the combinations of perceptual-motor (proxies), cognitive, and affective measures? Two criteria were used to evaluate the quality of the prediction model. The first is the multiple correlation (R) or the square of the multiple correlation (R^2). The current multiple regression yielded R of .56 and R^2 of .31. Thirty-one percent of the total variability in the record-fire performance was accounted for by the combination of predictors in the regression. This is only a moderate level of prediction given a set of nine carefully selected predictors, as the other 69% still remained unexplained.

The 95% confidence interval of predicted record-fire performance scores is the second criterion. Figure 7 displays the confidence intervals for all 105 participants analyzed in the regression. The length of interval varied across participants, the average being around 10; the smallest interval was 4.98 and the largest was 17.72. Some confidence intervals are fairly wide, suggesting that the level of prediction needs to be more precise for some participants.

One of the most conservative ways to assess participants in this framework is to disqualify participants who have the lowest value of the interval below 25 (this cutoff is based on USMC qualification categories). This results in disqualifying 5 of the 105 participants. The record-fire performance score of the 5 participants were 1, 27, 31, 35, and 40. In addition, 4 participants who had record-fire performance scores of less than 25 were not identified as unqualified. To better serve the classification purpose, more precise prediction is necessary.

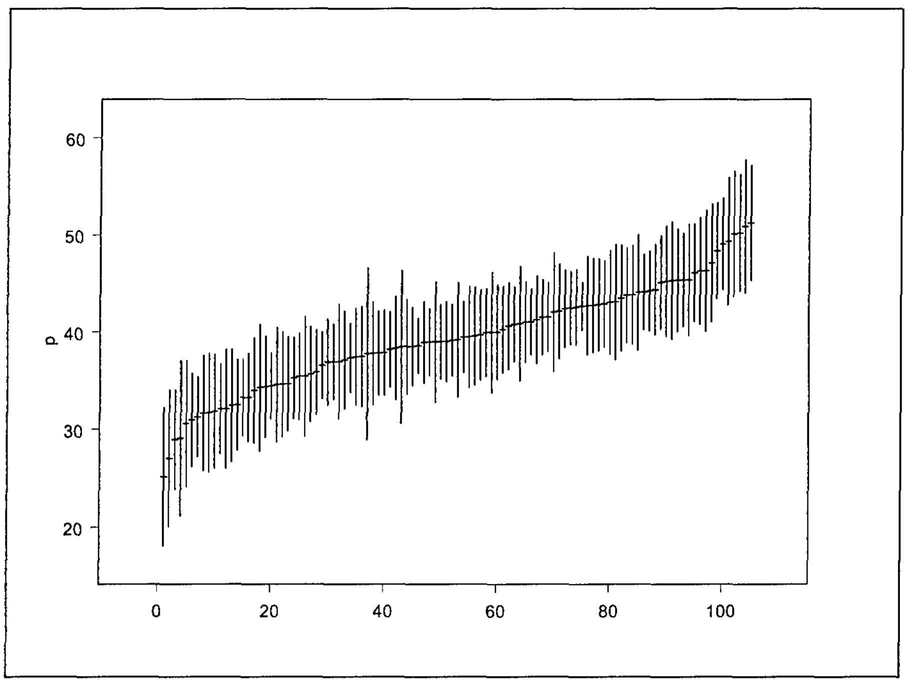

Figure 7. The 95% confidence intervals of predicted values from a regression analysis.

Prediction of Record-Fire Performance Based on the Subsamples

In addition to analyzing the entire sample, we attempted to create subgroups of the sample and make predictions separately for each subgroup. The rationale behind the subgroup analyses comes from the skill acquisition model. With a new skill, performance evolves over different stages of development. Presumably, the different stages are characterized by distinct cognitive and performance characteristics (e.g., Ackerman, 1987, 1992). From a regression perspective, this could allude to qualitatively different subgroups, each of which possibly have different sets of predictors or different relationships between record-fire performance and a set of predictors.

Four subgroups (high performers, medium performers, low performers, and learners) were created using two descriptive statistics: the average and the standard deviation of record-fire scores across two to four occasions (the available number of record-fire scores ranged from two to four for individual participants). The average of two to four record-fire scores indicates an average level of performance of an individual participant, whereas the standard deviation is indicative of the variability of the performance of a participant across different occasions. Note that the average and the standard deviation here are not across participants but across occasions within each participant. The criteria used for classifying participants was: learners, $M > 30$, $SD \geq 10$; high performers, $M \leq 45$, $SD < 10$; medium performers, $30 < M < 45$, $SD < 10$; and low performers, $M < 30$.

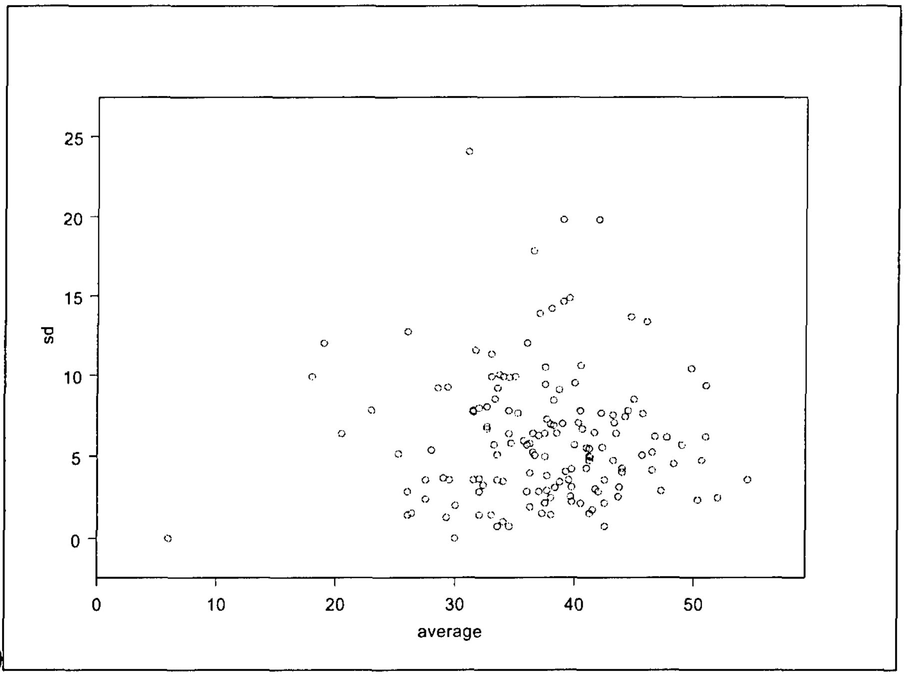

Figure 8. Subgroup classification based on a scatterplot of spread and mean of record-fire scores across occasions.

Figure 8 displays the classification of the four groups based on the two descriptive statistics. The learner group was separated out because the variability across occasions was apparently greater than the rest of the sample (the standard deviation was higher than 10). The variability of these participants normally comes from a low score in previous occasions and a high score in later occasions, with the exception of one case. We interpreted that participants in this group switched from a fairly low level, possibly the stage of novice, to a fairly high level in a relatively short period of time.

The identification of the other groups was based more on average level of performance (i.e., the average of record-fire scores), after separating out the learner group. However, the two cut-points that classify the three groups, 30 and 45, were determined making use of the standard deviation, as shown in Figure 8. The average scores of the high spread group (learners) begin at 30 and end at 45. The reasoning behind this was that high and low performers would be relatively stable in their performance across occasions. This classification is very sample-dependent and the assumption is open to more investigation.

Table 19 presents the descriptive statistics of final record-fire performance by subgroup. According to USMC qualification categories, record-fire scores below 25 indicate that a Marine is unqualified, scores of 25 to 34 indicate marksman, scores of

35 to 39 indicate sharpshooter, and scores of 40 to 65 indicate expert. This categorization is more detailed in that the cutoffs are on a finer scale and show a desirable level of performance (above 35) and a undesirable level of performance (below 25) in an absolute sense. However, it does not consider the dynamics of rifle marksmanship as a learned skill.

The comparison between the USMC qualification categories and the data-driven classification shown in Table 19 might be informative. Low performers were mostly unqualified and marksmen. Medium performers were mostly marksmen and sharpshooters, including some experts. High performers were all experts. Learners were on average close to high performers but were more heterogeneous, covering marksmen, sharpshooters, and experts.

Table 19

Descriptive Statistics of Record-Fire Performance by Subgroup

	n	*M*	Min.	Max.
Entire sample	156	39.92	1	58
Learners	17	47.24	28	54
Low performers	19	25.32	1	40
Medium performers	98	39.93	25	54
High performers	16	49.94	40	58

What combinations of perceptual-motor (proxies), cognitive, and affective measures yield the best (practical) predictors of record-fire performance? As expected from the theory of skill learning, different sets of predictors and different relationships showed up in four different subgroups. Table 20 summarizes which cognitive and background measures made a good set of predictors in each of the four groups. Table 21, Table 22, Table 23, and Table 24 present the results of multiple regression analyses for the four groups in the order of learners, high performers, medium performers, and low performers.

For the groups of learners and high performers, an additional multiple regression analysis was conducted without one observation (so-called leave-one-out analysis). In the high performer group, one observation was identified using the largest absolute value of the studentized residual (-2.97). In the learner group, one observation was identified for a substantive reason. One observation had a high previous performance and a low later performance, while all the other observations had a low previous performance and a high later performance.

Table 20

Regression Model Variables by Type of Analysis and Type of Measure

Analysis method	Cognitive measures	Background measures
Entire sample	1. Basic marksmanship knowledge	1. Most recent record-fire score
	2. Shot group depiction	2. Whether a shooting coach
	3. Proper position identification	3. Months since last sustainment-level training on marksmanship
	4. Knowledge map	
	5. Self-regulation (classroom training)	
	6. Perceived utility of marksmanship knowledge to shooting performance	
By subsample		
Learners	1. Basic marksmanship knowledge	1. Number of years in service
	2. Shot group depiction	2. Number of years of shooting experience prior to joining USMC
High performers	1. Basic marksmanship knowledge	1. Months since last sustainment-level training on marksmanship
Medium performers	1. Basic marksmanship knowledge	1. Most recent record-fire score
	2. Shot group depiction	2. Whether a shooting coach
	3. Self-regulation (classroom training; mean of worry and planning scales)	3. Months since last sustainment-level training on marksmanship
Low performers	1. Shot group depiction	1. Months since last sustainment-level training on marksmanship
	2. Perceived utility of marksmanship knowledge to shooting performance	2. Number of hours per year shooting as part of USMC duties
	3. Self-regulation (classroom training; worry scale)	

For learners, basic marksmanship knowledge, shot group depiction, number of years in service, and number of years of shooting experience prior to joining USMC made a good set of predictors. A participant in the learner group tended to fire more accurately by 2.9 points when shot group knowledge increased by 1 standard deviation (1.2 points), holding constant all the other variables in the regression; he is also expected to fire more accurately by 1.6 and 1.4 points when the number of years in service and the number of years of shooting experience prior to joining USMC increase by 1 standard deviation (1.5 and 4.8 years respectively). These magnitudes of relationships are based on the leave-one-out analysis, given the fact that one person cannot be considered a "learner" from a substantive perspective if he has a high score on a previous occasion and a low score on a later occasion.

Table 21

Regression Summary for Learners

Variable	Coefficient	*SE*	*p* value
Basic marksmanship knowledge	0.23	0.32	.47
Shot group depiction	3.07	1.41	.05
Number of years in service	1.75	1.01	.11
Number of years of shooting experience prior to joining USMC	0.34	0.26	.21
Leave-one-out analysis			
Basic marksmanship knowledge	0.15	0.21	.49
Shot group depiction	2.45	0.93	.02
Number of years in service	1.07	0.68	.14
Number of years of shooting experience prior to joining USMC	0.24	0.17	.19

For high performers, basic marksmanship knowledge and months since last sustainment-level training on marksmanship achieved some prediction, although there were no good predictors of performance for high performers. Possible technical reasons are the restrictive range of regression outcome (i.e., record-fire performance), ranging from 40 to 58, and thus possibly restrictive range of predictors, and the small sample size of 15. One substantive reason might be that, for high performers who are well past the cognitive phase of skill acquisition, firing has already been automatized such that cognitive knowledge or background is not predictive of the performance any longer.

Table 22

Regression Summary for High Performers

Variable	Coefficient	*SE*	*p* value
Months since last sustainment-level training on marksmanship	-0.31	0.26	.26
Basic marksmanship knowledge	0.06	0.28	.84
Leave-one-out analysis			
Months since last sustainment-level training on marksmanship	-0.34	0.20	.12
Basic marksmanship knowledge	0.23	0.23	.34

For medium performers, basic marksmanship knowledge, shot group depiction, and self-regulation on classroom training, among the cognitive measures, and most recent record-fire score, months since last sustainment-level training on marksmanship, and shooting coach status, among the background measures, achieved some prediction. This set of covariates is very similar to the results from analyzing the entire sample, in fact, sharing the same set of background measures and a subset of cognitive measures. This result can be thought of as cross-validation, verifying the analysis of the entire sample. A participant who has been a shooting coach tended to score 5.8 points higher in his record-fire performance, holding constant all the other variables in the regression ($p < .05$). Basic marksmanship knowledge and self-regulation reached statistical significance between .05 and .10. Controlling for all the other variables, a participant who is a medium performer tended to score 1.5 points higher in his record-fire performance when basic marksmanship knowledge or self-regulation on classroom training were higher by 1 standard deviation, 5.5 and 0.6 points respectively.

Table 23

Regression Summary for Medium Performers

Variable	Coefficient	*SE*	*p* value
Most recent record-fire score	0.05	0.16	.74
Basic marksmanship knowledge	0.27	0.16	.09
Shot group depiction	0.20	0.77	.80
Whether took coaches course	5.78	2.81	.04
Months since last sustainment-level training on marksmanship	-0.04	0.11	.71
Mean of self-regulation planning and checking scales	2.69	1.35	.05

For low performers, shot group depiction, perceived value of knowledge to shooting performance, and self-regulation on classroom training (worry scale) showed up among cognitive measures, while months since last sustainment-level training on marksmanship and number of hours per years shooting as part of USMC duties did among background measures. Participants who were low performers tended to score 5.2 points higher in their record-fire performance, if their last sustainment-level training on marksmanship was more recent by 6.7 months (1 standard deviation), holding constant all other variables in the regression ($p < .05$); they also tended to fire more accurately by 4.4 points as the perceived value of knowledge to shooting performance increased by 1 standard deviation (1.1 points).

Table 24

Regression Summary for Low Performers

Variable	Coefficient	*SE*	*p* value
Mean of self-regulation planning and checking scales	2.12	1.60	.21
Perceived utility of marksmanship knowledge to shooting performance	4.05	2.06	.08
Months since last sustainment-level training on marksmanship	-0.78	0.33	.04
Number of hours per year shooting as part of USMC duties	0.02	0.05	.64
Self-regulation worry	-4.54	4.42	.33

To what extent can record-fire performance be predicted from the combinations of perceptual-motor (proxies), cognitive, and affective measures?

As with the entire sample analysis, the level of prediction will be assessed by two criteria: the square of multiple correlation (R^2) and the 95% confidence interval of predicted record-fire performance. Table 25 presents multiple correlations (R) and the squares of multiple correlations (R^2) from the multiple regression analyses of the four groups. One can see that the level of prediction is fairly high in groups of learners and low performers. Sixty-six percent of the total variability in record-fire performance is accounted for in low performers, while 62% of the total variability is accounted for in learners (leave-one-out analysis). The predictions for high performers and low performers were moderate, 12% and 22% of the total variability in record-fire performance being accounted for respectively. This suggests that learners' and low performers' record-fire scores could be predicted very well from the set of covariates shown in Table 21 and Table 24, respectively. However, the findings from subgroup analyses *must be interpreted with caution* due to the small sample sizes of the subgroups. Note that only 15 to 17 participants are available in groups of learners, high performers, and low performers. The findings are sample-dependent and could be unstable.

Table 25

Multiple Correlation and the Square of Multiple Correlation of Regression by Subgroup

	Learner				**High performer**	
	Entire subgroup (n = 17)	**Leave-one-out** (n = 16)	**Low performer** (n = 17)	**Medium performer** (n = 69)	**Entire subgroup** (n = 15)	**Leave-one-out** (n = 14)
R	.76	.79	.81	.47	.35	.56
R^2	.59	.62	.66	.22	.12	.31

The 95% confidence intervals of each predicted value are plotted in Figure 9 to Figure 12, in the order of learners, high performers, medium performers, and low performers. For learners and high performers, confidence intervals from the leave-one-out analyses are plotted.

The prediction achieved more accuracy than the analysis for the entire sample, with average lengths of confidence intervals being 7.57, 8.07, and 7.21 for learners, high performers, and medium performers, respectively (the average length of the whole-group analysis was around 10). However, the lengths of confidence intervals for the low performers tended to be greater than those of the whole-group analysis. This is mainly due to the fact that the predictors chosen in the analysis of low performers had small ranges. The restricted ranges of predictors could lead to larger errors estimating the regression coefficient and thus to larger confidence intervals.

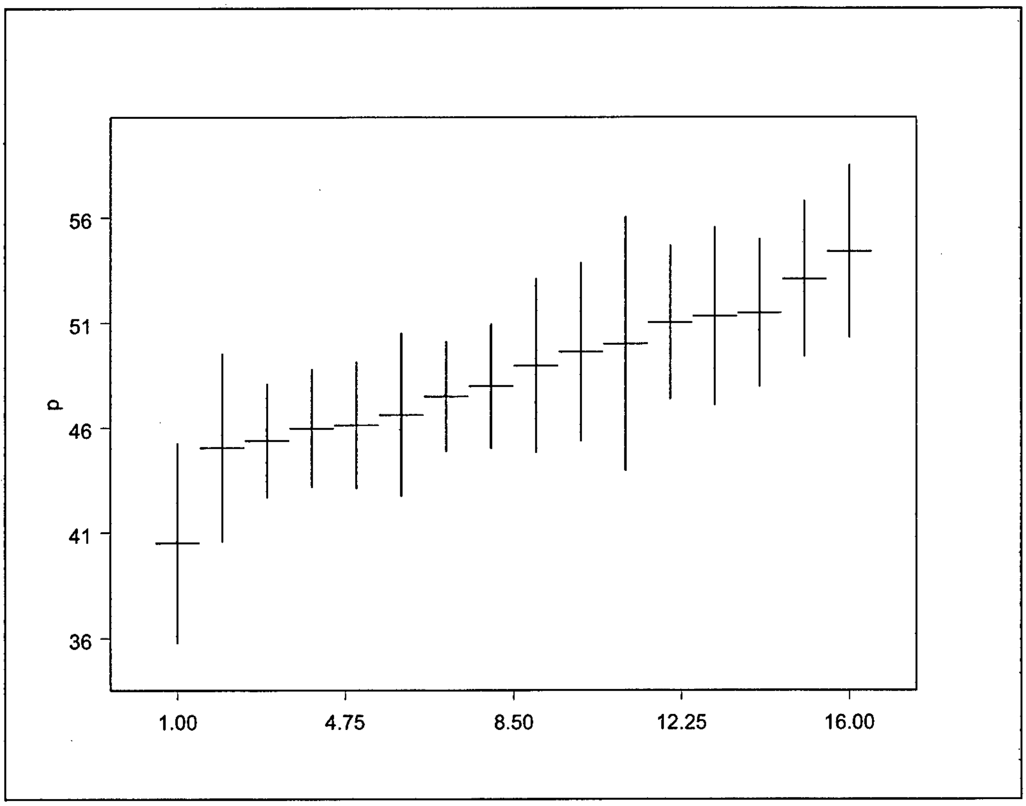

Figure 9. The 95% confidence interval of predicted values from analyses of learners.

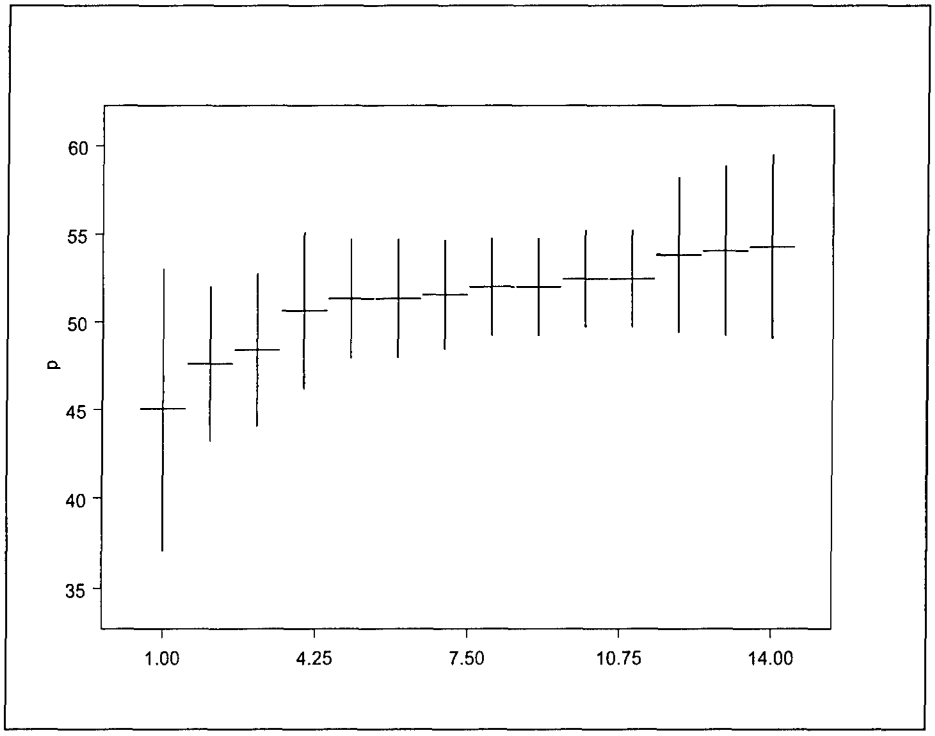

Figure 10. The 95% confidence interval of predicted values from a regression of high performers.

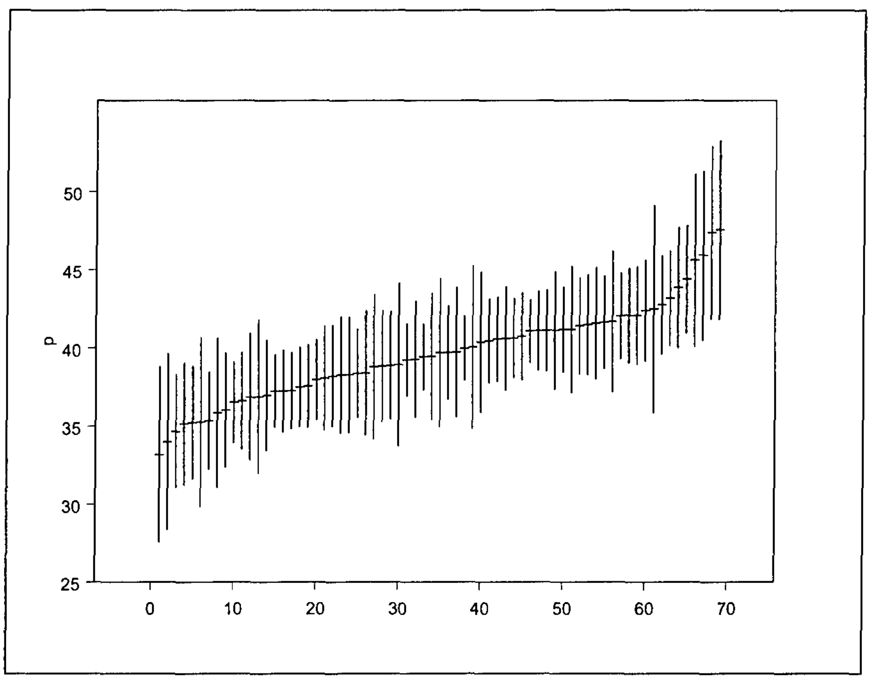

Figure 11. The 95% confidence interval of predicted values from analyses of medium performers.

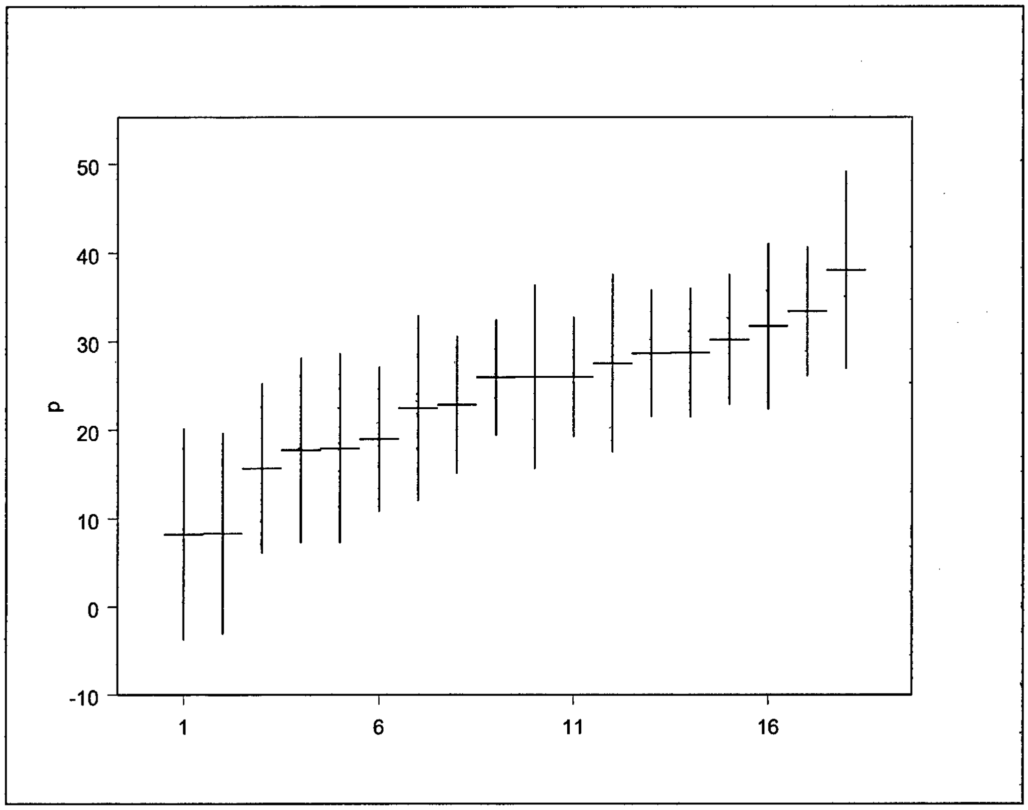

Figure 12. The 95% confidence interval of predicted values from analyses of low performers.

Reliability and Validity of the Measures of Rifle Marksmanship Knowledge

How reliable are our measures of rifle marksmanship knowledge? To answer this question, we calculated coefficient alphas for all the cognitive and affective measures on rifle marksmanship. Coefficient alpha is also referred to as Cronbach's coefficient alpha, and it suggests the internal consistency of a test by estimating the average correlation of items within a test. When multiple items in a test are designed to measure a construct, coefficient alpha could suggest the reliability of the test. Even though there is no legitimate cutoff point, a coefficient alpha above .70 would be acceptable. Table 26 presents the number of items within each measure, available participants for the calculation, and the coefficient alphas.

Table 26

Scale Reliabilities of Cognitive and Affective Measures

Measures	n	Cronbach's alpha	Number of items
Basic marksmanship knowledge	161	.83	43
Shot group depiction	154	.26	5
Self-regulation planning	156	.86	8
Self-regulation worry	156	.91	8
Self-regulation checking	156	.83	8
Self-regulation effort	156	.84	8

For basic marksmanship knowledge, the coefficient alpha was .84 with 43 items. The total score of the 43 items was used for analyses, of which the reliability was ensured. On the other hand, the coefficient alpha for shot group depiction knowledge was only .27 with 5 items. The bivariate correlations among the 5 items showed that the items were independent of each other rather than interrelated. Among the 10 pair-wise correlations, only one pair turned out to be significant (flinching and bucking, $r = .20$). The total score of the 5 items was used for analyses, but there remains a question if this scale or test captures a well-defined construct. The four subscales of self-regulation planning, worry, checking, and effort all showed high scale reliability, ranging from .83 to .92. For the other cognitive measures that were used in analyses, coefficient alpha was not applicable. Perceived utility of marksmanship knowledge to shooting performance is measured by 1 item.

What is the quality of the validity evidence for our measures of rifle marksmanship knowledge? In order to address the validity issue of our measures of rifle marksmanship knowledge, the measures were examined from various perspectives: the predictive validity and the incremental validity of sets of cognitive measures and their sensitivities to differentiating groups in record-fire performance.

Predictive validity. To see the quality of the predictive validity of cognitive and affective measures on rifle marksmanship knowledge, first we examined bivariate correlations between each of the measures and record-fire performance. Table 27 presents the results. For the entire sample, all knowledge measures other than knowledge map showed a positive and significant relationship with record-fire performance. For the subsamples, many correlations did not reach statistical significance mainly due to small sample sizes. However, one can still see that the magnitudes of correlations are considerable and that the directions are as expected. For learners, basic marksmanship knowledge and shot group depiction were highly and significantly correlated with record-fire performance.

Table 27

Correlation Between Record-Fire Performance and Cognitive Measures for the Entire Sample and by Subgroup. Sample Size Shown in Parentheses.

	BMK	SG	ESP	KM	SRP	SRW	PU
Entire sample	.29** (156)	.26** (151)	.19* (155)	.12 (148)	.16 (153)	.22** (153)	.19* (154)
Subgroup							
Learners	.55* (17)	.52* (17)	--	--	--	--	--
High	.29 (16)	--	--	--	--	--	--
Medium	.20 (98)	.13 (94)	--	--	.23* (97)	.24* (97)	--
Low	--	.36 (19)	--	--	--	-.20 (18)	.36 (19)

Note. BMK = basic marksmanship knowledge. SG = shot group depiction. ESP = evaluation of shooter positions. KM = knowledge map. SRP = self-regulation, planning scale. SRW = self-regulation, worry scale. PU = perceived utility of marksmanship knowledge.

Second, we examined the predictive validity of our cognitive and affective measures as a set instead of individually, conducting multiple regression analyses including only cognitive and affective measures as predictors. The bivariate correlations suggest the magnitudes of predictive validity of individual measures, whereas the multiple correlation or the square of the multiple correlation in the multiple regressions suggests the overall predictive validity that a set of cognitive measures simultaneously have.

Table 28 presents the results of all multiple regression analyses for the entire sample and for the subsamples. The set of cognitive and affective measures varied across analyses; sets for all analyses were summarized in Table 20. When all participants are analyzed together, the set of cognitive and affective measures (i.e., basic marksmanship knowledge, shot group depiction, proper position identification, knowledge map, self-regulation with respect to classroom training, perceived value of knowledge to shooting performance) accounted for 17% of the total variability in record-fire scores. For learners, 40% (46% for the leave-one-out analysis) were accounted for; for high performers, 9% (25% for the leave-one-out analysis); for medium performers, 12%; and for low performers, 46% were accounted for only by cognitive and affective measures, setting aside any background measures. Overall, one can conclude that the cognitive measures contributed to prediction to a considerable extent.

Table 28

Multiple Correlation and the Square of Multiple Correlation of Regression on Cognitive Measures by Subgroup

		Subsample analysis					
		Learner				High performer	
	Entire sample (*N* = 103)	Entire subgroup (*n* = 17)	Leave-one-out (*n* = 16)	Low performer (*n* = 17)	Medium performer (*n* = 69)	Entire subgroup (*n* = 15)	Leave-one-out (*n* = 14)
R	.41	.63	.68	.68	.34	.29	.50
R^2	.17	.40	.46	.46	.12	.09	.25

Incremental validity. Concerning the validity evidence for our cognitive and affective measures, one important aspect is the incremental validity. Even though the cognitive and affective measures are predictive of the record-fire performance, if the measures provide only overlapped prediction with background measures, then the usefulness of our measures will substantially decrease given that the background measures are much easier to collect. Incremental validity here asks the question if the cognitive and affective measures achieve additional prediction of record-fire performance over and beyond the background measures. Table 29 presents incremental validity for the entire sample and for subsamples in two scales: the multiple correlation (R) and the square of the multiple correlation (R^2).

Table 29

Incremental Validity (in Percent) of Cognitive Measures With Respect to Background Variables

		Subsample analysis					
		Learner				High performer	
Incremental Validity Measure	Entire sample (N = 103)	Entire subgroup (n = 17)	Leave-one-out (n = 16)	Low performer (n = 17)	Medium performer (n = 69)	Entire subgroup (n = 15)	Leave-one-out (n = 14)
$\Delta R(\%)$	7.25	31.35	40.99	9.99	11.69	0.44	5.88
$\Delta R^2(\%)$	7.61	38.42	48.12	15.35	9.66	0.32	6.25

Results of the multiple regression analyses indicated that the measures of knowledge of rifle marksmanship achieved incremental validity over background measures, record-fire performance being the criterion. For the entire sample, R^2 increased by around 8% due to cognitive measures after accounting for background measures. For the subsamples, the incremental validity is remarkably high in learners (R^2 increase = 38% and 48% for the leave-one-out analysis), fairly considerable in medium performers and low performers (R^2 increase = 10% and 15% respectively), and the least but still significant in high performers with the outlier eliminated (R^2 increase = 6%; 0.3% with the outlier).

Sensitivity to group differences. One goal regarding prediction of record-fire performance is to distinguish low performers from others, so that one can keep from attempting to qualify Marines who are not able to fire as accurately as expected. In relation to this, one aspect of validity evidence for cognitive measures would be to show differences between low performers and the others. To address this question, we conducted t tests of cognitive measures comparing low performers and others. The selection of low performers is based on the classification in Figure 8. Results of t tests showed that low performers (M = 24.20, SD = 3.85), compared to others (M = 27.26, SD = 5.49), scored significantly lower on the basic marksmanship measure (p = .02). There were no other significant differences on any of the other knowledge measures.

Summary and Discussion of Study 1

Reliability of measures. Overall, our measures demonstrated moderate to high reliabilities. The lowest reliability was with the shot group depiction task (α = .26). The basic marksmanship knowledge measure had high α (.83). The survey measures (i.e., affective) demonstrated high reliabilities too, with α in the .8 to .9 range.

Predictive validity. Overall, the best predictor of record-fire score was most recent record-fire score (r = .41, p < .01). Basic marksmanship knowledge, proper position identification, and number of months since the last Phase I training were related to record-fire score in the .2 to .4 range at the .10 significance level. When subgroup analyses were conducted (forming groups based on mean scores and standard deviations using record-fire scores across occasions), multiple regression analyses yielded *R*s from .4 to .8 across the different subgroups.

Construct validity. The subgroup analyses provided preliminary evidence that different variables mattered for different shooters. The subgroup classification was based on the expectation that the variability in record-fire scores would reflect where a participant was with respect to skill development (i.e., more varied performance would indicate a shooter still in the cognitive phase, while more stable performance would indicate a shooter further along in development).

Incremental validity analyses showed substantial contribution of knowledge measures to the prediction of record-fire score. Overall, across the entire sample, the set of cognitive and affective measures accounted for 17% of the total variability in record-fire scores. For learners only, cognitive and affective variables accounted for 40% of the variance, 9% for high performers, 12% for medium performers, and 46% for low performers. These values are above and beyond the variance accounted for by background measures. However, these results should be taken as preliminary as the sample sizes for the subgroups were small.

Overall, the results of Study 1 show a potentially strong cognitive component to shooting performance. Subgroup analyses suggested that different sets of variables mattered for participants classified as learners, low performers, medium performers, and high performers. In general, background and knowledge measures contributed to the prediction of record-fire scores for learners, low performers, and medium performers. There were no good predictors for high performers. Incremental validity analyses showed that knowledge measures contributed substantially to the prediction of record-fire scores, above and beyond background measures alone.

Study 2—Method

The purpose of Study 2 was to replicate our study at Quantico, VA. We also refined existing measures and tested new ones, given the results of Study 1. The reasons behind the replication effort were (a) potential sample difference, and (b) differences in the quality of the marksmanship instruction (i.e., for Phase I, Quantico uses trained instructors).

Participants

One-hundred fifty-two sustainment-level Marines participated in the study at WTBN Quantico, VA. A description of the sample is shown in Table 30 through Table 33. In general, the participants were male (94%), enlisted, with less than 4 years in service, and from a mix of support, base, and combat units. The mean prior qualification scores ranged from mid- to high sharpshooter. In addition, a few participants reported completing various coaches courses. Compared to the sample in Study 1, the current sample appeared older and slightly more experienced in shooting.

Table 30

Descriptive Statistics on Background Variables

Variable	*n*	*M*	*SD*	Min.	Max.
Most recent qualification score[a]	139	37.2	9.6	0	62
Second most recent qualification score[a]	89	38.9	8.7	23	65
Third most recent qualification score[a]	58	39.2	9.6	23	65
Age	143	23.2	4.0	18	38
Years in service	140	3.8	3.4	0.75	19
Frequency of shooting as part of duties[b]	145	2.0	1.2	1	5
Frequency of shooting outside of duties[b]	145	2.5	1.4	1	5
Years of shooting experience before Marines	142	4.0	5.2	0	16

[a]0 - 24 = unqualified; 25 - 34 = marksman; 35 - 39 = sharpshooter; 40 - 65 = expert. [b]1 = *Never*; 2 = *Once or twice*; 3 = *A few times*; 4 = *Often*; 5 = *Very often*.

Table 31

Distribution of Participants by Combat Status

	Frequency	Percent
Division[a]	40	30.8
FSSG[b]	14	10.8
Support/Base[c]	60	39.5
Other[d]	16	12.3

[a]Combat arms and combat support. [b]Force Service Support Group. [c]Base and formal schools. [d]Aviation.

Table 32

Distribution of Participants by Rank

Rank	Frequency	Percent
Private (E1)	1	0.6
Private First Class (E2)	8	5.0
Lance Corporal (E3)	60	37.5
Corporal (E4)	43	26.9
Sergeant (E5)	32	20.0
Staff Sergeant (E6)	12	7.5
Master Sergeant (E8)	1	0.6
Captain (O3)	3	1.9

Table 33

Distribution of Participants by Marksmanship Instructor Training

Course	No. of Participants Who Completed Course
Marksmanship Coaches Course (MOS 8530)	3
Marksmanship Instructor (MOS 8531)	5
Small Arms Weapons Instructor (MOS 8532)	3
Range Officer (MOS 9925)	1

Participants were given up to four days of live-fire practice. A fifth day was for qualification. However, anyone could elect to attempt to qualify on the third or fourth day of live-fire practice. All remaining participants were required to attempt to qualify on qualification day.

During practice, participants could get help from range coaches. During a qualification attempt, participants did not receive any help. If participants failed their first qualification attempt, they were provided with additional coaching and given the opportunity to attempt to qualify again on subsequent days. Marines who failed the second qualification attempt were at risk of being dropped from the Marine Corps.

Design

The tasks were administered to six groups over eight days. The first group was a dedicated group tested five out of the eight days. The remaining groups each contained different participants. This design reflected availability of participants, limitations in classroom testing space, and limitations in the number of computers. There were many more available participants than could be accommodated in a single setting.

Measures

The following measures were provided to us by the USMC or administered to Marines:

Record-fire score. The main outcome measure was the Marine's record-fire score. This score was the official score on record from the USMC database.

Most recent record-fire scores. These were self-reported qualification scores for the three most recent qualification trials.

Knowledge mapping. After Study 1, coaches and staff from WTBN Quantico reviewed the knowledge map task and revised the sets of terms and links. The revised set of terms were *3 elements of a good shooting position, 7 factors common to all shooting positions, aiming process, bone support, breath control, consistency, controlled muscular tension, eye on front sight post, eye relief, finger placement, follow-through, forward elbow placement, fundamentals of marksmanship, grip of firing hand, muscular relaxation, natural point of aim, natural respiratory pause, placement of buttstock in shoulder, rear elbow placement, sight alignment, sight picture, stable firing position, stock* *weld placement,* and *trigger control.* The set of links were *affects, decreases, follows, happens during, helps, increases, leads to, part of, requires,* and *uses.* The format of this measure was online.

Scoring was done using the same method as Study 1, except we used three criterion maps to score student maps against. The criterion maps were generated by three subject matter experts. These were primary marksmanship instructors at Quantico whose job was to teach rifle marksmanship. A participant's score was the total number of propositions, across the three criterion maps, in his or her map that were also in the criterion maps. The criterion map is given in Appendix J (Expert 1, 7, 8, screen shots) and Appendix K (Expert 1, 7, 8, propositions).

Basic marksmanship knowledge. We used a revised measure based on Study 1. Changes were made as a result of review by Quantico WTBN coaches and staff. In addition, we added about 6 items that required participants to consider hypothetical situations and 8 items that asked participants to predict effects on the weapon given a range of movement on the part of the shooter. The purpose of these items was to test for knowledge of causal relations in a selected-response format. The format of this measure was paper. A copy of the measure is given in Appendix L.

Shot group depiction. We used a paper version of the measure from Study 1. The format of this measure was paper. A copy of the measure is given in Appendix M.

State anxiety. We adopted a measure from O'Neil and Herl (1998) to measure participants' state anxiety about qualification prior to and after qualification. The format of this measure was paper.

Trait and state worry. We adopted a measure from O'Neil and Herl (1998) to measure participants' worry about qualification in general (trait measure) and just before or just after qualification (state measure). The format of these measures was paper. The trait measure is given in Appendix N and the state anxiety and state worry items are given in Appendix O.

Firing line experience. This was a new measure that we developed to gather information on participants' overall experience on the firing line. The format of this measure was paper. In addition, we administered a subset of the items to participants after they had qualified. A copy of the measure is given in Appendix P.

Perceived level of marksmanship knowledge. This was a new measure that we developed to gather participants' self-reported knowledge of the fundamentals. The format was paper. A copy of the measure is given in Appendix Q.

Perceived utility of marksmanship knowledge. This was a new measure that we developed to gather participants' perceptions of the utility of knowing the fundamentals of rifle marksmanship. The format was paper. A copy of the measure is given in Appendix R.

Background survey. We used the same measure from Study 1 with slight modifications to wording. We also asked Marines how much they know about rifle marksmanship, their perceived importance of knowledge of marksmanship to shooting performance, and the difficulty of our assessments. The format of this measure was paper. A copy of the measure is given in Appendix S.

Evaluation of shooter positions. We used the same measure from Study 1. The format of this measure was online.

Reliability of measures. Table 34 shows the reliabilities of the measures. In general, the measures showed high reliabilities. As in Study 1, the shot group measure had very low reliabilities. The basic knowledge measure showed a decrease in reliability over Study 1. While we had made some changes to the measures, the changes were refinements. Reliabilities for the other measures were acceptable.

Table 34

Reliability of Measures

Measure	n	Number of items	Cronbach's alpha
Knowledge map	144	3	.92
Basic marksmanship knowledge	113	37	.73
Evaluation of shooter positions	141	6	.64
Shot group depiction	144	5	.31
Trait worry	139	8	.93
State anxiety	119	5	.85
State anxiety (post-qual.)	51	5	.89
State worry	118	6	.79
State worry (post-qual.)	51	6	.69
Firing line experience	143	6	.83
Firing line experience (post-qual.)	33	6	.58
Perceived level of marksmanship knowledge	143	5	.95
Perceived utility of marksmanship knowledge	141	6	.79

Procedure

Measures were administered to participants in the order and allotted times shown in Table 35, across a total of eight occasions as shown in Table 36. Participants completed the tasks after they had completed classroom training or live fire for that day. In general, participants completed the tasks well within the times listed and were given more time if needed.

Table 35

Tasks and Time Allotted

Task	Time allotted
Introduction to study	5
Knowledge mapping training	5
Knowledge mapping task	20
Evaluation of shooter positions training	5
Evaluation of shooter positions task	20
Background survey	10
Basic marksmanship knowledge task	20
Shot group depiction task instructions and task	10
State worry survey	5
Trait worry survey	5
State firing line experience	5

Table 36

Administration Schedule

		Classroom training (Phase I)			Live-fire practice and qualification (Phase II)			
Group	*n*	Pre	Mid	Post	Practice -only	Practice or attempt to qualify	Qual-ification	Postqual-ification
1	38	ALL	KM	KM		KM		ALL
2	22			ALL				
3	29				ALL			
4	20					ALL		
5	19					ALL		
6	15						ALL	

Note. ALL = indicates administration of all measures. KM = Only knowledge map measure was administered.

Study 2—Results

Preliminary Analyses

Prior to conducting the main analyses, we checked for group differences on the record-fire scores and on the knowledge measures. Separate one-way ANOVAs were conducted to check for differences across groups on (a) record-fire scores, (b) knowledge mapping scores, (c) basic marksmanship knowledge scores, (d) shot group depiction scores, and (e) evaluation of shooter positions scores. There were no significant differences on any of the measures and thus we pooled the data across the groups.

Main Analyses

Table 37 to Table 39 show descriptive statistics of the perceptual-motor, cognitive, and affective variables. Table 40 to Table 42 present intercorrelations and correlations among the three groups of variables. The mean record-fire score is consistent with our prior studies, suggesting comparable shooting performance between Stone Bay and Quantico Marines undergoing sustainment-level qualification. In addition, participants reported generally positive firing line experiences in the past.

Table 37

Descriptive Statistics of Perceptual-Motor Variables

Variable	*n*	*M*	*SD*	Min.	Max.
Record-fire score[a]	138	38.89	8.25	14	56
Most recent record-fire score[a]	138	37.46	9.09	14	62
Second most recent record-fire score[a]	89	38.89	8.71	23	65
Third most recent record-fire score[a]	58	39.24	9.64	23	65
Frequency of shooting outside job[b]	145	2.47	1.43	1	5
Years of shooting experience before joining Marines	142	4.05	5.24	0	16
Firing line experience[c]	143	2.92	.60	1.17	4.00
Firing line experience (post-qual.)[c]	33	3.32	.39	2.50	4.00

[a]0 - 24 = unqualified; 25 - 34 = marksman, 35 - 39 = sharpshooter; 40 - 65 = expert. [b]1 = *Never*, 2 = *Once or twice*, 3 = *A few times*, 4 = *Often*, 5 = *Very often*. [c]1 = *Almost never*, 2 = *Sometimes*, 3 = *Often*, 4 = *Almost always* (higher values indicate higher positive experience).

With respect to marksmanship knowledge (Table 38), participants in general reported they had a moderate to large amount of knowledge of the fundamentals of marksmanship, and they perceived the value of knowledge of the fundamentals to shooting well. Further, when tested with our knowledge measures, performance on the basic knowledge measure was moderately high (mean score was 75% correct). However, on the more complex tasks (i.e., knowledge mapping, shot group depiction, and evaluation of shooter positions), overall performance was low.

Table 38

Descriptive Statistics of Knowledge Variables

Variable	*n*	*M*	*SD*	Min.	Max.
Basic marksmanship knowledge[a]	113	27.22	4.28	9	35
Shot group depiction[b]	144	1.97	1.15	0	4
Evaluation of shooter positions[c]	141	16.72	6.18	0	28
Knowledge map	144	3.43	5.11	0	28
Perceived level of marksmanship knowledge[d]	143	3.26	0.65	1	4
Perceived utility of marksmanship knowledge[e]	144	1.65	0.44	1	3

[a]Maximum possible is 37. [b]Maximum possible is 5. [c]Maximum possible is 63. [d]1 = *Not at all*, 2 =*Some*, 3 = *Moderate amount*, 4 = *Very much* (higher values indicate more self-reported knowledge). [e]1 = *Strongly agree*, 2 = *Agree*, 3 =*Disagree*, 4 = *Strongly disagree* (higher values indicate lower perceived value of marksmanship knowledge).

With respect to affective measures (Table 39), participants in general reported low (trait) worry about qualification in general. Similarly, when participants were asked to estimate how worried and anxious they were, participants reported low (state) worry and anxiety. Because this measure was administered to participants who were measured on different days, the measure asked these participants to estimate how they felt during qualification (if they had already attempted to qualify) or predict how they would feel during qualification (if they were going to attempt to qualify in the future). For the group of participants that were administered the state worry and anxiety measures after they had qualified, participants in this group reported a similar level of worry and anxiety during qualification.

Table 39

Descriptive Statistics of Affective Variables

Variable	*n*	*M*	*SD*	Min.	Max.
Trait worry[a]	139	1.77	0.75	1	4
State worry (pre-qual.)[b]	118	1.62	0.62	1	4
State worry (post-qual.)[b]	51	1.75	0.63	1	3.7
State anxiety (pre-qual.)[b]	119	1.94	0.68	1	4
State anxiety (post-qual.)[b]	51	1.76	0.77	1	4

[a]1 = *Almost never*, 2 = *Sometimes*, 3 = *Often*, 4 = *Almost always* (higher values indicate higher worry). [b]1 = *Not at all*, 2 =*Sometimes*, 3 = *Moderately so*, 4 = *Very much so* (higher values indicate higher worry/anxiety).

Bivariate correlations among the perceptual-motor variables (see Table 40) indicate low to moderate relationships. Especially interesting are the correlations with the record-fire score. The best predictor of record-fire score is firing line experience administered after the participants qualified. This is not surprising as the participants presumably have reasonable recollection of their overall shooting experience. Given this assumption, the magnitude of the firing line measure can be thought as of an upper bound against which other measures can be compared.

For the purposes of predicting a participant's score prior to qualification, the most recent record-fire score correlates with record-fire score in the .3 - .4 range, consistent with Pilot Study 1 (r = .38, p < .05), Pilot Study 2 (r = .36, p < .01), Study 1 (r = .41, p < .01), and prior research (e.g., Schendel et al., 1983; Smith & Hagman, 2000, Experiment 2).

Table 40

Intercorrelations Among Perceptual-Motor Variables

Variable	1	2	3	4	5	6	7
1. Record-fire score	--						
2. Most recent record-fire score	.34**	--					
3. Second most recent record-fire score	.31*	.37**	--				
4. Third most recent record-fire score	.27	.56**	.57**	--			
5. Frequency of shooting outside job	.27*	.32**	.18	.46**	--		
6. Years of shooting experience before joining Marines	.26*	.40**	.29*	.37*	.70**	--	
7. Firing line experience (pre-qual.)	.33**	.41**	.33*	.43**	.26*	.30**	--
8. Firing line experience (post-qual.)	.57**	.41*	.45	.61*	.34	.03	.74**

Bivariate correlations between the perceptual-motor variables and affective variables (see Table 41) indicate low to moderate negative relationships, a pattern consistent with prior research (e.g., Tierney et al., 1979). While the trait worry measures correlated significantly with record-fire score, the state worry measure did not. Comparing the state worry and state anxiety measures administered before the qualification attempt to the measure administered after the qualification attempt suggests interesting findings. First, assuming a relationship between shooting performance and worry and anxiety exists—it appears that participants who were asked to predict how they would feel at qualification (i.e., those who had yet to attempt qualification) were poor judges of their situation. Additional evidence for this interpretation is seen in significant and moderate correlations between pre-qualification worry and anxiety measures and the pre-qualification firing line experience measure, but non-significant correlations with the post-qualification firing line experience measure. In contrast, those shooters who were asked to reflect on their qualification experience were much better judges, as indicated by the higher relationship between the state worry and anxiety measures and record-fire performance.

Table 41

Correlations Between Perceptual-Motor Variables and Affective Variables, and Intercorrelations Among Affective Variables

	Perceptual/motor variable								Intercorrelation			
	Record-fire score											
Variable	Current	Most recent	2nd most recent	3rd most recent	FSOJ	YEXP	FLE-1	FLE-2	1	2	3	4
1. Trait worry	-.29**	-.34**	-.18	-.33*	-.27*	-.28**	-.48**	-.65**	–			
2. State worry (pre-qual.)	-.12	-.15	.08	-.07	-.18	-.21*	-.44**	-.24	.55**	–		
3. State worry (post-qual.)	-.42*	-.39*	-.12	-.13	-.37*	-.30*	-.21	-.46*	.50**	.20	–	
4. State anxiety (pre-qual.)	-.26*	-.31**	-.17	-.27	-.21*	-.27*	-.62**	-.47*	.56**	.58**	.17	–
5. State anxiety (post-qual.)	-.41*	-.33*	-.24	-.28	-.14	-.10	-.40**	-.64**	.56**	.12	.54**	.49*

Note. FSOJ = Frequency shooting outside of job. YEXP = Years of shooting experience before joining Marines. FLE-1 = Firing line experience (pre-qual). FLE-2 = Firing line experience (post-qual.).

Table 42

Correlations Between Perceptual-Motor Variables and Cognitive Variables, and Intercorrelations Among Cognitive Variables

	Perceptual/motor variable								Intercorrelation				
	Record-fire score												
Variable	Current	Most recent	2nd most recent	3rd most recent	FSOJ	YEXP	FLE-1	FLE-2	1	2	3	4	5
1. Basic marksmanship knowledge	.17	.18	.21	.20	.03	.03	.19*	.25	–				
2. Shot group depiction	.10	.05	.07	.22	.09	.10	.12	.06	.28**	–			
3. Evaluation of shooter positions	.05	.11	-.01	.05	.15	.14	.06	-.10	-.02	-.05	–		
4. Knowledge map	.15	.12	.09	.07	.03	.04	.15	.04	.21*	.05	.00	–	
5. Perceived level of marksmanship knowledge	.26*	.29**	.17	.01	.30**	.17*	.44**	.51**	.29**	.11	.02	.06	–
6. Perceived utility of marksmanship knowledge	.09	-.07	.00	.08	.09	.07	-.20*	-.17	-.10	.06	.01	-.07	-.32**

Note. FSOJ = Frequency shooting outside of job. YEXP = Years of shooting experience before joining Marines. FLE-1 = Firing line experience (pre-qual). FLE-2 = Firing line experience (post-qual.).

Bivariate correlations between the perceptual-motor variables and cognitive variables (see Table 42) indicate virtually no relationship. The only interesting relationship found was with participants' self-reported level of knowledge of the fundamentals of marksmanship. This was the only knowledge-related measure that related to record-fire score. When the intercorrelations among the knowledge measures were examined, basic knowledge of marksmanship was significantly related to other measures of knowledge, suggesting some overlap in the constructs measured.

Prediction of Record-Fire Performance

To predict record-fire performance, we conducted a series of multiple regression analyses as in Study 1. We were interested in replicating the whole-group and subgroup analyses; however, the sample size and distribution precluded the subgroup analyses. As shown in Table 43 and Figure 13, there were low numbers of participants classified as learners, low performers, and high performers.

A comparison with Study 1 shows similar means for the different groups with the exception of the learner groups (Study 1, M = 47.2; see Table 19). Thus, the regression analyses were conducted for the entire group; subgroup analyses based on prior record-fire scores were not performed.

Table 43

Descriptive Statistics of Record-Fire Performance by Subgroup

	n	*M*	*SD*	**Min.**	**Max.**
Entire sample	138	38.89	8.25	14	56
Learners	10	40.50	8.87	25	51
High performers	14	48.14	5.70	35	56
Medium performers	88	39.17	6.17	25	51
Low performers	13	26.92	8.63	14	45

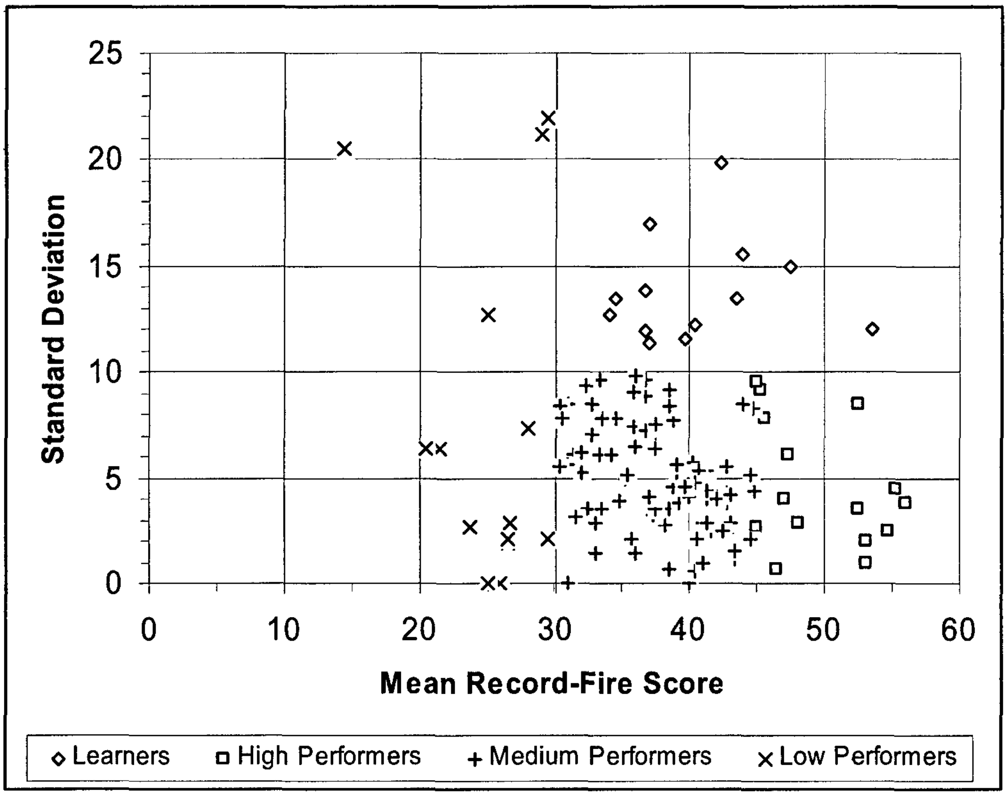

Figure 13. Subgroup classification based on scatterplot of average outcome scores (n = 136).

What combinations of perceptual-motor (proxies), cognitive, and affective measures yield the best (practical) predictors of record-fire performance?

As in Study 1, multiple regression analyses were used to predict record-fire scores. The dependent variable was record-fire score, and the independent variables were chosen based on theoretical considerations first, then empirical considerations second. That is, our basic model included perceptual-motor, cognitive, and affective variables and the particular variables chosen within each category were based on the magnitude of the bivariate correlation with record-fire score, and the magnitude of multiple correlation (R) of different analyses. In addition, the number of variables to include in the model was limited by the sample size. We attempted to maintain a ratio of number of cases to number of variables to at least 20. The final multiple regression model is made up of four variables shown in Table 44, R = .52 (R^2 = .27, adjusted R^2 = .24), SE = 7.17. A plot of the confidence intervals for the mean predicted score is shown in Figure 14.

Table 44

Multiple Regression Summary for Predicting Record-Fire Performance (n = 94)

Variable	Unstandardized coefficient	*SE*	*p* value
Most recent record-fire score	.17	.10	.099
Firing line experience (pre-qual.)	4.69	1.44	.002
Basic marksmanship knowledge	-.02	.20	.909
Trait worry	-1.44	1.22	.241

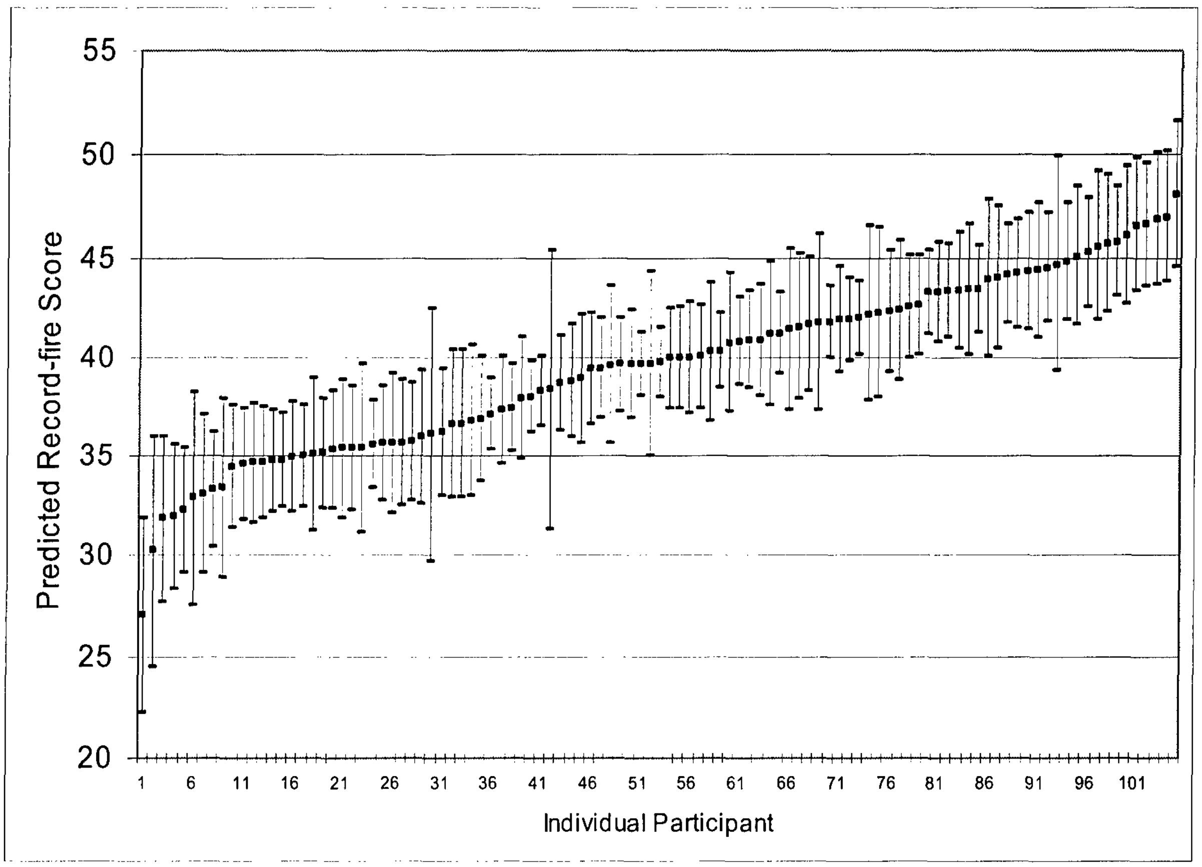

Figure 14. The 95% confidence interval for the mean predicted record-fire scores (n = 107).

Incremental validity. An incremental validity analysis was conducted using hierarchical regression analyses. The purpose of this analysis was to examine how much additional variance the cognitive and affective measures accounted for in the prediction of record-fire scores. Table 45 shows the incremental validity of additional variables beyond the most recent record-fire score. The order of the entry was based on the presumed order of importance given our theoretical framework.

The addition of firing line experience resulted in a substantial increase in the change in R^2 over most recent record-fire score alone. The additional variance accounted for by basic marksmanship knowledge and trait worry was negligible. Overall, the largest contributors to the prediction of record-fire score were perceptual-motor variables. Of these variables, the use of firing line experience contributed more to the prediction overall when used in conjunction with basic marksmanship knowledge and trait worry. While the cognitive and affective variables accounted for very little of the variance, their combination increased the amount of variance explained by the perceptual-motor variables. That is, R^2 was .15 (R = .39) when the predictors were only most recent record-fire score and firing line experience.

Table 45

Incremental Validity Analyses (n = 95)

	Regression statistic					
Variable	R	R^2	**Adj.** R^2	SE	ΔR^2	p **value**
Most recent record-fire score	.38	.13	.12	7.72	.13	<.000
Firing line experience (pre-qual.)	.51	.26	.24	7.15	.13	<.000
Basic marksmanship knowledge	.51	.26	.24	7.19	.00	.805
Trait worry	.52	.27	.24	7.17	.01	.241

Sensitivity to group differences. To test the sensitivity of our measures, t tests were conducted between low performers (defined using the same criteria as in Study 1) and others (i.e., non-low performers). As shown in Table 46, significant differences were found between low performers and others on nearly all perceptual-motor variables, with low performers showing lower performance on the various measures than others. Similarly, low performers were significantly lower than others on measures of basic marksmanship knowledge, knowledge map, and self-reported level of knowledge of the fundamentals of marksmanship. Finally, low performers had significantly higher scores on the trait worry measure (indicating more worry about qualification in general), and higher scores on the state anxiety measure (indicating higher anxiety when asked to predict how they would feel during qualification [1 to 3 days into the future]).

These results support the classification scheme, and provide evidence of the sensitivity of the basic knowledge measure and knowledge map measure to differences in experience.

A second set of comparisons on our measures were conducted between participants who had just completed the coaches course and participants in the SLR training. Of interest are comparisons on the knowledge measures—presumably, participants who had just completed the coaches course should perform higher on our knowledge measures than SLR participants. The coaches course trains Marines to be rifle marksmanship coaches and covers the fundamentals in much greater depth than the classroom training SLR Marines receive.

Table 46

t tests of Cognitive Measures Between Low Performers and Others

	Low			Others			
Measure	*n*	*M*	*SD*	*n*	*M*	*SD*	*p* value
Perceptual-motor							
Record-fire score	13	26.92	8.63	112	40.41	0.66	< .001
Most recent record-fire score	14	25.57	7.25	121	39.01	0.75	< .001
Second most recent record-fire score[a]	5	25.6	0.89	84	39.68	0.91	.001
Third most recent record-fire score[a]	4	25.25	2.63	54	40.28	1.24	.002
Frequency of shooting outside job	15	1.8	1.32	121	2.55	0.13	.052
Years of shooting experience before joining Marines	13	1.38	4.17	120	4.28	0.48	.021
Firing line experience (pre-qual.)	18	2.38	.64	122	2.99	.55	< .001
Firing line experience (post-qual.)[a]	6	2.86	.25	27	3.43	.33	< .001
Cognitive							
Basic marksmanship knowledge	12	24.33	3.85	96	27.67	0.43	.011
Shot group depiction	15	2	1.25	120	1.99	0.1	.942
Evaluation of shooter positions	14	15.64	5.18	112	16.72	0.61	.419
Knowledge map	15	1.27	2.28	114	3.74	0.5	.038
Perceived level of marksmanship knowledge	15	2.8	0.75	118	3.31	0.06	.008
Perceived utility of marksmanship knowledge	15	1.62	0.49	119	1.65	0.04	.798
Affective							
Trait worry	13	2.27	0.94	117	1.68	0.06	.018
State worry (pre-qual.)	15	1.78	0.74	95	1.56	0.06	.212
State worry (post-qual.)[a]	7	2.08	0.44	44	1.7	0.1	.059
State anxiety (pre-qual.)	15	2.39	0.79	96	1.86	0.07	.010
State anxiety (post-qual.)[a]	7	2	0.83	43	1.69	0.12	.224

[a]Non-parametric test (Kruskal-Wallis).

As shown in Table 47, significant differences were observed in the shot group depiction and the knowledge map. Unfortunately, the participants in the coaches course were unavailable to take the basic marksmanship knowledge assessment. The most remarkable difference is seen in the knowledge map scores. Participants in the coaches course on average scored almost 3.5 propositions higher than SLR participants. This difference is interesting because it is consistent with the idea that the knowledge map measures conceptual knowledge—the coaches course curriculum emphasizes cause-effect relations among position, aiming, trigger, and breathing topics, presumably what knowledge mapping is suited to capture.

Table 47

t tests of Cognitive Measures Between Marines in the Coaches Course and Participants

	SLR			**Coaches course**			
	n	*M*	*SD*	*n*	*M*	*SD*	*p* **value**
Perceptual-motor							
Most recent record-fire score	139	37.19	9.6	15	44.87	2.39	.004
Second most recent record-fire score	89	38.89	8.71	13	46.23	1.88	.004
Third most recent record-fire score	58	39.24	9.64	11	48.64	1.46	.002
Frequency of shooting outside job	145	2.47	1.43	15	2.6	0.34	.734
Years of shooting experience before joining Marines	142	4.05	5.24	15	2.73	1.48	.361
Firing line experience (pre-qual.)	143	2.92	.60	15	3.23	.47	.031
Cognitive							
Shot group depiction[a]	143	1.98	1.15	15	3.07	0.25	.001
Evaluation of shooter positions	141	16.72	6.18	14	17.21	1.64	.774
Knowledge map[a]	143	3.45	5.12	15	6.87	1.82	.004
Perceived level of marksmanship knowledge	143	3.26	0.65	15	3.52	0.12	.127
Perceived utility of marksmanship knowledge	144	1.65	0.44	15	1.5	0.09	.200
Affective							
Trait worry	139	1.77	0.75	15	1.45	0.60	.109

[a]Non-parametric test (Kruskal-Wallis).

Sensitivity to instruction. The final set of analyses examined differences between a posttest and pretest of the measures administered to the same sample of participants. As shown in Table 48, there were significant gains over the period spanning classroom training (Phase I), live-fire practice, and qualification (Phase II) on basic marksmanship knowledge and knowledge mapping. Interestingly, the differences in knowledge map scores increased over occasion. There was an average of 6.25 more correct propositions in the posttest map on the fifth occasion over the initial map. Similarly, there was an average of 1.8 propositions gained over the classroom training period. Note that the knowledge mapping tasks were slightly different. On the fifth occasion, participants recreated their maps from scratch whereas on the third occasion, participants made changes to an existing map (i.e., their knowledge map from the previous mapping occasion).

Table 48

Paired-Sample Tests of Mean Differences Between Measures Administered Before Classroom Training and After Qualification Attempt

		Pretest			Posttest				
	n	*M*	*SD*	*SE*	*M*	*SD*	*SE*	Mean difference	*p* value
Basic marksmanship knowledge	22	26.91	4.25	0.91	28.77	3.94	0.84	1.86	.002[a]
Shot group depiction	33	2.06	1.14	0.20	2.12	1.02	0.18	0.06	.853[b]
Evaluation of shooter positions	29	15.41	5.98	1.11	15.62	6.31	6.31	-.21	.630
Knowledge map (occasion 5 vs. 1)	16	4.88	8.09	2.02	11.10	12.97	3.24	6.25	.004[a]
Knowledge map (occasion 3 vs. 1)	31	6.48	8.25	1.48	4.65	6.98	1.25	1.84	< .001[a]

[a]Paired *t* test. [b]Non-parametric test (paired Wilcoxon).

Summary and Discussion of Study 2

Reliability of measures. Overall, our measures demonstrated moderate to high reliabilities. The lowest reliability was with the shot group depiction task (α = .31), similar to Study 1. The basic marksmanship knowledge measure had a moderate α (.73). The survey measures (i.e., affective, firing line experience, perceived level of marksmanship knowledge, perceived utility of marksmanship knowledge) demonstrated high reliabilities, with α in the .8 to .9 range. The exception to this was firing line experience on qualification day (α = .58). The knowledge map measures also demonstrated high reliabilities when scores from three expert criterion maps were used as items (α = .92).

Predictive validity. The best predictor of record-fire score was firing line experience administered after the participants qualified (r = .57, p < .01). When this measure was administered prior to qualification, the relationship was lower (r = .33, p < .01), comparable to participants' self-reported most recent record-fire score (r = .34, p < .01). Affective variables correlated negatively with record-fire score, ranging from -.1 to -.4. In general, the magnitude of the correlations was higher when the measure was administered after participants attempted to qualify. Interestingly, trait worry was a moderately good negative predictor of performance (r = -.29, p < .01). With respect to cognitive predictors of record-fire score, only the perceived level of marksmanship knowledge predicted record-fire score (r = .26, p < .05).

Construct validity. Overall, the sample in Study 2, compared to Study 1, was older and more experienced in shooting. For this reason, we expected this sample to be slighter further along in skill development. Compared to a novice sample, in a more experienced sample the skill-development model (Ackerman, 1987, 1992; Fitts & Posner, 1967) suggests that cognitive variables (e.g., aptitude and content-related abilities and presumably knowledge) have less influence on performance, and perceptual and motor variables would have more impact on performance. We considered prior shooting scores and other shooting-related variables as proxies for the perceptual-motor construct.

Overall, there were no significant relationships between record-fire scores and measures of knowledge. Only perceived level of marksmanship knowledge was related to record-fire score (r = .26, p < .05). With respect to perceptual-motor variables, record-fire scores were related with most recent record-fire score (r = .34, p < .01) and prior firing line experience (r = .33, p < .01). Interestingly, there was a low but significant relationship between basic marksmanship and prior firing line experience (r = .19, p < .05). This set of relationships are consistent with the skill-development model that suggests that content-related abilities are less influential on performance compared to perceptual-motor variables for more experienced shooters.

The correlations among record-fire score, firing line experience, state anxiety, and state worry were consistent with expectations. The direction of the relationship and the large magnitudes suggest that the measures were working as intended. Firing line experience was negatively associated with state anxiety and state worry. Participants who reported more positive shooting experience also reported lower anxiety and worry. Similarly, participants with more anxiety also reported more worry. Trait worry was correlated significantly and moderately with firing line experience (negatively), state worry (positively), and state anxiety (positively), a result that also is consistent with expectations.

Sensitivity of measures. Low performers, compared to others, scored lower on current and prior record-fire scores, reported less shooting experience prior to joining the Marines, and reported poorer firing line experiences. In addition, they scored lower on the basic marksmanship knowledge and knowledge map measures, consistent with expectations. There were no differences on the shot group depiction and evaluation of shooter positions performance measures. Low performers also reported more trait worry and pre-qualification anxiety than others.

When the SLR sample was compared to participants who just completed the coaches course, coaches scored higher on all previous record-fire scores and reported more positive firing line experiences. Coaches also scored higher on the knowledge map and shot group depiction performance measures. There was no difference between the samples on the evaluation of shooter positions performance measure, and due to time restrictions, the coaches did not take the basic marksmanship knowledge measure.

Study 3—Method

The purpose of Study 3 was to test our measures on entry-level officers (i.e., 2nd Lieutenants [LT]). Also, we wanted to replicate the findings from Study 2 regarding firing line experience, knowledge map sensitivity, and anxiety measures. We also pilot tested new measures.

The second aspect of this sample was that the participants were entry-level and thus had little or no prior shooting or marksmanship training. We could thus focus on the prediction of shooting performance based solely on our measures without the confounding factor of prior shooting experience.

Participants

Fifty-three entry-level 2nd LT Marines participated in the study at WTBN Quantico, VA. A description of the sample is shown in Table 49. In general, the Marines were male (88%) with little prior shooting experience.

Table 49

Sample Descriptive Statistics

Variable	*n*	*M*	*SD*	Min.	Max.
Age	53	23.70	1.78	21	28
Years in service	48	0.63	1.00	0	6
Frequency of shooting as part of duties[a]	53	1.32	0.78	1	4
Frequency of shooting outside of duties[a]	53	1.98	1.03	1	5
Years of shooting experience before Marines	52	2.25	3.95	0	15

[a]1 = *Never*, 2 = *Once or twice*, 3 = *A few times*, 4 = *Often*, 5 = *Very often*.

As part of the normal training process, participants receive about two days of classroom instruction on the fundamentals of rifle marksmanship. The next day is spent "zeroing" the rifle (calibrating the rifle sights for a particular distance). The following five days are spent on the firing range. The first four of these days are for live-fire practice. The last day is reserved for qualification trials. During practice, participants could get help from range coaches (the ratio of coaches to students was 1 to 3 or 4 students). During qualification, participants received no help. If participants failed their first qualification attempt, they were provided with additional coaching and given the opportunity to attempt to qualify again in subsequent days. Marines who failed the second qualification attempt were at risk of being dropped from the Marine Corps. All Marines in the current study qualified.

Design

Three groups of participants were administered tasks over a two-week period. Groups 2 and 3 differed by type of knowledge mapping task. Group 3 was provided with the same set of links as Group 2, but in addition, they had the option to type in their own links. There was only one instance of this occurring across all administrations of the tasks; thus, we collapsed the sample into a single group. We tested an instructional intervention in Group 1 on one day but otherwise, Group 1 was identical to Group 2.

Measures

The following measures were provided to us by the USMC or administered to Marines:

Record-fire scores. Official qualification scores were provided to us by WTBN.

Knowledge mapping. The set of terms and links and scoring method remained the same as Study 2.

Knowledge mapping of problem solving (shot-to-shot). The task is given in Appendix T. This measure was included for pilot testing purposes (usability) and will not be discussed further.

Knowledge mapping of procedural knowledge (data book procedure). The task is given in Appendix U. This measure was included for pilot testing purposes (usability) and will not be discussed further.

Basic marksmanship knowledge. We used a revised measure based on Study 2. The format of this measure was paper. The revised measure is given in Appendix V.

General Classification Test (GCT) scores. Official GCT scores were provided to us by the USMC. This test is administered only to commissioned and warrant officers. GCT is used as a measure for aptitude.

Classroom Test of Scientific Reasoning. Lawson's Classroom Test of Scientific Reasoning (revised 24-item multiple choice edition) was used to measure scientific reasoning (Lawson, 1987, 2000). This measure was included for pilot testing purposes (usability) and will not be discussed further. The task is given in Appendix W.

Shot group depiction task. We used the same measure from Study 2. The format of this measure was paper.

State anxiety survey. We used the same set of measures as Study 2 to measure participants' state anxiety about their shooting during practice days and during qualification. The format of this measure was paper.

State worry. We used the same set of measures as Study 2 to measure participants' worry about their shooting during practice days and during qualification. The format of this measure was paper.

Firing line survey. This was a revised measure that we used to gather information on participants' overall experience on the firing line. The format of this measure was paper.

Perceived level of marksmanship knowledge. We used the same measure as Study 2.

Perceived utility of marksmanship knowledge. We used the same measure as Study 2.

Background survey. We used the same measure from Study 2 with slight modifications to adjust for the new (i.e., entry-level) sample. The format of this measure was paper.

Evaluation of shooter positions (ESP). We revised the software from Study 2 given comments from WTBN. WTBN supervised the positioning of the Marine model. In addition, new doctrine specified the use of the loop sling, which was not reflected in the Study 2 ESP task. The scoring rubric is given in Appendix X.

As with the previous version of ESP, the task for the Marine was to diagnose problems with the shooter. The participant was presented with a shooter (as shown in Figure 15). The figure was a QuickTime VR image, so the participant could rotate the image and have a 360-degree view. The participant was required to judge the extent to which each body element was in its proper position, and indicate this judgment by selecting the radio button for each position element (lower left corner of Figure 15).

If the participant selected any option other than "proper," the participant was required to fix the position element. Clicking on the "Correct It" button opened a video window. The video was of a Marine exercising the full range of motion that spanned correct and incorrect positions. The participant was required to use the slider bar to indicate the correct position.

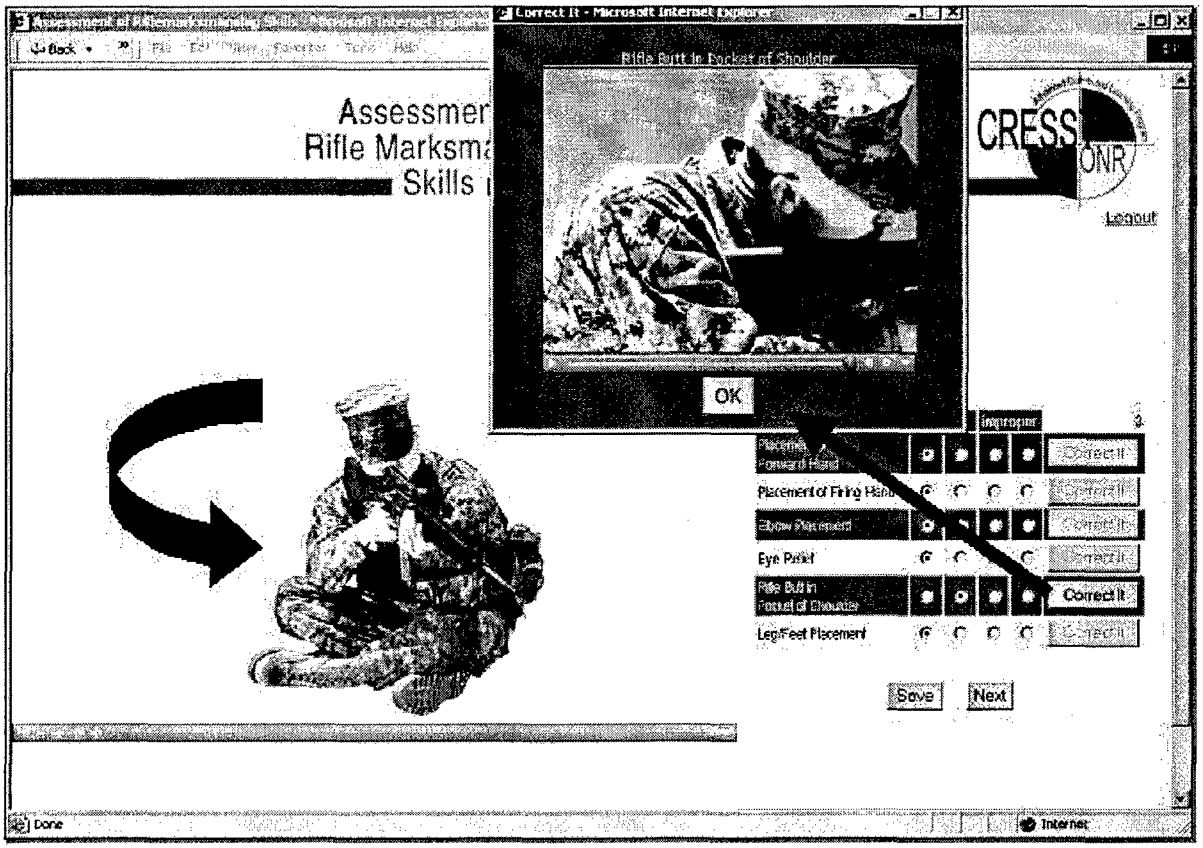

Figure 15. Revised ESP task user interface.

Reliability of measures. Table 50 shows the reliabilities of the measures. In general, the measures showed high reliabilities. As in Study 1 and Study 2, the shot group measure showed very low reliabilities. The basic knowledge measure showed a decrease in reliability from Study 2.

Table 50

Reliability of Measures

Measure	*n*	Number of items	Cronbach's alpha
Basic marksmanship knowledge	48	35	.64
Perceived level of marksmanship knowledge	53	5	.93
Perceived utility of marksmanship knowledge	53	6	.76
Knowledge map			
Day 1	50	3	.91
Day 2	45	3	.92
Day 3	46	3	.92
Day 4	44	3	.91
Day 5 (qualification day)	45	3	.92
Day 6	50	3	.93
Knowledge map (shot to shot)	52	2	.98
Classroom test of scientific reasoning	44	22	.84
Shot group depiction	49	5	.23
State worry			
Day 1	53	6	.67
Day 3	51	6	.82
Day 5 (qualification day)	49	6	.82
State anxiety			
Day 1	52	5	.87
Day 3	51	5	.88
Day 5 (qualification day)	50	5	.93
Firing line experience			
Day 1	53	6	.78
Day 2	52	6	.81
Day 3	53	6	.88
Day 4	53	6	.83
Day 5 (qualification day)	50	6	.84

Procedure

Measures were administered to participants in the order and allotted times shown in Table 51. In general, participants completed the tasks well within the times listed and were given more time if needed. Because of a technical problem, the evaluation of shooter positions measure was rescheduled from the first occasion to the second occasion.

Table 51

Administration Schedule

		Classroom training (Phase I)				Live-fire practice (Phase II)							
		Pre (Wed)		Post (Fri)		Practice (Mon)		Practice (Wed)		Qualification (Fri)		Post-qualification (Tue)	
Group	*n*	Task	Time	Task	Time	Task	Time	Task	Time	Task	Time	Task	Time
1	17	KM	20	ESP	20	ONT	50	PF	10	PF	10	KM-P	20
		CTSR	20	BMK	20	BMK-P	20	KMSS	35	KMDB	35	ESP-P	20
				KM	20	KM	10	KM	10	KM	10		
				ATT	10	PF	10						
2	18	PK	20	ESP	20	PF	10	PF	10	PF	10	KM-P	20
		CTSR	20	KM	20	KM	10	KMSS	35	KMDB	35	ESP-P	20
		KM	25	ATT	10			KM	10	KM	10	BMK-P	20
3	18	PK	20	ESP	20	PF	10	PF	10	PF	10	KM-P	20
		CTSR	20	ATT	10	KM	10	KMSS	35	KMDB	35	ESP-P	20
		KM	25	KM	20			KM		KM	10	BMK-P	20

Note. Groups 2 and 3 were collapsed for data analysis purposes. Group 1 was dropped because of extremely poor weather during their qualification, plus they received an instructional intervention.

KM = knowledge mapping task (revise previous knowledge map); CTSR = classroom test of scientific reasoning; ESP = evaluation of shooter positions. ATT = attitudes toward marksmanship knowledge; KMSS = knowledge mapping (shot-to-shot explanation); KMDB = knowledge mapping (data book procedure); PF = post-fire surveys (firing line experience, state anxiety, state worry); KM-P = post-training knowledge mapping (create a new knowledge map); BMK-P = post-training basic marksmanship knowledge test; ESP-P = post-training ESP; ONT = ontology pilot test (reported in Chung, Delacruz, Dionne, & Bewley, 2003).

Study 3—Results

Preliminary Analyses

Prior to conducting the main analyses, we checked for group differences on the record-fire scores and on the knowledge measures. Separate one-way ANOVAs were conducted to check for differences across groups on (a) record-fire scores, (b) knowledge mapping scores, (c) basic marksmanship knowledge scores, (d) shot group depiction scores, and (e) ESP scores.

There were no significant differences on GCT, ESP, basic marksmanship knowledge, knowledge mapping pretest, frequency of shooting outside of duties, and years of shooting experience prior to joining the Marines. There was a significant difference on the record-fire scores ($F(2,50) = 5.96$, $MSE = 63.8$, $p = .005$). Pair-wise comparisons indicated Group 2 performed significantly higher ($M = 43.7$, $SD = 8.5$, $n = 18$) than Group 1 ($M = 34.5$, $SD = 8.02$, $n = 17$) and Group 3 ($M = 37.6$, $SD = 7.5$, $n = 18$). A review of the range conditions during qualification indicated that Group 1 participants qualified in a severe thunderstorm. In addition, Group 1 received an instructional intervention. Thus, Group 1 was dropped from the analyses reported in this section. Table 52 shows descriptive statistics for the revised sample.

Table 52

Revised Sample Descriptive Statistics

Variable	*n*	*M*	*SD*	Min.	Max.
Age	36	23.5	1.8	21	28
Years in service	34	0.70	1.14	0	6
Frequency of shooting as part of duties[a]	36	1.11	.52	1	4
Frequency of shooting outside of duties[a]	36	1.92	.94	1	4
Years of shooting experience before Marines	36	2.17	3.92	0	15

[a]1 = *Never*, 2 = *Once or twice*, 3 = *A few times*, 4 = *Often*, 5 = *Very often*.

Main Analyses

Table 53, Table 55, and Table 58 show descriptive statistics of the perceptual-motor, cognitive, and affective variables. Table 54, Table 56, Table 57, Table 59, and

Table 60 present intercorrelations and correlations among the three groups of variables. Interestingly, the mean record-fire score for the entry-level participants is similar in magnitude with our prior sustainment-level samples. In general, as indicated by the firing line experience surveys, participants reported increasingly positive firing line experience as the week went on, with the most positive firing line experience reported on qualification day. Additional analyses conducted on the shooting scores over the live-fire period in general show a positive fast and rapid improvement in shooting scores at the beginning of the week, with shooting scores improving at an increasingly slower rate. A detailed analysis is reported in Appendix Y.

Table 53

Descriptive Statistics for Perceptual-Motor Variables

Variable	*n*	*M*	*SD*	Min.	Max.
Record-fire score[a]	36	40.64	8.44	25	57
Frequency of shooting outside job[b]	36	1.92	0.94	1	4
Years of shooting experience before joining Marines	36	2.17	3.92	0	15
Firing line experience[c]					
Live-fire practice Day 1	36	2.48	.42	1.67	3.67
Live-fire practice Day 2	35	2.62	.54	1.67	3.83
Live-fire practice Day 3	36	2.88	.65	1.33	4
Live-fire practice Day 4	36	3.07	.59	1.67	4
Qualification day	34	3.18	.61	2	4

Note. ELR record-fire scores were converted to SLR equivalent scores. See Appendix G for the conversion table.
[a]0 - 24 = unqualified, 25 - 34 = marksman, 35 - 39 = sharpshooter, 40 - 65 = expert. [b]1 = *Never*, 2 = *Once or twice*, 3 = *A few times*, 4 = *Often*, 5 = *Very often*. [c]1 = *Almost never*, 2 = *Sometimes*, 3 = *Often*, 4 = *Almost always* (higher values indicate higher positive experience).

Intercorrelations among the perceptual-motor variables (see Table 54) show significant relationships among record-fire score and firing line experience. The best predictor of record-fire score is the firing line measure administered after the participants qualified, as in Study 2. Interestingly, in general, the previous day's firing line experience was not always a predictor of the next day's experience, although each day's firing line experience was predictive of record-fire scores.

Table 54

Intercorrelations (Pearson) Among Perceptual-Motor Variables

Variable	1	2	3	4	5	6	7
1. Record-fire score	–						
2. Frequency of shooting outside job	.30	–					
3. Years of shooting experience before joining Marines	.26	.71**	–				
4. Firing line experience, live-fire practice Day 1	.35*	.16	.25	–			
5. Firing line experience, live-fire practice Day 2	.51*	.23	-.01	.30	–		
6. Firing line experience, live-fire practice Day 3	.34*	.16	.11	.10	.62**	–	
7. Firing line experience, live-fire practice Day 4	.49*	.08	.03	.42*	.55**	.38*	–
8. Firing line experience, qualification day	.77**	.20	.05	.38*	.46*	.33	.29

With respect to cognitive variables (Table 55), participants in general reported they had a moderate amount of knowledge of the fundamentals of marksmanship, and they perceived the value of knowledge of the fundamentals to shooting well. Further, when tested with our knowledge measures, performance on the basic knowledge measure was moderately high (mean score was 80% correct). Interestingly, performance on the shot group depiction task was similar to the Study 2 sample. When the participants in Study 3 were compared to the SLR and coaches course participants in Study 2, the ELR officers performed significantly higher than both groups. The mean difference between the ELR and SLR samples was on average 9.9 propositions, $t(58.12) = 6.69$, $p < .001$, and the mean difference with the participants in the coaches course was 6.5 propositions, $t(63) = 2.33$, $p = .02$.

Table 55

Descriptive Statistics for Cognitive Variables

Variable	*n*	*M*	*SD*	Min.	Max.
General Classification Test	36	124.14	10.78	100	150
Basic marksmanship knowledge[a]	34	28.32	3.00	22	33
Shot group depiction[b]	33	2.06	0.93	0	4
Evaluation of shooter positions (pre-live fire)[c]	33	42.33	3.48	37	50
Evaluation of shooter positions (post-qualification)[c]	36	43.69	3.55	31	49
Knowledge map					
Pre-classroom training	34	7.76	7.19	0	24
Post-classroom training	28	8.93	7.17	0	27
Live-fire practice Day 1	29	9.34	7.47	0	27
Live-fire practice Day 3	29	10.24	8.30	0	28
Qualification day	31	9.65	7.85	0	26
Post-qualification	33	12.76	8.39	0	27
Perceived level of marksmanship knowledge, post-classroom training[d]	36	3.00	0.42	2.2	3.8
Perceived utility of marksmanship knowledge, post-classroom training[e]	36	1.39	0.36	1	2.17

[a]Maximum possible is 35. [b]Maximum possible is 5. [c]Administered at the beginning of live-fire practice and after live-fire practice. [d]1 = *Not at all*, 2 =*Some*, 3 = *Moderate amount*, 4 = *Very much* (higher values indicate more self-reported knowledge). [e]1 = *Strongly agree*, 2 = *Agree*, 3 =*Disagree*, 4 = *Strongly disagree* (higher values indicate lower perceived utility of marksmanship knowledge).

Intercorrelations among the cognitive variables shown in Table 56 suggest that the knowledge measures were in part operating as intended. Basic marksmanship knowledge was significantly related to aptitude and self-reported level of knowledge. These results are consistent with the idea that the capacity to learn mediated how much was learned.

Table 56

Intercorrelations Among Cognitive Variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. General classification test	--											
2. Basic marksmanship knowledge	.48*	--										
3. Shot group depiction	.29	.14	--									
4. Evaluation of shooter positions (pre-live fire)	-.08	-.14	.10	--								
5. Evaluation of shooter positions (post-qual.)	-.23	.01	.07	.50*	--							
6. Knowledge map, pre-classroom training	.51*	.31	.45*	.02	-.20	--						
7. Knowledge map, post-classroom training	.36	.10	.41*	-.03	-.20	.86**	--					
8. Knowledge map, live-fire practice Day 1	.21	.01	.44*	.06	.03	.86**	.98**	--				
9. Knowledge map, live-fire practice Day 3	.27	.15	.43*	.24	.04	.84**	.96**	.96**	--			
10. Knowledge map, qualification day	.27	.11	.52*	.25	.11	.85**	.94**	.96**	.96**	--		
11. Knowledge map, post-qualification	.32	.21	.30	.28	.17	.50*	.24	.31	.42*	.50*	--	
12. Self-rating of knowledge of fundamentals	.25	.37*	-.05	.08	.04	-.01	.02	-.16	.06	-.13	-.17	--
13. Perceived utility of marksmanship knowledge	-.25	.15	-.41*	-.21	-.08	-.21	-.21	-.13	-.20	-.24	-.32	.04

The most interesting results were with the knowledge maps. The mean scores shown in Table 55 show slow, positive changes over occasions. The pre-classroom-training knowledge map correlated significantly with all subsequent knowledge maps. The occasion-to-occasion correlation between map scores (i.e., where participants were revising their maps from the previous occasion) was consistently high. The magnitude dropped considerably, however, when participants were retested after qualification (i.e., participants were given a blank map). This drop in magnitude suggests that learning occurred differentially over the course of classroom training and live-fire practice. The map scores increased on average by 5 propositions, and the correlation between the pretest and posttest suggests that changes were less than uniform across participants.

Occasion-to-occasion map scores were very consistent, with correlations in the mid .90s. This result suggests that there were either few changes or the changes that were made were inconsequential (i.e., resulted in little changes in the scores). The most interesting occasion-to-occasion change was between the knowledge map scores on qualification day and the map scores on the posttest. The correlation in this case dropped to .50.

Bivariate correlations between the perceptual-motor variables and cognitive variables (see Table 57) show significant and moderate relationships between record-fire score and a variety of aptitude and knowledge measures. The highest correlation with record-fire score was GCT, followed by participants' self-ratings of how much they know about the fundamentals, and the basic knowledge of marksmanship measure. The self-rating measure also correlated with firing line experience during qualification day and with two other live-fire practice days.

Table 57

Correlations Between Perceptual-Motor Variables and Cognitive Variables

	Perceptual-motor variable							
Variable	RF	FSOJ	YEXP	FLE1	FLE2	FLE3	FLE4	FLEQ
1. General classification test	.45*	.25	.17	-.18	.26	.17	.28	.16
2. Basic marksmanship knowledge	.38*	.13	.21	.05	.28	.36*	.31	.20
3. Shot group depiction	.11	.28	.12	.14	.11	.04	.37*	-.22
4. Evaluation of shooter positions (pre-live fire)	-.38*	-.20	.00	-.24	-.13	-.03	-.01	-.42*
5. Evaluation of shooter positions (post-qual.)	-.13	-.18	-.09	.12	-.23	-.12	.07	-.13
6. Knowledge map, pre-classroom training	.29	.31	.06	-.19	.29	.22	.21	.13
7. Knowledge map, post-classroom training	.25	.39*	.04	-.02	.44*	.13	.39*	.13
8. Knowledge map, live-fire practice Day 1	.19	.32	.05	-.06	.29	.10	.31	-.01
9. Knowledge map, live-fire practice Day 3	.17	.22	.09	-.09	.31	.11	.28	.07
10. Knowledge map, qualification day	.10	.24	.01	-.16	.20	-.08	.10	-.10
11. Knowledge map, post-qualification	.03	-.02	-.03	-.06	.11	.19	.02	-.05
12. Perceived level of know. of the fundamentals	.41*	-.22	.04	.22	.28	.27	.43*	.34*
13. Perceived utility of marksmanship knowledge	-.18	-.03	.10	.08	.04	-.03	-.10	-.02

Note. RF = Record-fire score. FSOJ = Frequency shooting outside of job. YEXP = Years of shooting experience before joining Marines. FLE1-FLEQ = Firing line experience, live-fire practice Day 1 to Day 4, and qualification day.

With respect to affective measures (Table 58), participants in general reported low worry and low anxiety throughout live-fire practice and on qualification day. These results are consistent with participants' self-reported positive firing line experience shown in Table 53. Interestingly, there are no appreciable increases in worry and anxiety on qualification day compared to practice days.

Table 58

Descriptive Statistics for Affective Variables

Variable	*n*	*M*	*SD*	Min.	Max.
Trait worry, post-qualification[a]	35	3.61	0.45	1.88	4
State worry					
Live-fire practice Day 1[b]	36	1.69	0.40	1	2.5
Live-fire practice Day 3[b]	35	1.68	0.55	1	2.83
Qualification day[b]	33	1.70	0.63	1	3.67
State anxiety					
Live-fire practice Day 1[b]	35	1.99	0.51	1	2.8
Live-fire practice Day 3[b]	35	1.94	0.64	1	3.6
Qualification day[b]	33	1.83	0.69	1	3.4

[a]1 = *Almost never*, 2 = *Sometimes*, 3 = *Often*, 4 = *Almost always* (higher values indicate higher worry). [b]1 = *Not at all*, 2 =*Sometimes*, 3 = *Moderately so*, 4 = *Very much so* (higher values indicate higher worry/anxiety).

Intercorrelations among the affective measures are generally moderate, with scores on the most recent occasion predicting scores on qualification day significantly and moderately. In general, worry and anxiety were consistent with each other, especially on qualification day. Interestingly, the relationship between the trait worry measure and the state worry and state anxiety measures increased in general the nearer qualification day approached.

Table 59

Intercorrelations Among Affective Variables

Variable	1	2	3	4	5	6	7
1. Trait worry, post-qualification	--						
2. State worry, live-fire practice Day 1	-.36*	--					
3. State worry, live-fire practice Day 3	-.62**	.48*	--				
4. State worry, qualification day	-.59**	.26	.38*	--			
5. State anxiety, live-fire practice Day 1	-.19	.34*	.01	.46*	--		
6. State anxiety, live-fire practice Day 3	-.40*	.44*	.79**	.31	.06	--	
7. State anxiety, qualification day	-.52*	.15	.27	.83**	.33	.37*	--

*$p < .05$. **$p < .01$.

Bivariate correlations between the perceptual-motor variables and affective variables (see Table 60) show significant and moderate to large relationships. The best predictors of record-fire score were the state measures of worry and anxiety at qualification; however, state worry and anxiety at practice day 3 predicted record-fire score as well, although at lower magnitudes. Interestingly, the trait worry measure (administered four days after qualification) was as good a predictor of record-fire scores as practice day 3 worry and anxiety measures.

The large and significant correlations between the state worry and anxiety measures and the firing line experience measure suggest that these measures were working as intended. Participants' negative affective states (i.e., anxiety, worry) were inversely related to firing line experience.

Table 60

Correlations Between Perceptual-Motor Variables and Affective Variables

	Perceptual-motor variable							
Variable	**RF**	**FSOJ**	**YEXP**	**FLE1**	**FLE2**	**FLE3**	**FLE4**	**FLEQ**
1. Trait worry, post-qualification	-.45*	-.05	.09	-.28	-.31	-.36*	-.36*	-.58**
2. State worry, live-fire practice Day 1	-.31	-.26	-.08	-.36*	-.32	-.41*	-.21	-.39*
3. State worry, live-fire practice Day 3	-.47*	-.06	.10	.03	-.58**	-.75**	-.42*	-.37*
4. State worry, qualification day	-.64**	.08	.20	-.36*	-.36*	-.19	-.40*	-.78**
5. State anxiety, live-fire practice Day 1	-.22	-.12	-.20	-.56**	-.10	.07	-.10	-.31
6. State anxiety, live-fire practice Day 3	-.52*	-.12	-.05	-.03	-.58**	-.78**	-.56**	-.38*
7. State anxiety, qualification day	-.61**	-.06	.02	-.31	-.25	-.25	-.39*	-.79**

Note. RF = Record-fire score. FSOJ = Frequency shooting outside of job. YEXP = Years of shooting experience before joining Marines. FLE1-FLEQ = Firing line experience, Day 1 to Day 4, and qualification day.
$^{*}p < .05$. $^{**}p < .01$.

Prediction of Record-Fire Performance

To predict record-fire performance, we conducted a series of multiple regression analyses. Given that small sample size, we limited the number of variables in the regression model to at most three. Five models were tested: (a) perceptual-motor variables; (b) cognitive variables only; (c) affective variables; (d) cognitive and affective variables; and (e) perceptual-motor, cognitive, and affective variables. As shown in Table 61, for each regression model we also conducted an incremental validity analysis. Figure 16 shows confidence intervals for the predicted scores.

Firing line experience, GCT, and state worry were the strongest predictors in their respective categories. For each type of variable (i.e., perceptual-motor, cognitive, affective), adding more variables contributed little to the prediction of record-fire scores. When only cognitive and affective variables are considered (R = .76), the combination of aptitude and state worry is as high as firing line experience. The full model combining all three variables results in an increase of R by 13% to .86.

Table 61

Incremental Validity Analyses for Regression Models Representing Background Only, Background and Cognitive, and Background, Cognitive, and Affective Predictors ($n = 32$)

Model	Variable in regression equation	R	R^2	Adj. R^2	SE	ΔR^2	p value
Perceptual-motor variables	Firing line experience	.77	.60	.59	5.28	.60	<.001
	Firing line experience, frequency of shooting outside job	.79	.62	.59	5.24	.02	.233
Cognitive variables	GCT	.46	.21	.19	7.75	.21	.006
	GCT, basic marksmanship knowledge	.49	.24	.20	7.70	.03	.243
	GCT, basic marksmanship knowledge, perceived level of knowledge of the fundamentals	.55	.30	.23	7.53	.06	.132
Affective variables	State worry	.64	.42	.40	6.44	.42	<.001
	State worry, state anxiety	.66	.43	.40	6.43	.02	.318
Cognitive and affective variables	GCT	.46	.21	.18	7.49	.21	.008
	GCT, state worry	.76	.57	.55	5.58	.37	<.000
Variables from each facet	Firing line experience	.75	.56	.55	5.42	.56	<.001
	Firing line experience, GCT	.84	.71	.69	4.48	.15	.001
	Firing line experience, GCT, state worry	.86	.74	.71	4.30	.03	.074

Note. Firing line experience, state worry, and state anxiety measures are with respect to qualification day. Order of variables reflects order of entry in the regression analyses.

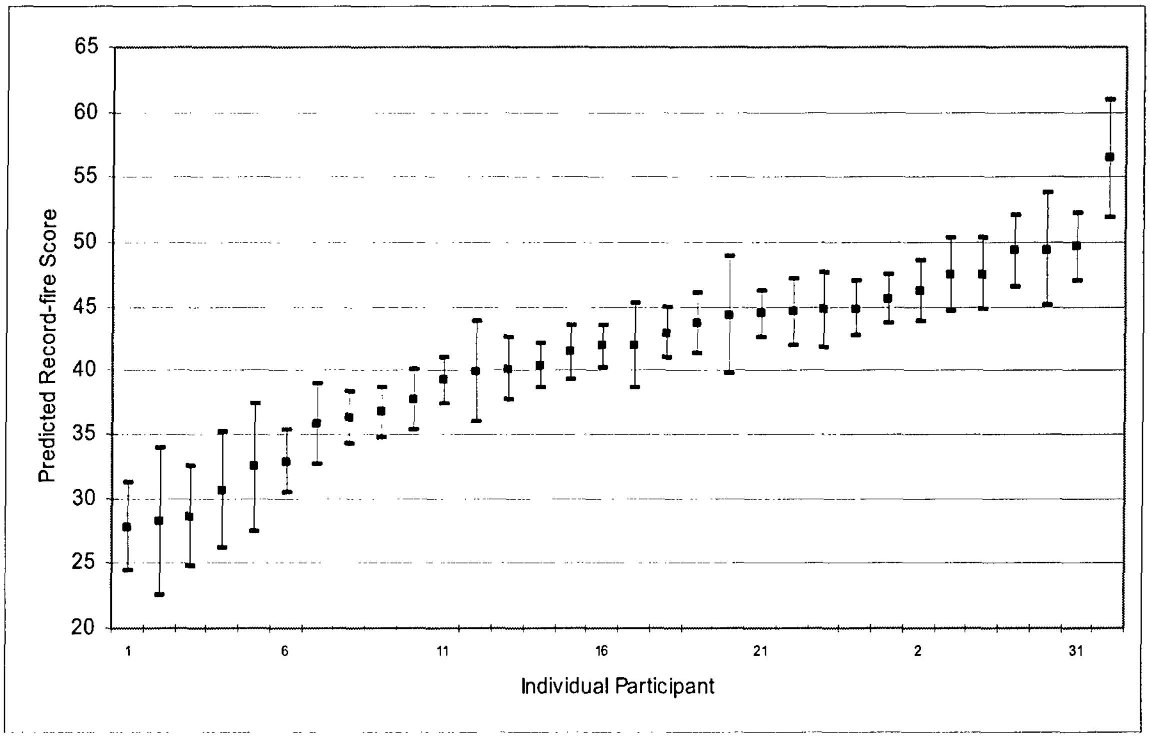

Figure 16. The 95% confidence interval for the mean predicted record-fire scores (n = 32).

Sensitivity to group effects. In a series of analyses we examined whether group differences existed between participants who qualified expert and participants who qualified as something else (i.e., sharpshooter or marksman). Note that most of the participants reported having little prior shooting experience and were undergoing basic training. Thus, this sample is relatively "uncontaminated."

Table 62 shows descriptive statistics and results of t tests comparing participants who qualified experts and participants who qualified other than experts. A significant difference was found between experts and non-experts, supporting the classification. In general, participants classified as experts reported having a more positive experience than non-experts. With the exception of the first practice day, the differences in scores were significant or approached significance. These results suggest that those participants who qualified expert were having consistently better experiences throughout the practice period.

Table 62

t tests of Background Measures Between Non-Experts and Experts

	Performance classification						
	Sharpshooter or marksman			Expert			
Measure	*n*	*M*	*SD*	*n*	*M*	*SD*	*p* value
Record-fire score	15	32.73	4.94	21	46.29	5.22	<.001
Frequency of shooting outside job	15	1.67	0.90	21	2.10	0.21	.180
Years of shooting experience before joining Marines	15	1.13	1.88	21	2.90	1.05	.137
Firing line experience							
Live-fire practice Day 1	15	2.36	0.38	21	2.57	0.09	.131
Live-fire practice Day 2	15	2.33	0.45	20	2.84	0.11	.004
Live-fire practice Day 3	15	2.64	0.79	21	3.04	0.10	.069
Live-fire practice Day 4	15	2.82	0.60	21	3.25	0.11	.027
Qualification day	14	2.74	0.59	20	3.48	0.09	<.000

Table 63 shows descriptive statistics of cognitive measures and results of *t* tests comparing participants who qualified as experts and participants who qualified as other than experts. Significant differences were found between experts and non-experts on aptitude (GCT) and the basic marksmanship measure. Participants' perceived level of marksmanship knowledge is consistent with these findings, with experts reporting a higher level of understanding than non-experts. There were no significant differences between experts and non-experts on any other measures of knowledge.

An interesting result is the variation of scores for each group. Participants in the non-expert group had significantly higher variation across all measures, compared to participants in the expert group.

Table 63

t tests of Background Measures Between Non-Experts and Experts

Measure	Sharpshooter or marksman *n*	*M*	*SD*	Expert *n*	*M*	*SD*	*p* value
GCT	15	117.80	7.39	21	128.67	2.33	.002
Basic marksmanship knowledge	14	27.00	3.11	20	29.25	0.58	.029
Shot group depiction	13	2.08	0.86	20	2.05	0.22	.937
Evaluation of shooter positions	13	43.46	3.31	20	41.60	0.78	.135
Knowledge map							
Pre-classroom training	15	6.33	6.88	19	8.89	1.70	.310
Post-classroom training	14	8.21	7.49	14	9.64	1.88	.607
Live-fire practice Day 1	11	10.00	8.09	18	8.94	1.72	.719
Live-fire practice Day 3	13	9.15	8.48	16	11.13	2.08	.535
Qualification day	12	10.00	8.28	19	9.42	1.79	.845
Post-qualification	14	12.93	8.61	19	12.63	1.94	.922
Perceived level of marksmanship knowledge	15	2.77	0.42	21	3.16	0.07	.004
Perceived utility of marksmanship knowledge	15	1.39	0.37	21	1.39	0.08	1.000

Table 64 shows descriptive statistics of affective measures and results of *t* tests comparing participants who qualified experts and participants who qualified other than experts. Significant differences were on all worry measures (trait and state) and two of three state anxiety measures. Consistent with firing line experience, experts reported lower amounts of worry and anxiety than non-experts.

Table 64

t tests of Affective Measures Between Non-Experts and Experts

	Performance classification						
	Sharpshooter or marksman			Expert			
Measure	*n*	*M*	*SD*	*n*	*M*	*SD*	*p* value
Trait worry, post-qualification	14	3.39	0.59	21	3.75	0.06	.048
State worry							
Live-fire practice Day 1	15	1.89	0.37	21	1.54	0.08	.007
Live-fire practice Day 3	15	1.97	0.56	20	1.46	0.10	.005
Qualification day	14	2.04	0.65	19	1.45	0.11	.006
State anxiety							
Live-fire practice Day 1	14	2.11	0.48	21	1.91	0.11	.257
Live-fire practice Day 3	15	2.31	0.65	20	1.67	0.11	.002
Qualification day	14	2.09	0.74	19	1.64	0.14	.068

Overall, the analyses that compared non-experts to experts are consistent with the idea that there exists a cognitive component to shooting. Experts had significantly higher record-fire scores, reported more positive firing line experience, had less worry and anxiety in general, and most compellingly, scored higher on the cognitive measure of aptitude (GCT), basic marksmanship knowledge, and perceived level of marksmanship knowledge. Interestingly, there was no difference on the performance assessment measures (shot group depiction, evaluation of shooter positions, and knowledge mapping).

Sensitivity to learning. In a second set of analyses we examined whether differences existed on test scores administered before training started and after qualification. The purpose of these analyses was to gather information on whether our knowledge measures were sensitive to presumed changes in learning over the classroom and live-fire practice period. As Table 65 shows, there were significant increases in scores across all measures except the evaluation of shooter positions. In this case, the change was negative and unexpected, although the magnitude of the change was small. Additional longitudinal analyses were conducted on the knowledge mapping scores, and in general show significant and large change over the instructional period. An in-depth analysis and discussion is given in Appendix Z.

Table 65

Paired-Sample Tests of Mean Differences Between Measures Administered Before Classroom Training and After Qualification Attempt

		Posttest			Pretest			Difference		
	n	*M*	*SD*	*SE*	*M*	*SD*	*SE*	*M*	*SD*	*p* value
Basic marksmanship knowledge[a]	29	28.55	2.77	0.51	22.55	3.95	0.73	6.00	4.07	<.001
Shot group depiction[a]	32	2.06	0.95	0.17	1.69	1.03	0.18	0.38	1.04	.050
Knowledge map, post-qualification	31	12.77	8.58	1.54	7.84	7.41	1.33	4.94	8.02	.002
Evaluation of shooter positions[a]	33	42.33	3.48	0.61	43.67	3.58	0.62	-1.33	3.54	.038

[a]Post-classroom training.

Summary and Discussion of Study 3

Study 3 examined the prediction of record-fire scores with entry-level 2nd LTs. Unlike Study 1 or Study 2, the sample was officers and shooting novices overall.

Limitations. The biggest limitation of this study was that one group of participants was dropped due to presumed weather effects on their performance. A second limitation is that the results of this study may generalize only to officers (college educated in general) who are novice shooters. The skill-development theory suggests differential effects of perceptual-motor and cognitive variables depending on the experience of the individual, with cognitive variables having the most impact on performance during the learning stage and perceptual-motor variables having the most impact on performance after the learning phase.

Reliability of measures. Overall, our measures demonstrated moderate to high reliabilities. The lowest reliability was with the shot group depiction task (α = .23), similar to prior studies. The basic marksmanship knowledge measure also had a low α (.64), given the number of items. The reliability of this measure has decreased over studies; the reason behind this decline is unclear. The survey measures (e.g., affective, firing line experience) demonstrated high reliabilities, with α in the .7 to .9

range. The knowledge map measures also demonstrated high reliabilities when scores from the different expert criterion maps were used as items. α was in the low .9 range.

Predictive validity evidence. The best predictors of record-fire scores were aptitude (GCT), basic marksmanship knowledge, firing line experience, and affective measures (worry and anxiety). Firing line experience was the largest perceptual-motor predictor (r = .77), GCT the largest cognitive predictor (r = .45), and state worry the largest affective (r = .64). Incremental validity analyses indicated that within each category of variables, adding more variables contributed little to the prediction of record-fire scores. The multiple R based on these three variables was .86. These results should be interpreted with caution—the sample size was small for these analyses (n = 32).

Construct validity evidence. Consistent with Ackerman's (1987, 1992) theory of individual differences, particularly that performance during the cognitive phase is influenced by aptitude and content-relevant abilities, we found moderate positive correlations between record-fire scores and aptitude, basic marksmanship knowledge, and perceived level of marksmanship knowledge. However, incremental validity analyses showed that GCT was the best predictor and the addition of the knowledge variables contributed little to the prediction of record-fire scores.

The correlations among record-fire score, firing line experience, state anxiety, and state worry were consistent with expectations. Among the measures administered on the same day, the direction of the relationship and the large magnitudes suggest that the measures were working as intended. Firing line experience was negatively associated with state anxiety and state worry. Participants who reported more positive shooting experience also reported lower anxiety and worry. Similarly, participants who reported more anxiety also reported more worry. Trait worry was correlated significantly and moderately with firing line experience (negatively), state worry (positively), and state anxiety (positively), a result that also is consistent with expectations.

Sensitivity of measures. Evidence was found for a difference across nearly all measures when participants who qualified as expert were compared to others (i.e., sharpshooter or marksman). Expert-qualified participants had more positive firing line experiences, higher aptitude, and more marksmanship knowledge, and experienced lower worry and anxiety while shooting. Evidence was also found for the sensitivity of our knowledge of marksmanship measures to training, with the exception of ESP. Post-training scores (after classroom and live-fire practice) showed significant gains compared to pre-classroom training or pre-live-fire training.

DISCUSSION

The set of studies conducted was intended to investigate research questions related to predicting record-fire scores and in general, gathering validity evidence. The type of validity evidence gathered was (a) construct—evidence of knowledge and skill performance consistent with the skill-acquisition model; (b) predictive—the extent to which our knowledge, perceptual-motor, and affective measures predicted record-fire performance; (c) evidence of a relationship among knowledge measures; and (d) evidence of the sensitivity of knowledge measures—to instructional effects and knowledge differences. Table 66 to Table 68 summarize the empirical evidence regarding the predictability of record-fire scores, and group differences with respect to perceptual-motor, cognitive, and affective variables for shooters of different backgrounds (i.e., performance and experience).

Table 66

Correlations With Record-Fire Score by Study Across Different Types of Measures (All Correlations Significant at the .05 Level Unless Otherwise Noted)

Study	r or R	Type of measure: Perceptual-motor	Cognitive	Affective
Pilot Study 1	.62	Frequency of shooting outside duties	Whether took coaches course	
	.38	Self-reported previous year's qualification score		
	.36[§]		Knowledge map	
Pilot Study 2	.53	1. Self-reported most recent qualification score 2. Combat status of the Marine's job	1. No. of months since last Phase I training 2. Score on the basic marksmanship knowledge measure	Average of scores on the self-regulation planning and checking scales with respect to classroom learning
	.36	Self-reported previous year's qualification score		
	.29	Rated job as non-combat		
	.21		Basic marksmanship knowledge	
	-.25		No. of months since last Phase I training	

		Type of measure		
Study	r or R	Perceptual-motor	Cognitive	Affective
Study 1	.56	Most recent record-fire score	1. Basic marksmanship knowledge§ 2. Shot group depiction¶ 3. Evaluation of shooter positions§ 4. Knowledge map¶ 5. Whether took coaches course¶ 6. Perceived utility of marksmanship knowledge¶ 7. No. of months since last Phase I training§	Average of scores on the self-regulation planning and checking scales with respect to classroom learning¶
	.41	Self-reported previous year's qualification score		
	.29 .55		Basic marksmanship knowledge (entire sample), and for learner subsample (n = 17)	
	.27 .52		Shot group depiction (entire sample), and for learner subsample (n = 17)	
	.20		Evaluation of shooter positions	
	-.26		No. of months since last Phase I training	
	.22			Average of scores on the planning and checking scales with respect to classroom learning
Study 2	.52	1. Most recent record-fire score§ 2. Firing line experience (pre-qual.)	Basic marksmanship knowledge¶	Trait worry¶
	.34	Most recent record-fire score		
	.27	Frequency of shooting outside job		

		Type of measure		
Study	r or R	Perceptual-motor	Cognitive	Affective
	.26	Years of shooting experience prior to joining the USMC		
	.33	Firing line experience (pre-qual.)		
	.57	Firing line experience (qualification)		
	.26		Perceived level of marksmanship knowledge	
	-.29			Trait worry
	-.42			State worry
	-.41			State anxiety
	-.41			State anxiety
Study 3 (n = 32)	.86	Firing line experience	GCT	State worry[§]
	.77	Firing line experience		
	.45		GCT	
	.38		Basic marksmanship knowledge	
	-.38		Evaluation of shooter positions	
	.41		Perceived level of marksmanship knowledge	
	-.45			Trait worry
	-.64			State worry
	-.61			State anxiety

[§] $p < .10$. [¶] n.s.

Table 67

Group Comparisons by Experience and Performance on Perceptual-Motor, Cognitive, and Affective Measures (All Differences Are Significant at the .05 Level Unless Otherwise Noted)

	Type of measure		
Study	**Perceptual-motor**	**Cognitive**	**Affective**
Study 1		Basic marksmanship knowledge: Low performers < Others	Trait worry: Low performers > Others
Study 2	Record-fire score: Low < Others SLR < Coaches Most recent record-fire score: Low < Other SLR < Coaches Second most recent record-fire score: Low < Others SLR < Coaches Third most recent record-fire score: Low < Others SLR < Coaches Years of shooting experience before joining Marines: Low < Others Firing line experience (pre-qual.): Low < Others SLR < Coaches Firing line experience (post-qual.): Low < Others	Basic marksmanship knowledge: Low performers < Others Knowledge map: Low performers < Others SLR < Coaches Perceived level of marksmanship knowledge: Low performers < Others Shot group depiction: SLR < Coaches	State anxiety: Low performers > Others

	Type of measure		
Study	**Perceptual-motor**	**Cognitive**	**Affective**
Study 3[a] (n = 32)	Record-fire score Others < Expert-qualified Firing line experience (Live-fire practice Day 2, 3[§], 4, and qualification day): Others < Expert-qualified	GCT Others < Expert-qualified Basic marksmanship knowledge: Others < Expert-qualified Perceived level of marksmanship knowledge: Others < Expert-qualified	Trait worry: Others > Expert-qualified State worry (live-fire practice Day 1 and 3, and qualification day): Others > Expert-qualified State anxiety (live-fire practice Day 3, and qualification day[§]): Others > Expert-qualified

[a]Others = sharpshooter- and marksman-qualified

[§]$p < .10$.

Table 68

Pretest-Posttest Differences on Cognitive Measures

Study	Measure	Direction of Group Difference
Study 2	Basic marksmanship knowledge	Posttest > pretest
	Knowledge map	Posttest > pretest
Study 3 (*n* = 32)	Basic marksmanship knowledge	Posttest > pretest
	Knowledge map	Posttest > pretest
	Shot group depiction	Posttest > pretest
	Evaluation of shooter positions	Posttest < pretest

In the following sections we summarize the empirical evidence with respect to the broad research questions guiding the studies. Table 5 contains a more detailed mapping of the evidence and specific expectations.

To What Extent Can Record-Fire Scores Be Predicted?

Evidence of predictive validity was obtained via multiple regression analyses and bivariate correlations. Combining perceptual-motor, cognitive, and affective variables to predict record-fire scores for Pilot Studies 1 and 2, and Studies 1, 2, and 3, resulted in the following *R*s: .62, .53, .56, .52, and .86 (note small sample size for Study 3).

Bivariate correlations between various measures and record-fire scores were obtained in the .2 to .8 range. Perceptual-motor measures—intended to reflect experience—were consistently a good predictor of performance. The most recent record-fire score predicted record-fire score at the .3 to .4 range. The best single predictor of record-fire score was the firing line experience survey, which yielded correlation coefficients from .6 to .8. Cognitive measures (aptitude and knowledge related to marksmanship) in less experienced samples related to record-fire score in the .2 to .4 range. No relationships between record-fire score and knowledge measures were found in the more experienced sample. Affective measures (worry, anxiety) predicted record-fire scores in the -.3 to -.6 range and in general, for the affective and firing line experience measures, state measures had coefficients of higher magnitude than the trait versions.

Consistent with our expectations, there appeared to be a general difference between samples with respect to the sensitivity of our perceptual-motor and cognitive measures. Perceptual-motor measures were better predictors of performance in the more experienced sample, and cognitive measures were better predictors of performance in the less experienced sample. Worry appeared to be an important factor as well, showing up as moderate to strong negative predictors of shooting performance in Studies 2 and 3 (unfortunately, we did not use the measure in earlier studies).

The magnitude of the predictive validity of our measures was similar to prior work. The highest reported correlation was in the .8 to .9 range, and this result was part of a test-retest analysis of Army soldiers' qualification scores on the M1 rifle (McGuigan & MacCaslin, 1955). Prior shooting experience and aptitude jointly predicted record-fire scores in the .7 range (MacCaslin & McGuigan, 1956) as did rifle steadiness (Humphreys et al., 1936). Interestingly, performance on an M16A2 rifle simulator related to record-fire performance in the .5 to .7 range (Hagman, 1998; Schendel, et al., 1985; Smith & Hagman, 2000; Torre et al., 1987).

The particular finding that simple measures of firing line experience and worry can predict record-fire scores as well as performance on a rifle simulator is remarkable and of high practical utility. That is, these measures—quick to complete and simple to administer—could be used as a screening device. Marines identified as at-risk for poor performance could then be routed for early remediation training. Assessment used in conjunction with Web-based delivery could be used to identify knowledge gaps and provide online remediation—before the shooter ever reaches the firing line.

What Is the Role of Cognitive Variables in Rifle Marksmanship Performance?

Aptitude. The clearest example that aptitude matters is shown in Study 3, the only study where aptitude was available. GCT scores were a very strong predictor of shooting scores and expert-qualified participants had higher GCT scores than lower performing participants. This finding is consistent with Ackerman's model of individual differences (1987, 1992), which specifies aptitude and content-related abilities as important predictors of skill development for trainees learning a new skill.

Knowledge. Analyses of group differences by performance and by experience clearly show differences in knowledge. Basic marksmanship knowledge consistently showed correlations with record-fire scores (*r*s in the .2 to .3 range) in less experienced samples. Tests of group differences also showed coaches and high performers, compared to others, consistently scored higher on the basic marksmanship measure.

However, the unique contribution of knowledge toward the prediction of record-fire score is not nearly as strong as perceptual-motor measures (e.g., most recent record-fire score). This is consistent with expectations. We speculate the role of knowledge may be a second-order effect; that is, knowledge may be important to shooting well, but specific circumstances at the time of qualification may be the best predictor of performance. Given the extreme sensitivity of shooting to minute movements, factors that unsettle the shooter (e.g., poor weather, intimidating coach, an off day) may result in episodic performance. For example, the strongest predictors of record-fire scores were the measures that asked about participants' state at the time of qualification: how was their firing experience, and how worried or how anxious were shooters when they attempted to qualify. Trait measures of worry and firing line experience show a lower (but still significant) relationship with record-fire score, compared to state versions of the measure. Thus, it may be necessary to examine performance over time to get a more stable estimate of where trainees are in their skill development.

In Study 1 we had a sample distribution that allowed us to conduct an exploratory analysis using such an approach (i.e., categorize shooters in terms of their consistency and level of performance over time). In this case, the correlation of basic marksmanship knowledge to record-fire scores was nearly twice as large for participants classified as learners (i.e., $r = .55$, $p < .05$; participants with high standard deviations of shooting scores over time) compared to participants classified as high performers ($r = .29$, *n.s.*).

Overall, the results of these studies suggest that there exist differences in knowledge of rifle marksmanship between participants' pre-classroom training and post-classroom training, between more experienced participants and less experienced participants, between high performers and low performers, and between higher aptitude and lower aptitude. What remains unclear is how knowledge of rifle marksmanship operates to influence shooting performance. That is, how much knowledge and what kind of knowledge does a shooter need in order to practice effectively and rapidly transition from a cognitive (i.e., learning) phase to an associative (i.e., practice) phase.

What Is the Overall Quality of the Assessment Measures?

Overall, our cognitive measures predicted record-fire scores best with less experienced samples. Of all the knowledge measures, the basic marksmanship knowledge was the most consistent measure, yielding low to moderate correlations with record-fire score.

Analyses of performance on our knowledge measures by experience and by performance were consistent with expectations. Low performers scored lower on the basic marksmanship knowledge measure, and they perceived their level of marksmanship knowledge to be lower than high performers. This finding was observed in every study. In addition, in Study 2, participants who had just completed the Marksmanship Coaches Course, compared to the main SLR sample, scored higher on the knowledge map and shot group depiction tasks (the coaches were not available to take the basic marksmanship knowledge task). Finally, for participants in Studies 2 and 3 who were available for pre- and post-testing, higher scores on the posttest were observed for the basic marksmanship knowledge and knowledge mapping measures.

Low to moderate intercorrelations among the knowledge measures were observed in Studies 1 and 2. In particular, the correlations between the basic marksmanship knowledge and shot group depiction and knowledge, were higher in Study 1 (the less experienced sample) than in Study 2. However, these relationships were not observed in Study 3, the least experienced sample. In general, the correlations among the knowledge measures in Study 1 were most consistent with expectations (related but not complete overlap). Study 2 showed no correlations among the performance measures (only the basic marksmanship knowledge measure related with other measures).

Study 3 provided an interesting sample: A measure of aptitude was available and was shown to relate to knowledge mapping (pretest) and the basic marksmanship knowledge score. The pretest knowledge map scores were related significantly to the posttest knowledge map scores, but the post-classroom training knowledge map scores did not relate to the posttest knowledge map scores. This is interesting because (as discussed in Delacruz, Chung, & Bewley, 2003), many participants' initial maps reflect higher conceptual relations, only to be changed after instruction to reflect hierarchical relations (as taught in the training). In any case, the mean knowledge map scores increased over occasion. While posttest map scores were significantly higher than pretest scores, the relative ranking of participants changed over time.

Overall, we have gathered evidence that in general suggests that our knowledge measures are sensitive to instruction, and knowledge measures can predict record-fire scores moderately in less experienced samples, and when combined with other variables within the stages-of- skill-processing framework, can predict record-fire scores as well as scores from a rifle simulator.

While we expected that perceptual-motor variables would be the most important predictor of performance, the low predictive validity of our performance measures (particularly the knowledge mapping and evaluation of shooter positions tasks) was unexpected. Our review of tasks and measures with respect to the SLR curriculum and training suggests that the performance tasks may have demanded too much of participants. From a practical stance, entry-level and sustainment-level marksmanship training is limited in scope and focuses on communicating to large groups of Marines a basic level of knowledge: safety, weapons handling, positions, and the bare minimum of declarative and procedural knowledge of the fundamentals of marksmanship. Causal relations are covered briefly if at all (e.g., how movement in one part of the body affects movement in another part), and the task of identifying poor shooting positions is considered a coaching rather than a shooter function.

The idea that our performance tasks targeted too deep a level of knowledge is consistent with our findings in two ways. First, of all the knowledge-based measures, the basic marksmanship knowledge test was consistently the best predictor of record-fire score (although low to moderate). Second, in Study 2, participants who had just completed the Marksmanship Coaches Course performed significantly higher on the knowledge map and shot group depiction tasks than the main SLR sample.

Conclusion

In the series of studies on the prediction of rifle marksmanship performance we found broad evidence for the idea that rifle marksmanship—shooting performance and knowledge of rifle marksmanship—was consistent with the stages of skill acquisition framework. We found evidence of performance and knowledge differences by participants presumably in different stages of development (i.e., learning vs. practice stages), evidence that our measures were sensitive to instruction, and evidence that our measures differentiated between those who presumably know more and those who know less. We found the relative contribution of perceptual-motor measures to be good predictors of shooting performance in general, although knowledge was also predictive (but lower in magnitude) of shooting performance. We also found evidence that state worry was the highest predictor of shooting performance.

Our findings are provocative for two reasons. First, the evidence suggests that record-fire scores can be predicted with a variety of measures, as well as other forms of performance. This is particularly promising if screening or remediation will be via

ADL: ADL rules out the observation of shooting performance; thus, being able to predict shooting performance via background and knowledge measures is essential. Additionally, using knowledge measures also yields diagnostic information (i.e., what participants do not know).

Second, the general finding that less experienced shooters and lower performing shooters had less rifle marksmanship knowledge is encouraging as well. This finding is important for practical reasons. Bolstering knowledge is feasible in an ADL context. If screening is combined with diagnosis of knowledge gaps, then training replicating the content of current classroom instruction can be done using existing technology platforms and standards (e.g., SCORM).

Rifle marksmanship is a complex psychomotor skill sensitive to variations in the individual, equipment, and environment. It is unlikely that variation in the equipment and environment can be reduced much, thus leaving the individual as the only area for improvement. Prior research in other sports (e.g., tennis) suggests that improving the motor dimension involves physical practice of the skill and takes much longer to gain competency than improving the knowledge dimension associated with the skill. Given that we have found a cognitive component to rifle marksmanship performance, it may be that improving a Marine's knowledge of rifle marksmanship will have the most cost-effective payoff. What is unclear is how large the effect would be on overall shooting performance and how lasting the improvement would be.

Next Steps

A clear next step is to develop screening measures that can identify individual Marines likely to fail qualification. Given the large contribution of perceptual-motor variables to the predictability of record-fire score it may be that an efficient method to identify potential UNQs would be to develop a prediction model using individual-level data from the Marine Corps Central Master File of the Marine Corps Total Force System (MCTFS) database. This research would analyze record-fire performance with respect to the phases-of-skill-learning model that we have adopted. Potential marksmanship data to be examined include rifle, pistol, and field-firing performance. Longitudinal information is available from the MCTFS that includes marksmanship qualification history, test scores, billet history, and military and civilian education history. Potential approaches may be to develop a prediction model based on experience and capacity-to-learn variables, and test on a cross-validation sample.

Such a study would have theoretical and practical implications. With respect to theory, a longitudinal analysis should inform us on how rifle marksmanship follows the phases-of-skill-learning model. Presumably, aptitude variables should be more related to shooting for less experienced personnel, and less related to performance for more experienced personnel. High-aptitude personnel should perform higher given the same level of experience, but this difference should diminish over time. In general, shooting scores should follow the power law: rapid increase in scores initially with diminishing increases over time. The practical outcome of this research would be a way to quickly identify Marines at risk for failing to qualify. Once a Marine is identified, then diagnostic assessments could be administered, and remediation can occur via ADL-based instruction prior to the Marine reaching the firing line.

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APPENDIX A

KEY KNOWLEDGE COMPONENTS

Keywords	Knowledge	Type of Knowledge	Source/Citation
Weapons condition: Readiness for firing	Condition 1: Safety on, magazine inserted round in chamber, bolt forward, ejection port cover closed. Condition 2: Not applicable to the M16A2 rifle. Condition 3: Safety on, magazine inserted, chamber empty, bolt forward, ejection port cover closed. Condition 4: Safety on, magazine removed, chamber empty, bolt forward, ejection port cover closed.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 3 Section 3002 Page 3-1

Keywords	Knowledge	Type of Knowledge	Source/Citation
Determining a weapon's condition: Preparing a weapon for firing	• Determine if a magazine is present. • Ensure the rifle is on safe. • Conduct a chamber check. • Bring the left hand back against the magazine well. • Extend the fingers of the left hand and cover the ejection port… • Grasp the charging handle with the index and middle fingers of the right hand. • Pull the charging handle slightly to the rear and visually and physically inspect the chamber… Right-handed Marines, insert one finger of the left hand into the ejection port and feel whether a round is present. Left-handed Marines, insert the thumb of the right hand into the ejection port and feel whether a round is present. • CAUTION: Pulling the charging handle too far to the rear while inspecting the chamber may cause double feed or ejection of one round of ammunition.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3003 Page 3-1 & 3-2
	• Release the charging handle and observe the bolt going forward. • Tap the forward assist. • Close the ejection port cover (if time and the situation permit).	[Procedural Explanation]	
	• Remove the magazine (if present) and observe if ammunition is present. If time permits, count the rounds. Reinsert the magazine into magazine well.	Procedural (knowledge of subject-specific skills)	

Keywords	Knowledge	Type of Knowledge	Source/Citation
Weapons commands: Commands for loading and unloading the rifle	Six commands are used in weapons handling: Load. This command is used to take the weapon from Condition 4 to Condition 1. Make Ready. This command is used to take the weapon from Condition 3 to Condition 1. Fire. This command is used to specify when a Marine may engage targets. Cease-Fire. This command is used to specify when a Marine must stop target engagement. Unload. This command is used to take the weapon from any condition to Condition 4. Unload and Show Clear. This command is used when an observer must check the weapon to verify that no ammunition is present before the rifle is placed in Condition 4.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 3 Section 3004 Page 3-2
Loading the rifle	• Ensure the rifle is on safe. • Withdraw the magazine from the magazine pouch. • Observe the magazine to ensure it is filled. • Fully insert the magazine in the magazine well. Without releasing the magazine, tug downward on the magazine to ensure it is seated. • Close the ejection port cover. • Fasten the magazine pouch.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3004 Page 3-3

Keywords	Knowledge	Type of Knowledge	Source/Citation
Making the rifle ready	• Pull the charging handle to the rear and release. There are two methods of doing this: Grip the pistol firmly with the right hand and pull the charging handle with the left hand to its rearmost position and release… Or grip the handguards firmly with the left hand and pull the charging handle with the right hand to its rearmost position and release… • To ensure ammunition has been chambered, conduct a chamber check (see para. 3003) to ensure a round has been chambered. • Check the sights (to ensure proper battlesight zero [BZO] setting, correct rear sight aperture, etc.). • Close ejection port cover.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3004 Page 3-3
Fire: Knowing when to fire	On the command "Fire," aim the rifle, take the rifle off safe, and pull the trigger.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3004 Page 3-3
Cease fire	On the command "Cease Fire," perform the following steps: • Place your trigger finger straight along the receiver. • Place the weapon on safe.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3004 Page 3-3

Keywords	Knowledge	Type of Knowledge	Source/Citation
Unloading the rifle	• Ensure the weapon is on safe. • Remove the magazine from the rifle and retain it on your person. • Cup the left hand under the ejection port, rotate the weapon until the ejection port faces down. • Pull the charging handle to the rear and catch the round in the left hand… • Lock the bolt to the rear. • Put the weapon on safe if the selector lever would not move to safe earlier. • Ensure the chamber is empty and that no ammunition is present. • Depress the bolt catch and observe the bolt moving forward on an empty chamber… • Close the ejection port cover. • Check the sights (for proper BZO setting, correct rear sight aperture, etc.). • Place any ejected round into the magazine and return the magazine to the magazine pouch and close the magazine pouch.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3004 Page 3-3 & 3-4

Keywords	Knowledge	Type of Knowledge	Source/Citation
Unloading & showing the rifle clear	The Marine– • Ensures the weapon is on safe. • Removes the magazine from the rifle and retains it. • Cups the left hand under the ejection port, rotates the weapon until the ejection port faces down. • Pulls the charging handle to the rear and catches the round in the left hand. • Locks the bolt to the rear and ensures the chamber is empty and that no ammunition is present. • Has another Marine inspect the weapon to ensure no ammunition is present. The observer– • Visually inspects the chamber to ensure it is empty, no ammunition is present, and the magazine is removed. • Ensures the weapon is on safe. • Acknowledges the rifle is clear. The Marine, after receiving acknowledgement that the rifle is clear– • Depresses the bolt catch and observes the bolt moving forward on an empty chamber. • Closes the ejection port cover. • Checks the sights (for proper BZO setting, correct rear sight aperture, etc.). • Places any ejected round into the magazine and returns the magazine to the magazine pouch and closes the magazine pouch.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3004 Page 3-4

Keywords	Knowledge	Type of Knowledge	Source/Citation
Reloading the rifle: Condition 1 (replacing the magazine before it runs out of ammunition)	• Withdraw a filled magazine from the magazine pouch. With the same hand, press the magazine button and remove the partially filled magazine so it can be retained in the remaining fingers. • Fully insert the filled magazine into the magazine well and tug downward on the magazine to ensure it is properly seated. • Store the partially filled magazine in the magazine pouch with rounds up and projectiles pointing away from the body. • Fasten the magazine pouch.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3006 Page 3-7
Reloading the rifle: Dry reload (magazine in the weapon has been emptied and the bolt has locked to the rear)	• Press the magazine release button. • Remove the empty magazine and retain it on your person when time permits. • Fully insert a filled magazine into the magazine well and tug downward on the magazine to ensure it is properly seated. • Depress the bolt catch to allow the bolt carrier to move forward and observe the round being chambered. This places the rifle in Condition 1.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3006 Page 3-7
Remedial action	If the rifle fails to fire, a Marine performs remedial action. Remedial action is the process of investigating the cause of the stoppage, clearing the stoppage, and returning the weapon to operation. Observe for Indicators Once the rifle ceases firing, the Marine must visually or physically observe the ejection port to identify the problem before he can clear it. The steps taken to clear the weapon are based on observation of one of the following three indicators: Indicator: The bolt is forward to the ejection port cover is closed.... To return the weapon to operation-- • Seek cover if the tactical situation permits. • Tap–Tap the bottom of the magazine.	Declarative, factual (knowledge of terminology) Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 3 Section 3007 Page 3-7 & 3-8

Keywords	Knowledge	Type of Knowledge	Source/Citation
	• Rack–Pull the charging handle to the rear and release it. • Bang–Sight in and attempt to fire.		
	Indicator: Brass is obstructing chamber area (usually indicating a double feed or failure to eject)... To return the weapon to operation– • Seek cover if the tactical situation permits. • Attempt to remove the magazine. • Attempt to lock the bolt to the rear.		
	If the bolt will not lock to the rear, rotate the rifle so the ejection port is facing down; hold the charging handle to the rear as far as it will go and shake the rifle to free the round(s). If the rounds do not shake free, hold the charging handle to rear and strike the butt of the rifle on the ground or manually clear the round. Conduct and reload. Sight in and attempt to fire.		
	Indicator: The bolt is locked to the rear.... To clear return the weapon to operation– Note: Although a dry weapon is not considered a true stoppage or mechanical failure, the Marine must take action to return the weapon to operation. • Seek cover if the tactical situation permits. • Conduct a dry reload. • Sight in and attempt to fire.		
	Audible Pop or Reduced Recoil An audible pop occurs when only a portion of the propellant is ignited. It is normally identifiable by reduced recoil and is sometimes accompanied by excessive smoke escaping from the chamber area. To clear the rifle in a combat environment:	Declarative, factual (knowledge of terminology)	

Keywords	Knowledge	Type of Knowledge	Source/Citation
	• Place the rifle in Condition 4. • Move take down pin from left to right as far as it will go to allow the lower receiver to pivot. • Remove the bolt carrier group. • Inspect the bore for an obstruction from the chamber end. • Insert a cleaning rod into the bore from the muzzle end and clear the obstruction. • Reassemble the rifle. • Conduct a reload. • Sight in and attempt to fire.	Procedural (knowledge of subject-specific skills)	
Fundamentals of Marksmanship	• The fundamentals of marksmanship are aiming, breathing, and trigger control. • For rifle fire to be effective, it must be accurate. • The fundamentals of marksmanship, when applied correctly, form the basis for delivering accurate fire on enemy targets. • These skills must be developed so that they are applied instinctively.* • The fundamentals are more critical to accurate engagement as the range to the target increases.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 4 Introduction Page 4-1
Physical preparation	*To be effective in combat, the Marine must train to perfect the physical skills of shooting so those skills become second nature. Mastery of physical skills allow the Marine to concentrate on the mental aspects of target engagement; e.g., scanning for targets, detection of targets, selection and use of cover. The more physical skills that a Marine can perform automatically, the more concentration he can give to the mental side of target engagement.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 1 Section 1003 Page 1-2
Aiming Sight alignment	• Sight alignment is the relationship between the front sight post and rear sight aperture and the aiming eye.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-1

Keywords	Knowledge	Type of Knowledge	Source/Citation
Sight alignment	This relationship is the most critical to aiming and must remain consistent from shot to shot. A sight alignment error results in a misplaced shot.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-2
Insert Fig. 4-4	This error grows proportionally greater as the distance to the target increases.	[Procedural Explanation]	
Sight alignment Insert Fig.4-1	• Center the tip of the front post vertically and horizontally in the rear sight aperture. • Imagine a horizontal line drawn through the center of the rear sight aperture. The top of the front sight post will appear to touch the line. • Imagine a vertical line drawn through the center of the rear sight aperture. The line will appear to bisect the front sight post.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-1
Sight picture Insert Fig. 4-2	Sight picture is the placement of the tip of the front sight post in relation to the target while maintaining sight alignment.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-1
Sight picture Insert Fig. 4-4	Correct sight alignment but improper sight placement on the target will cause the bullet to impact the target incorrectly on the spot where the sights were aimed when the bullet exited the muzzle.	Conceptual (knowledge of principles and generalizations) [Procedural Explanation]	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-1
Sight picture Insert Fig. 4-3	To achieve correct sight picture, place the tip of the front sight post at the center of the target while maintaining sight alignment…	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-1 & 4-2

Keywords	Knowledge	Type of Knowledge	Source/Citation
Sight picture	Center mass is the correct aiming point so that point of aim/point of impact is achieved.	Declarative, factual (knowledge of terminology) [Procedural Explanation]	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-1 & 4-2
Sight picture	An error in sight picture...remains constant regardless of the distance to the target.	Declarative, factual (knowledge of specific details and elements) Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-2
Stock weld	Stock weld is the point of firm contact between the cheek and the stock of the rifle.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-2
Stock weld	The head should be as erect as possible to enable the aiming eye to look straight through the rear sight aperture..... The eye functions best in its natural forward position. Changing the placement of the cheek up or down on the stock from shot to shot may affect the zero on the rifle due to the perception of the rear sight aperture. A consistent and proper stock weld is critical to the aiming process because it provides consistency in eye relief, which affects the ability to align the sights.	Declarative, factual (knowledge of specific details and elements) Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-2

Keywords	Knowledge	Type of Knowledge	Source/Citation
Eye relief	Eye relief is the distance between the rear sight aperture and the aiming eye.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-2
Eye relief	Normal eye relief is two to six inches from the rear sight aperture. The distance between the aiming eye and the rear sight aperture depends on the size of the Marine and the firing position. While eye relief varies slightly from one position to another, it is important to have the same eye relief for all shots fired from a particular position.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-2
Eye relief	If the eye is too close to the rear sight aperture, it will be difficult to line up the front sight post in the rear sight aperture… Moving the eye back form the rear sight aperture will make the aperture appear smaller and allow the tip of the front sight post to be easily lined up inside the rear sight aperture. If the eye is too far from the rear sight aperture, it will be difficult to acquire the target and to maintain a precise aiming point.	Declarative, factual (knowledge of specific details and elements) [Procedural Explanation]	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-2 & 4-4
Acquiring and maintaining sight alignment and sight picture	For accurate shooting, it is important to focus on the tip of the front sight post.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-4
Acquiring and maintaining sight alignment and sight picture	As rifle sights become level with the aiming eye, a Marine visually locates the target through the rear sight aperture. As the rifle settles, a Marine's focus shifts back to the front sight post to place the tip of the post on the target and obtain sight alignment and sight picture. To maintain sight alignment and sight picture, the Marine's focus should shift repeatedly from the front sight post to the target until correct alignment and sight picture are obtained. This enables the detection of minute errors in sight alignment and sight picture.	Procedural (knowledge of subject-specific skills) [Procedural Explanation]	(MCRP) 3-01A Chapter 4 Section 4001 Page 4-4

Keywords	Knowledge	Type of Knowledge	Source/Citation
Breath control	Proper breath control is critical to the aiming process. Breathing causes the body to move. This movement transfers to the rifle making it impossible to maintain proper sight picture. Breath control allows the Marine to fire the rifle at the moment of least movement.	Conceptual knowledge (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 4 Section 4002 Page 4-5
Breath control during long-range or precision fire (slow fire)	It is critical that Marines interrupt their breathing at a point of natural respiratory pause before firing a long-range shot or a precision shot from any distance. A respiratory cycle lasts 4 to 5 seconds. Inhaling and exhaling each require about 2 seconds. A natural pause of 2 to 3 seconds occurs between each respiratory cycle. The pause can be extended up to 10 seconds.	Declarative factual (knowledge of terminology) Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4002 Page 4-5
Breath control during long-range or precision fire (slow fire)	During the pause, breathing muscles are relaxed and the sights settle at their natural point of aim. To minimize movement, Marines must fire the shot during the natural respiratory pause.	Conceptual knowledge (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 4 Section 4002 Page 4-5
Breath control during long-range or precision fire (slow fire)	The basic technique is as follows: • Breathe naturally until the sight picture begins to settle. • Take a slightly deeper breath. • Exhale and stop at the natural respiratory pause. • Fire the shot during the natural respiratory pause.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 4 Section 4002 Page 4-5
Trigger control	Trigger control is the skillful manipulation of the trigger that causes the rifle to fire without disturbing sight alignment or sight picture.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6

Keywords	Knowledge	Type of Knowledge	Source/Citation
Trigger control	Controlling the trigger is a mental process, while pulling the trigger is a physical process.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Grip	A firm grip is essential for effective trigger control. The grip is established before starting the application of trigger control and it is maintained through the duration of the shot.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Grip	To establish a firm grip on the rifle, position the "V" formed between the thumb and index finger on the pistol grip behind the trigger. The fingers and the thumb are placed around the pistol grip in a location that allows the trigger finger to be placed naturally on the trigger and the thumb in a position to operate the safety.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Grip	Once established, the grip should be firm enough to allow manipulation of the trigger straight to the rear without disturbing the sights.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Trigger finger placement	Correct trigger finger placement allows the trigger to be pulled straight to the rear without disturbing sight alignment.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Uninterrupted trigger control	After obtaining sight picture, the Marine applies smooth, continuous pressure rearward on the trigger until the shot is fired.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6

Keywords	Knowledge	Type of Knowledge	Source/Citation
Interrupted trigger control	Interrupted trigger control is used at any time the sight alignment is interrupted or the target is temporarily obscured.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Interrupted trigger control	To perform interrupted trigger control: • Move the trigger to the rear until an error is detected in the aiming process. • When this occurs, stop the rearward motion on the trigger, but maintain the pressure on the trigger, until sight picture is achieved. • When the sight picture settles, continue the rearward motion on the trigger until the shot is fired.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Resetting the trigger	During recovery, release the pressure on the trigger slightly to reset the trigger after the first shot is delivered (indicated by an audible click). Do not remove the finger from the trigger.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Resetting the trigger	This places the trigger in position to fire the next shot without having to reestablish trigger finger placement.	Conceptual knowledge (knowledge of principles and generalizations) [Procedural Explanation]	(MCRP) 3-01A Chapter 4 Section 4003 Page 4-6
Follow-through	Follow-through is the continued application of the fundamentals until the round has exited the barrel.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 4 Section 4004 Page 4-7

Keywords	Knowledge	Type of Knowledge	Source/Citation
Follow-through	In combat, follow-through is important to avoid altering the impact of the round by keeping the rifle as still as possible until the round exits the barrel.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4004 Page 4-7
Recovery	It is important to get the rifle sights back on the target for another shot. This is known as recovery.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 4 Section 4004 Page 4-7
Recovery	Shot recovery starts immediately after the round leaves the barrel. To recover quickly, a Marine must physically bring the sights back on target as quickly as possible.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 4 Section 4004 Page 4-7
Rifle firing positions	There are four basic firing positions: prone, sitting, kneeling, and standing.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5001 Page 5-1
Rifle firing positions	Any firing position must provide stability, mobility, and observation of the enemy.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5001 Page 5-1
Stability	A firing position must provide a stable platform for accurate and consistent shooting.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 5 Section 5001 Page 5-1

Keywords	Knowledge	Type of Knowledge	Source/Citation
Stability	If the position is solid, the front sight can be held steady and the rifle sights should recover after recoil to the same position on the target. This allows for rapid engagement of the enemy. The prone position provides the most stability for firing, while the standing position provides the least stability.	Declarative, factual (knowledge of specific details and elements) [Procedural Explanation]	(MCRP) 3-01A Chapter 5 Section 5001 Page 5-1
Types and uses of the rifle web sling	The rifle sling, when adjusted properly, provides maximum stability for the weapon, and helps hold the front sight still and reduce the effects of the rifle's recoil. Once a sling adjustment is found that provides maximum control of the weapon, the same sling adjustment should be maintained.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5001 Page 5-1
Types and uses of the rifle web sling	Varying the sling tension extensively will affect the strike of the bullet, which will make maintaining a BZO difficult. Using the same sling adjustment will ensure the accuracy of rounds on target.	Conceptual knowledge (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 5 Section 5001 Page 5-1
Types and uses of the rifle web sling	There are two basic types of rifle sling adjustments: the hasty sling and loop sling.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5001 Page 5-1
Factors common to all shooting positions	There are seven factors that are common to all shooting positions that affect the ability to hold the rifle steady, maintain sight alignment, and control the trigger.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-4
Left hand	Placement of the left hand affects placement of left elbow, eye relief, stock weld, and sling tension.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-4

Keywords	Knowledge	Type of Knowledge	Source/Citation
Hasty sling	In a hasty sling configuration, the sling is attached to the upper and lower sling swivels of the rifle.	Declarative (knowledge of terminology)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-4
Hasty sling	When the left arm is placed in the hasty sling, tension created by the sling travels from side to side. The tension created by the sling affects how the position is established.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-4
Grip of the right hand	Proper placement of the right hand high on the pistol grip allows the trigger to be moved straight to the rear without disturbing sight alignment.	Conceptual (knowledge of principles and generalizations) [Procedural Explanation]	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-6
Right elbow	The right elbow should be positioned naturally to provide balance to the position and create a pocket in the shoulder for the rifle butt.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-6
Right elbow	The exact placement of the elbow varies with each shooting position but should remain consistent from shot to shot, ensuring the resistance to recoil remains constant.	Declarative, factual (knowledge of specific details and elements) Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-6

Keywords	Knowledge	Type of Knowledge	Source/Citation
Stock weld	The placement of the shooter's cheek against the stock should remain firm and consistent from shot to shot. Consistency of stock weld is achieved through proper placement of the rifle butt in the pocket of the shoulder.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-6
Stock weld	A firm contact between the cheek and the stock enables consistent eye relief and enables the head and rifle to recoil as a single unit. Stock weld provides quick recovery between rapid fire shots, keeps the aiming eye centered in the rear sight aperture, and prevents the head from bouncing off the stock during recoil.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-6
Breathing	Breathing causes chest movement and a corresponding movement in the rifle and its sights. Applying breath control will minimize this movement and the effect it has on aiming.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-6
Muscular Tension- Hasty sling	With the hasty sling donned, the shooter must apply an amount of controlled muscular tension in the left arm to keep the sling taut and stabilize the weapon sights. Resistance against the hasty sling controls the point at which the rifle sights will settle. The muscular tension is applied outward against the sling rather than in an effort to hold the rifle up. However, muscular tension should not be excessive to cause the shooter to shake, tremble, or experience fatigue.	Declarative, factual (knowledge of specific details and elements) [Procedural Explanation]	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-6
Muscular relaxation– Loop sling	When using the loop sling, the muscles should be relaxed. Relaxation prevents undue muscle strain and reduces excessive movement. If proper relaxation is achieved, natural point of aim and sight alignment are more easily maintained.	Declarative, factual (knowledge of specific details and elements) [Procedural Explanation]	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-6 & 5-7
Elements of a good shooting position	There are three elements of a good shooting position that apply when using a loop sling: bone support, muscular relaxation, and natural point of aim.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-7

Keywords	Knowledge	Type of Knowledge	Source/Citation
Bone support	The body's skeletal structure provides a stable foundation to support the rifle's weight. A weak shooting position will not withstand a rifle's repeated recoil when firing at the sustained rate or buffeting from wind.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-7
Bone support	To attain a correct shooting position, the body's bones must support as much of the rifle's weight as possible. Proper use of the sling provides additional support. The weight of the weapon should be supported by bone rather than muscle because muscles fatigue whereas bones do not. By establishing a strong foundation for the rifle utilizing bone support, the Marine can relax as much as possible while minimizing weapon movement due to muscle tension.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-7
Muscular relaxation	Once bone support is achieved, muscles are relaxed. Muscular relaxation helps to hold the rifle steady and increase the accuracy of the aim. Muscular relaxation also permits the use of maximum bone support to create a minimum arc of movement and consistency in resistance to recoil. Muscular relaxation cannot be achieved without bone support. During the shooting process, the muscles of the body must be relaxed as much as possible. Muscles that are tense will cause excessive movement of the rifle, disturbing the aim. When proper bone support and muscular relaxation are achieved, the rifle will settle onto the aiming point, making it possible to apply trigger control and deliver a well-aimed shot.	Declarative, factual (knowledge of specific details and elements) Conceptual (knowledge of principles and generalizations) [Procedural Explanation]	(MCRP) 3-01A Chapter 5 Section 5003 Page 5-7
Natural point of aim	The point at which the rifle sights settle when in a firing position is called the natural point of aim.	Declarative (knowledge of terminology)	(MCRP) 3-01A Chapter 5 Section 5004 Page 5-7

Keywords	Knowledge	Type of Knowledge	Source/Citation
Natural point of aim	When in a shooting position with proper sight alignment, the position of the tip of the front sight post will indicate the natural point of aim. When completely relaxed, the tip of the front sight post should rest on the desired aiming point.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5004 Page 5-7
Natural point of aim	One method of checking for natural point of aim is to aim in on the target, close the eyes, take a couple of breaths, and relax as much as possible. When the eyes are opened, the tip of the front sight post should be positioned on the desired aiming point while maintaining sight alignment.	Procedural (knowledge of subject-specific skills and algorithms)	(MCRP) 3-01A Chapter 5 Section 5004 Page 5-7
Natural point of aim	In all positions, the natural point of aim can be adjusted by– • Varying the placement of the left hand in relation to the handguards. • Moving the left hand forward on the handguards to lower the muzzle of the weapon, causing the sights to settle lower on the target. • Moving the left hand back on the handguards to raise the muzzle of the weapon, causing the sights to settle higher on the target. • Varying the placement of the stock in the shoulder. • Moving the stock higher in the shoulder to lower the muzzle of the weapon, causing the sights to settle lower on the target. • Moving the stock lower in the shoulder to raise the muzzle of the weapon, causing the sights to settle higher on the target. • Natural point of aim can be adjusted right or left by adjusting body alignment in relation to the target.	Procedural (knowledge of subject-specific skills and algorithms)	(MCRP) 3-01A Chapter 5 Section 5004 Page 5-7
Prone position	The prone position provides a very steady foundation for shooting and presents a low profile for maximum concealment. However, the prone position is the least mobile of the shooting positions and may restrict a Marine's field of view for observation. In this position, the Marine's weight is evenly distributed on the elbows, providing maximum support and good stability for the rifle.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5005 Page 5-8

Keywords	Knowledge	Type of Knowledge	Source/Citation
Sitting position	There are three variations of the sitting position: crossed ankle, crossed leg, and open leg.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5006 Page 5-12
Kneeling position	The kneeling position is quick to assume and easy to maneuver from....A tripod is formed by the left foot, right foot, and right knee when the Marine assumes the position, providing a stable foundation for shooting. The kneeling position also presents a higher profile to facilitate a better field of view as compared to the prone and sitting positions.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5007 Page 5-15
Standing position	The standing position is supported by the shooter's legs and feet and provides a small area of contact with the ground. In addition, the body's center of gravity is high above the ground. Therefore, maintaining balance is critical in this position.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 5 Section 5008 Page 5-18
Effects of weather	Wind, temperature, and precipitation can affect the trajectory of the bullet. In addition, all weather conditions have a physical and psychological effect on Marines.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 8 Introduction Page 8-1

Keywords	Knowledge	Type of Knowledge	Source/Citation
Physical effects of wind on the bullet	The weather condition that presents the greatest problem to shooting is the wind. Wind affects a bullet's trajectory. The effect of wind on the bullet as it travels down range is referred to as deflection. The wind deflects the bullet laterally in its flight to the target... The bullet's exposure time to the wind determines the amount the bullet is deflected from its original trajectory. Deflection increases as the distance to the target increases. There are three factors that affect the amount of deflection of the bullet: • Velocity of the wind–The greater the velocity of the wind, the more the bullet will be deflected. • Range to the target–As the distance to the target increases, the speed of the bullet slows allowing the wind to have a greater effect on shot placement. • Velocity of the bullet–A bullet with a high muzzle velocity will not be affected by the wind as much as a bullet with a low muzzle velocity.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 8 Section 8001 Page 8-1
Determining windage adjustments to offset wind effects	The velocity and direction of the wind in relationship to the bullet must be determined to offset the wind's effects.	Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 8 Section 8001 Page 8-1
Wind direction	Determine wind direction by observing direction vegetation is moving, by feeling the wind blow against the body, or by observing direction of a flag (in training).	Procedural (knowledge of subject-specific skills and algorithms)	(MCRP) 3-01A Chapter 8 Section 8001 Page 8-1

Keywords	Knowledge	Type of Knowledge	Source/Citation
Wind value classifications	Winds are classified according to the direction from which they are blowing in relation to the direction of fire. The clock system indicates wind direction and value… Winds can be classified as half value, full value, or no value. The target is always located at 12 o'clock.	Conceptual (knowledge of classifications and categories)	(MCRP) 3-01A Chapter 8 Section 8001 Page 8-1
Wind velocity	There are two methods used to determine wind velocity : observation and flag.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 8 Section 8001 Page 8-2
Flag method	The flag method is primary method used on the KD range.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 8 Section 8001 Page 8-2
Flag method	To estimate wind velocity in miles per hour: Estimate the angle created between the flagpole and the flag in degrees. • Divide the angle by four to estimate wind velocity in miles per hour.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 8 Section 8001 Page 8-2

Keywords	Knowledge	Type of Knowledge	Source/Citation
Windage adjustments	After identifying wind direction, wind classification, and wind velocity, windage adjustments needed to enable the bullet to strike the target are estimated in the following ways: Observation Method. Using the windage chart provided in figure 8-4, match the wind velocity, wind direction, and range to the target to the information in the chart to estimate the correct number of clicks to apply to the windage knob. Flag Method. Using the windage chart provided in figure 8-5, match the wind velocity, wind direction, and range to the target to the information in the chart to determine the correct number of clicks to apply to the windage knob. Once the number of windage clicks is determined, turn the windage knob causing the rear sight aperture to move into the direction of the wind.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 8 Section 8001 Page 8-2
Wind: physical and psychological effects	The Marine can combat the wind in a number of ways: • Make subtle changes to the basic shooting positions, such as increasing muscular tension, to reduce movement of the rifle sights. • Select a more stable firing position. • Seek support to stabilize the rifle. • Hold the shot and apply the fundamentals during a lull in the wind.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 8 Section 8003 Page 8-4
Zeroing	Zeroing is adjusting the sights on the weapon to cause the shots to impact where the Marine aims.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Introduction Page 8-5

Keywords	Knowledge	Type of Knowledge	Source/Citation
Elements of zeroing	There are five basic elements involved in zeroing a rifle: line of sight, aiming point, centerline of the bore, trajectory, and range.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9001 Page 9-1
Line of sight	The line of sight is a straight line, which begins with the shooter's eye, proceeds through the center of the rear sight aperture, and passes across the tip of the front sight post to a point of aim on a target.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9001 Page 9-1
Aiming point	The aiming point is the precise point where the tip of the front sight post is placed in relationship to target.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9001 Page 9-1
Centerline of the bore	Centerline of the bore is an imaginary straight-line beginning at the chamber end of the barrel, proceeding out of the muzzle, and continuing indefinitely.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9001 Page 9-1
Trajectory	In flight, a bullet does not follow a straight line but travels in a curve or arc, called trajectory.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9001 Page 9-1
Trajectory	As the bullet exits the muzzle, it travels on an upward path, intersecting the line of sight (because the sights are above the muzzle). As the bullet travels farther, it begins to drop and intersects the line of sight again.	Declarative, factual (knowledge of specific details and elements) Conceptual (knowledge of principles and generalizations)	(MCRP) 3-01A Chapter 9 Section 9001 Page 9-1

Keywords	Knowledge	Type of Knowledge	Source/Citation
Range	Range is the KD from the rifle muzzle to the target.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9001 Page 9-2
Battlesight zero	A BZO is the elevation and windage settings required to place a single shot, or the center of a shot group, in a predesignated location on a target at 300 yards/meters, under ideal weather conditions (i.e., no wind).	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9002 Page 9-2
Zero	A zero is the elevation and windage settings required to place a single shot, or the center of a shot group, in a predesignated location on a target at a specific range, from a specific firing position, under specific weather conditions.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9002 Page 9-2
True zero	A true zero is the elevation and windage settings required to place a single shot, or the center of a shot group, in a predesignated location on a target at a specific range other than 300 yards/meters, from a specific firing position, under ideal weather conditions (i.e., no wind).	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9002 Page 9-2
M16A2 sighting system	The sighting system of the M16A2 service rifle consists of a front sight post and two rear sight apertures windage and elevation knob.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9003 Page 9-2
Front sight	The front sight post is used to adjust for elevation. The front sight consists of a square, rotating sight post with a four-position, spring-loaded detent…	Declarative, factual (knowledge of terminology) Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9003 Page 9-2

Keywords	Knowledge	Type of Knowledge	Source/Citation
Front sight	To *adjust* for elevation, use a *pointed instrument* (or the *tip of a* cartridge) to depress the detent and rotate the front sight post... To raise the strike of the bullet, rotate the post clockwise (in the direction of the arrow marked UP) or to the right. To lower the strike of the bullet, rotate the post counter-clockwise (in the opposite direction of the arrow) or to the left.	Procedural (knowledge of subject-specific skills)	(MCRP) 3-01A Chapter 9 Section 9003 Page 9-2
Rear sight	The rear sight consists of two sight apertures, a windage knob, and an elevation knob.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9003 Page 9-2
Elevation knob	The rear sight elevation knob is used to adjust the sight for a specific range to target.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9003 Page 9-2
Windage knob	The windage knob is used to adjust the strike of the round right or left.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9003 Page 9-2
Windage and elevation rules	Moving the front sight post, elevation knob or windage knob one graduation or notch is referred to as moving one "click" on the sight.	Declarative, factual (knowledge of terminology)	(MCRP) 3-01A Chapter 9 Section 9004 Page 9-3
Windage and elevation rules	The windage and elevation rules define how far the strike of the round will move on the target for each click of front and rear sight elevation or rear sight windage for each 100 yards/meters of range to the target.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9004 Page 9-3

Keywords	Knowledge	Type of Knowledge	Source/Citation
Front sight elevation rule	One click of front sight elevation adjustment will move the strike of the round on target approximately 1.25 inches for every 100 yards of range to the target or 3.5 centimeters for every 100 meters of range to the target.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9004 Page 9-3
Rear sight elevation rule	One click of rear sight elevation adjustment will move the strike of the round on the target approximately 1 inch for every 100 yards of range to the target or 2.5 centimeters for every 100 meters of range to the target.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9004 Page 9-4
Windage rules	One click of windage adjustment will move the strike of the round on the target approximately 0.5 inch for every 100 yards of range to the target or 1.25 centimeters for every 100 meters of range to the target.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9004 Page 9-4
Uniform	The wearing of full battle gear changes eye relief, placement of the rifle in the shoulder pocket, and the way the rifle is supported on the handguard. Marines must establish their BZOs while wearing the uniform and equipment they will be wearing while engaging targets.	Declarative, factual (knowledge of specific details and elements)	(MCRP) 3-01A Chapter 9 Section 9008 Page 9-6

APPENDIX B

KEY RIFLE MARKSMANSHIP FACTS

Topic	Description
Weapons handling	A Marine carries the rifle at Tactical Carry when there is no immediate threat present.
Weapons handling	Definition of remedial action Remedial action is investigating the cause of the stoppage, clearing the stoppage, and returning the weapon to operation.
Weapons handling: Weapon condition	Different weapons conditions (could be graphic) CONDITION 1: Magazine inserted, round in chamber, bold forward, safety on, ejection port cover closed CONDITION 2: Not Applicable CONDITION 3: Magazine inserted, chamber empty, bolt forward, safety on, ejection port cover closed CONDITION 4: Magazine removed, chamber empty, bold forward, safety on, ejection port cover closed
Weapons handling: Remedial Action	Three indicators of remedial action and their corresponding actions (1)Bolt is forward or ejection port cover is closed. ACTION Tap, rack, bang (2)Bolt is locked to the rear. ACTION Conduct a dry reload, (3)Brass is obstructing chamber area (usually indicates double feed or failure to eject) ACTION Remove magazine. Lock bolt to rear. Shake rounds out. Conduct a reload.
Weapons handling: Rifle transfer	Two procedures to use to transfer a rifle from one Marine to another Clear transfer Condition Unknown Transfer
Weapons handling: Safety Rules	Four safety rules that most strongly enforce muzzle awareness. Treat every weapon as if it were loaded. Never point a weapon at anything you do not intend to shoot. Keep your finger straight and off the trigger until you are ready to fire. Keep the weapon on safe until you intend to fire.
Fundamentals of Marksmanship	The three fundamentals of marksmanship Aim Breathing Control Trigger control
Fundamentals of Marksmanship: Aiming	Obtaining a natural point of aim Align sights, breathe in, close your eyes, exhale, and open your eyes.
Fundamentals of Marksmanship: Aiming	Achieving a correct sight picture. Place the tip of the front sight post at the center of the target while maintaining sight alignment.
Fundamentals of Marksmanship: Aiming	Definition of center mass. The correct aiming point so that point of aim/point of impact is achieved.

Topic	Description
Fundamentals of Marksmanship: Aiming	Where the shooter's main point of focus should be when he/she fires a shot Center mass or center of target
Fundamentals of Marksmanship: Breath control	The technique for breath control is as follows: Breathe naturally until the sight picture begins to settle. Take a slightly deeper breath Exhale and extend your natural respiratory pause Stop breathing at your point of NRP before firing a long-range shot
Fundamentals of Marksmanship: Trigger control	Definition of uninterrupted Trigger Control. Definition of interrupted Trigger Control Uninterrupted Trigger Control: After the initial slack of the trigger is taken up, the trigger is pulled with a single, smooth motion straight to the rear with no interruption Interrupted Trigger Control: After the initial slack is taken up, the trigger is moved to the read unless an error is detected in the aiming process. When this occurs, rearward motion is topped until sight picture is achieved. Then the rearward motion continues until the shot breaks.
Fundamentals of Marksmanship: Trigger Control	Use of interrupted trigger control In extremely windy conditions when the weapon will not settle, forcing the Marine to pause until the sights return to his aiming point.
Fundamentals of Marksmanship: Trigger Control	Uninterrupted trigger control is the preferred method in a combat environment
Fundamentals of Marksmanship: Trigger Control	Definition of a follow-through The continued applications of the fundamentals until the round has exited the barrel.
Rifle firing positions: Stability	The most stable position is the prone position. The least stable position is the standing position
Rifle firing positions: Mobility	The least mobile of the shooting positions Prone
Rifle firing positions: Observation of the enemy	The best firing position that normally provides the best field of view is standing
Rifle firing positions: Types and uses of Rifle web sling	The two basic types of rifle sling adjustments Hasty Sling and Loop Sling
Rifle firing positions: Types and uses of Rifle web sling	If body alignment is correct, the weapon's recoil is absorbed by the whole body

Topic	Description
Rifle firing positions: Types and uses of Rifle web sling	The rifle sling provides maximum stability for the weapon and helps stabilize the front sight and reduce the effects of the rifle's recoil.
Rifle firing positions: Elements of a good shooting position	Three elements of a good shooting position. Bone support Muscular Relaxation Natural Point of Aim
Rifle firing positions: Elements of a good shooting position	Seven factors that are common to all shooting positions as they apply with the Hasty Sling Left hand Rifle Butt in the Pocket of the Shoulder Grip of the Right Hand Right Elbow Stock Weld Breathing Muscular Tension
Rifle firing positions: Elements of a good shooting position	In the kneeling position, a <u>right-handed</u> shooter should have his/her <u>right</u> elbow supported.
Effects of weather: On marines	Weather factors that affect the shooter Wind Temperature Precipitation
Effects of weather: On the bullet	Wind affect the bullet's trajectory laterally
Zeroing: Elements of zeroing	Five basic elements involved in zeroing the rifle Line of sight Point of aim Centerline of the bore Trajectory Range
Zeroing: Types of zeros Battlesight Zero	A BZO is the elevation and windage setting that is used in combat to engage point targets from 0-300 yards/meters under now wind conditions.
Zeroing: Battlesight Zero	Factors that affect the accuracy of a BZO Forward hand, grip, right elbow, stock weld, rifle butt in the pocket of the shoulder, relaxation, breathing Sling tension, trigger control, slight picture

Topic	Description
Zeroing: Reconfirmation of BZO	Some factors that cause a BZO to be reconfirmed. Rifle maintenance, temperature, climate, ground elevation, and uniform
Zeroing: Sight alignment	Front sight is used to adjust for elevation
Zeroing: Sight alignment	The direction to rotate the front sight post in order to move the strike of the round up. And down. To move it up, move it right (or clockwise) To move it down, move it left (or counterclockwise)
Zeroing: Sight alignment	During the zeroing process, all elevation adjustments should be made on the front sight post
Zeroing: Sight alignment	The direction to turn the rear sight windage knob in order to move the strike of the round to the right. To the right or clockwise
Zeroing: Sight alignment	The rear sight elevation should be set on 8/3 - 2 when firing at the 200-yd line
Engagement techniques: Target indicators	Three target indicators Movement Sound Improper Camouflage

APPENDIX C

KEY RIFLE MARKSMANSHIP CAUSE-EFFECT RELATIONS

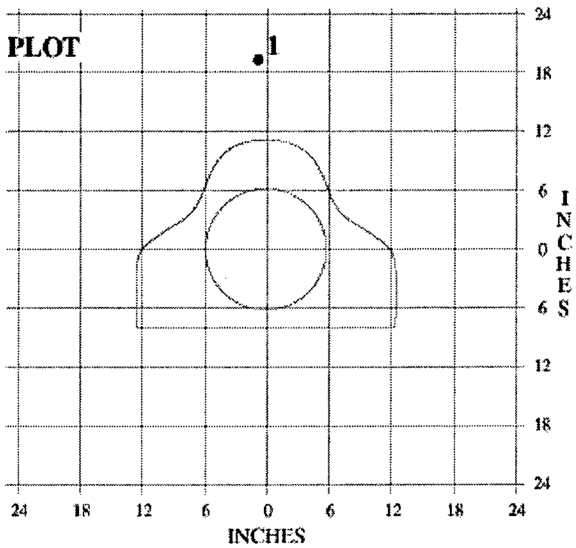
Fundamental	Impacts	Explanation
Stock weld	Sight picture and alignment	Maintains an erect head position, which places the eye in its natural forward position, enabling the aiming eye to look straight through the rear sight picture. If the position of the Marine's head causes him to look across the bridge of his nose or out from under his eyebrow, the eye will be strained.
Varying the stock weld placement	Perception of the rear sight aperture	Changes eye relief
Eye relief (eye is too close to the rear sight aperture)	Sight picture and alignment	Makes it difficult to line up the front sight post if the eye is too close to the rear sight aperture.
Eye relief (eye is too far from the rear sight aperture)	Sight picture and alignment	Makes it difficult to acquire the target and to maintain a precise aiming point.
Focus of eye on front sight post	Sight picture and alignment	Enables detection of minute errors in sight alignment and sight picture. Marine's focus should shift repeatedly from the front sight post to the target until correct sight alignment and sight picture are obtained.
Focus of eye on front sight post when shot is fired	Sight alignment	Distorts the image when staring at the front sight post for longer than a few seconds, making it difficult to detect minute errors in sight alignment.
Increasing distance to the target	Ability to aim at center of mass and maintain a center mass sight picture	Front sight post covers more of the target making it difficult to establish a center of mass.
Looking at the target	Impact of shots	Lowers the tip of the front sight post, which causes shots to impact low or miss the target completely.
Breath control	Sight picture	Allows the Marine to fire the rifle at the moment of least movement since breathing causes the body to move which transfers to the rifle, making it impossible to maintain proper sight picture
Trigger control (firm grip)	Sights	If it is firm enough, it should allow manipulation of the trigger without disturbing the sights.
Trigger control (finger placement)	Sight alignment	If the trigger finger contacts the trigger naturally, it should allow the trigger to be pulled straight to the rear without disturbing sight alignment
Follow-through	Impact of the round	Keeps rifle as still as possible until round exits the barrel.

Fundamental	Impacts	Explanation
Stable firing position	Sights	Front sight can be held steady and the rifle sights should recover after recoil to the same position on the target.
Mobile firing position	Engagement	Standing allows the most lateral movement for engagement of widely dispersed targets.
Rifle sling	Sight alignment and rifle recoil	Provides maximum stability for the weapon, which reduces the effects of rifle recoil and offers resistance against the sling, which enables the rifle sights to be held steady.
Varying of sling tension	BZO	Changes the strike of the bullet.
Controlled muscle tension of hasty sling	Sights	Offers resistance against the sling, keeping sights steady.
Forward hand placement	Stability of rifle	A straight and locked forward hand's wrist creates resistance on the sling close to the muzzle, stabilizing the rifle. If the rifle rests across the palm of the hand, the only resistance created is where the sling meets the triceps. Resistance is further from the muzzle, making stabilizing the rifle more difficult.
Excessively tightened loop sling	Rifle sights	Restricting blood flow causes an excessive pulse beat to be transmitted through the rifle sling to the rifle, and causes a rhythmic movement of the rifle sights.
Tension on the rifle sling	Rifle recoil	Causes the rifle butt to be forced rearward into the pocket of the shoulder, keeping butt plate in the shoulder pocket during recoil.
Bone support	Weapon movement	Provides a stable foundation to support the rifle's weight because muscles fatigue whereas bones do not.
Muscular relaxation	Accuracy of aim	Creates a minimum arc of movement and consistency in resistance to recoil by permitting the use of maximum bone support. Tense muscles cause excessive movement of the rifle, which disturbs aim.
Velocity of wind	Deflection of the bullet	The greater the velocity of the wind, the more the bullet will be deflected.
Rifle chamber's pressure (cold weather)	Point of aim	In cold weather, the rifle chamber's pressure decreases, which causes the bullet to exit the muzzle at a lower velocity, which impacts the target below the point of aim.
Rifle chamber's pressure (extreme heat)	Point of aim	In extreme heat, the rifle chamber's pressure increases, which causes the bullet to exit the muzzle at a higher velocity, which impacts the target above the point of aim.

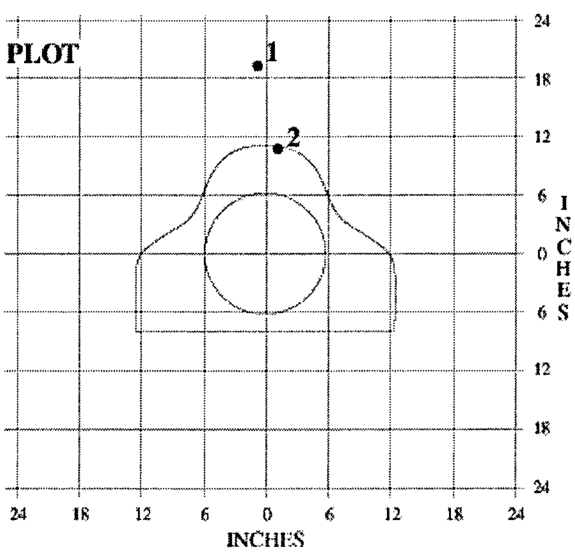
Fundamental	Impacts	Explanation
Rapid fatigue	Sight alignment	Rapid fatigue causes muscle cramps, heat exhaustion, heat stroke, blurred vision, and reduced concentration, which results in inaccurate shooting.
Sweat running into the eyes	Sights	Sweat running into the eyes can cause irritation, which makes it difficult to see the sights.
Heat waves or mirages	Sights	Distorts the target shape or the appearance of the front sight post, reducing the Marine's ability to see the sight clearly.
Extreme cold	Trigger control	If hands are numb, the Marine will have difficulty holding a rifle and executing effective trigger control.
Precipitation	Sight alignment and picture	When it collects on rear sight aperture, it can make it difficult to establish sight alignment and sight picture.
Bright light	Appearance of a target	Makes a target appear smaller and farther away.
Overcast	Appearance of a target	Makes the target appear larger and closer.
Haze	Sight picture	Makes a target appear indistinct.
Temperature	BZO	Causes chamber pressure to increase or decrease, causing the shots to impact the target high or low (respectively).
Climate	BZO	Changes air density, moisture content, temperature or barometric pressure.
Ammunition	BZO	Inconsistencies in the production of ammunition affects BZO.
Ground elevation	BZO	Creates changes in air density, moisture content, temperature, or barometric pressure.
Uniform	BZO	Changes eye relief, placement of the rifle in the shoulder pocket, and the way the rifle is supported on the handguard.

APPENDIX D

SHOT-TO-SHOT EXPLANATION TASK EXAMPLE (PILOT STUDY 1)



- [ ] Increased wind velocity.
- [ ] Decreased wind velocity.
- [ ] Wind is blowing from the left but inadequate sight adjustments were made to compensate.
- [ ] Wind is blowing from the right but inadequate sight adjustments were made to compensate.
- [ ] Not executing proper follow-through.
- [ ] Moved forward hand forward on the handguard, while firing.
- [x] Moved forward hand backward on the handguard, while firing.
- [x] Improper breathing control.
- [x] Did not attain natural point if aim.
- [x] Moved the buttstock placement lower on the shoulder, while firing.
- [ ] Moved the buttstock placement higher on the shoulder, while firing.
- [ ] Moved forward elbow forward on the knee, while firing.
- [ ] Moved forward elbow back on the knee, while firing.
- [ ] Flinched when the shot was fired.
- [ ] Bucked the rifle.
- [ ] Jerked the trigger.
- [x] Improper sight alignment.
- [x] Improper sight settings.
- [ ] Position slipping.
- [ ] Opened stance in standing position.
- [ ] Closed stance in standing position.



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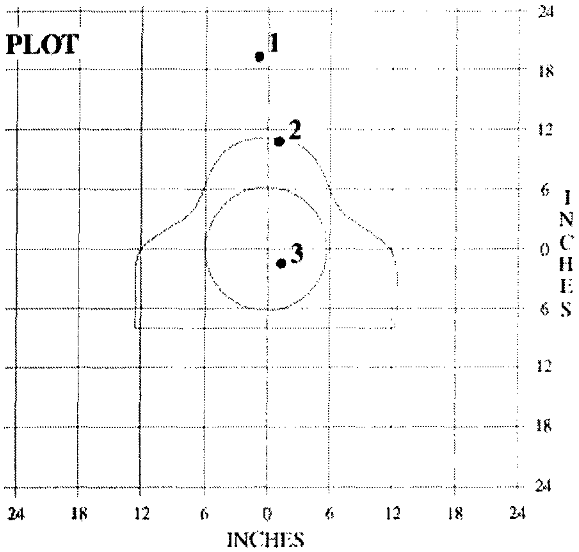

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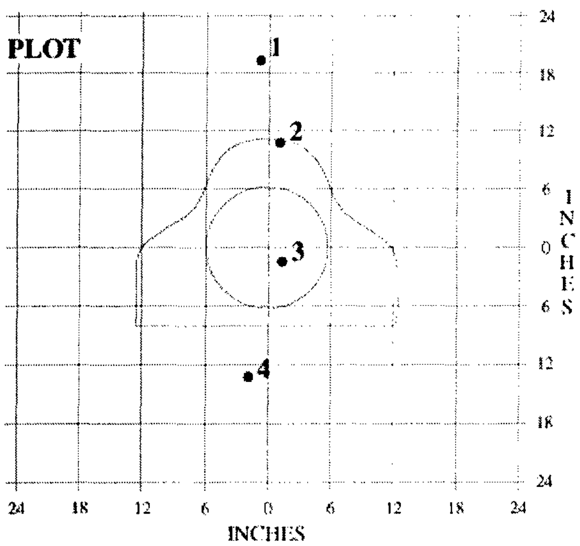

- [ ] Increased wind velocity.
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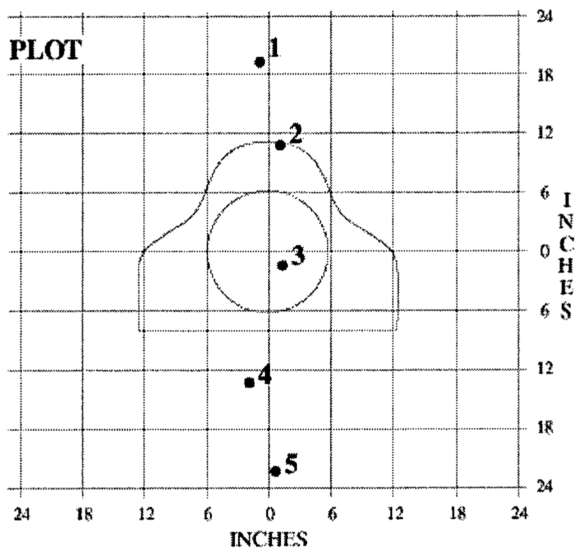

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- [ ] Improper sight settings.
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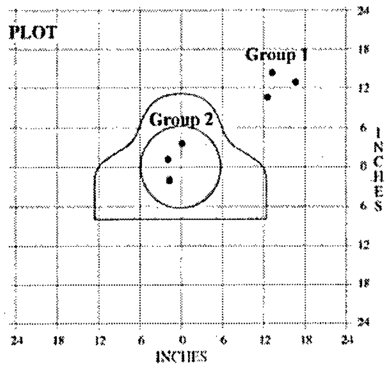
APPENDIX E

SHOT GROUP PATTERN ANALYSIS TASK (PILOT STUDY 1)



1. Look at the difference between shot **group 1** and shot **group 2**. What are the most likely adjustment(s) the shooter made between the two groups? Please explain your answer.

Adjustment(s):

Explanation:

2. Look at shot **group 2** above.
Does this shot group show

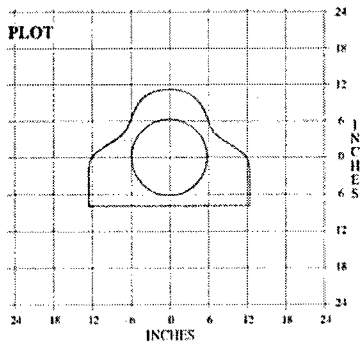
a) proper marksmanship fundamentals? ☐ Yes ☐ No
Why / Why not?

b) correct sight adjustment? ☐ Yes ☐ No
Why / Why not?

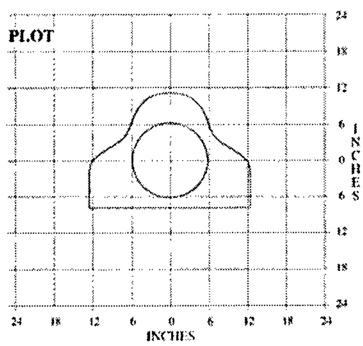
APPENDIX F

SHOT GROUP DEPICTION TASK (PILOT STUDY 1)

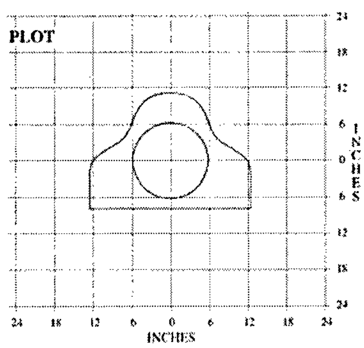
INSTRUCTIONS
Read each condition below. On the target grid to the left, **plot five bullets** that reflects the condition at 300 yards in the kneeling position. Number each shot to show the shot sequence.



Condition 1: Breathing problem (does not fire during the natural respiratory pause)



Condition 2: Bucks the rifle



Condition 3: Jerks the trigger

APPENDIX G

MAPPING BETWEEN SUSTAINMENT-LEVEL (SLR) AND ENTRY-LEVEL (ELR) RIFLE MARKSMANSHIP SCORES

Expert		Sharpshooter		Marksman		Unqualified	
SLR	ELR	SLR	ELR	SLR	ELR	SLR	ELR
65	250	39	218	34	208	24	183
64	248	38	216	33	206	23	176
63	247	37	214	32	204	22	169
62	246	36	212	31	202	21	162
61	245	35	210	30	200	20	155
60	244			29	198	19	148
59	242			28	196	18	141
58	241			27	194	17	134
57	240			26	192	16	127
56	239			25	190	15	120
55	238					14	113
54	236					13	106
53	235					12	99
52	234					11	92
51	233					10	85
50	232					9	78
49	230					8	71
48	229					7	64
47	228					6	57
46	227					5	50
45	226					4	43
44	224					3	36
43	223					2	28
42	222					1	22
41	221						
40	220						

APPENDIX H

AUTOMATED SCORING FOR SHOT GROUP ANALYSIS TASK

(PILOT STUDY 2)

Data from 113 students were collected for five different errors having to do with Breathing, Target Focus, Flinching, Bucking, and Sight Adjustment. Student records were scored dynamically, on the fly, and the results were compared with human grading. The final results are listed below:

Table I1

Percent Agreement Between Human Rater and Automated Scoring System (*N* = 113)

Type	Percent
Breathing	91.2
Target Focus	88.5
Flinching	96.5
Bucking	94.7
Sight Adjustment	88.5

In order to score student records on the fly, various statistical measures of the shot groups were taken into account including the center of mass of the shot group and its distance from the center (0,0) as well as the shot group's orientation, maximum and minimum (highest and lowest shots and the horizontal and vertical ranges), the mean radius, area of dispersion, and finally the standard deviation.

These measures were then compared with expert maps and scores were calculated. There are two factors that play a vital role in dynamic scoring: statistical measures and criteria applied in order to compare student maps with the experts. On the other hand, in human grading, the grader uses his or her general knowledge and understanding of the problems as well as his or her experience in the field.

One factor that may contribute to the slightly different results is the expert map in the case of dynamic scoring, which puts more restrictions in terms of the location (coordinates) of each shot to be acceptable. The effect of the expert map is bigger in more complicated shot patterns like the Target Focus and Sight Adjustment Problems (10.6%) compared to more straightforward cases like Bucking (5.3%) and Flinching (3.5%). In the case of human grading, there is no particular expert map to follow. Another factor is specific criteria that the algorithm has to follow in scoring on the fly, and how close this criterion is to the vision of an expert who does the grading.

Shot Group Analyses Scoring Methodology

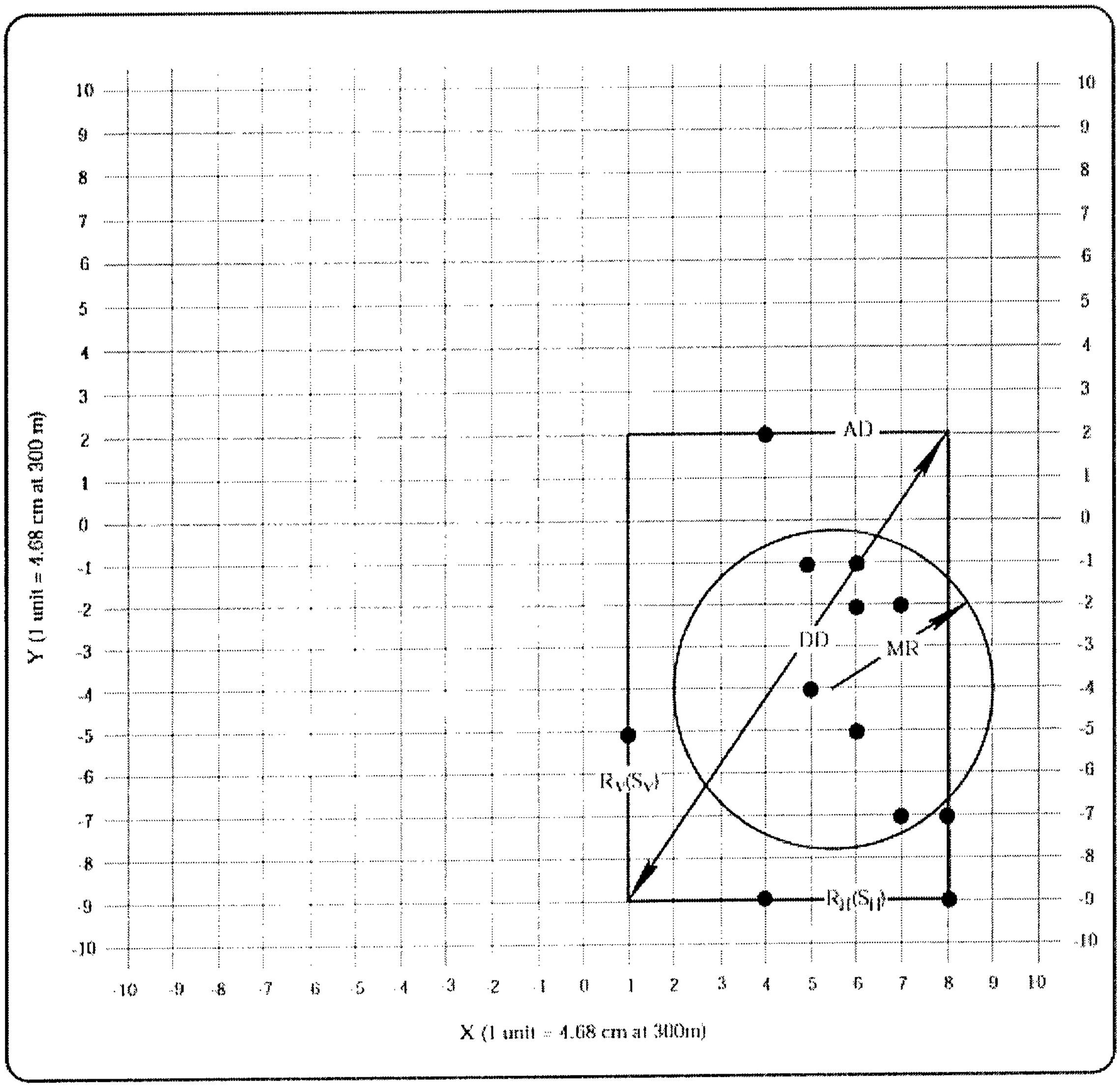


Figure I1. Shot group measures.

Measures

Center of the shot group (CSG)

$$\text{CSG} = (\bar{x}, \bar{y}) = \left(\frac{\sum x_i}{n}, \frac{\sum y_i}{n} \right)$$

CSG is the center of mass (CM) of the shot group. CSG must be calculated for both the expert and the student.

Constant Error

This is the distance between the two centers of mass (student and expert). It is better known as the "Constant Error."

$$\mathrm{DCM_{SG}} = \sqrt{(\overline{x_s} - \overline{x_e})^2 + (\overline{y_s} - \overline{y_e})^2}$$

For the purpose of this report, a shot group may be considered functionally accurate if the constant error, $\mathrm{DCM_{SG}}$ is less than or equal to 6.

Shooting Error

The average of the separate straight lines between each student's shot and the CM of the expert shots.

$$\mathrm{DCM_S} = \frac{\sum \sqrt{\left(x_i - x_{CM\,\mathrm{expert}}\right)^2 + \left(y_i - y_{CM\,\mathrm{expert}}\right)^2}}{n}$$

$\mathrm{DCM_S}$ is a useful measure of marksmanship accuracy because it gives information on whether each shot actually comes close to the center of the target.

Precision, The mean Radius: (Fig. 1)

$$\mathrm{MR} = \frac{\sum \sqrt{\left(x_i - \overline{x}\right)^2 + \left(y_i - \overline{y}\right)^2}}{n}$$

Refers to the average of the distances between the CSG and each shot. MR gives the shooter important information about the overall shot group tightness. Shot group tightness is a popular term for marksmanship precision and is the magnitude of dispersion of a group of shots.

In scoring, we have to compare:

$$\mathrm{MR_{Student}} \Leftrightarrow \mathrm{MR_{expert}}$$

the max permissible value for $|\ \mathrm{MR_{Student}} - \mathrm{MR_{expert}}\ | \leq 6$.

Area of Dispersion (AD) and Diagonal of Dispersion (DD) (see Figure I1)

$$AD = (x_{Max} - x_{Min})(y_{Max} - y_{Min})$$

$$DD = \sqrt{(x_{Max} - x_{Min})^2 + (y_{Max} - y_{Min})^2}$$

For each expert and student these parameters are calculated and compared.

$$AD_{student} \Leftrightarrow AD_{expert}$$

$$DD_{student} \Leftrightarrow DD_{expert}$$

Standard deviation:

a) Horizontal Component, S_H

$$S_H = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

b) Vertical Component, S_V

$$S_V = \sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}}$$

c) Radial Component, S_R

$$S_R = \sqrt{(S_H)^2 + (S_V)^2}$$

Standard deviation is a very efficient measure of variable error.

Scoring Criteria for Shot-Group Task

Breathing problem (does not fire during the natural respiratory pause).

The following conditions must be satisfied:

1- Shots should be vertically lined up around the center line x = 0 with (±1 unit) away.

2- $AD_{student}$ vs AD_{expert} should be comparable ($1- \frac{AD_{student}}{AD_{expert}} \leq 25$)

3- Highs AND lows of the student and expert shots should not be more than 1 unit.

Bucking the rifle:

1- All shots must be located at the third quarter.

2- Shots must be close together so that $AD_{student}$ vs AD_{expert} should be comparable ($1- \frac{AD_{student}}{AD_{expert}} \leq 25$)

Flinching:

1- All shots must be located at the first quarter.

Not focusing on front sight tip:

1- All shots must be well distributed around the center of the target (0,0)

2- $MR_{Student}$ vs MR_{expert} must be comparable.

3- Shots must be close together so that $AD_{student}$ vs AD_{expert} should be comparable ($1- \frac{AD_{student}}{AD_{expert}} \leq 25$)

Sight adjustment:

1- With the wind blowing from the right, all the shots must appear in the far left from the center, around the line y = 0.

2- The shots must be as close as possible so the $AD_{student}$ vs AD_{expert} should be comparable ($1- \frac{AD_{student}}{AD_{expert}} \leq 25$).

Data File Format

Column	Description
B	Xs=Xmax Xmax of the shooter shots
C	Xe=Xmax Xmax of the expert shots
D	ratio of column B / column C
E	Xs=Xmin Xmin of the shooter shots
F	Xe=Xmax Xmin of the expert shots
G	ratio of column E / column F
H-M repeats the same for the Y	
N	RHs refers to the Horizontal range for the shooter
O	RHe refers to the Horizontal range for the expert
P	ratio of Column N/Column O
Q-S repeats the same for the vertical ranges	
T	ADs is the area covered by the shooter shots
U	ADe is the area covered by the expert shots
V	ratio of Column T/Column U
W	Xbar-s is the X coordinate of the center of mass for the shooter shots
X	Xbar-e is the X coordinate of the center of mass for the expert shots
Y	ratio of Column W/Column X
Z-AB repeats the same for the Y coordinates	
AC	MRs is the mean Radius of the shooter shots
AD	MRe is the mean Radius of the expert shots
AE	ratio of Column AC/Column AD
AF	dsFromCenter refers to the distance from the center of mass to point(0,0) of the shooter shots
AG	deFromCenter refers to the distance from the center of mass to point(0,0) of the expert shots
AH	ratio of column AF / column AG
AI	alphaS is the angle between horizontal line (where y=0 and x>0) and the line from the center of mass and (0,0) for the shooter.
AJ	alphaE is the angle between horizontal line (where y=0 and x>0) and the

	line from the center of mass and (0,0) for the expert.
AK	ratio of Column AI/Column AJ
AL	StandardDev_Horizontal
AM	StandardDev_Vertical
AN	StandardDev_Radial
AO	Scores
AP	Details

Note.

1. *s* means the shooter or the student, and *e* means the expert.

2. With the pair (dsFromCenter, alphaS) you can find the exact orientation of the center of mass with respect to where the quarter is located. This information is particularly important for scoring Sight Adjustment and Flinching.

APPENDIX I

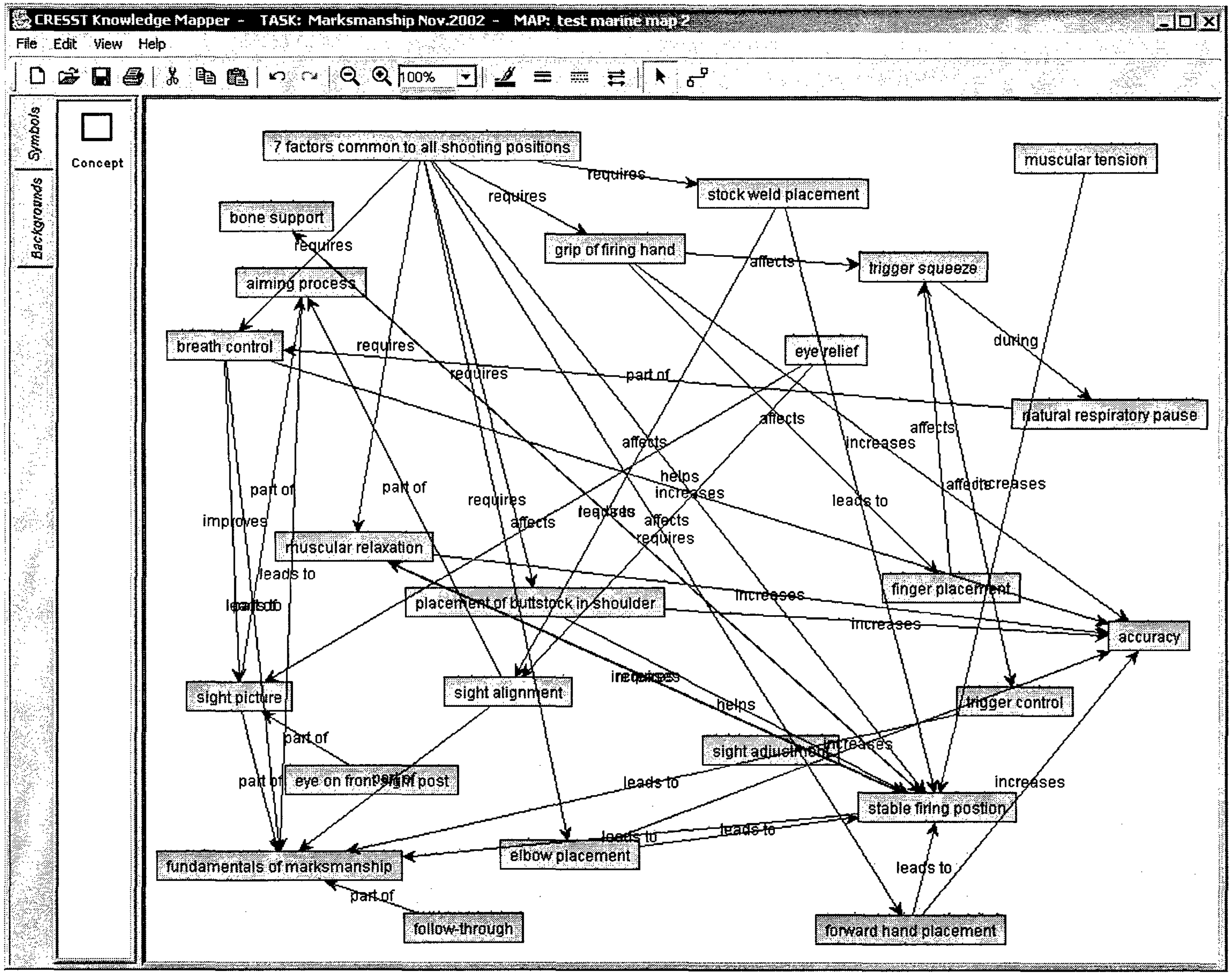
SHOT GROUP TASK SCORING RUBRIC

(PILOT STUDY 2)

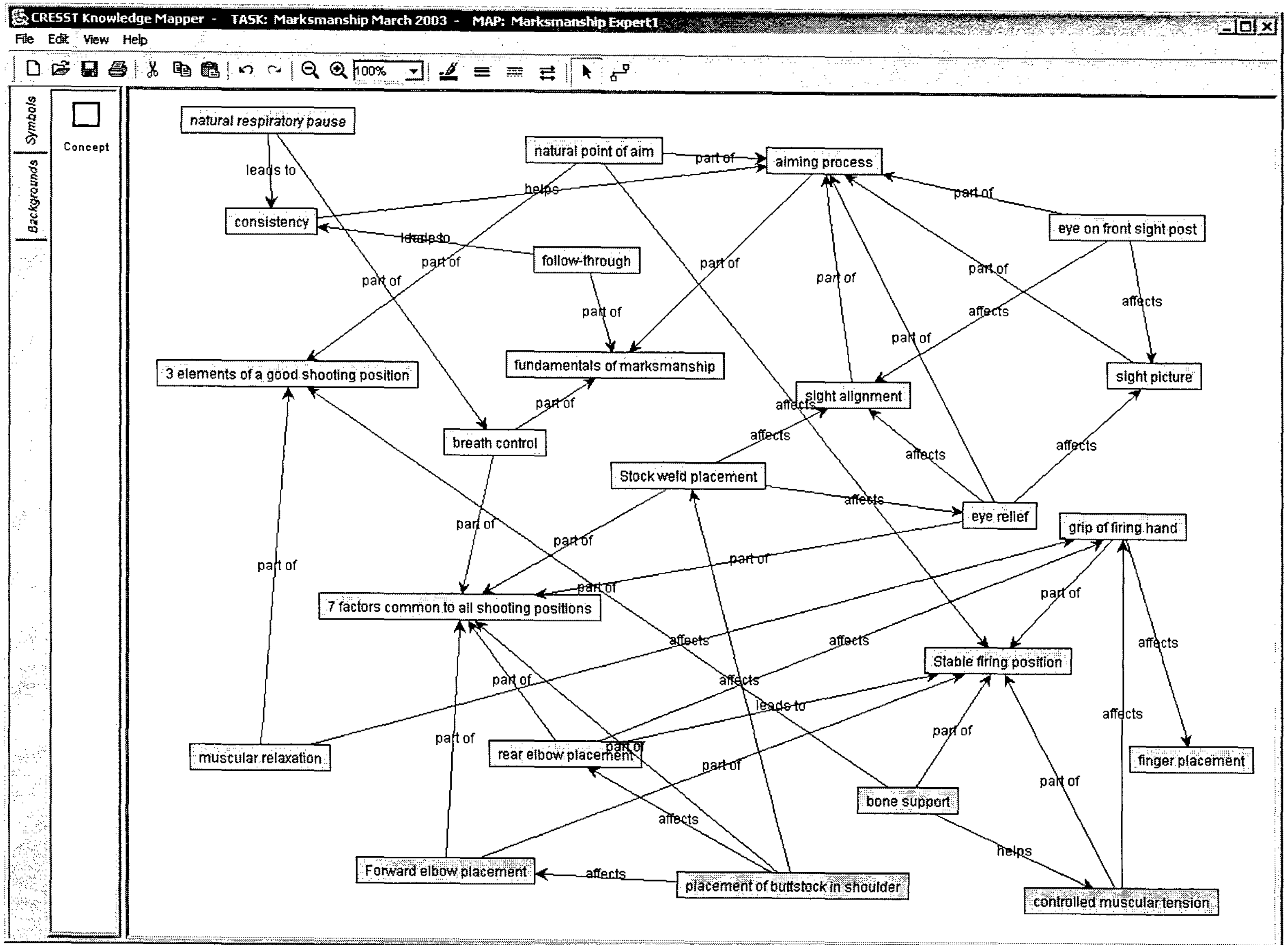
Shooter problem	Score	Criteria
Breathing	1	If ≥ 4 shots are within the middle two columns in a vertical pattern
	0	If shot pattern does not follow the "1" pattern
Flinching	1	If ≥ 4 shots fall in the upper right quadrant
	0	If shot pattern does not follow the "1" pattern
Focus on Target	1	If shots form a circular pattern around the target
	0	If shot pattern does not follow the "1" pattern
Bucking	1	If ≥ 4 shots fall in the lower left quadrant
	0	If shot pattern does not follow the "1" pattern
Sight Adjustment	1	If ≥ 4 shots fall clustered to the left of the target, within the two middle rows
	0	If shot pattern does not follow the "1" pattern

APPENDIX J

CRITERION KNOWLEDGE MAPS FOR MARKSMANSHIP (SCREEN SHOTS)

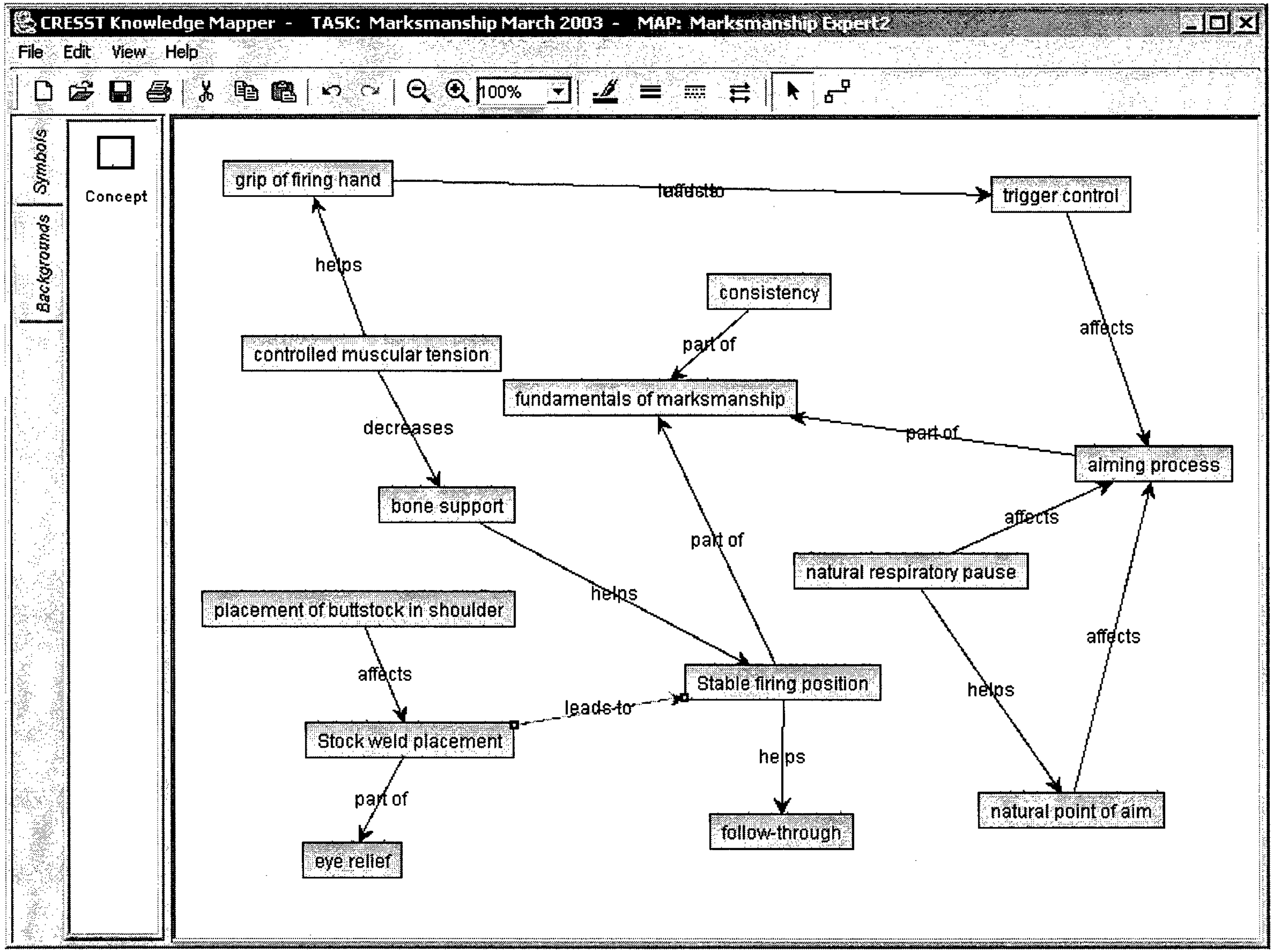


Expert map for scoring in Nov./Dec. 2002 **Expert A**

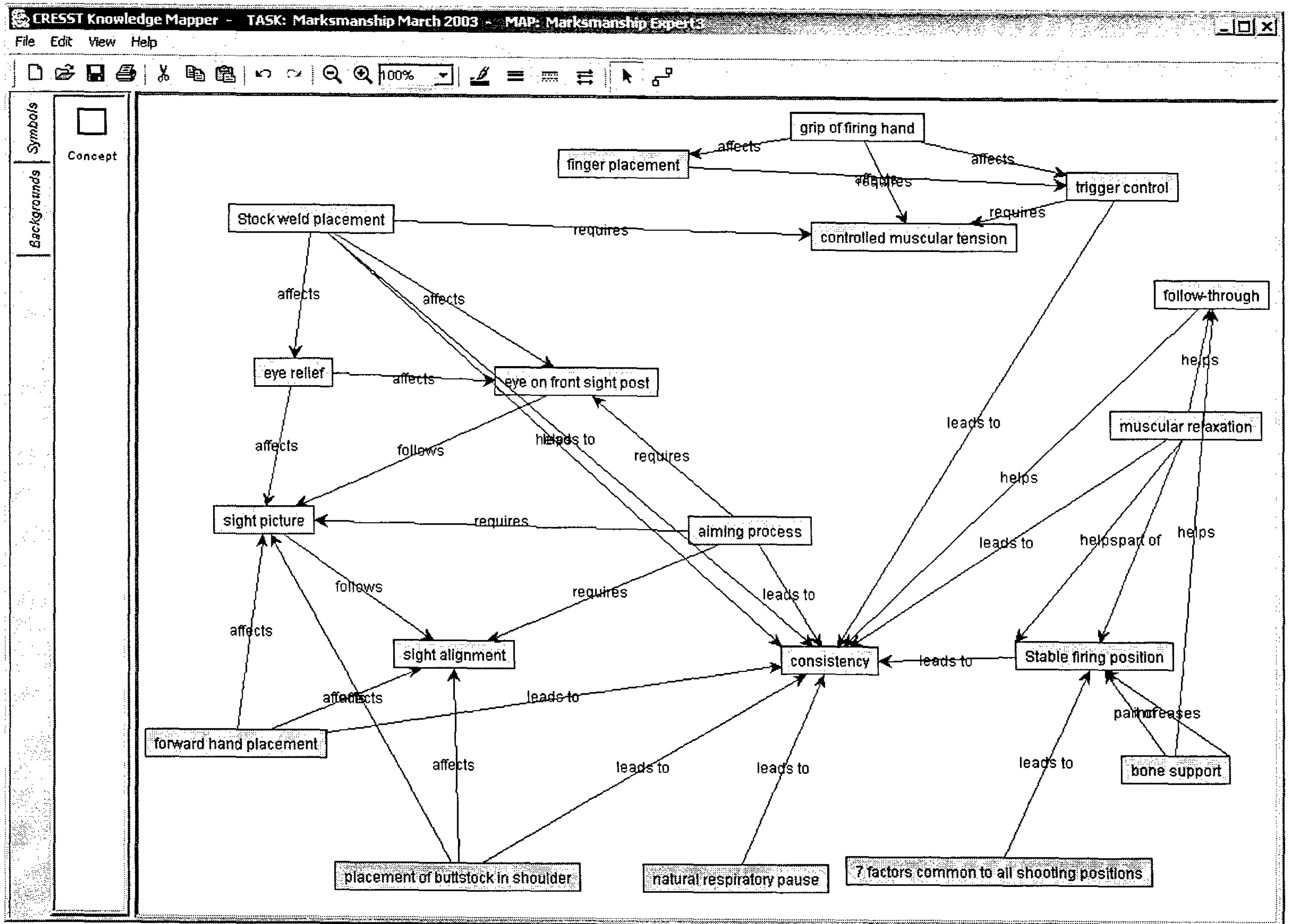


Expert map for scoring in March/May 2003

Expert 1

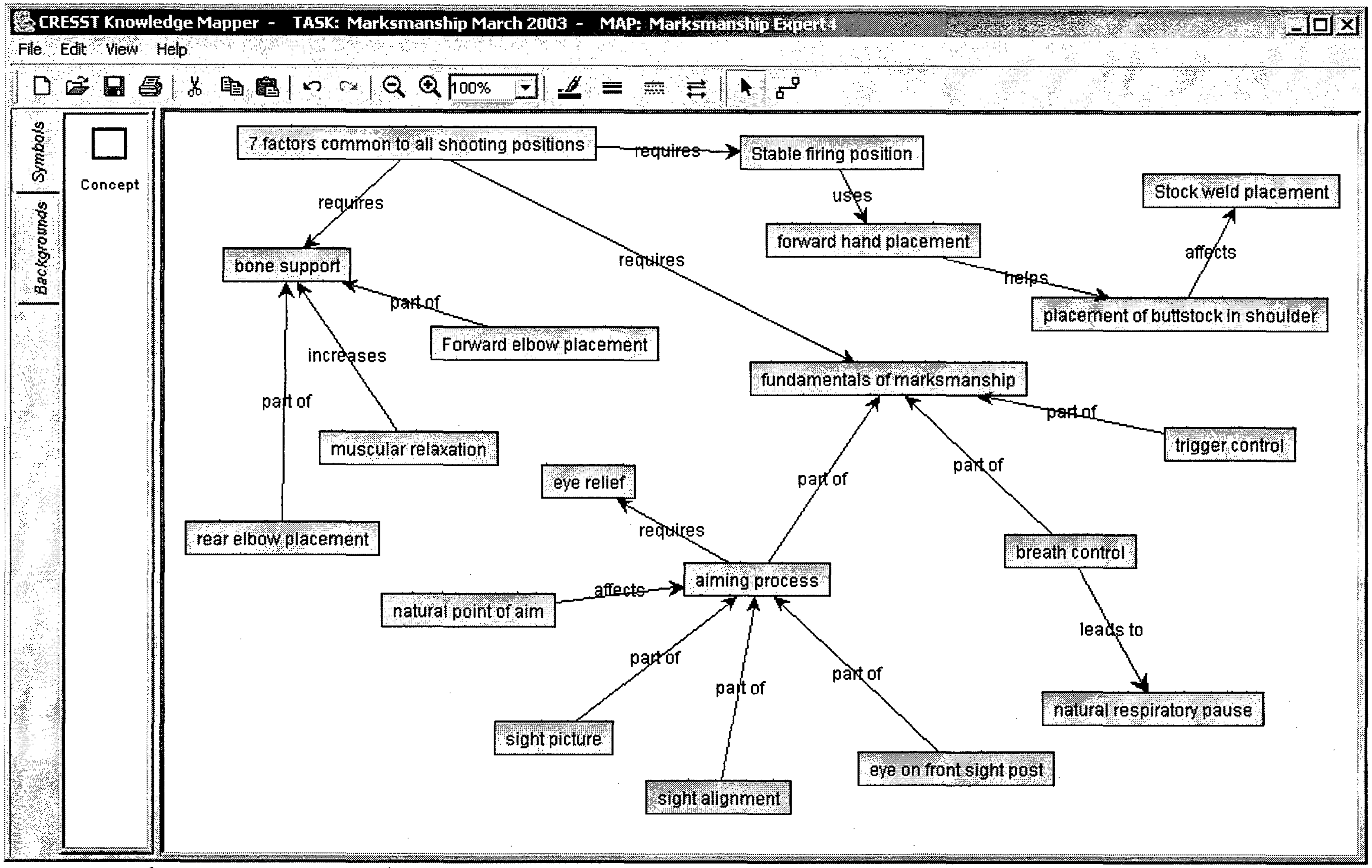


Expert map for scoring in March/May 2003 **Expert 2**

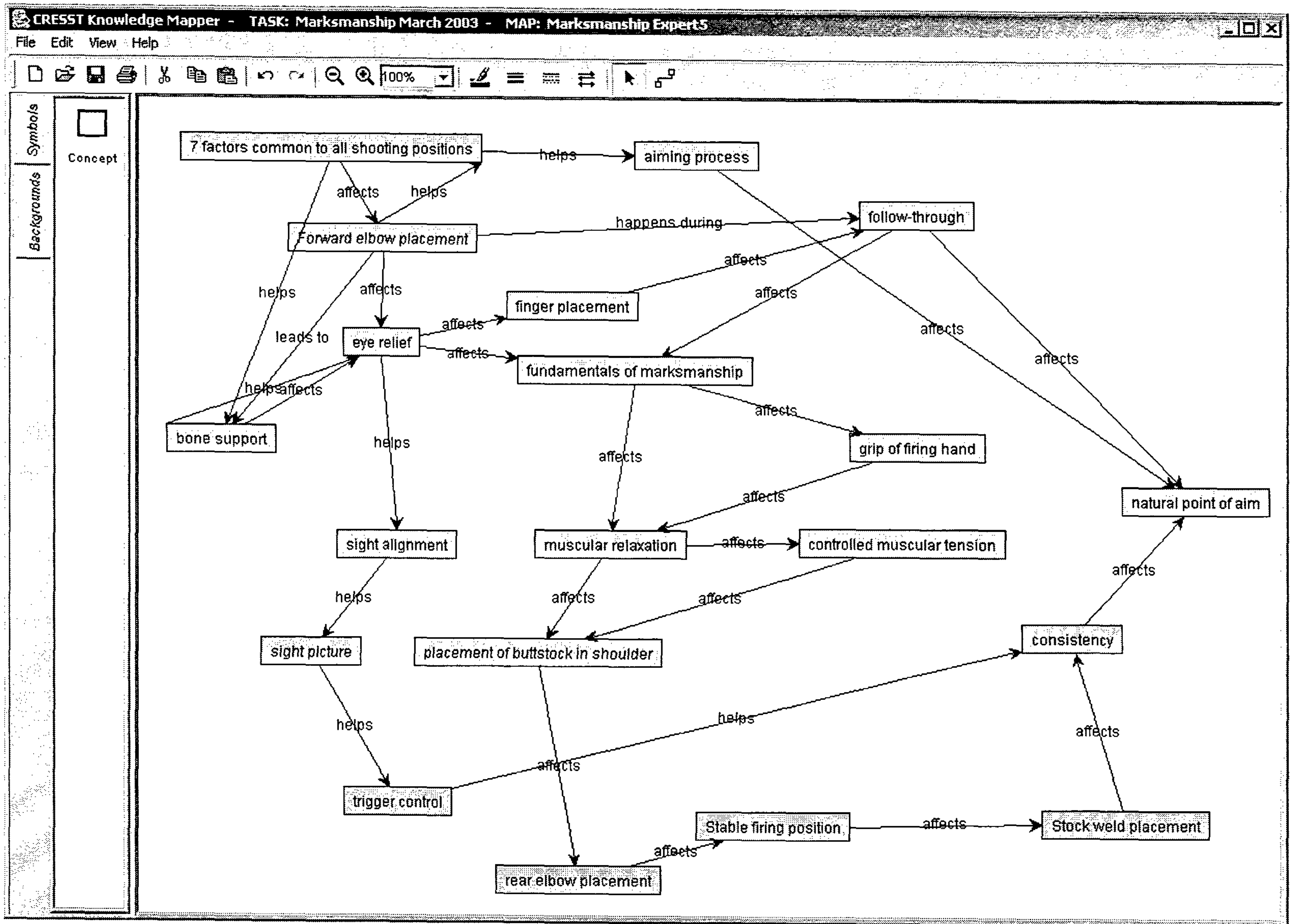


Expert map for scoring in March/May 2003

Expert 3

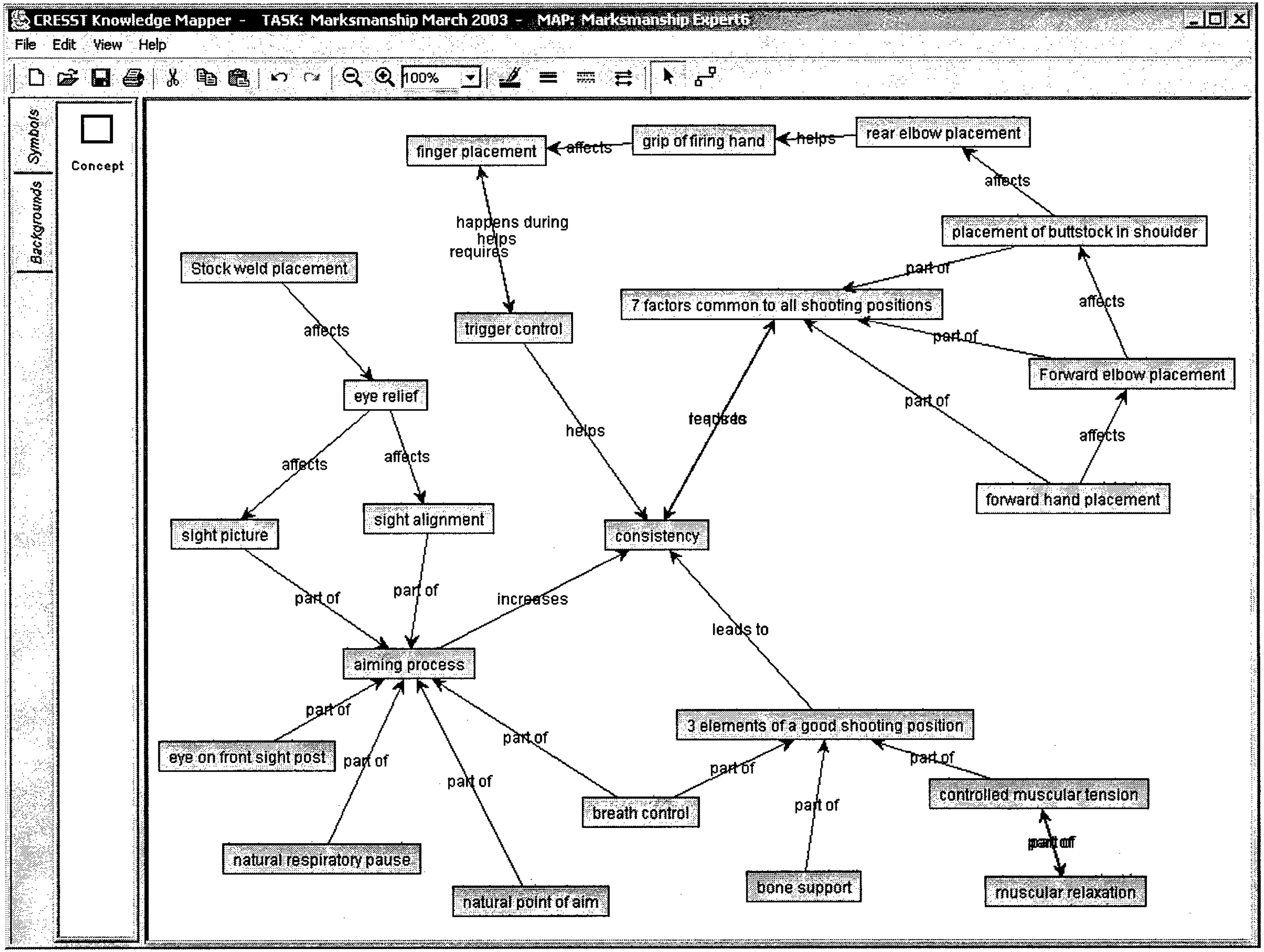


Expert map for scoring in March/May 2003 **Expert 4**

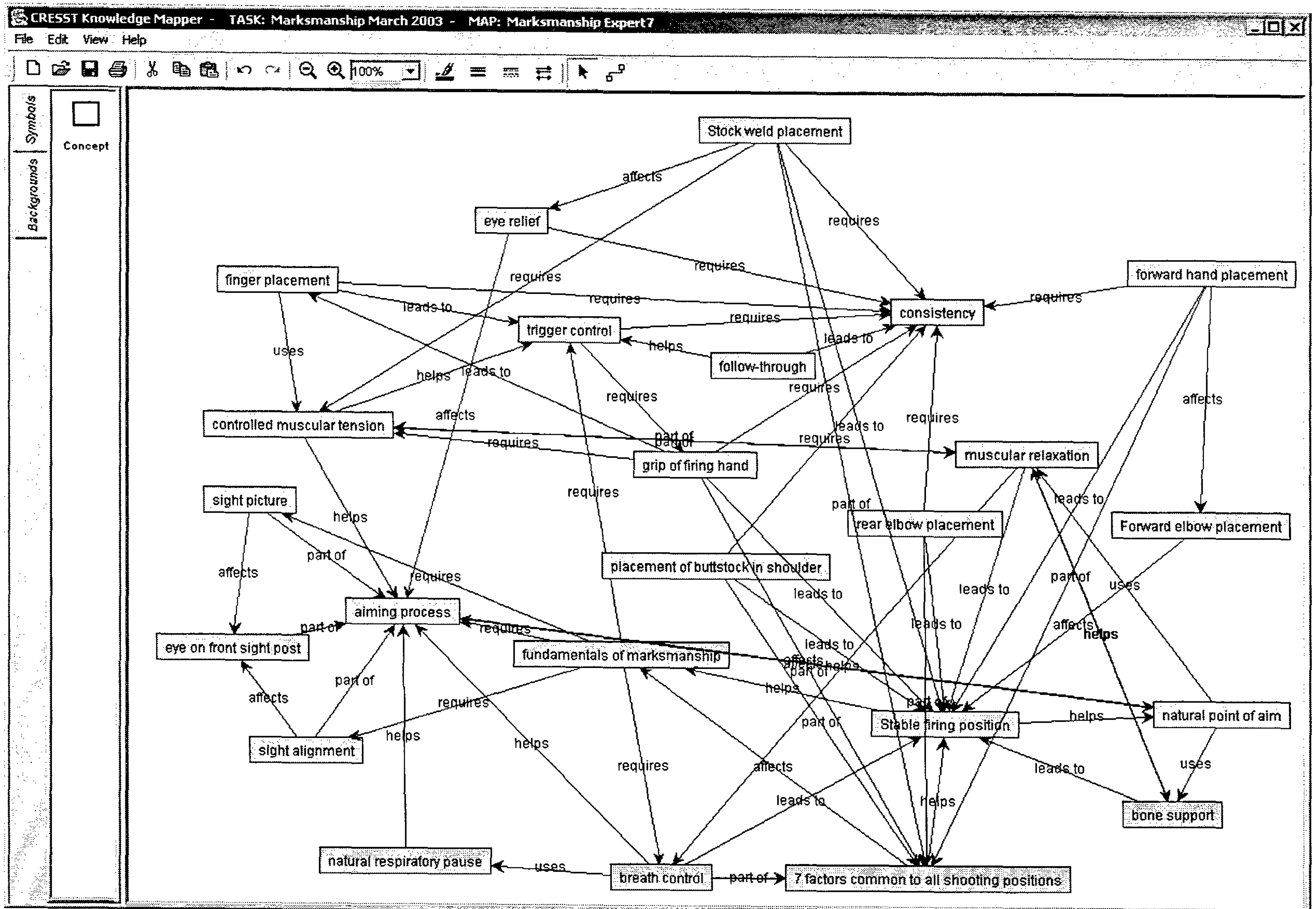


Expert map for scoring in March/May 2003

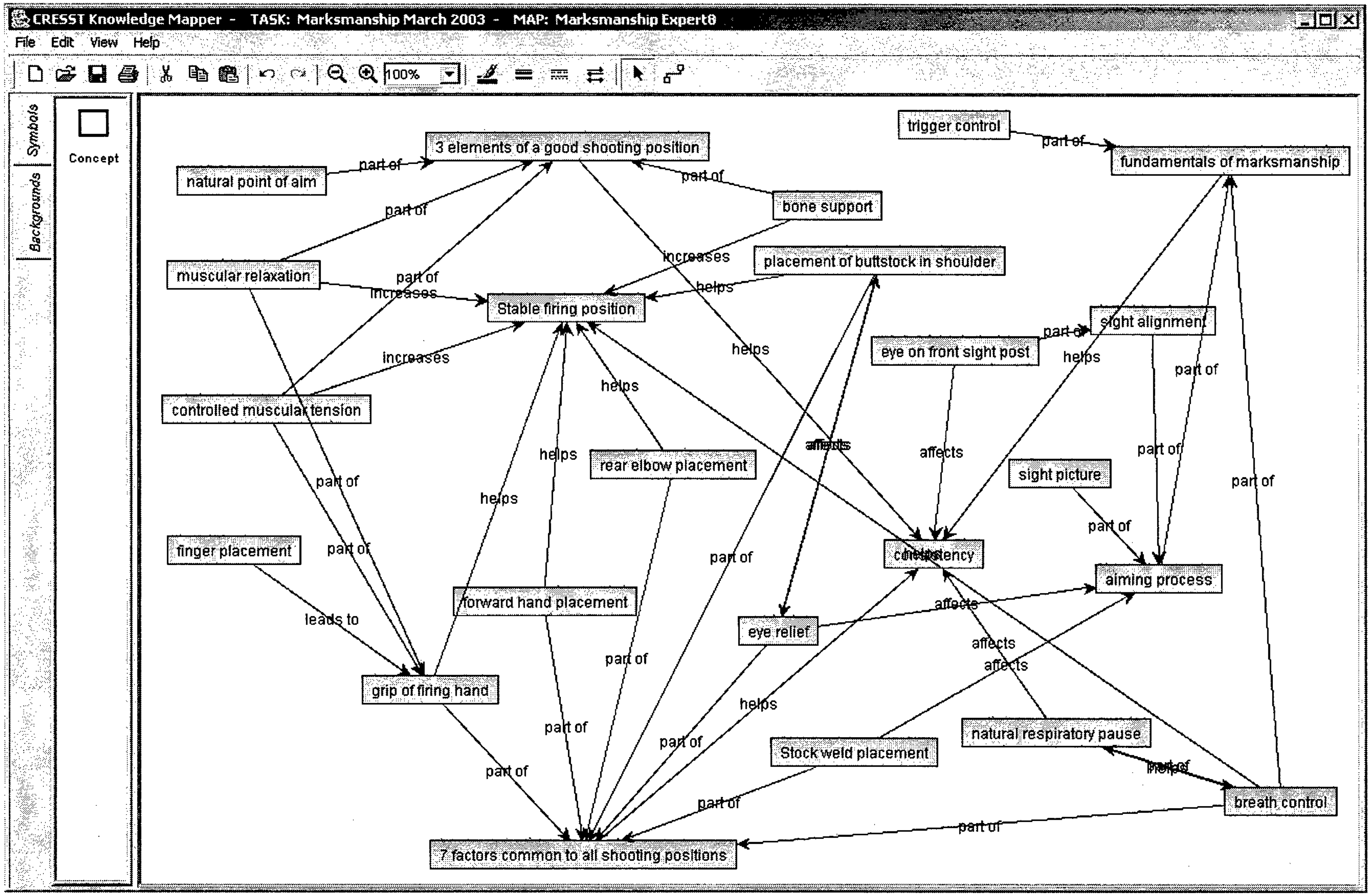
Expert 5



Expert map for scoring in March/May 2003 Expert 6



Expert map for scoring in March/May 2003 **Expert 7**



Expert map for scoring in March/May 2003 Expert 8

APPENDIX K

CRITERION KNOWLEDGE MAPS FOR MARKSMANSHIP (PROPOSITIONS)

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
Expert Nov./Dec. 2002	1	7 factors common to all shooting positions	helps	stable firing position
	2	7 factors common to all shooting positions	requires	breath control
	3	7 factors common to all shooting positions	requires	stock weld placement
	4	7 factors common to all shooting positions	requires	elbow placement
	5	7 factors common to all shooting positions	requires	forward hand placement
	6	7 factors common to all shooting positions	requires	grip of firing hand
	7	7 factors common to all shooting positions	requires	muscular relaxation
	8	7 factors common to all shooting positions	requires	placement of buttstock in shoulder
	9	aiming process	leads to	fundamentals of marksmanship
	10	breath control	improves	sight picture
	11	breath control	leads to	fundamentals of marksmanship
	12	breath control	part of	fundamentals of marksmanship
	13	stock weld placement	affects	sight alignment
	14	stock weld placement	leads to	stable firing position
	15	elbow placement	leads to	stable firing position
	16	eye on front sight post	part of	sight picture
	17	eye relief	affects	sight alignment
	18	eye relief	affects	sight picture
	19	finger placement	affects	trigger squeeze
	20	follow-through	part of	fundamentals of marksmanship
	21	forward hand placement	leads to	stable firing position
	22	grip of firing hand	affects	finger placement
	23	grip of firing hand	affects	trigger squeeze
	24	muscular relaxation	increases	stable firing position

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	25	muscular tension	increases	stable firing position
	26	natural respiratory pause	part of	breath control
	27	placement of buttstock in shoulder	helps	stable firing position
	28	sight alignment	part of	aiming process
	29	sight alignment	part of	fundamentals of marksmanship
	30	sight picture	part of	fundamentals of marksmanship
	31	sight picture	part of	aiming process
	32	stable firing position	increases	muscular relaxation
	33	stable firing position	leads to	fundamentals of marksmanship
	34	stable firing position	requires	muscular relaxation
	35	trigger control	leads to	fundamentals of marksmanship
	36	trigger squeeze	affects	trigger control
	37	trigger squeeze	during	natural respiratory pause
	38	bone support	leads to	stable firing position
	39	stable firing position	requires	bone support
	40	breath control	increases	accuracy
	41	elbow placement	increases	accuracy
	42	forward hand placement	increases	accuracy
	43	grip of firing hand	increases	accuracy
	44	muscular relaxation	increases	accuracy
	45	placement of buttstock in shoulder	increases	accuracy
Expert 1	1	natural respiratory pause	leads to	consistency
	2	natural respiratory pause	part of	breath control
	3	breath control	part of	fundamentals of marksmanship
	4	follow-through	leads to	consistency
	5	follow-through	helps	consistency

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	6	follow-through	part of	fundamentals of marksmanship
	7	breath control	part of	7 factors common to all shooting positions
	8	consistency	helps	aiming process
	9	aiming process	part of	fundamentals of marksmanship
	10	sight alignment	part of	aiming process
	11	eye relief	affects	sight alignment
	12	eye relief	part of	aiming process
	13	eye relief	affects	sight picture
	14	eye on front sight post	part of	aiming process
	15	eye on front sight post	affects	sight alignment
	16	eye on front sight post	affects	sight picture
	17	natural point of aim	part of	aiming process
	18	eye relief	part of	7 factors common to all shooting positions
	19	stock weld placement	affects	sight alignment
	20	stock weld placement	affects	eye relief
	21	stock weld placement	part of	7 factors common to all shooting positions
	22	placement of buttstock in shoulder	affects	stock weld placement
	23	placement of buttstock in shoulder	affects	rear elbow placement
	24	placement of buttstock in shoulder	affects	forward elbow placement
	25	placement of buttstock in shoulder	part of	7 factors common to all shooting positions
	26	rear elbow placement	leads to	stable firing position
	27	forward elbow placement	part of	stable firing position
	28	rear elbow placement	part of	7 factors common to all shooting positions
	29	forward elbow placement	part of	7 factors common to all shooting positions
	30	rear elbow placement	affects	grip of firing hand

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	31	grip of firing hand	part of	stable firing position
	32	natural point of aim	affects	stable firing position
	33	controlled muscular tension	part of	stable firing position
	34	bone support	part of	stable firing position
	35	bone support	helps	controlled muscular tension
	36	muscular relaxation	part of	3 elements of a good shooting position
	37	bone support	part of	3 elements of a good shooting position
	38	natural point of aim	part of	3 elements of a good shooting position
	39	grip of firing hand	affects	finger placement
	40	sight picture	part of	aiming process
	41	muscular relaxation	affects	grip of firing hand
	42	controlled muscular tension	affects	grip of firing hand
Expert 2	1	grip of firing hand	affects	trigger control
	2	grip of firing hand	leads to	trigger control
	3	controlled muscular tension	helps	grip of firing hand
	4	controlled muscular tension	decreases	bone support
	5	bone support	helps	stable firing position
	6	stock weld placement	leads to	stable firing position
	7	placement of buttstock in shoulder	affects	stock weld placement
	8	stable firing position	helps	follow-through
	9	stable firing position	part of	fundamentals of marksmanship
	10	consistency	part of	fundamentals of marksmanship
	11	aiming process	part of	fundamentals of marksmanship
	12	natural respiratory pause	affects	aiming process

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	13	trigger control	affects	aiming process
	14	natural respiratory pause	helps	natural point of aim
	15	stock weld placement	part of	eye relief
	16	natural point of aim	affects	aiming process
Expert 3	1	eye relief	affects	eye on front sight post
	2	stock weld placement	affects	eye relief
	3	stock weld placement	affects	eye on front sight post
	4	eye relief	affects	sight picture
	5	aiming process	requires	eye on front sight post
	6	aiming process	leads to	consistency
	7	aiming process	requires	sight picture
	8	aiming process	requires	sight alignment
	9	eye on front sight post	follows	sight picture
	10	forward hand placement	affects	sight picture
	11	forward hand placement	affects	sight alignment
	12	placement of buttstock in shoulder	affects	sight alignment
	13	sight picture	follows	sight alignment
	14	placement of buttstock in shoulder	affects	sight picture
	15	forward hand placement	leads to	consistency
	16	placement of buttstock in shoulder	leads to	consistency
	17	stock weld placement	requires	controlled muscular tension
	18	grip of firing hand	requires	controlled muscular tension
	19	grip of firing hand	affects	trigger control
	20	grip of firing hand	affects	finger placement
	21	finger placement	affects	trigger control
	22	trigger control	requires	controlled muscular tension
	23	trigger control	leads to	consistency
	24	natural respiratory pause	leads to	consistency
	25	muscular relaxation	leads to	consistency
	26	muscular relaxation	part of	stable firing position

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	27	muscular relaxation	helps	stable firing position
	28	muscular relaxation	helps	follow-through
	29	follow-through	helps	consistency
	30	stable firing position	leads to	consistency
	31	7 factors common to all shooting positions	leads to	stable firing position
	32	bone support	part of	stable firing position
	33	bone support	increases	stable firing position
	34	bone support	helps	follow-through
	35	stock weld placement	leads to	consistency
	36	stock weld placement	helps	consistency
Expert 4	1	aiming process	requires	eye relief
	2	aiming process	part of	fundamentals of marksmanship
	3	natural point of aim	affects	aiming process
	4	sight picture	part of	aiming process
	5	sight alignment	part of	aiming process
	6	eye on front sight post	part of	aiming process
	7	breath control	leads to	natural respiratory pause
	8	breath control	part of	fundamentals of marksmanship
	9	trigger control	part of	fundamentals of marksmanship
	10	7 factors common to all shooting positions	requires	fundamentals of marksmanship
	11	7 factors common to all shooting positions	requires	bone support
	12	7 factors common to all shooting positions	requires	stable firing position
	13	muscular relaxation	increases	bone support
	14	forward elbow placement	part of	bone support
	15	rear elbow placement	part of	bone support
	16	stable firing position	uses	forward hand placement

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	17	forward hand placement	helps	placement of buttstock in shoulder
	18	placement of buttstock in shoulder	affects	stock weld placement
Expert 5	1	7 factors common to all shooting positions	affects	forward elbow placement
	2	forward elbow placement	affects	eye relief
	3	forward elbow placement	leads to	bone support
	4	bone support	affects	eye relief
	5	bone support	helps	eye relief
	6	eye relief	affects	fundamentals of marksmanship
	7	fundamentals of marksmanship	affects	muscular relaxation
	8	muscular relaxation	affects	placement of buttstock in shoulder
	9	eye relief	affects	finger placement
	10	finger placement	affects	follow-through
	11	follow-through	affects	fundamentals of marksmanship
	12	fundamentals of marksmanship	affects	grip of firing hand
	13	placement of buttstock in shoulder	affects	rear elbow placement
	14	rear elbow placement	affects	stable firing position
	15	stable firing position	affects	stock weld placement
	16	stock weld placement	affects	consistency
	17	grip of firing hand	affects	muscular relaxation
	18	muscular relaxation	affects	controlled muscular tension
	19	controlled muscular tension	affects	placement of buttstock in shoulder
	20	consistency	affects	natural point of aim
	21	forward elbow placement	during	follow-through
	22	follow-through	affects	natural point of aim

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	23	forward elbow placement	helps	7 factors common to all shooting positions
	24	7 factors common to all shooting positions	helps	aiming process
	25	7 factors common to all shooting positions	helps	bone support
	26	aiming process	affects	natural point of aim
	28	eye relief	helps	sight alignment
	29	sight alignment	helps	sight picture
	30	sight picture	helps	trigger control
	31	trigger control	helps	consistency
Expert 6	1	eye on front sight post	part of	aiming process
	2	sight alignment	part of	aiming process
	3	sight picture	part of	aiming process
	4	eye relief	affects	sight picture
	5	eye relief	affects	sight alignment
	6	stock weld placement	affects	eye relief
	7	natural point of aim	part of	aiming process
	8	breath control	part of	aiming process
	9	natural respiratory pause	part of	aiming process
	10	bone support	part of	3 elements of a good shooting position
	11	breath control	part of	3 elements of a good shooting position
	12	controlled muscular tension	part of	3 elements of a good shooting position
	13	controlled muscular tension	part of	muscular relaxation
	14	muscular relaxation	part of	controlled muscular tension
	15	placement of buttstock in shoulder	part of	7 factors common to all shooting positions
	16	forward hand placement	part of	7 factors common to all shooting positions
	17	forward elbow placement	part of	7 factors common to all shooting positions

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	18	forward hand placement	affects	forward elbow placement
	19	forward elbow placement	affects	placement of buttstock in shoulder
	20	placement of buttstock in shoulder	affects	rear elbow placement
	21	rear elbow placement	helps	grip of firing hand
	22	grip of firing hand	affects	finger placement
	23	finger placement	during	trigger control
	24	trigger control	requires	finger placement
	25	finger placement	helps	trigger control
	26	trigger control	helps	consistency
	27	7 factors common to all shooting positions	leads to	consistency
	28	consistency	requires	7 factors common to all shooting positions
	29	3 elements of a good shooting position	leads to	consistency
	30	aiming process	increases	consistency
Expert 7	1	finger placement	requires	consistency
	2	follow-through	leads to	consistency
	3	finger placement	leads to	trigger control
	4	follow-through	helps	trigger control
	5	grip of firing hand	requires	consistency
	6	grip of firing hand	leads to	finger placement
	7	finger placement	uses	controlled muscular tension
	8	grip of firing hand	requires	controlled muscular tension
	9	controlled muscular tension	helps	trigger control
	10	trigger control	requires	grip of firing hand
	11	trigger control	requires	consistency
	12	natural point of aim	uses	muscular relaxation
	13	breath control	leads to	stable firing position
	14	muscular relaxation	leads to	stable firing position
	15	muscular relaxation	helps	breath control

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	16	natural point of aim	uses	bone support
	17	bone support	leads to	stable firing position
	18	stable firing position	helps	natural point of aim
	19	breath control	helps	aiming process
	20	breath control	uses	natural respiratory pause
	21	natural respiratory pause	helps	aiming process
	22	controlled muscular tension	helps	aiming process
	23	fundamentals of marksmanship	requires	trigger control
	24	stock weld placement	requires	controlled muscular tension
	25	fundamentals of marksmanship	requires	breath control
	26	sight picture	affects	eye on front sight post
	27	eye on front sight post	part of	aiming process
	28	sight alignment	affects	eye on front sight post
	29	sight picture	part of	aiming process
	30	fundamentals of marksmanship	requires	aiming process
	31	fundamentals of marksmanship	requires	sight alignment
	32	fundamentals of marksmanship	requires	sight picture
	33	stable firing position	helps	fundamentals of marksmanship
	34	stock weld placement	affects	eye relief
	35	stock weld placement	requires	consistency
	36	eye relief	requires	consistency
	37	rear elbow placement	requires	consistency
	38	placement of buttstock in shoulder	requires	consistency
	39	forward hand placement	requires	consistency
	40	stock weld placement	leads to	stable firing position
	41	forward elbow placement	affects	stable firing position
	42	sight alignment	part of	aiming process

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	43	eye relief	affects	aiming process
	44	7 factors common to all shooting positions	helps	stable firing position
	45	7 factors common to all shooting positions	affects	fundamentals of marksmanship
	46	forward hand placement	affects	forward elbow placement
	47	forward hand placement	leads to	stable firing position
	48	placement of buttstock in shoulder	leads to	stable firing position
	49	grip of firing hand	leads to	stable firing position
	50	rear elbow placement	leads to	stable firing position
	51	forward hand placement	part of	7 factors common to all shooting positions
	52	placement of buttstock in shoulder	part of	7 factors common to all shooting positions
	53	grip of firing hand	part of	7 factors common to all shooting positions
	54	rear elbow placement	part of	7 factors common to all shooting positions
	55	stock weld placement	part of	7 factors common to all shooting positions
	56	breath control	part of	7 factors common to all shooting positions
	57	natural point of aim	affects	aiming process
	58	aiming process	affects	natural point of aim
	59	muscular relaxation	part of	controlled muscular tension
	60	controlled muscular tension	part of	muscular relaxation
	61	muscular relaxation	helps	bone support
	62	bone support	helps	muscular relaxation
Expert 8	1	bone support	increases	stable firing position
	2	controlled muscular tension	increases	stable firing position
	3	muscular relaxation	increases	stable firing position
	4	natural point of aim	part of	3 elements of a good shooting position

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	5	bone support	part of	3 elements of a good shooting position
	6	controlled muscular tension	part of	3 elements of a good shooting position
	7	muscular relaxation	part of	3 elements of a good shooting position
	8	3 elements of a good shooting position	helps	consistency
	9	7 factors common to all shooting positions	helps	consistency
	10	stock weld placement	part of	7 factors common to all shooting positions
	11	eye relief	part of	7 factors common to all shooting positions
	12	placement of buttstock in shoulder	part of	7 factors common to all shooting positions
	13	breath control	part of	7 factors common to all shooting positions
	14	rear elbow placement	part of	7 factors common to all shooting positions
	15	grip of firing hand	part of	7 factors common to all shooting positions
	16	forward hand placement	part of	7 factors common to all shooting positions
	17	placement of buttstock in shoulder	affects	eye relief
	18	eye relief	affects	placement of buttstock in shoulder
	19	breath control	part of	natural respiratory pause
	20	natural respiratory pause	helps	breath control
	21	breath control	part of	fundamentals of marksmanship
	22	trigger control	part of	fundamentals of marksmanship
	23	aiming process	part of	fundamentals of marksmanship
	24	fundamentals of marksmanship	helps	consistency

Expert	Proposition No.	Source Concept	Relationship	Destination Concept
	25	stock weld placement	affects	aiming process
	26	eye relief	affects	aiming process
	27	eye on front sight post	affects	consistency
	28	natural respiratory pause	affects	consistency
	29	eye on front sight post	part of	sight alignment
	30	sight alignment	part of	aiming process
	31	sight picture	part of	aiming process
	32	controlled muscular tension	part of	grip of firing hand
	33	muscular relaxation	part of	grip of firing hand
	34	placement of buttstock in shoulder	helps	stable firing position
	35	breath control	helps	stable firing position
	36	rear elbow placement	helps	stable firing position
	37	grip of firing hand	helps	stable firing position
	38	forward hand placement	helps	stable firing position
	39	finger placement	leads to	grip of firing hand

APPENDIX L

BASIC MARKSMANSHIP KNOWLEDGE MEASURE

(STUDY 2)

Rifle Marksmanship Study
Prior Knowledge
March 2003

Matching
Directions: On the line to the left of each definition, write the letter of the term which best matches the definition. Each term may be used only once. There are more terms than definitions.

Definition	Term
____1. The firm consistent contact of the cheek with the weapon's butt stock	a) Bone support
____2. The distance between the rear sight aperture and the aiming eye	b) Eye relief
____3. The body's skeletal structure supporting the rifle's weight	c) Firing hand placement
____4. The point in the breathing cycle during which the body is most relaxed, allowing the sights to settle at the natural point of aim	d) Firm pistol grip
____5. The skillful manipulation of the trigger that causes the rifle to fire without disturbing sight alignment or sight picture	e) Follow-through
____6. "V" formed between the thumb and index finger on the trigger	f) Muscular relaxation
____7. Continued application of the fundamentals until the round has exited the barrel	g) Natural respiratory pause
____8. The process used to adjust the rifle sights that causes the rifle to shoot at the point of aim at a desired range	h) Recovery
____9. The state of tension required to properly control the rifle	i) Sight adjustment
	j) Sight alignment
	k) Stable firing position
	l) Stock weld
	m) Trigger control

Below are some **HYPOTHETICAL** situations. Indicate how much you agree with each statement.	Strongly agree	Agree	Disagree	Strongly disagree
If a shooter's muscles never got fatigued …				
10. … it would be OK to "muscle" the rifle into position.	❑	❑	❑	❑
11. … there would be little need for bone support.	❑	❑	❑	❑
Consistency is important in shooting because …				
12. … even very small changes in body position from one shot to the next can result in a poor shot.	❑	❑	❑	❑
13. … it helps you figure out what to adjust shot to shot.	❑	❑	❑	❑
A very long natural respiratory pause (over 15 seconds) …				
14. … will improve the stability of a shooter's position.	❑	❑	❑	❑
15. … will probably not affect the shooter too much.	❑	❑	❑	❑

16. Given a randomly shaped target, which figure best shows the correct aiming point?
    a) Figure 1
    b) Figure 2
    c) Figure 3

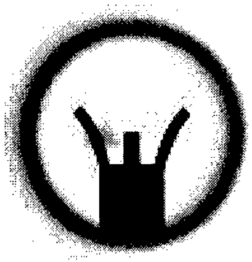
Figure 1

Figure 2

Figure 3

Multiple Choice

Directions: Use this picture when answering questions 17 and 18. For each question, select the alternative that best answers the question.



17. Which best describes the sight picture/sight alignment shown in the picture above?
    a) Proper sight picture, proper sight alignment
    b) Proper sight picture, improper sight alignment
    c) Improper sight picture, proper sight alignment
    d) Improper sight picture, improper sight alignment

18. Given the above sight picture/sight alignment, which figure below best shows where the round would strike? Assume a properly zeroed rifle, no wind or weather effects, and a properly fired weapon at 300 yards.
    a) Figure 1
    b) Figure 2
    c) Figure 3
    d) Figure 4

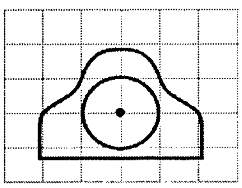


Figure 1

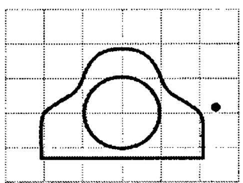


Figure 2

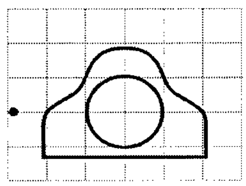


Figure 3

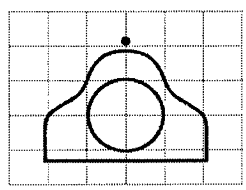
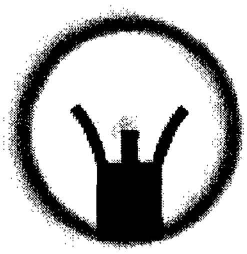


Figure 4

Directions: Use this picture when answering questions 19 and 20. For each question, select the alternative that best answers the question.



19. Which best describes the sight picture/sight alignment shown in the picture above?
    a) Proper sight picture, proper sight alignment
    b) Proper sight picture, improper sight alignment
    c) Improper sight picture, proper sight alignment
    d) Improper sight picture, improper sight alignment

20. Given the above sight picture/sight alignment, which figure below best shows where the round would strike? Assume a properly zeroed rifle, no wind or weather effects, and a properly fired weapon at 300 yards.
    a) Figure 1
    b) Figure 2
    c) Figure 3
    d) Figure 4

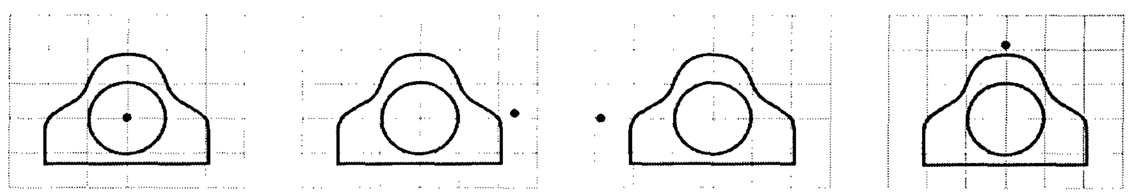
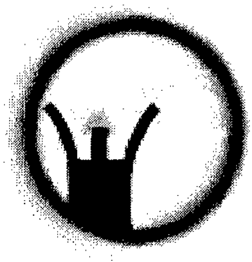


Figure 1 Figure 2 Figure 3 Figure 4

Directions: Use this picture when answering questions 21 and 22. For each question, select the alternative that best answers the question.



21. Which best describes the sight picture/sight alignment shown in the picture above?
    a) Proper sight picture, proper sight alignment
    b) Proper sight picture, improper sight alignment
    c) Improper sight picture, proper sight alignment
    d) Improper sight picture, improper sight alignment

22. Given the above sight picture/sight alignment, which figure below best shows where the round would strike? Assume a properly zeroed rifle, no wind or weather effects, and a properly fired weapon at 300 yards.
    a) Figure 1
    b) Figure 2
    c) Figure 3
    d) Figure 4

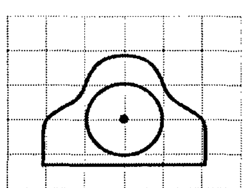


Figure 1

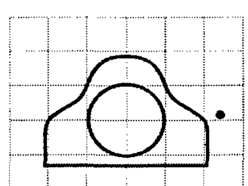


Figure 2

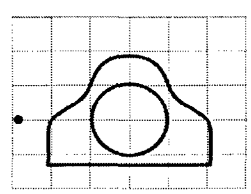


Figure 3

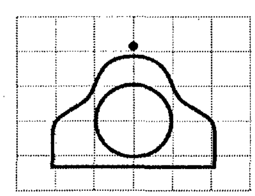
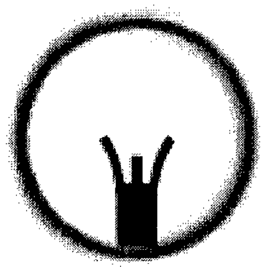


Figure 4

Directions: Use these pictures when answering questions 23 to 25. For each question, select the alternative that best answers the question.

Sight picture #1

Sight picture #2



Sight picture #3

Note: It may be helpful to read all 3 questions before answering.

23. Which sight picture above best reflects the Marine's eye relief shown in the picture to the left?
    a) Sight picture #1
    b) Sight picture #2
    c) Sight picture #3

24. Which sight picture above best reflects the Marine's eye relief shown in the picture to the left?
    a) Sight picture #1
    b) Sight picture #2
    c) Sight picture #3

25. Which sight picture above best reflects the Marine's eye relief shown in the picture to the left?
    a) Sight picture #1
    b) Sight picture #2
    c) Sight picture #3

Multiple Choice

26. In the sitting position, which direction does the rifle muzzle move when the rifle is fired while inhaling? Assume breathing from the chest.
    a) Up
    b) Down
    c) Left
    d) Right

27. Which of the following safety rules best enforces muzzle awareness?
    a) Treat every weapon as if it were loaded.
    b) Never point a weapon at anything you do not intend to shoot.
    c) Keep your finger straight and off the trigger until you are ready to fire.
    d) Keep the weapon on safe until you intend to fire.

28. Which of the following is the proper rear sight elevation setting when firing at the 300-yard line? Assume a zeroed rifle.
    a) 5
    b) 5/3
    c) 8/3
    d) 8/3-2

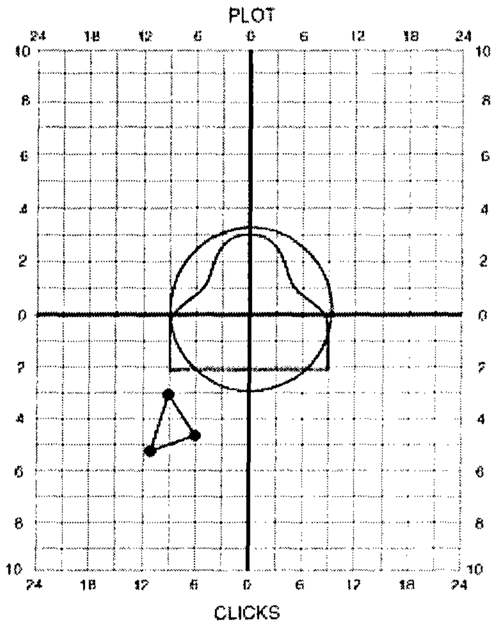
29. How far will 2 clicks of the rear sight windage move the strike of the round at 500 yards?
    a) 1 inch
    b) 2 1/2 inches
    c) 3 3/4 inches
    d) 5 inches

30. Suppose you have perfect sight alignment and sight picture (D-target). At the moment of the shot, the muzzle moves **UP** 1/16 inches (a width of a quarter). About how far off the center line do you think the round will strike at 200 yards?
    a) A couple of inches (a hit, still in the center ring)
    b) Almost 6 inches (a hit, still in center ring, barely)
    c) Around 10 inches (a miss, above black silhouette by almost an inch)
    d) Around 16 inches (a miss, well above black)

31. Which reason best explains the function of bone support?
    a) To provide a strong frame to absorb the rifle recoil
    b) To help support the weight of the rifle
    c) To provide rigid contact with the ground
    d) To allow the shooter to resist strong crosswinds in the field

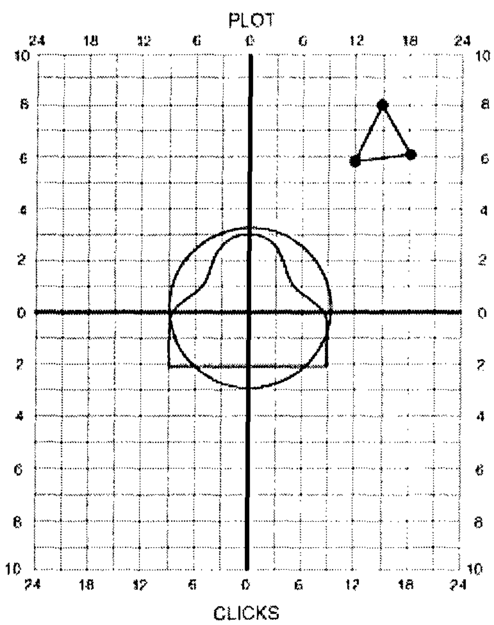
Questions 32–33:
Triangulate the shot group. Write the windage and elevation adjustments needed to place the **center of the shot group** into the center of the target. Specify the number of clicks and the direction. Keep in mind the rifle is set at the initial sight setting (flush and center) for **each** question.

UNITS ARE IN CLICKS. YOU DO NOT HAVE TO PERFORM ANY CONVERSIONS.



32. FSP: _____ clicks, ❑ up ❑ down
    RSW: _____ clicks, ❑ left ❑ right

UNITS ARE IN CLICKS. YOU DO NOT HAVE TO PERFORM ANY CONVERSIONS.



33. FSP: _____ clicks, ❑ up ❑ down
    RSW: _____ clicks, ❑ left ❑ right

UNITS ARE IN CLICKS. YOU DO NOT HAVE TO PERFORM ANY CONVERSIONS.

	Up / down	Left / right	Erratic	No change
In which direction will the natural point of aim shift (right-handed shooter, KNEELING) …				
34. … if the left hand is moved along the handguard?	❑	❑	❑	❑
35. … if the rifle butt is moved up or down in the shoulder?	❑	❑	❑	❑
36. … if the left elbow is moved along the knee?	❑	❑	❑	❑
37. … if the entire body is moved in relation to the target?	❑	❑	❑	❑
In which direction will the rifle muzzle shift from shot to shot …				
38. … if the trigger finger is in contact with the receiver or pistol grip while firing?	❑	❑	❑	❑
39. … if the shooter is holding his breath too long?	❑	❑	❑	❑
40. … if the shooter has high muscle fatigue?	❑	❑	❑	❑
41. … if the shooter's position is constantly changing?	❑	❑	❑	❑

APPENDIX M

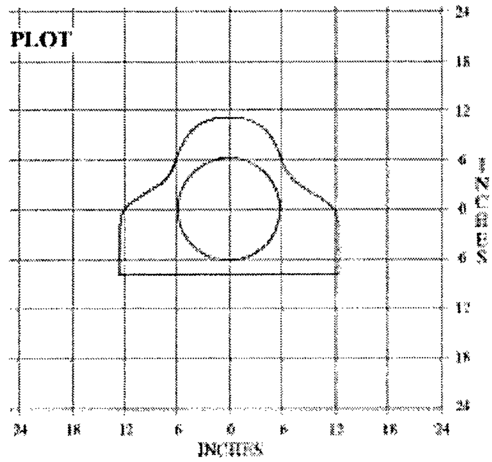
SHOT GROUP DEPICTION MEASURE

(STUDY 2)

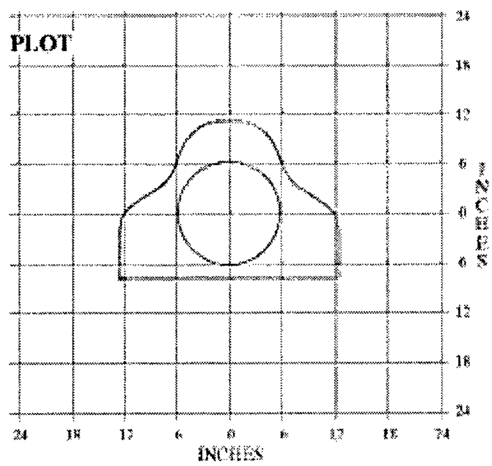
Rifle Marksmanship Study
Shot Group Analysis
March 2003

<u>Directions</u>: Each question describes a particular shooter error. On the target to the right, **plot five bullet strikes** that reflect the conditions at 300 yards of a right-handed shooter in the kneeling position. Unless otherwise stated, assume no wind/weather effects.

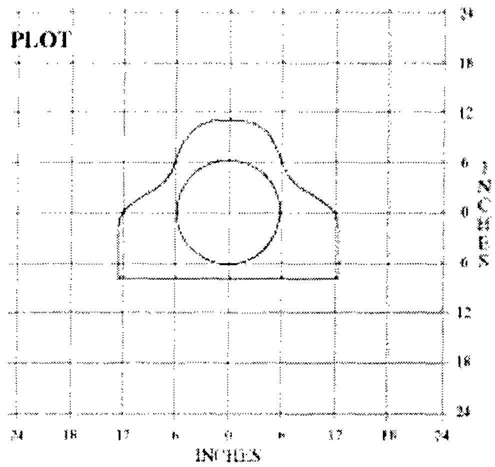
1. Breathing while firing



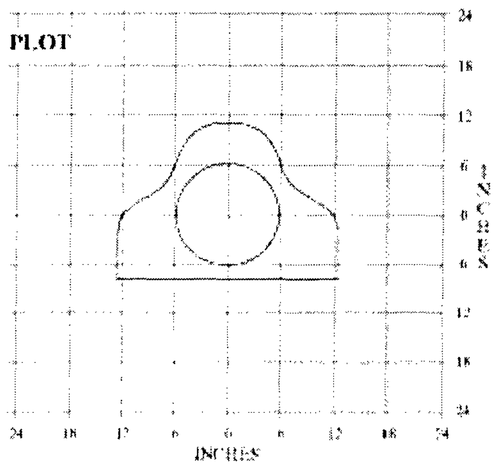
2. Bucking the shoulder into the rifle stock while firing



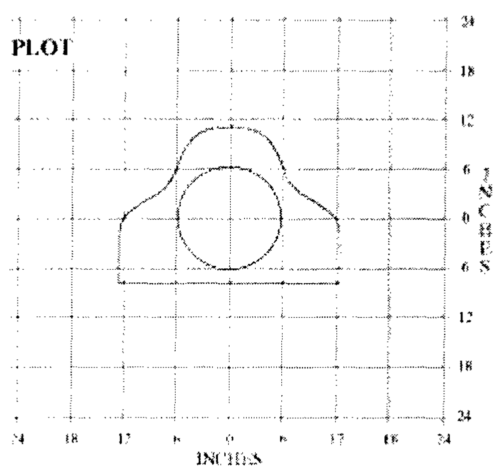
3. Flinching the body while firing (sudden small backward movement of body)

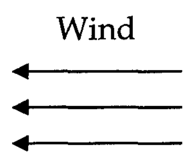


4. Aiming eye focused on the target instead of the front sight post while firing



5. Sight adjustment problem (inadequate compensation) with wind blowing from the right





APPENDIX N

TRAIT WORRY MEASURE

How often do you feel or think the following?	Almost always	Often	Some-times	Almost never
Thinking about my score interferes with my shooting during qualification.	❑	❑	❑	❑
I freeze up during qualification.	❑	❑	❑	❑
During qualification I find myself thinking about whether I'll ever get through it.	❑	❑	❑	❑
The more I think during qualification, the more confused I get.	❑	❑	❑	❑
I seem to defeat myself during qualification.	❑	❑	❑	❑
During qualification I find myself thinking about the consequences of failing.	❑	❑	❑	❑
Thoughts of doing poorly interfere with my concentration during qualification.	❑	❑	❑	❑
During qualification I get so nervous that I forget skills and information I really know.	❑	❑	❑	❑

APPENDIX O

STATE ANXIETY AND STATE WORRY MEASURE

Directions: A number of statements which people have used to describe themselves are given below. Read each statement and find the word or phrase that best indicates how you think or feel right now. Circle the number for your answer. There are no right or wrong answers. Do not spend too much time on any one statement. Remember, give the answer which seems to describe how you think or feel right now.

		Very much so	Moderately so	Somewhat	Not at all
1.	I do not feel confident about my performance during qualification.	❑	❑	❑	❑
2.	I feel calm.	❑	❑	❑	❑
3.	I think my score will be so bad that everybody, including myself, will be disappointed.	❑	❑	❑	❑
4.	I feel tense.	❑	❑	❑	❑
5.	I am afraid that I should have prepared more for qualification.	❑	❑	❑	❑
6.	I feel at ease.	❑	❑	❑	❑
7.	I will not be happy with my performance during qualification.	❑	❑	❑	❑
8.	I feel jittery.	❑	❑	❑	❑
9.	I will feel regretful about my performance during qualification.	❑	❑	❑	❑
10.	I feel relaxed.	❑	❑	❑	❑
11.	I am concerned about what will happen if I do poorly.	❑	❑	❑	❑

Odd numbers are state worry items. Even numbers are state anxiety items.

APPENDIX P

FIRING LINE EXPERIENCE MEASURE

(STUDY 2)

Trait Version

In general, when you are on the firing line, how often do you …	Almost always	Often	Some-times	Almost never
… know how the shot went (good or bad) as soon as you fired the rifle?	❑	❑	❑	❑
… know how to adjust your position based on your prior shot(s)?	❑	❑	❑	❑
… know how to adjust your rifle sights based on your prior shot(s)?	❑	❑	❑	❑
… reach the "zone" – smooth and calm performance, unaware of time pressure, effortless shooting.	❑	❑	❑	❑
… get distracted mentally (negative thoughts – "I can't seem to control myself" or "There, I moved again", and so on)	❑	❑	❑	❑
… get help from the coaches?[a]	❑	❑	❑	❑
… feel confident about your shooting performance?	❑	❑	❑	❑
… feel anxious or worried about your shooting performance?[b]	❑	❑	❑	❑
… use the databook?[a]	❑	❑	❑	❑

[a]Dropped from analyses due to poor reliability. [b]Excluded from main analyses (Study 2) but included for longitudinal analyses (Appendix Z).

APPENDIX Q

PERCEIVED LEVEL OF MARKSMANSHIP KNOWLEDGE

(STUDY 2)

General questions about how much you know about USMC rifle marksmanship. How much do you know about …	Very much	Moderate amount	Some	Not much at all
… the fundamentals of rifle marksmanship?	❑	❑	❑	❑
… trigger control?	❑	❑	❑	❑
… breath control?	❑	❑	❑	❑
… the aiming process?	❑	❑	❑	❑
… how trigger control, breath control, and the aiming process all **affect** each other?	❑	❑	❑	❑

APPENDIX R

PERCEIVED UTILITY OF MARKSMANSHIP KNOWLEDGE

(STUDY 2)

Please indicate how much you agree with each statement.	Strongly agree	Agree	Disagree	Strongly disagree
A Marine can shoot well (qualify Expert) …				
… without knowing what the fundamentals are.	❑	❑	❑	❑
… without correctly applying the fundamentals.	❑	❑	❑	❑
… by shooting a lot.[a]	❑	❑	❑	❑
… by instinct.	❑	❑	❑	❑
Knowledge of the fundamentals (Phase I training) …				
… is important to shooting well.[a]	❑	❑	❑	❑
… is important to improving shooting performance.	❑	❑	❑	❑
… is used by snipers and other top shooters.	❑	❑	❑	❑
… is useful to shooting.	❑	❑	❑	❑

[a]Dropped from analyses due to poor reliability.

APPENDIX S

BACKGROUND SURVEY

(STUDY 2)

Rifle Marksmanship Study
Background Information
March 2003

GENERAL INFORMATION

1. Age: ________ years

2. Gender: ❑ Male ❑ Female

3. Ethnicity: ❑ African American ❑ Native American
   ❑ Asian/Pacific Islander ❑ White
   ❑ Hispanic ❑ Other ______________________

4. AFQT (Armed Forces Qualifying Test) score: ________ ❑ Don't remember
   (sometimes called "ASVAB score")

5. AFQT category (I, II, IIIA, IIIB, IVA, IVB, IVC, IV): ________ ❑ Don't remember

6. AFQT line scores (if you remember):
   ❑ CL _____ (clerical, Administrative, Supply & Finance)
   ❑ FA _____ (field artillery, cannon, rocket, artillery)
   ❑ MM _____ (mechanical maintenance, vehicle and aircraft maintenance)
   ❑ CO _____ (combat, armor, infantry)
   ❑ GM _____ (general maintenance, construction, utility, hazmat)
   ❑ OF _____ (operators and food, food service, drivers and missile operators)
   ❑ EL _____ (electronics repair, missile repair, electronics and communication)
   ❑ GT _____ (general technical, special and officer programs)
   ❑ Other ______________
   ❑ Don't know

7. Highest level of education that you completed:
   ❑ 4-year college or university ❑ High school
   ❑ 2-year college ❑ Other ________________________
   ❑ Trade or technical school

CURRENT SERVICE INFORMATION

8. Number of years in service: ______ years

9. Rank:

Enlisted	Officer	Warrant Officer
❑ Private (E-1)	❑ Second Lieutenant (O-1)	❑ Warrant Officer (W-1)
❑ Private First Class (E-2)	❑ Second Lieutenant (O-1E)	❑ Warrant Officer 2 (W-2)
❑ Lance Corporal (E-3)	❑ First Lieutenant (O-2)	❑ Warrant Officer 3 (W-3)
❑ Corporal (E-4)	❑ First Lieutenant (O-2E)	❑ Warrant Officer 4 (W-4)
❑ Sergeant (E-5)	❑ Captain (O-3)	❑ Warrant Officer 5 (W-5)
❑ Staff Sergeant (E-6)	❑ Captain (O-3E)	
❑ Gunnery Sergeant (E-7)	❑ Other ____________	
❑ Master Sergeant (E-8)		
❑ First Sergeant (E-8)		
❑ Other ______________		

10. Unit

Division	Wing	Force Service Support Group	Support
❑ Combat arms (infantry, artillery, armor, etc.)	❑ Aviation (squadron or group)	❑ Combat service support (supply, motor transport, maintenance, etc.)	❑ Base/station
❑ Combat support (engineer, communications, etc.)	❑ Aviation command and control	❑ Staff	❑ Formal schools
❑ Staff	❑ Aviation ground support		❑ Marine security guard defense
	❑ Staff		

11. Job Information:

Primary MOS	Billet MOS
______________________	______________________
______________________	______________________
______________________	______________________
______________________	______________________
______________________	______________________

Please indicate which courses you have completed:	Completed	Did not take or did not complete
12. Marksmanship Coach (MOS 8530)	❑	❑
13. Marksmanship Instructor (MOS 8531)	❑	❑
14. Small Arms Weapons Instructor (MOS 8532)	❑	❑
15. Range Officer (MOS 9925)	❑	❑

RIFLE MARKSMANSHIP EXPERIENCE

Shooting AS PART of Your USMC Duties

16. In general, how frequently do you shoot a rifle as part of your USMC duties (excluding requalification)?
❑ Never ❑ Once or twice ❑ A few times ❑ Often ❑ Very often

17. Please estimate the number of days you spend shooting a rifle as part of your USMC duties (excluding requalification): __________

Recreational Shooting

18. In general, how frequently do you shoot weapons outside of your USMC duties (for hunting, skeet shooting, and so on)?
❑ Never ❑ Once or twice ❑ A few times ❑ Often ❑ Very often

19. Please estimate the number of days per year you spend shooting a rifle outside of your USMC duties: __________

20. Number of years of rifle shooting experience prior to joining the Marines: ______ years

21. How frequently have you shot competitively?
❑ Never ❑ Once or twice ❑ A few times ❑ Often ❑ Very often

In general, when you are on the firing line, how often do you …	Almost always	Often	Some-times	Almost never
22. … know how the shot went (good or bad) as soon as you fired the rifle?	❑	❑	❑	❑
23. … know how to adjust your position based on your prior shot(s)?	❑	❑	❑	❑
24. … know how to adjust your rifle sights based on your prior shot(s)?	❑	❑	❑	❑
25. … reach the "zone" – smooth and calm performance, unaware of time pressure, effortless shooting.	❑	❑	❑	❑
26. … get distracted mentally (negative thoughts – "I can't seem to control myself" or "There, I moved again", and so on)	❑	❑	❑	❑
27. … get help from the coaches?	❑	❑	❑	❑
28. … feel confident about your shooting performance?	❑	❑	❑	❑
29. … feel anxious or worried about your shooting performance?	❑	❑	❑	❑
30. … use the databook?	❑	❑	❑	❑

How often do you feel or think the following?	Almost always	Often	Some-times	Almost never
31. Thinking about my score interferes with my shooting during qualification.	❑	❑	❑	❑
32. I freeze up during qualification.	❑	❑	❑	❑
33. During qualification I find myself thinking about whether I'll ever get through it.	❑	❑	❑	❑
34. The more I think during qualification, the more confused I get.	❑	❑	❑	❑
35. I seem to defeat myself during qualification.	❑	❑	❑	❑
36. During qualification I find myself thinking about the consequences of failing.	❑	❑	❑	❑
37. Thoughts of doing poorly interfere with my concentration during qualification.	❑	❑	❑	❑
38. During qualification I get so nervous that I forget skills and information I really know.	❑	❑	❑	❑

QUALIFICATION INFORMATION

When was your last …	None	Last week	Other
39. … training on the fundamentals of rifle marksmanship (Phase I)?	❑	❑	Date (MM/YY): _________
40. … dry-fire practice (Phase I)?	❑	❑	Date (MM/YY): _________
41. … live-fire practice (Phase II)?	❑	❑	Date (MM/YY): _________
42. … live-fire qualification trial (Phase II)?	❑	❑	Date (MM/YY): _________

Please list your 3 most recent final qualification scores, starting with the most recent one. Please estimate if you don't remember your exact score.

43. Qualification score: ______ (most recent) Date (MM/YY): ______

44. Qualification score: ______ ❑ Don't have one Date (MM/YY): ______

45. Qualification score: ______ ❑ Don't have one Date (MM/YY): ______

APPENDIX T

TASK DIRECTIONS FOR SHOT-TO-SHOT KNOWLEDGE MAPPING

Knowledge of Rifle Marksmanship Study
Shot-to-Shot Analysis
May 2003

Task:
You will be given pictures of a sequence of 5 shots. Your task is to analyze the shot sequence and, using the Knowledge Mapper, indicate reasons that might explain a shot's placement given the relationship among the shots or the location of the prior shot.

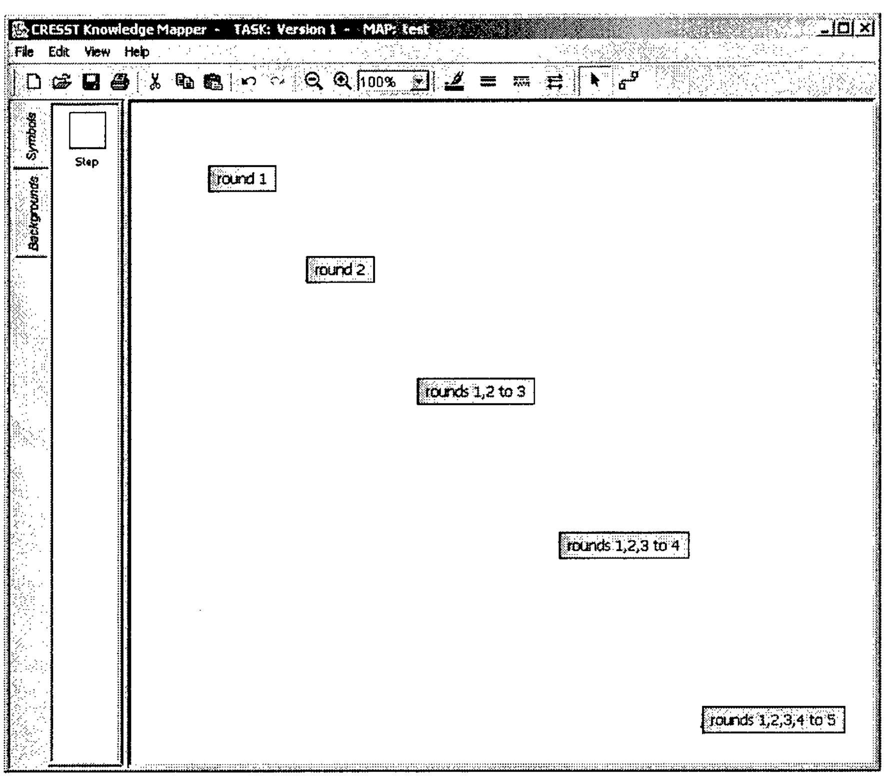
For example, given the strike of round 1, what are some reasons that might explain round 2's strike?

This task is intended to approximate what a shooter has to mentally go through on the firing line. After the shooter fires a shot, he/she sees where the round strikes the target. The shooter then uses the shot information to analyze the shot given prior shots and help diagnose any problems. As more rounds are fired, more information becomes available.

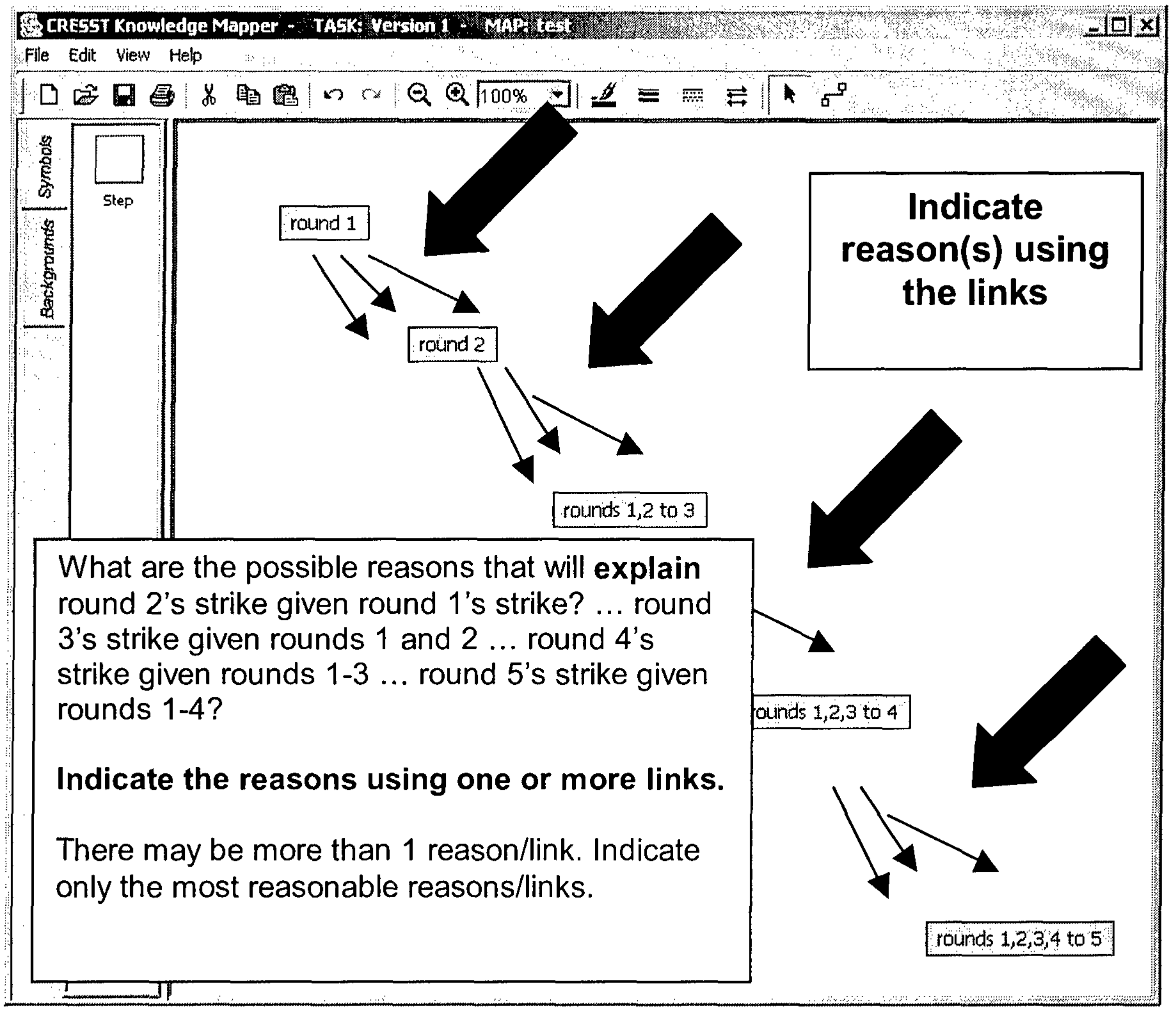
Situation:
You can assume the following:
1. All shots called center
2. 200-yd slow-fire sitting position

Knowledge Mapping Instructions

Step 1: First lay out the nodes as shown below. Each node represents a "step" in the firing sequence. You will be given pictures on the next page that show the shot patterns.



Step 2: Connect the steps (nodes). The links represent the **reasons** that may explain each shot, given the previous shots.



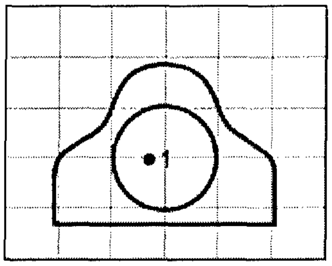
Notes:

1. **Use the links to indicate possible reasons that help explain a round's strike given prior shots.**
2. **There may be more than 1 reason.**
3. **There may be no problems, some problems, or many problems—use your judgment.**
4. **Reasons may change from shot to shot—each additional shot provides more information. CHANGING REASONS FROM SHOT TO SHOT IS OK—THIS IS WHAT HAPPENS ON THE FIRING LINE. DON'T GO BACK AND CHANGE ALL THE PREVIOUS REASONS TO MAKE THEM "MATCH."**

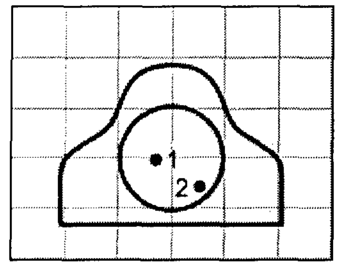
Knowledge Mapper Nodes/Steps and Links/Reasons

Nodes/Steps	Reasons/Links
round 1	no problem(s)
round 1to 2	unable to tell
rounds 1, 2 to 3	eye focused on target
rounds 1, 2, 3 to 4	breathing while firing
rounds 1, 2, 3, 4 to 5	flinching (sudden backward movement of body) at time of shot
	bucking rifle (movement of shoulder into the rifle stock) while firing
	jerking trigger while firing
	improper sight alignment
	improper sight picture
	improper elevation setting
	improper windage setting
	moved forward hand backward while firing
	moved forward hand forward while firing
	wind from left
	wind from right

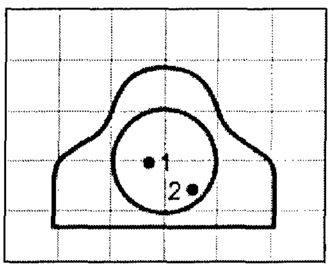
Round 1 —— ? ——> Round 2



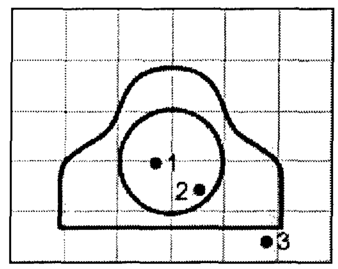
Given the strike of round 1, what are all the **reasonable reasons** that may have caused round 2 to strike as shown?



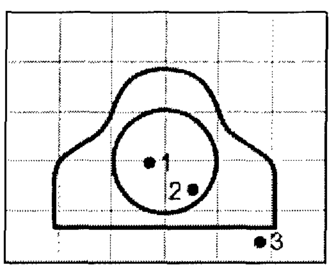
Rounds 1 and 2 —— ? ——> Round 3



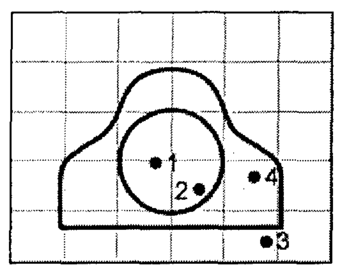
Given the strike of rounds 1 and 2, what are all the **reasonable reasons** that may have caused round 3 to strike as shown?



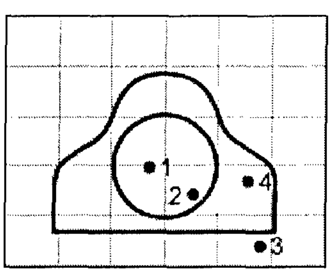
Rounds 1 thru 3 —— ? ——> Round 4



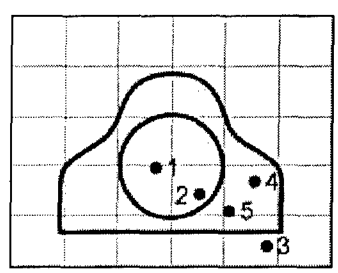
Given the strike of rounds 1 through 3, what are all the **reasonable reasons** that may have caused round 4 to strike as shown?



Rounds 1 thru 4 —— ? ——> Round 5



Given the strike of rounds 1 through 4, what are all the **reasonable reasons** that may have caused round 5 to strike as shown?



APPENDIX U

TASK DIRECTIONS FOR DATA BOOK PROCEDURE KNOWLEDGE MAPPING

Knowledge of Rifle Marksmanship Study
Data Book Procedure
May 2003

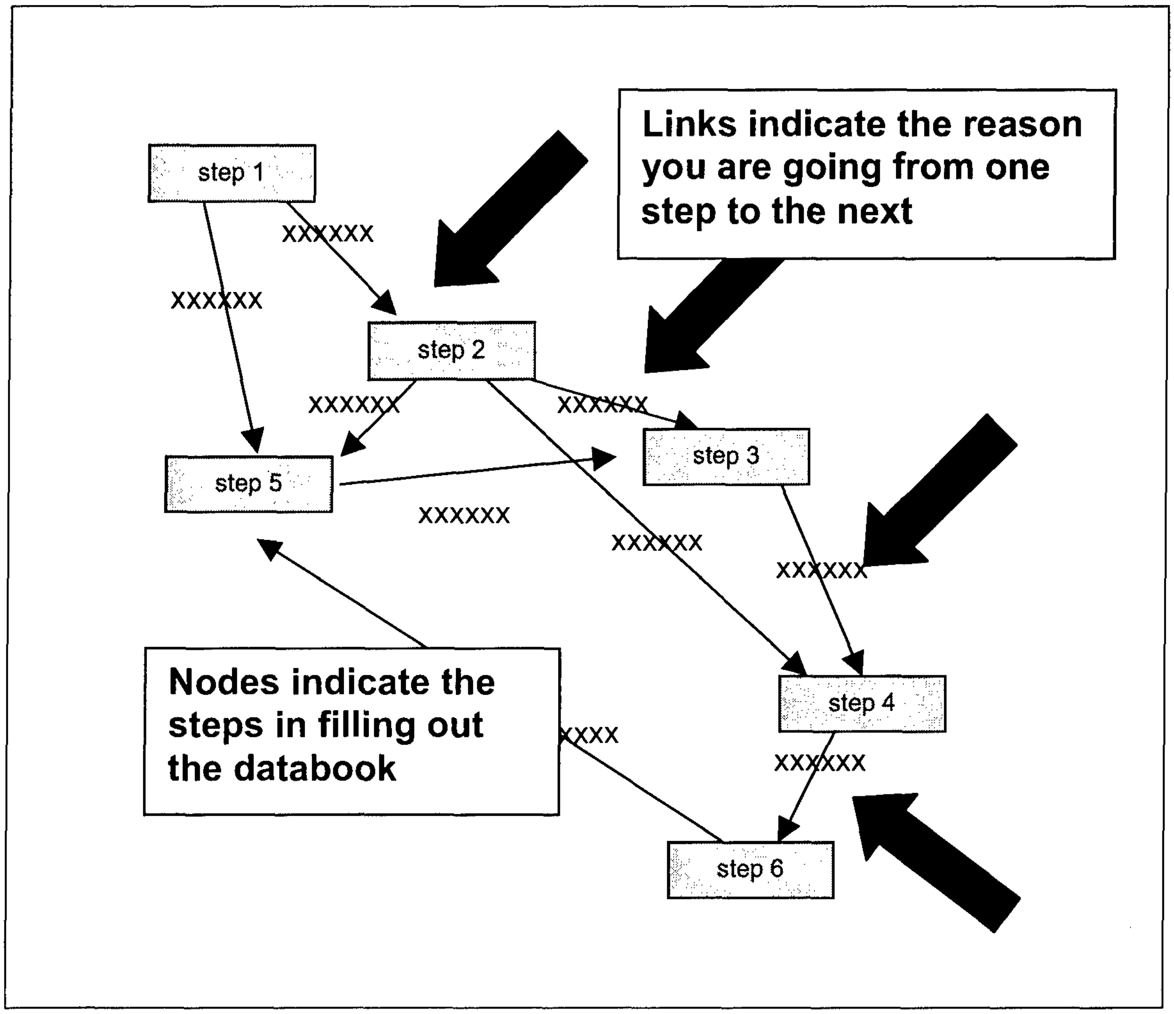
Task:
Your task is to use the Knowledge Mapper to show your understanding of how to fill out the data book and how to use it as a tool to improve your shooting. Use what you learned during Phase I training and your experience on the firing line to show the steps a Marine should use to fill out the data book.

Situation:
You can assume the following:

1. 200-yd slow-fire kneeling position
2. Wind is blowing in from the right at half value

Knowledge Mapping Instructions

In this task, the knowledge map will be used to depict a procedure—filling out the data book. The nodes in the knowledge map represent steps in the procedure, and the links represent the reasons why you are going from one step to the next.



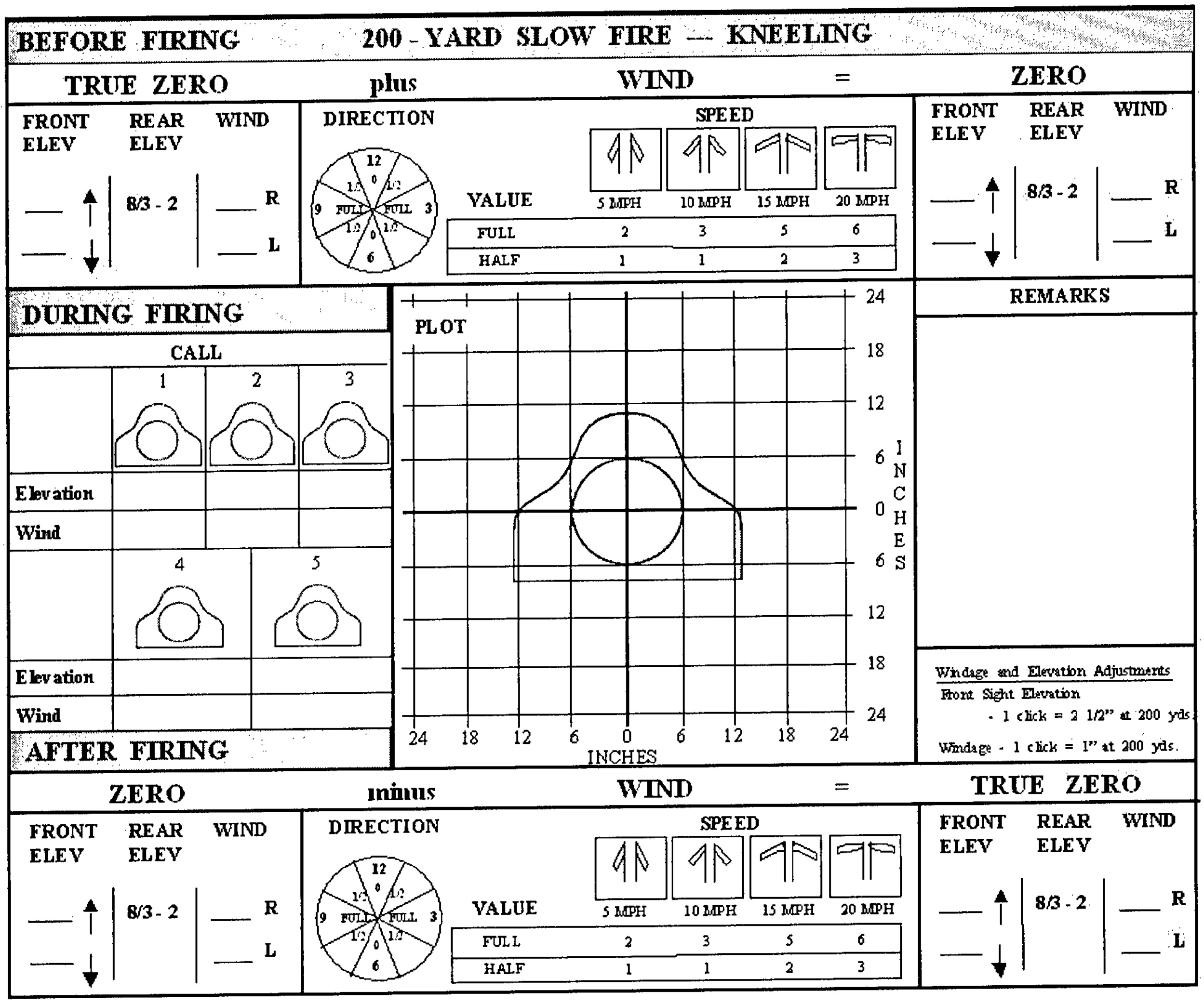
Notes:

1. **Use the links to indicate why you are going from one step to another.**
2. **For reasons that are obvious or require no explanation, use "Next Step." However, if you can provide a reason, do so. In general, "Next Step" is the weakest possible answer.**
3. **THERE IS NO SINGLE CORRECT ANSWER! THE TASK IS DESIGNED TO ALLOW FOR MULTIPLE CORRECT PROCEDURES. THE IMPORTANT PART IS THE QUALITY OF THE REASONS BETWEEN STEPS.**

Knowledge Mapper Nodes/Steps and Links/Reasons

Nodes/Steps	Links/Reasons
• Calculate and enter elevation adjustments • Calculate and enter windage adjustments • Call shot • Circle number of clicks where wind value and wind speed intersect • Circle rear sight elevation knob settings • Determine direction of wind • Determine value of wind • Enter post-fire true zero FSP settings • Enter post-fire true zero RSW settings • Enter pre-fire zero FSP settings Enter pre-fire zero RSW settings • Enter remarks • Establish true zero • Establish zero • Fire shot • Observe bullet strike • Observe flag on range • Plot shot	• After firing • Analyze • As required Before firing • Compare • Compensate • Make sight adjustments • Next step • Record information

Data Book Page
Kneeling Position
Slow Fire, 200 Yards



APPENDIX V

BASIC MARKSMANSHIP KNOWLEDGE MEASURE

(STUDY 3)

Knowledge of Rifle Marksmanship Study
Prior Knowledge
May 2003

Matching

Directions: On the line to the left of each definition, write the letter of the term which best matches the definition. Each term may be used only once. There are more terms than definitions.

Definition	Term
____1. The firm consistent contact of the cheek with the weapon's butt stock	n) Bone support
____2. The distance between the rear sight aperture and the aiming eye	o) Eye relief
____3. The body's skeletal structure supporting the rifle's weight	p) Firing hand placement
____4. The point in the breathing cycle during which the body is most relaxed, allowing the sights to settle at the natural point of aim	q) Firm pistol grip
____5. The skillful manipulation of the trigger that causes the rifle to fire without disturbing sight alignment or sight picture	r) Follow-through
____6. "V" formed between the thumb and index finger on the trigger	s) Muscular relaxation
____7. Continued application of the fundamentals until the round has exited the barrel	t) Natural respiratory pause
____8. Centering the clear tip of the front sight post both horizontally and vertically in the rear sight aperture	u) Recovery
____9. The state of tension required to properly control the rifle	v) Sight alignment
	w) Stable firing position
	x) Stock weld
	y) Trigger control
	z) Zeroing

	Strongly agree	Agree	Disagree	Strongly disagree
Suppose a shooter's muscles never got fatigued (this is a hypothetical question) …				
10. … it would be OK to "muscle" the rifle into position.	❑	❑	❑	❑
11. … there would be little need for bone support.	❑	❑	❑	❑
Consistency is important in shooting because …				
12. … even very small changes in body position from one shot to the next can result in a poor shot.	❑	❑	❑	❑
13. … it helps you figure out what to adjust shot to shot.	❑	❑	❑	❑

14. Given a randomly shaped target, which figure best shows the correct aiming point?
    d) Figure 1
    e) Figure 2
    f) Figure 3

Figure 1

Figure 2

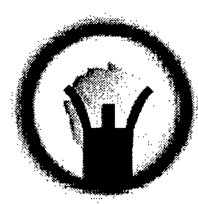
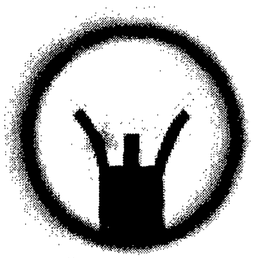


Figure 3

Multiple Choice

Directions: Use this picture when answering questions 15 and 16. For each question, select the alternative that best answers the question.



15. Which best describes the sight picture/sight alignment shown in the picture above?
    e) Proper sight picture, proper sight alignment
    f) Proper sight picture, improper sight alignment
    g) Improper sight picture, proper sight alignment
    h) Improper sight picture, improper sight alignment

16. Given the above sight picture/sight alignment, which figure below best shows where the round would strike? Assume a properly zeroed rifle, no wind or weather effects, and a properly fired weapon at 300 yards.
    e) Figure 1
    f) Figure 2
    g) Figure 3
    h) Figure 4

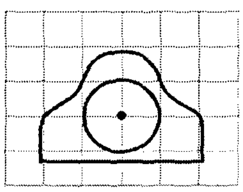


Figure 1

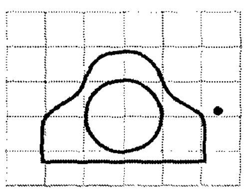


Figure 2

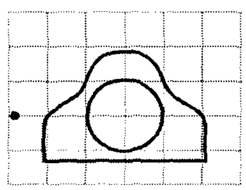


Figure 3

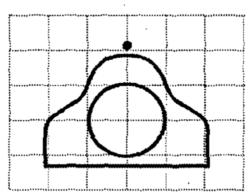
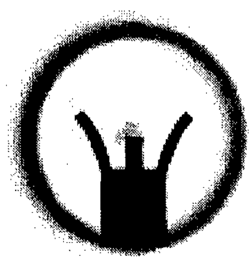


Figure 4

Directions: Use this picture when answering questions 17 and 18. For each question, select the alternative that best answers the question.



17. Which best describes the sight picture/sight alignment shown in the picture above?
    e) Proper sight picture, proper sight alignment
    f) Proper sight picture, improper sight alignment
    g) Improper sight picture, proper sight alignment
    h) Improper sight picture, improper sight alignment

18. Given the above sight picture/sight alignment, which figure below best shows where the round would strike? Assume a properly zeroed rifle, no wind or weather effects, and a properly fired weapon at 300 yards.
    e) Figure 1
    f) Figure 2
    g) Figure 3
    h) Figure 4

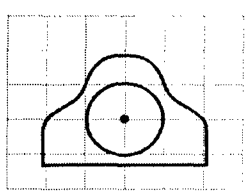


Figure 1

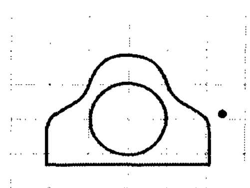


Figure 2

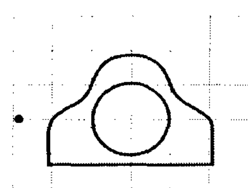


Figure 3

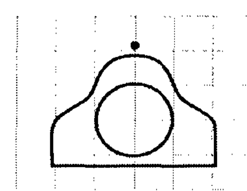
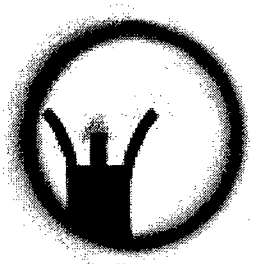


Figure 4

Directions: Use this picture when answering questions 19 and 20. For each question, select the alternative that best answers the question.



19. Which best describes the sight picture/sight alignment shown in the picture above?
    e) Proper sight picture, proper sight alignment
    f) Proper sight picture, improper sight alignment
    g) Improper sight picture, proper sight alignment
    h) Improper sight picture, improper sight alignment

20. Given the above sight picture/sight alignment, which figure below best shows where the round would strike? Assume a properly zeroed rifle, no wind or weather effects, and a properly fired weapon at 300 yards.
    e) Figure 1
    f) Figure 2
    g) Figure 3
    h) Figure 4

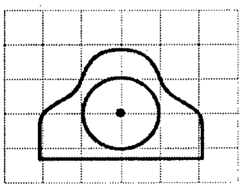


Figure 1

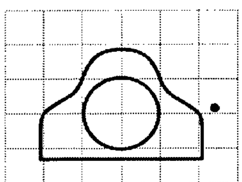


Figure 2

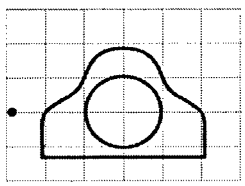


Figure 3

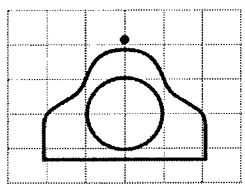
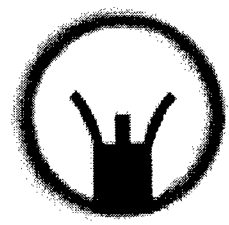
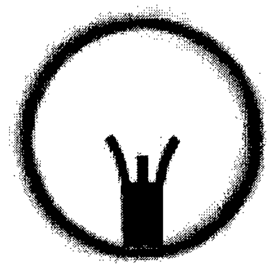


Figure 4

<u>Directions</u>: Use these pictures when answering questions 21 to 23. For each question, select the alternative that best answers the question.


Sight picture #1


Sight picture #2


Sight picture #3

Note: It may be helpful to read all 3 questions before answering.

21. Which sight picture above best reflects the Marine's eye relief shown in the picture to the left?
    d) Sight picture #1
    e) Sight picture #2
    f) Sight picture #3

22. Which sight picture above best reflects the Marine's eye relief shown in the picture to the left?
    d) Sight picture #1
    e) Sight picture #2
    f) Sight picture #3

23. Which sight picture above best reflects the Marine's eye relief shown in the picture to the left?
    d) Sight picture #1
    e) Sight picture #2
    f) Sight picture #3

Multiple Choice

24. In the sitting position, which direction does the rifle muzzle move when the rifle is fired while inhaling? Assume breathing from the chest.
    e) Up
    f) Down
    g) Left
    h) Right

25. Which of the following safety rules best enforces muzzle awareness?
    e) Treat every weapon as if it were loaded.
    f) Never point a weapon at anything you do not intend to shoot.
    g) Keep your finger straight and off the trigger until you are ready to fire.
    h) Keep the weapon on safe until you intend to fire.

26. Which of the following is the proper rear sight elevation setting when firing at the 300-yard line? Assume a zeroed rifle.
    e) 5
    f) 5/3
    g) 8/3
    h) 8/3-2

27. How far will 2 clicks of the rear sight windage move the strike of the round at 500 yards?
    e) 1 inch
    f) 2 1/2 inches
    g) 3 3/4 inches
    h) 5 inches

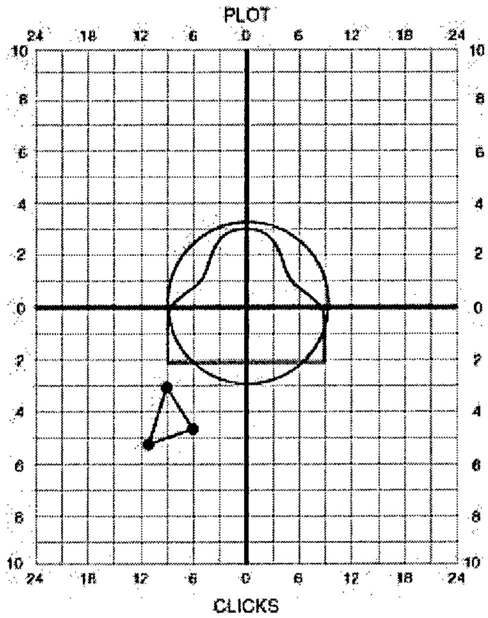
28. If the Marine's head is not erect or is creeping up on the rear sight, what does this indicate?
    a) Improper grip
    b) Improper stock weld
    c) Improper sling tension
    d) Improper sling assembly

29. Which reason best explains the function of bone support?
    a) To provide a strong frame to absorb the rifle recoil
    b) To help support the weight of the rifle
    c) To provide rigid contact with the ground
    d) To allow the shooter to resist strong crosswinds in the field

30. If a Marine is using improper breath control during rifle firing, what is most likely to occur?
    a) The Marine will see the front sight post move up and down.
    b) The Marine will be consistently inhaling and exhaling at the same point in time during the respiratory cycle for each shot.
    c) The Marine's right elbow will be placed against his or her rib cage.
    d) The rifle butt will move in the Marine's shoulder.

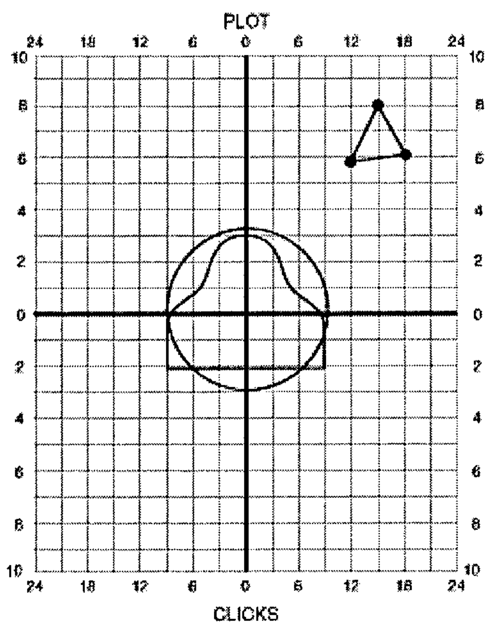
Questions 31–32:
Triangulate the shot group. Write the windage and elevation adjustments needed to place the **center of the shot group** into the center of the target. Specify the number of clicks and the direction. Keep in mind the rifle is set at the initial sight setting (flush and center) for **each** question.

UNITS ARE IN CLICKS. YOU DO NOT HAVE TO PERFORM ANY CONVERSIONS.



31. FSP: _____ clicks, ❑ up ❑ down
    RSW: _____ clicks, ❑ left ❑ right

UNITS ARE IN CLICKS. YOU DO NOT HAVE TO PERFORM ANY CONVERSIONS.



32. FSP: _____ clicks, ❑ up ❑ down
    RSW: _____ clicks, ❑ left ❑ right

UNITS ARE IN CLICKS. YOU DO NOT HAVE TO PERFORM ANY CONVERSIONS.

	Up or down	Left or right	Erratic	No change
In which direction will the natural point of aim shift (right-handed shooter, KNEELING) …				
33. … if the left hand is moved along the handguard?	❑	❑	❑	❑
34. … if the rifle butt is moved up or down in the shoulder?	❑	❑	❑	❑
35. … if the left elbow is moved along the knee?	❑	❑	❑	❑
36. … if the entire body is moved left in relation to the target?	❑	❑	❑	❑
In which direction will the rifle muzzle shift from shot to shot …				
37. … if the trigger finger is in contact with the receiver or pistol grip while firing?	❑	❑	❑	❑
38. … if the shooter is holding his breath too long?	❑	❑	❑	❑
39. … if the shooter has high muscle fatigue?	❑	❑	❑	❑
40. … if the shooter's position is constantly changing?	❑	❑	❑	❑

APPENDIX W

CLASSROOM TEST OF SCIENTIFIC REASONING

Knowledge of Rifle Marksmanship Study
Scientific Reasoning
May 2003

Your responses will be kept completely confidential. The results of this survey will be reported only for this study as a whole. Your particular responses will not be identifiable in any way.

Directions to Students:

This is a test of your ability to apply aspects of scientific and mathematical reasoning to analyze a situation to make a prediction or solve a problem. Circle the letter next to the best answer for each item. If you do not fully understand what is being asked in an item, please ask the test administrator for clarification.

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO

1. Suppose you are given two balls of clay of equal size and shape. The two balls also weigh the same. One of the balls is flattened into a pancake-shaped piece. *Which of these statements is correct?*

   a. The pancake-shaped piece weighs more than the ball
   b. The two pieces still weigh the same
   c. The ball weighs more than the pancake-shaped piece

2. *because*

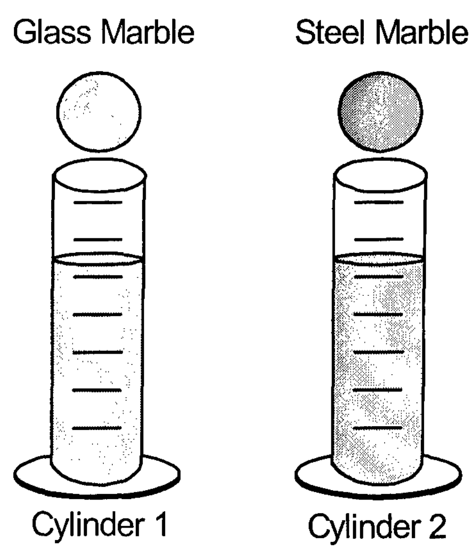
   a. the flattened piece covers a larger area.
   b. the ball pushes down more on one spot.
   c. when something is flattened it loses weight.
   d. clay has not been added or taken away.
   e. when something is flattened it gains weight.

3. To the right are drawings of two cylinders filled to the same level with water. The cylinders are identical in size and shape.

   Also shown at the right are two marbles, one glass and one steel. The marbles are the same size, but the steel one is much heavier than the glass one.

   When the glass marble is put into Cylinder 1, it sinks to the bottom and the water level rises to the 6th mark. *If we put the steel marble into Cylinder 2, then the water will rise*

   a. to the same level as it did in Cylinder 1
   b. to a higher level than it did in Cylinder 1
   c. to a lower level than it did in Cylinder 1



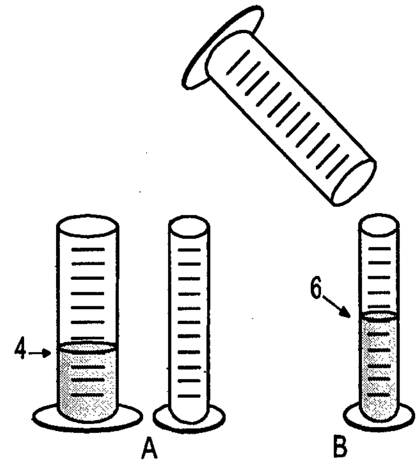
4. *because*

   a. the steel marble will sink faster.
   b. the marbles are made of different materials.
   c. the steel marble is heavier than the glass marble.
   d. the glass marble creates less pressure.
   e. the marbles are the same size.

5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).

   Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*

   a. to about 8
   b. to about 9
   c. to about 10
   d. to about 12
   e. none of these answers is correct



6. *because*

   a. the answer cannot be determined with the information given.
   b. it went up 2 more before, so it will go up 2 more again.
   c. it goes up 3 in the narrow for every 2 in the wide.
   d. the second cylinder is narrower.
   e. one must actually pour the water and observe to find out.

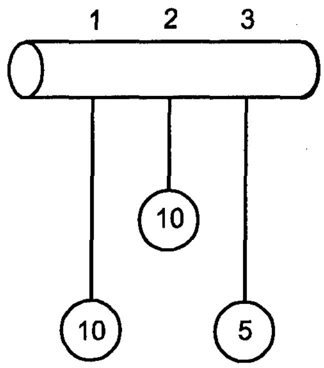
7. Water is now poured into the narrow cylinder (described in Item 5 above) up to the 11th mark. *How high would this water rise if it were poured into the empty wide cylinder?*

   a. to about 7 1/2
   b. to about 9
   c. to about 8
   d. to about 7 1/3
   e. none of these is correct

8. *because*

   a. the ratios must stay the same.
   b. one must actually pour the water and observe to find out.
   c. the answer cannot be determined with the information given.
   d. it was 2 less before so it will be 2 less again.
   e. you subtract 2 from the wide for every 3 from the narrow.

9. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.



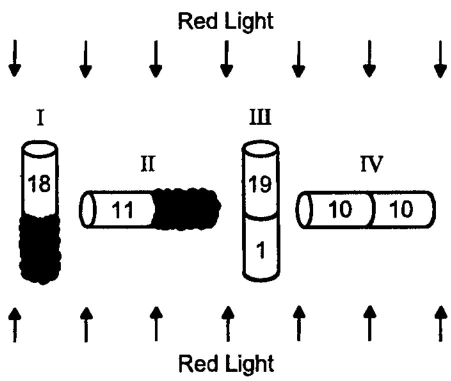
Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which string(s) would you use to find out?*

a. only one string
b. all three strings
c. 2 and 3
d. 1 and 3
e. 1 and 2

10. *because*

a. you must use the longest strings.
b. you must compare strings with both light and heavy weights.
c. only the lengths differ.
d. to make all possible comparisons.
e. the weights differ.

11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.



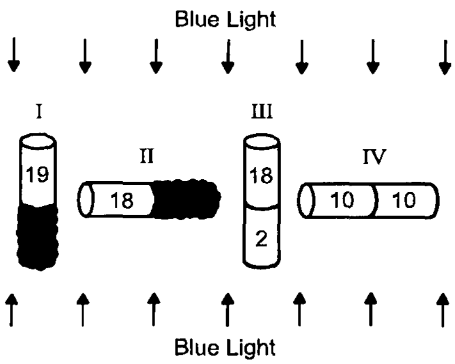
This experiment shows that flies respond to (respond means move to or away from):

a. red light but not gravity
b. gravity but not red light
c. both red light and gravity
d. neither red light nor gravity

12. *because*

a. most flies are in the upper end of Tube III but spread about evenly in Tube II.
b. most flies did not go to the bottom of Tubes I and III.
c. the flies need light to see and must fly against gravity.
d. the majority of flies are in the upper ends and in the lighted ends of the tubes.
e. some flies are in both ends of each tube.

13. In a second experiment, a different kind of fly and blue light was used. The results are shown in the drawing.



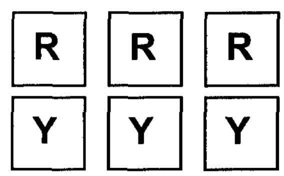
These data show that these flies respond to (respond means move to or away from):

a. blue light but not gravity
b. gravity but not blue light
c. both blue light and gravity
d. neither blue light nor gravity

14. *because*

a. some flies are in both ends of each tube.
b. the flies need light to see and must fly against gravity.
c. the flies are spread about evenly in Tube IV and in the upper end of Tube III.
d. most flies are in the lighted end of Tube II but do not go down in Tubes I and III.
e. most flies are in the upper end of Tube I and the lighted end of Tube II.

15. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red?*

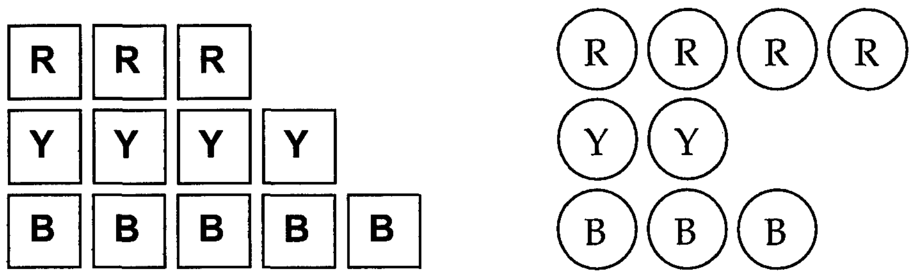


a. 1 chance out of 6
b. 1 chance out of 3
c. 1 chance out of 2
d. 1 chance out of 1
e. cannot be determined

16. *because*

a. 3 out of 6 pieces are red.
b. there is not way to tell which piece will be picked
c. only 1 piece of the 6 in the bag is picked.
d. all 6 pieces are identical in size and shape.
e. only 1 red piece can be picked out of the 3 red pieces.

17. Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about. Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece.



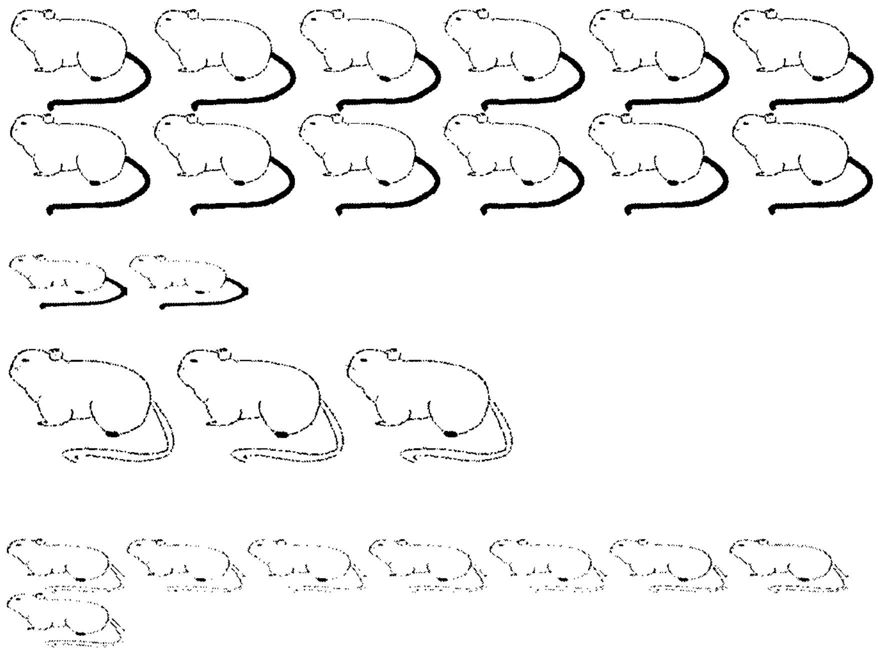
What are the chances that the piece is a red round or blue round piece?

a. cannot be determined
b. 1 chance out of 3
c. 1 chance out of 21
d. 15 chances out of 21
e. 1 chance out of 2

18. *because*

a. 1 of the 2 shapes is round.
b. 15 of the 21 pieces are red or blue.
c. there is no way to tell which piece will be picked.
d. only 1 of the 21 pieces is picked out of the bag.
e. 1 of every 3 pieces is a red or blue round piece.

19. Farmer Brown was observing the mice that live in his field. He discovered that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.



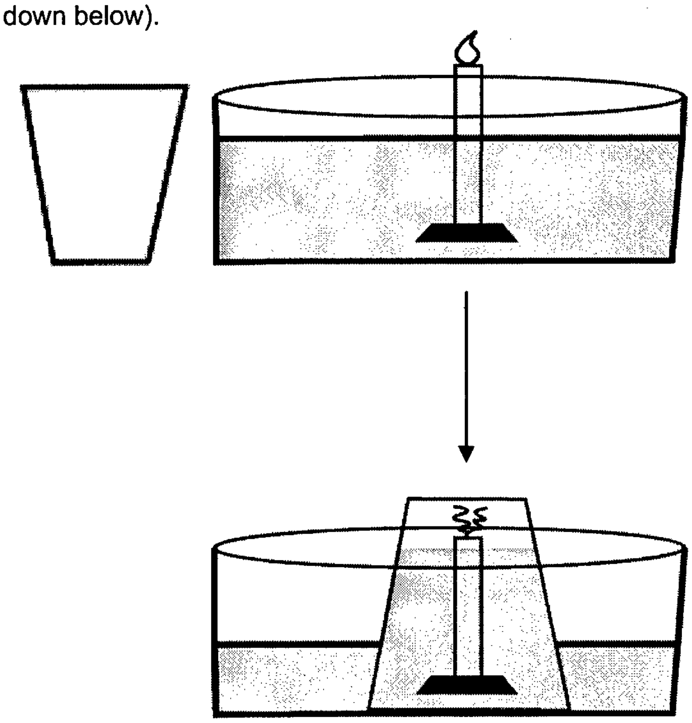
Do you think there is a link between the size of the mice and the color of their tails?

a. appears to be a link
b. appears not to be a link
c. cannot make a reasonable guess

20. *because*

a. there are some of each kind of mouse.
b. there may be a genetic link between mouse size and tail color.
c. there were not enough mice captured.
d. most of the fat mice have black tails while most of the thin mice have white tails.
e. as the mice grew fatter, their tails became darker.

21. The figure below at the left shows a drinking glass and a burning birthday candle stuck in a small piece of clay standing in a pan of water. When the glass is turned upside down, put over the candle, and placed in the water, the candle quickly goes out and water rushes up into the glass (as shown down below).



This observation raises an interesting question: Why does the water rush up into the glass?

Here is a possible explanation. The flame converts oxygen into carbon dioxide. Because oxygen does not dissolve rapidly into water but carbon dioxide does, the newly-formed carbon dioxide dissolves rapidly into the water, lowering the air pressure inside the glass.

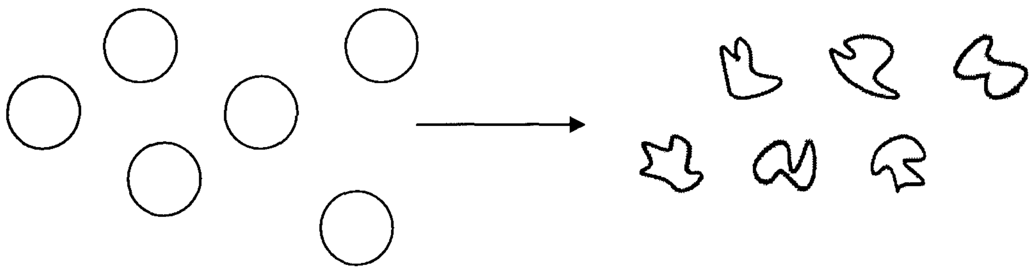
Suppose you have the materials mentioned above plus some matches and some dry ice (dry ice is frozen carbon dioxide). *Using some or all of the materials, how could you test this possible explanation?*

a. Saturate the water with carbon dioxide and redo the experiment noting the amount of water rise.
b. The water rises because oxygen is consumed, so redo the experiment in exactly the same way to show water rise due to oxygen loss.
c. Conduct a controlled experiment varying only the number of candles to see if that makes a difference.
d. Suction is responsible for water rise, so put a balloon over the top of an open-ended cylinder and place the cylinder over the burning candle.
e. Redo the experiment, but make sure it is controlled by holding all independent variables constant; then measure the amount of water rise.

22. What result of your test (mentioned in #21 above) would show that your explanation is probably wrong?

a. The water rises the same as it did before.
b. The water rises less than it did before.
c. The balloon expands out.
d. The balloon is sucked in.

23. A student put a drop of blood on a microscope slide and then looked at the blood under a microscope. As you can see in the diagram below, the magnified red blood cells look like little round balls. After adding a few drops of salt water to the drop of blood, the student noticed that the cells appeared to become smaller.



Magnified Red Blood Cells After Adding Salt Water

This observation raises an interesting question: Why do the red blood cells appear smaller?

Here are two possible explanations: 1. Salt ions (Na+ and Cl-) push on the cell membranes and make the cells appear smaller. 2. Water molecules are attracted to the salt ions so the water molecules move out of the cells and leave the cells smaller.

To test these explanations, the student used some salt water, a very accurate weighing device, and some water-filled plastic bags, and assumed the plastic behaves just like red-blood-cell membranes. The experiment involved carefully weighing a water-filled bag, then placing the bag in a salt solution for ten minutes, and then reweighing the bag after it was taken out of the solution.

What result of the experiment would best show that explanation I is probably wrong?

a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller

24. What result of the experiment would best show that explanation II is probably wrong?

a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller

Classroom Test of Scientific Reasoning Key

Question No.	Correct answer
1	b
2	d
3	a
4	e
5	b
6	c
7	d
8	a
9	e
10	c
11	b
12	a
13	c
14	d
15	c
16	a
17	b
18	e
19	a
20	d
21	a
22	a
23	a
24	b

APPENDIX X

ESP SCORING RUBRIC (STUDY 3)

Scenerio	Position	Correct
1	prone	all position elements correct
2	prone	contains incorrect position elements
3	sitting	all position elements correct
4	sitting	contains incorrect position elements
5	kneeling	all position elements correct
6	kneeling	contains incorrect position elements
7	standing	all position elements correct
8	standing	contains incorrect position elements

Sce-nerio	fwd hand	firing hand	elbow	eye relief	leg/feet placment	rifle butt	leg	foot	body
2			1		1		n/a	n/a	1
4		1	1		1		n/a	n/a	n/a
6					n/a	1	1	1	n/a
8			1		1		n/a	n/a	1

Note. A "1" indicates an incorrect position element. "n/a" indicates position element not part of scenario.

APPENDIX Y

ESTIMATING CHANGE TRAJECTORIES OF RECORD-FIRE PERFORMANCE

This study focused on the 53 second LTs in Study 3 who went through entry-level marksmanship training. The training was composed of classroom instruction on rifle marksmanship in the beginning, live-fire practice for four days, and a qualifying trial on the last day. For each of the live-fire practices and the qualifying trial, all 53 2nd LTs completed surveys which asked about their record-fire scores for each day and about how they thought or felt about their own record-fire performance for that day.

This section is concerned with estimating change trajectories of Marines' record-fire performance over 5 days, via applying growth modeling techniques to the survey data. Growth modeling techniques are a well-established method and have been extremely useful in various research areas when there is a moderate number of repeated observations for a moderate number of subjects (e.g., in education, Raudenbush & Bryk, 2002). Estimation of the change trajectories may suggest how 2nd LTs with no prior knowledge change in their shooting performance over a short but intensive training period (e.g., in this study, 2 days of classroom instruction and 5 days of live-fire practice or qualifying trial). Growth modeling techniques can be used to address the following questions:

1. What is the expected level of record-fire performance for a typical Marine in the beginning of the study (i.e., initial status)?
2. How fast does a typical Marine change his shooting performance (i.e., growth rate)?
3. What is the individual variation around the expected level (1) or the expected change rate (2)?
4. Which characteristics of a Marine relate to the level of shooting performance?
5. Which characteristics of a Marine relate to the change rate of shooting performance?

Questions 1 and 2 concern the estimation of the change trajectories of a typical 2nd LT. Question 3 concerns individual variations around the change trajectories. Questions 4 and 5 concern the correlates of the level or the change. Questions 4 and 5 are reserved in this section for future analyses.

Before presenting the statistical models and the results, it would be helpful to discuss two features of the data. First, there were five repeated measures—the surveys of five consecutive days. However, the observations made on the first day have not been used in the analysis. Because there were too many missing observations on the first day, it was hard to assume that the mechanisms underlying the missing data would be "ignorable" (Little & Rubin, 1987). When missing-data mechanisms are "nonignorable," the data analysis has to deal with it, since many statistical software such as SAS Proc Mixed assumes that data are missing at random (MAR), which belongs to an ignorable missing mechanism. Although there are more advanced ways to deal with nonignorable missing data (Hedeker & Gibbons, 1997; Little, 1995; Little & Rubin, 1987, chap. 11), in this section, we analyze the data excluding the observations for the first occasion.

Table 69 presents descriptive statistics of repeated measures on each day: The first panel shows all available observations, and the second panel shows the repeated observations for only the 2nd LTs who reported their shooting scores on the first day (Day1). From the first panel, it is clear that no low-performing people reported data on the first day, as the minimum score for the first day is 193, in comparison to 170 and 175 for the next three days. It is further confirmed in the second panel of the table. The minimum scores for the participants who reported on the first day were 186-190 for the later days, while for all available participants the minimum scores were 170-190 for the later days. Thus, one may conclude that the missing-data mechanism on the first day is nonignorable (Little & Rubin, 1987).

Table 69

Descriptive Statistics of Repeated Measures of Record-Fire Performance

	n	*M*	*SD*	**Min.**	**Max.**
Day1	10	206.50	9.76	193	222
Day2	32	213.37	17.43	170	237
Day3	40	216.17	14.28	175	235
Day4	47	215.72	15.83	175	240
Day5	53	214.45	14.46	190	240
Day1	10	206.50	9.76	193	222
Day2	9	214.66	17.09	186	237
Day3	10	218.30	14.87	186	234
Day4	10	214.80	15.59	188	234
Day5	10	217.40	14.22	190	231

For the second special feature of the data, the observations on the last day (i.e., the fifth day) are substituted by the record-fire performance of the qualifying trial. The last-day observations in the post-fire surveys are supposed to be equivalent to the record-fire scores of the qualifying exam. The difference is that the observations in the post-fire surveys were self-reported, while the qualifying record-fire scores are official scores on record. Given that the qualifying record-fire scores would be more reliable than self-reported scores, we used qualifying record-fire scores instead of self-reported scores in the survey.

As expected, the two scores are not equivalent for many people. Figure 17 presents a stem-and-leaf plot and a boxplot of the difference values between self-reported and qualifying record-fire scores (i.e., difference = self-reported scores - qualifying scores). The difference values mostly range between -4 and 4; within this range the scores make a bell-shaped distribution. It seems to be random errors of self-reported scores due to forgetfulness, for example. There are also three outliers with values of 7 and two 13s.

```
Stem Leaf                          #          Boxplot
  13 00                            2             *
  12
  11
  10
   9
   8
   7 0                             1             0
   6
   5
   4 00                            2             |
   3 00                            2             |
   2 000000000                     9          +-----+
   1 000                           3          |  +  |
   0 00000000000000000000000      23          *-----*
  -0                                             |
  -1 0000                          4             |
  -2 0                             1             |
  -3
  -4 000                           3             0
```

Figure 17. A stem-and-leaf plot and a boxplot of the difference values, which is calculated by subtracting qualifying exam scores from self-reported scores.

In sum, the data have four repeated measures of shooting performance from the second live-fire day to the qualifying day (i.e., the fifth day), with the measures of the last occasion being replaced by the qualifying record-fire scores.

The following statistical model is posed for the data:

$$Y_{ti} = \pi_{0i} + \pi_{1i}\,(Day_{ti} - Day_{..}) + \pi_{2i}\,(Day_{ti} - Day_{..})^2 + e_{ti} \qquad r_{ti} \sim N(0, \sigma^2)\,, \qquad (1)$$

where Y_{ti} is a measure of knowledge map of a Marine i at occasion t, t=1, ... 4; and Day is the number of days since the first live-fire practice day (i.e., takes on values of 2, 3, 4, and 5).

$$\begin{aligned} \pi_{0i} &= \beta_{00} + r_{0i} && r_{0i} \sim N(0, \tau_{00}), \\ \pi_{1i} &= \beta_{10} + r_{1i} && r_{1i} \sim N(0, \tau_{11}), \qquad (2) \\ \pi_{2i} &= \beta_{20}. \end{aligned}$$

Equation (1) is a level-1 model that estimates the change trajectory of a 2nd LT i, which is also referred to as a within-individual model. The equation includes a second order polynomial of the time-clocking variable (i.e., Day), to capture a curvature in the change pattern. The existence of a curvature in the change pattern implies that the instantaneous change rate (i.e., a change rate at a given time point) is not constant over time. Raudenbush and Bryk (2002) term this kind of change pattern a "quadratic growth model," while Singer and Willet (2003) term this a "quadratic change trajectory." In comparison to a linear change trajectory, a quadratic change trajectory fitted slightly better ($\chi^2_{df=1}$ = 3.4, p value = .065; and AIC is 1363.3 for the quadratic change and 1364.7 for the linear change).

The time-clocking variable (i.e., Day) is centered at the average of the Day variable (i.e., 3.5). By virtue of this centering, the parameter π_{0i} represents the level of record-fire performance of a 2nd LT i in the middle of the training period; and the parameter π_{1i} represents the instantaneous change rate of a 2nd LT i in the middle of the training period. The parameter π_{2i} captures the curvature parameter that is not contingent on the centering or the acceleration in the change pattern. While the meaning of the other parameters is contingent upon the centered value (e.g., average of the Day variable, which is 3.5), the meaning of the curvature parameter is not. Centering at the average of the time-clocking variable is desirable in higher order polynomial models, as it decreases a high correlation between the time variables (e.g., in this analysis, the first and the second polynomial of the Day variable).

Equation (2) is a level-2 model that is also referred to as a between-individual model. The performance level and the change rate in the middle of the training period are posed to be random (i.e., varying across Marines). The curvature parameter is posed to be fixed. In comparison to the random curvature, the fixed curvature model fitted better to the data ($\chi^2_{df=3}$ = 1.3, p value = .73; and AIC is 1363.3 for the fixed curvature and 1368.0 for the random curvature).

Table 70 presents the results of the analysis. The upper panel presents fixed effects, which captures an average change trajectory for a typical 2nd LT. In the middle of the live-fire training period, a typical Marine is expected to score about 215 points. In the middle of the period, a typical Marine increases his score 1.4 points per day. The curvature is minus 1.26 points, i.e., the deceleration is 1.26. The Marines tend to increase their live-fire performance at a faster rate in the beginning and at a slower rate at the end of the training period.

Table 70

Results of Fitting the Above Growth Model (N = 53)

Parameter			Estimate
Fixed effects			
Mean shooting score in the middle of the training period		β_{00}	215.12*** (2.03)
Mean change rate in the middle of the training period		β_{10}	1.41* (0.84)
Mean curvature		β_{20}	-1.26* (0.67)
Variance components			
Level-1:	Within-person	σ^2	20.78***
Level-2:	Within-individual	σ^2	70.27***
	In status in the middle of the training period	τ_{00}	156.26***
	In change rate in the middle of the training period	τ_{11}	13.30**

Note: The model is estimated using SAS Proc Mixed. The covariance component was estimated but not displayed for the simplicity of presentation.
* $p < .05$. ** $p < .01$. *** $p < .001$.

The lower panel presents variance components. The level-2 variance components estimate between-individual variation around the corresponding fixed effects. Second LTs are significantly different in their status and change rate in the middle of the training period. Figure 18 displays the estimated change trajectories of three hypothetical 2nd LTs. The middle trajectory is the average trajectory; the increasing trajectory is the trajectory of a Marine who has the change rate of 1 standard deviation above the mean change rate; and the decreasing trajectory is that of a Marine who has the change rate of 1 standard deviation below the mean. One may see the wide variation across individuals in the change pattern. On average, a 2nd LT tended to roughly increase over time, but faster in the beginning and slower toward the end, scoring around 215 in the middle of the training. However, there is a wide range in the average performance and the change rate across 2nd LTs. Some increase more rapidly, and others even decrease over time. The great range of variation between individuals may be understood when one considers that the 2nd LTs had no prior experience with marksmanship. According to the phases-of-skill-learning theory, when one begins to learn skills such as marksmanship, performance tends to be inconsistent and fallible.

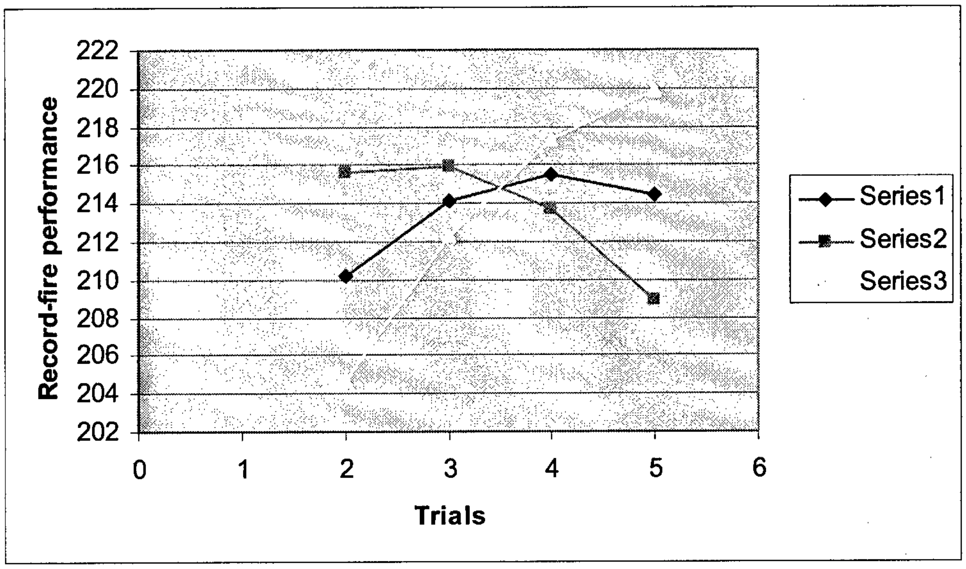


Figure 18. Three estimated change trajectories: the average, one standard deviation below the average change rate, and one standard deviation above the average change rate.

APPENDIX Z

LONGITUDINAL ANALYSES OF KNOWLEDGE MAPPING

Repeated measures of knowledge maps in a short span of time could help us understand the process of learning. In settings where learning is actively aided by intended interventions, repeated measures over a short span of time could provide insight on how people have changed their knowledge maps in response to the interventions.

This study's sample is the 2nd LTs going through entry-level marksmanship training in Study 3 (N = 53). In this study, knowledge maps were administered on six occasions: before and after classroom instruction, two times during live-fire practice, and two times after qualification. To investigate how Marines change their knowledge maps in response to classroom instruction or live-fire experience, we employed the statistical tool of growth modeling techniques.

Growth modeling techniques are a well-established method in statistics and have been extremely useful in various research areas when there is a moderate number of repeated observations for a moderate number of subjects (e.g., in education, Raudenbush & Bryk, 2002). However, the techniques have not yet been employed in studying knowledge maps. Growth modeling techniques would help provide pertinent insights to the study of knowledge maps by examining the following questions:

1. What is the expected level for a typical Marine's knowledge map at the beginning of the study (i.e., initial status)?
2. How fast does a typical Marine change his knowledge maps to be more like those of experts (i.e., growth rate)?
3. How much is the individual variation around the expected initial status (1) or the expected growth rate (2)?
4. Which characteristics of a Marine relate to the initial level of knowledge maps?
5. Which characteristics of a Marine relate to the growth rate of knowledge maps?

Questions 1-3 quantify growth patterns of Marines in their knowledge maps. As the 53 second LTs had no prior experience with rifles, their knowledge maps provided data to study the growth patterns in knowledge maps of beginner learners when they are exposed to intensive classroom instruction followed by live-fire practice.

However, these questions may be viewed from a different perspective. If most Marines change their knowledge maps to be more like those of experts in response to classroom instruction or live-fire experience at a significant rate, it could provide evidence that knowledge maps are sensitive to classroom instruction or live-fire experience. The questions for this strand of inquiry are:

1. How sensitive are knowledge maps to classroom instruction?
2. How sensitive are knowledge maps to the live-fire practice sessions that follow classroom instruction?

To examine the questions addressed above (Questions 4 and 5 are reserved in this section for future analyses), a statistical model is posed as follows:

$$Y_{ti} = \pi_{0i} + \pi_{1i}\,\text{Time1} + \pi_{2i}\,\text{Time2} + e_{ti} \qquad r_{ti} \sim N(0, \sigma^2)\,, \qquad (1)$$

where Y_{ti} is a measure of the knowledge map of a Marine i at occasion t, t=1, ... 6; Time1 is the number of days since the first measure during classroom instruction; and Time2 is the number of days since the end of classroom instruction during live-fire practice, qualification, and after qualification.

$$\pi_{0i} = \beta_{00} + r_{0i} \qquad r_{0i} \sim N(0, \tau_{00}),$$

$$\pi_{1i} = \beta_{10} + r_{1i} \qquad r_{1i} \sim N(0, \tau_{11}), \qquad (2)$$

$$\pi_{2i} = \beta_{20} + r_{2i} \qquad r_{2i} \sim N(0, \tau_{22}).$$

Equation (1) is a level-1 model that deals with repeated measures within a 2nd LT i; and equations that follow are a level-2 model that examines the growth pattern parameters at level 1 as an outcome. Thus, the level-1 model can be viewed as a within-individual model while the level-2 model can be viewed as a between-individual model.

The key parameters are β_{10} and β_{20}, which are the expected rate of change during classroom instruction and the expected rate of change during live-fire experience, respectively. The variance components, τ_{11} and τ_{22}, capture individual variations around the expected rates, β_{10} and β_{20}, respectively.

Note that in this particular study, there are two time clocking variables, Time1 and Time2 (Equation 1). One clocks time during the classroom instruction and the other clocks time during the live-fire experience that followed the classroom instruction. This is based on the strong rationale that the Marines will change at a faster rate during the classroom instruction period than the other period, because it intensively teaches the Marines so that they can construct knowledge maps closer to those of experts. Thus different slopes (i.e., rates of change) for the different periods are initially hypothesized in the model, using two time clocking variables Time1 and Time2. Raudenbush and Bryk (2002) refer to this parameterization as piecewise growth models, and Singer and Willet (2003) term this as discontinuous individual change.

Table 71 presents the results. A typical 2nd LT tends to score 12.99 in the knowledge map measures before any instruction or any live-fire experience. During the classroom instruction, a 2nd LT increases 1.76 points a day on average; and during the following live-fire experience, he tends to increase 0.37 points a day. That is, on average, a 2nd LT changes his knowledge maps at a significantly fast rate into those of experts in response to the classroom instruction, and at a significant but slower rate in response to the live-fire experience that followed the classroom instruction. It is notable that the change rate during the first period is more than 4 times the change rate during the second period.

Table 71

Results of Fitting the Above Growth Model (n = 53)

Parameter			**Estimate**
Fixed effects			
Expected initial status		β_{00}	12.99*** (1.39)
Expected rate of change during classroom instruction		β_{10}	1.76** (0.59)
Rate of change during live-fire experience		β_{20}	0.37* (0.14)
Variance Components			
Level-1:	Within-person	σ^2	20.78***
Level-2:	In initial status	τ_{00}	79.15***
	In rate of change during classroom instruction	τ_{11}	9.11**
	In rate of change during live-fire experience	τ_{22}	0.75**

Note. The model is estimated using SAS Proc Mixed. All relevant covariance components were estimated but not displayed for the simplicity of presentation.

* $p < .05$. ** $p < .01$. *** $p < .001$.

In addition, there is a significant variation around all growth parameters, initial status, the rate of change during classroom instruction, and the rate of change during live-fire experience. This suggests that 2nd LTs show individual differences in where they begin, how fast they grow in response to classroom instruction, and how fast they grow in response to live-fire experience. For example, a 2nd LT who is one standard deviation above the rate of change during classroom instruction tends to increase 4.78 points per day during the classroom instruction, while a 2nd LT who is one standard deviation below decreases 1.26 points per day during the classroom instruction. Figure 19 displays growth patterns of three hypothetical 2nd LTs with an average, one standard deviation above, and one standard deviation below rate of change during classroom instruction, other growth parameters (i.e., initial status and the rate of change during live-fire experience) being their averages.

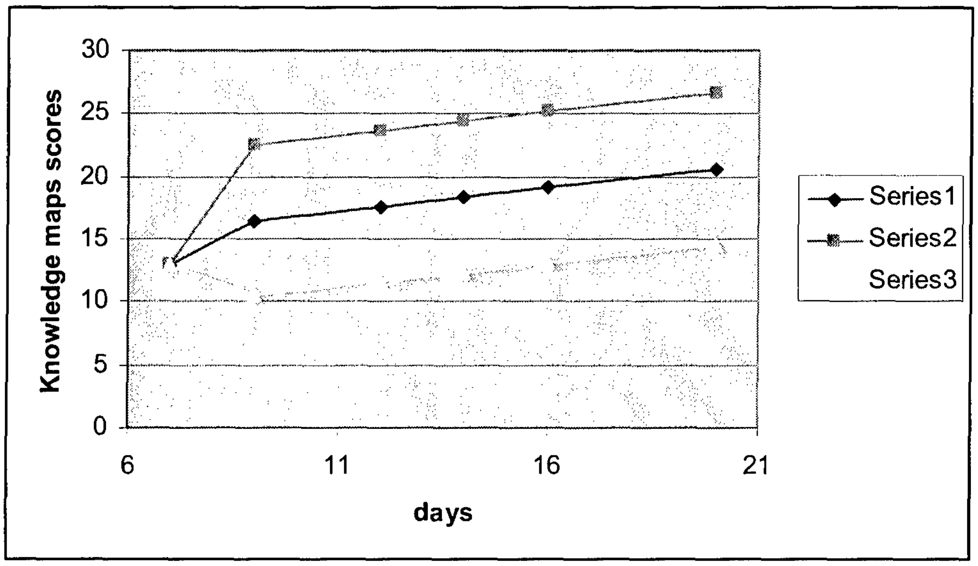


Figure 19. Estimated change trajectories in knowledge maps for three hypothetical 2nd LTs.

The process of learning (the change in knowledge maps over time) with intervening instruction or practice sessions could in turn provide information on the sensitivity of knowledge maps as a measure of knowledge to instruction or practice in the domain of rifle marksmanship. As explained above, on average, a 2nd LT's knowledge map scores increase at a fast and significant rate (1.76 points per day) during classroom instruction, but there is significant individual variation around it. Thus, it may suggest that knowledge maps tend to be sensitive to classroom instruction for 2nd LTs, but that the extent of sensitivity depends on the individuals. It would be interesting to further examine the correlates of the extent of sensitivity, i.e., which characteristics of the 2nd LTs relate to greater sensitivity to classroom instruction.

Also, a 2nd LT still shows gains in his knowledge map scores during live-fire exercises after classroom instruction (0.37 points per day), although the rate was much slower than during classroom instruction. This may also suggest that the knowledge map measure tends to be sensitive to the post-instruction live-fire experience for 2nd LTs, but that the extent of sensitivity depends on the individuals.

Knowledge maps of the current sample have been scored in more than one way. The same statistical model has been applied to the other scores of knowledge maps. The patterns of change are fairly similar to the results of the scores analyzed in this section, in that the change rate was high and significant during the classroom instruction period, and slower but still significant during the post-instruction live-fire experience period, and also in that there was significant variation in the growth pattern across individuals. However, the level of scores varied substantially between different kinds of scores. This is expected, because the scoring schemes varied in terms of leniency. Consistency across different types of scores supports the results and the implications.