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Effects of Rifle Handling, Target Acquisition, and Trigger Control on Simulated Shooting Performance

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14. ABSTRACT
Recent technological innovations have made highly-specific measurements related to shooting performance available to researchers. This study utilized data from several simulated shooting experiments to analyze specific patterns among rifle handling and trigger control, and to determine how they affect reaction time and accuracy among shooters of differing skill levels. Results demonstrated that relatively consistent patterns of specific variables occur among shooters of varying skill level; however, the magnitude of correlation between these variables, reaction time, and shot accuracy differ depending on shooter skill (e.g., trigger pull in skilled shooters seems to be more affected by reaction time than in less-skilled shooters). Findings suggest that Engagement Skills Trainer shot variables have the potential to be a useful measure of highly-precise marksmanship performance across multiple populations.

15. SUBJECT TERMS
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Introduction

Effective marksmanship is a cornerstone of military success for Soldiers at any level. The ability to shoot, maintain, employ, and engage with an assigned weapon is the first priority of Soldier training, and marksmanship skills are assessed annually as part of all Soldiers' performance evaluations (Department of the Army, 2012). The ability to effectively use a weapon is affected by a complex interaction of a shooter's sensory input, cognitive processing, and fine motor control. These elements have proven difficult to measure as they are relatively subtle and occur almost simultaneously. Recent technological innovations have made highly-specific measurements related to processes occurring before, during, and immediately after each shot more available to researchers, yielding valuable information for the development of military weapons training. However, the suitability of these precise measurements as a reliable way to compare marksmanship across shooter conditions has not yet been established. This study used archival data from past U.S. Army Aeromedical Research Laboratory (USAARL) studies on the Engagement Skills Trainer (EST) 2000 to analyze specific patterns among rifle handling and trigger control, and how they affect reaction time and accuracy between shooters of differing skill levels. Analyses were conducted on both data pooled from all shooters and data separated by the marksmanship skill level of the shooter to determine frequencies of significant bivariate correlations between EST variables, reaction time, and accuracy. An analysis of correlation strengths was conducted between shooter skill level groups and pooled shooter correlations to determine if variable relationships were consistent between shooters or if they changed with shooter skill.

Background

Military weapons training

Weapon proficiency is a core learning objective achieved during a Soldier's basic training. After a brief introduction period and basic tactical and Army heritage training, all Soldiers must complete what is referred to as Phase 2, or the "White Phase" of basic training. This 3-week period prepares new Soldiers to successfully pass the Army marksmanship qualification task, and covers all of the training requirements listed in the Soldier's Manual of Common Tasks: Warrior Skills Level 1 handbook (Department of the Army, 2012). Marksmanship skills are listed under Subject Area 1: Shoot/Maintain, Employ, and Engage with Assigned Weapon System and include the performance cornerstones listed in table 1.

Table 1.
Warrior Skill Level 1 marksmanship requirements.

Task number	Task name	Re-assessment frequency
071-COM-0032	Maintain an M16 series rifle/M4 series carbine	Annually
071-COM-0029	Perform a function check on an M16 series rifle/M4 series carbine	Quarterly
071-COM-0028	Load an M16 series rifle/M4 series carbine	Semi-annually
071-COM-0027	Unload an M16 series rifle/M4 series carbine	Semi-annually
071-COM-0030	Engage targets with an M16 series rifle/M4 series carbine	Semi-annually
071-COM-0033	Correct malfunctions of an M16 series rifle/M4 series carbine	Quarterly
071-COM-0031	Zero an M16 series rifle/M4 series carbine	Semi-annually

Specific marksmanship training guides have evolved over time to incorporate empirically-based methods for Soldiers to improve their performance. Generally, these modifications to training guides have been the result of technological advances that allow for more specific accuracy measurement and better determination of causal factors in skilled shooting. Findings from an Army Research Institute (ARI) study at Fort Benning, GA (Smith et al., 1980) suggested that basic marksmanship training at the time was rife with problems, including a lack of feedback on where shots hit targets, lack of instruction for zeroing individual weapons, and insufficient practice time. Army-wide improvements were implemented to address these issues, which were found in controlled studies to improve novice shooter performance by up to 29 percent (Smith et al., 1980). Since the improvements made in 1980, Army marksmanship training doctrine has continued to include specific exercises and techniques for improvement. The most recent training manual provides guidance to improve overall body strength and minimize sway, presents techniques to more accurately zero a weapon, and explains the physical foundations of bullet trajectory and the impact of pre-shot muzzle movement (James and Dyer, 2011).

To date, repetition appears to be the best tool for increasing marksmanship performance (Chung et al., 2006). However, pure repetition may not be the most efficient training tool, as it requires a great deal of time. The integration of sensory input, cognition, and fine motor control are not yet understood in the specific and practical way that would allow for more direct and standardized training based on common Soldier errors. If discernible patterns in these core elements of marksmanship were discovered between Soldiers of varying skill levels or between accurate and inaccurate shots, an extremely efficient and valuable training regimen could be developed based on common shot variables.

Existing correlates of marksmanship performance

Shooters are required to identify and track a target in order to make an accurate shot, so it is no surprise that acuity of sensory perception (with specific emphasis on visual acuity) is a strong correlate of marksmanship ability. Recent studies exploring the effect of vision on weapon utilization found that visual acuity accounts for more than 50 percent of variance in marksmanship performance on a standard EST weapons qualification task for participants whose

Snellen acuity ratings were manipulated between 20/20 and 20/60 with various contact lenses (Wells et al., 2009). Similar studies found that image resolution was also a significant correlate of shot accuracy, with shooter performance decreasing as the target's image resolution decreased (Temby et al., 2005). While a great deal of research assessing vision as an indicator of marksmanship performance has focused on basic ability to see and track a target, the ability to synthesize sensory input with fine motor control and cognitive processes related to making an accurate shot must be considered as a core component as well. Understanding the interaction of vision with other shooter processes and skills (even among shooters with good visual acuity) may be significantly enhanced through the analysis of aim path patterns (i.e., a shooter's point of aim recorded before, during, and after a shot) (Jones, King, and Gaydos, 2011). Such information could provide insight into measureable processes occurring during the target tracking phase immediately preceding a shot.

Connections between fine motor control and effective military marksmanship have been established in the literature for decades. A study in 1936 found a strong correlation between "rifle steadiness" and marksmanship ability (Humphreys, Buxton, and Taylor, 1936). Malone and Rasch (1964) determined that there was a significant correlation between arm-hand steadiness and marksmanship performance on the U.S. Marine Corps rifle course nearly 50 years ago. Additional research has found that the control of subtle motions prior to and during a shot (especially for shooters engaging a long-distance target) can have a significant effect on accuracy. The seemingly-insignificant motion resulting from breathing, heart beats, and instability related to fatigue can be the difference between a hit and missed target (Chung et al., 2005). While the specific relationship between shot accuracy and muzzle displacement as a result of subtle movements immediately preceding a shot has been studied in great detail (Torre, Maxey, and Piper, 1987; Department of the Army, 1989), a more complex analysis of small shifts in gun movement, aim path, and trigger pressure and their effects on accuracy and shot reaction time are not currently available.

Cognitive correlates of marksmanship have had mixed effects across shooters compared to sensory and fine motor correlates. A number of studies have attempted to understand the role of cognition in effective marksmanship through subjective, behavioral, and physiological measures. Significant correlations have been detected between cognitive abilities (as measured by cognitive screeners such as the CogScreen computerized battery or the Adult Decision-Making Competence battery) and performance of qualification tasks on the EST 2000 (Kelley et al., 2011). When comparing cognitive battery performance scores and shooting task performance, the cognitive abilities with the strongest correlations to shooting performance are attention, special orientation, and visual scanning (Kelley et al., 2011). Researchers have consistently demonstrated that cognitive effects are related to the skill of the shooter, with the impact of cognitive processes decreasing as a shooter becomes more practiced. A meta-analysis of shooting performance studies by Chung et al. (2006) found that cognitive factors were more influential on a novice shooter's performance, while sensory-motor factors were more important to an expert shooter's performance. Likewise, electroencephalographic (EEG) measures during standard qualification shooting tasks have shown that expert shooters have lower levels of cross-cortical communication between cognition and motor process centers during a shooting task than less-skilled shooters (Deeny et al., 2003), suggesting that shooters with more skill have a greater level of automatization during shooting tasks. This increased cognitive component in novice shooters results in a higher perceived workload during marksmanship tasks and a higher susceptibility to poor performance as a result of various unintended influences on the shot (e.g., equipment malfunctions, anxiety, discomfort) (Chung et al., 2006; Kerick and Allender, 2004). A more thorough analysis of specific differences in weapon handling and aiming among shooters of different levels would be useful in the determination of how cognitive workload differences between skilled and unskilled shooters may influence marksmanship performance.

Most studies into correlates or predictors of marksmanship performance exclusively focus on accuracy, weapon stability, or shot precision. While these dependent measures of performance are important, they do not give a great deal of diagnostic information on how the shot was affected by external variables, or how specific behaviors of skilled shooters can be taught to less-skilled shooters in order to improve overall accuracy and reaction time. Including additional covariates (e.g., trigger pressure, aim path length, pre-shot muzzle movement, etc.) when analyzing accuracy and reaction time provides additional insight into exactly how each measure differs from another (especially, how good shots differ from bad ones), and offers a foundation for future specific marksmanship improvement efforts. The present study aims to increase the understanding of how highly specific shot variables differ among shooters of various skills, and how the interaction of multiple variables differs among successful shots.

Engagement Skills Trainer 2000

The EST 2000 is a marksmanship training device used extensively throughout the Army to develop, train, and sustain essential individual and collective marksmanship skills (Department of the Army, 2008). The EST 2000 has the capability to replicate 11 weapons, including various models of rifles, carbines, pistols, machine guns, grenade launchers, and others (Department of the Army, 2008).

The EST 2000 apparatus consists of an instructor-operator station, high-resolution projector (1600 by 1200 pixels), detection system, air compressor, projection screen, cabling and air hoses to connect to lane position weapon boxes, and the associated training weapons (figure 1). The basic setup includes five firing position lanes; however, not all USAARL studies require the use of multiple lanes. The weapons are slightly modified to interface with the system, but still maintain their form, fit, feel, and function. All archival data utilized in the present analysis were collected using a demilitarized M4-series rifle.

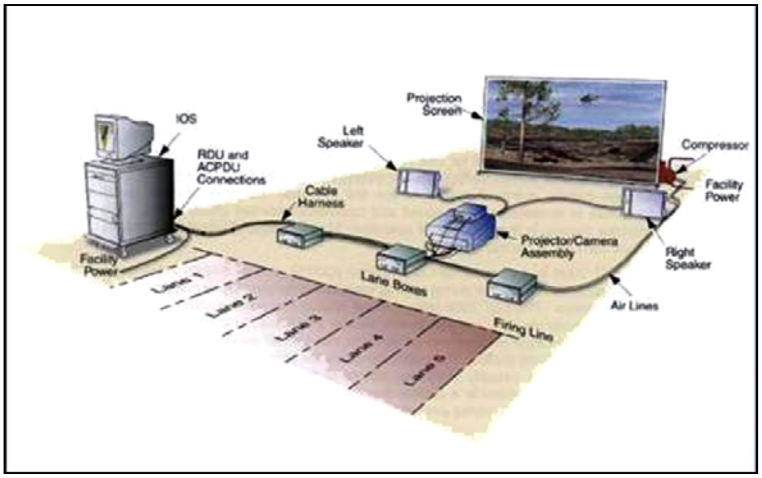

Figure 1. EST 2000 set-up (Anthony, 2006).

The EST 2000 system used by researchers at USAARL has been modified to include a number of advanced variables that are calculated and reported during each shooting task. These variables, which include precise measures of aim path, trigger pressure, shot accuracy, muzzle speed, and gun movement, are collected approximately 30 times per second (Jones, King, and Gaydos, 2011). Upon completion of data collection, all of the data are manually entered into a custom-made application that provides averages and total output measures for each shot. These measures provide a detailed analysis of shots that can then be analyzed both within-subjects (each shooter takes multiple shots within each scenario) or between-subjects (multiple shooters complete the shot scenarios), allowing for a meaningful analysis of shot variable patterns that offers a more complete description of the shot before, during, and after the trigger pull.

Methods

All data included in the analyses outlined in this study were archival in nature, and were extracted from a previous study carried out by investigators at the USAARL Warfighter Health Division (WHD) from 2010 to 2013. All subjects participated in this study after giving their free and informed voluntary consent. Forty-two healthy shooters were included in the analysis. Shooters had indicated during participation in the original study that they had no history of head injury; had no diagnoses of conditions that may have negatively impacted their vision, balance, or cognition; nor did they report participation in any activities that would place them at risk for any sensory, cognitive, or vestibular dysfunction. A vision test was conducted to ensure that all Soldiers' eyesight was at least 20/40 at the time of the study. All shooter data were de-identified prior to inclusion in this analysis.

Specific variables of interest that were included in the analysis are listed in table 2. A full list of the variables exported by the EST 2000, as well as a list of those included in the USAARL-developed algorithm application used to aid in the analysis, are included in appendices A and B.

Table 2.
EST 2000 variables included in analysis.

Dataset Name	Specific Variable(s)	Unit(s)	Description
Sensor Data	CantMin	Degrees (deg)	Minimum angle of rotation along the x-axis (figure 2)
	CantMax	Degrees (deg)	Maximum angle of rotation along the x-axis (figure 2)
	CantAvg	Degrees (deg)	Average angle of rotation along the x-axis
	CantSD	Degrees (deg)	Standard deviation of the angle of rotation along the X axis
	PitchMin	Degrees (deg)	Minimum angle of rotation along the y-axis (figure 2)
	PitchMax	Degrees (deg)	Maximum angle of rotation along the y-axis (figure 2)
	PitchAvg	Degrees (deg)	Average angle of rotation along the y-axis
	PitchSD	Degrees (deg)	Standard deviation of the angle of rotation along the y-axis
	MinTrigPress	Percentage (%)	Minimum logged pressure on trigger
	MaxTrigPress	Percentage (%)	Maximum logged pressure on trigger
	DurTrigPress	Milliseconds (ms)	Duration of time any pressure on trigger was registered
	tReact	Milliseconds (ms)	Time from presentation of target to completion of the shot
Aim Path Data	AimPath	Meters (m)	Aim path length from first point on target to final shot point
	PathRatio	N/A	Aim path length divided by shortest distance from first point on target to target center
	PreShotSpeed	Millimeters per second (mm/sec)	Average speed of aim point movement during 500 ms before shot
	PostShotSpeed	Millimeters per second (mm/sec)	Average speed of aim point movement during 150 ms after shot
Accuracy Data	OffRad	Meters (m)	Shot radius offset (distance of the shot from target center)
	HitMiss	"Hit"/"Miss"	Binary determination of whether shot was within a 0.25 m radius around target center

Weapon pitch and cant refer to directions of rotation during rifle handling. Pitch is a measure, in degrees, of vertical rifle movement around the weapon's z-axis. Cant is a measure of rifle tilt to the left or right, around the weapon's x-axis. There is no measure of rotation around the weapon's y-axis (or movement of the barrel from left to right) in the EST software used for this study. In the pitch measure, a negative value indicates that the gun is pointed below level, while a positive value indicates that the gun is pointed above level. Likewise, negative cant values indicate tilt to the left, while positive values indicate tilt to the right. Both of the rotational measures are illustrated in figure 2.

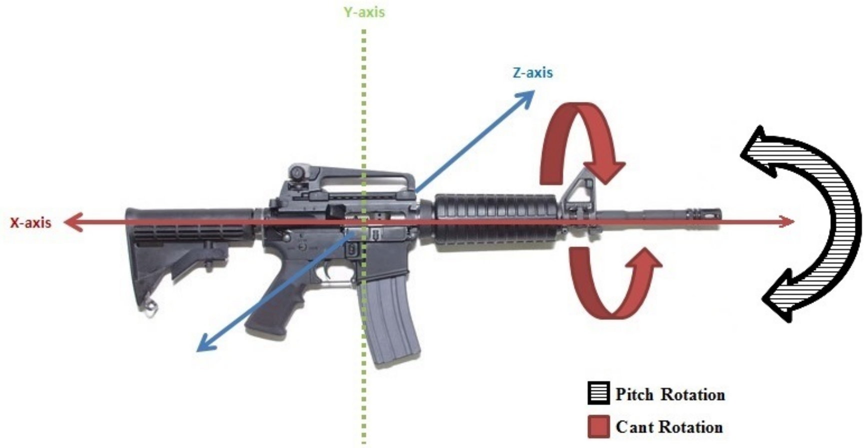

Figure 2. Weapon rotation directions.

Marksmanship task

All participants were asked to complete a standard marksmanship qualification task on the EST 2000. Marksmanship task data included subject number, target number, distance, and all shot variables listed in appendix A. Shooters had up to 40 rounds to hit 40 targets, although the number of shots taken by each shooter varied. Participants were required to hit targets from three positions: prone-supported (20 targets, 120 sec total), prone-unsupported (10 targets, 60 sec total), and kneeling (10 targets, 60 sec total). Targets were scaled to replicate distances from 50 to 300 m. All participants utilized a modified M4-series rifle that maintained the feel and function of a standard-issue M4.

No shooter-specific data were provided with the shot dataset except the original study inclusion criteria (the shooters had visual acuity of at least 20/40 and no history of head injury). Marksmanship ratings were calculated according to standard Army guidelines based upon the number of targets hit during the qualification task (Expert: 36 to 40 hits, Sharpshooter: 30 to 35 hits, Marksman: 23 to 29 hits, and Did Not Qualify [DNQ]: 22 or fewer hits). To account for inconsistent numbers of shooters in each group, skill level groups were created by combining Expert- and Sharpshooter-rated shooters in one group ("Skilled Shooters"), and Marksman-rated and non-qualifying shooters in a second group ("Less-Skilled Shooters").

Statistical analysis

The primary objective of this study was to identify any potential patterns in shot variables among shooters with varying levels of marksmanship ability. Therefore, the nature of the statistical analysis was exploratory and there were no formal hypotheses. Analyses were conducted both within- and between-subjects when appropriate in order to account for high rates of error variance. For most of the procedures conducted, only data from accurate shots were included in the analysis, as these shots were more relevant in the context of understanding how shooters of varying skill levels are able to successfully hit a target. Only an initial descriptive analysis and comparison of shot data included missed shots in order to determine whether or not the two skill level groups were significantly different overall. Analyses included measures of shot variable differences between shooters of varying skill level, in addition to correlations of shot variables with shot offset radius (OffRad) and reaction time (tReact) for all shooters, as well as shooters divided by skill level. Differences between correlation strengths for both shooter levels were also analyzed for significance. Since raw shot data did not meet the assumptions for parametric procedures, nonparametric tests and parametric analysis of ranked data were used. Differences in shot variable distributions between skill groups were determined with a multivariate analysis of variance (MANOVA) performed on rank transformations. Spearman's rank was used to determine bivariate correlation coefficients between shot variables, and a Mann-Whitney U test was used to assess differences in correlation strengths between groups.

Results

Of the 42 healthy shooters who completed the standard qualification task on the EST 2000, 4 qualified as Experts (approximately 10 percent), 14 qualified as Sharpshooters (approximately 33 percent), 8 qualified as Marksmen (approximately 19 percent), and 16 DNQ (approximately 38 percent). In order to create a more even distribution of membership for each skill level group and increase the sample available for study in each skill level group, shooters were placed in two groups: skilled shooters (Experts and Sharpshooters) and less-skilled shooters (Marksmen and DNQ). Descriptive performance statistics for each group are included in table 3. These statistics include values from all shots made during the qualification task, including both hits and misses.

Table 3.
Descriptive statistics for shot results by marksmanship skill level.

Group	No. of cases	No. of accurate shots	*M* target hits	*M* hits per second	*M* reaction time (ms)	*M* radius offset (m)
Skilled Shooters	18	350	35.52	.295	2977.82	0.161
Less-Skilled Shooters	24	246	19.72	.145	3489.84	0.415

An independent-samples Kruskall-Wallis test and independent-samples median test demonstrated significant differences in each variable across rating groups in distribution and median value, respectively ($p < .05$).

Prior to any correlational or analyses of group differences in shot variables, it was critical to determine initial descriptive statistics for each of the variables collected during the shooting task by the EST. Few studies have had access to the large number of shot variables, so normative values are not established for a generalized population. Only values from accurate shots were included in the data set. The skilled shooters accurately shot 350 targets, while the less-skilled shooters accurately shot only 246 targets, so the total number of shots included in each group's analysis was not equal. The mean (*M*), median (*Mdn*), range, and standard deviation (*SD*) for all shot variables, separated by skill level, are included in table 4. Broad review of the shot patterns between the two groups suggested initial evidence of the theory presented by Chung et al. (2006)

that less-skilled shooters demonstrate higher cognitive demand and lack of familiarity with fine motor control aspects, including higher reaction time, higher post-shot speed times, and longer aim paths as compared to the skilled shooters.

Table 4.
Descriptive statistics for shot variables of accurate shots by marksmanship skill level.

	Skilled shooters (*N*=350)				Less-skilled shooters (*N*=246)			
Shot Variables	*M*	*Mdn*	Range	*SD*	*M*	*Mdn*	Range	*SD*
OffRad	0.15	0.14	0.41	0.08	0.18	0.17	0.43	0.09
tReact	2947.33	2645.85	9246.90	1249.00	3312.10	2976.90	8021.60	1303.88
PreShotSpeed	533.25	431.74	2395.12	402.11	565.03	431.08	4092.55	505.58
PostShotSpeed	690.83	584.30	3227.62	515.89	758.67	569.36	3942.83	663.55
PathRatio	2.03	1.52	42.23	2.34	2.45	1.74	73.74	3.92
AimPath	7.58	6.71	95.89	6.97	8.33	7.16	52.18	6.78
MinTrigPress	45.63	54.90	96.86	30.35	39.23	31.37	96.47	34.84
MaxTrigPress	67.81	78.04	97.65	27.96	65.75	77.06	97.26	31.44
DurTrigPress	656.95	98.70	6120.10	1168.99	805.39	129.90	5964.90	1323.88
CantMin	-3.85	-3.87	11.65	1.68	-3.57	-3.55	14.31	2.19
CantMax	-2.46	-2.51	10.09	1.41	-1.69	-1.60	12.44	2.13
CantAvg	-3.05	-3.05	10.97	1.41	-2.52	-2.38	10.11	1.87
PitchMin	3.51	3.97	6.89	1.45	2.96	3.80	13.30	2.34
PitchMax	4.84	5.23	9.95	1.42	4.49	5.18	14.85	2.12
PitchAvg	4.41	4.84	6.09	1.37	3.96	4.78	11.45	2.15

After a preliminary observation of shot variable patterns between the skill level groups, a one-way MANOVA was conducted to determine which group differences were statistically significant. Initial observation of skew and kurtosis values for the shot variables suggested that the data were not normally distributed, and a Shapiro-Wilk test confirmed that univariate normality was not present. As the shot variable data did not meet the assumptions required for parametric analysis, the MANOVA was conducted on rank-transformed data, as proposed by Conover (1999) for non-normal data. Findings from the MANOVA are listed in table 5. A significant overall difference in shot variable distribution between skill level groups was identified ($F[17, 578] = 6.56$, $p < .001$). Follow-up tests indicated that the distributions of shot offset radius, shot reaction time, aim path ratio, minimum trigger pressure, minimum cant, maximum cant, average cant, cant standard deviation, and minimum pitch differed significantly ($p < .05$) between accurate shots made by skilled and less-skilled shooters (table 5).

Table 5.
Significant differences in shot variable value distribution for accurate shots between marksmanship skill levels.

Shot variables	Degrees of freedom	F value	Sig (α = .05)
Overall effect	17	6.56	.000
OffRad	1	25.96	.000
tReact	1	7.77	.005
PathRatio	1	8.89	.003
MinTrigPress	1	5.57	.019
CantMin	1	4.15	.042
CantMax	1	27.34	.000
CantAvg	1	16.84	.000
CantSD	1	9.68	.002
PitchMin	1	5.16	.023

After determining which shot variables differed significantly between skilled and less-skilled shooters in accurate shots, a correlation analysis was conducted to determine what factors correlate significantly with accuracy, as measured by OffRad, and tReact. An initial analysis was conducted on all accurate shots pooled between both skill level groups in order to establish a general, universal pattern of correlation between shot variables, reaction time, and accuracy for all shooters to be compared with group-specific patterns. A bivariate Spearman's rank test was conducted between all shot variables, OffRad, and tReact. Significant correlations are included in table 6, with medium and large effect sizes denoted. As OffRad represents distance from target center, a positive correlation indicates that increases in the correlated shot variable correlate with increased distance from the bull's-eye. For all shooters, regardless of skill level, the strongest accuracy correlations were observed for AimPath (as AimPath increased, distance from the target increased), PitchMax (as PitchMax increased, distance from the target increased), and PitchAvg (as PitchAvg increased, distance from the target increased). Significant direct correlations with OffRad were also found for tReact, suggesting that the longer a shooter takes to fire a shot, the further the hit will be from target center. Only MinTrigPress demonstrated an indirect correlation to OffRad, suggesting that as the minimum trigger pressure decreases, the shot will be further from target center (table 6).

There were a greater number of significant tReact correlates than OffRad correlates, which suggests that, in general, reaction time is more inter-related to the observed shot variables than accuracy. The strongest shot variable correlation for tReact was DurTrigPress, which indicates that the longer that pressure is held on the trigger, the longer the overall shot time will be. MinTrigPress was also related to tReact, indicating that the lower the minimum pressure registered on the trigger, the longer the overall shot reaction time will be. AimPath, PitchMax, and PitchAvg were also strong correlates of shot reaction time, suggesting that increased rifle movement (whether rotating the rifle up and down, or tracking the target over a longer aim path distance) is associated with increased shot reaction time. In addition to MinTrigPress, PreShotSpeed and PostShotSpeed demonstrate indirect correlations with tReact, which indicates that the slower the weapon moves before and after the shot, the longer the shot reaction time will be (table 6).

Table 6.
Correlation of shot variables with offset radius and reaction time for all accurate shots.

Offset radius			Reaction time		
Correlates	Correlation coefficient	Significance ($p = .05$)	Correlates	Correlation coefficient	Significance ($p = .05$)
tReact	0.298	.000	OffRad	0.298	.000
PostShotSpeed	0.129	.001	PreShotSpeed	-0.283	.000
AimPath*	0.333	.000	PostShotSpeed	-0.12	.003
MinTrigPress	-0.13	.001	PathRatio	0.235	.000
MaxTrigPress	0.22	.000	AimPath*	0.471	.000
DurTrigPress	0.253	.000	MinTrigPress*	-0.303	.000
PitchMin	0.235	.000	MaxTrigPress	0.263	.000
PitchMax*	0.311	.000	DurTrigPress**	0.556	.000
PitchAvg*	0.306	.000	CantMax	0.145	.000
PitchSD	0.129	.001	CantAvg	0.111	.005
			CantSD	0.099	.013
			PitchMin	0.276	.000
			PitchMax*	0.495	.000
			PitchAvg*	0.445	.000
			PitchSD	0.204	.000

*Medium effect size (Cohen, 1988)
**Large effect size (Cohen, 1988)

Considering the significant differences in shooting performance between the two skill level groups, correlation analyses were conducted within groups to determine if significant accuracy and/or reaction time correlates differ by shooter skill level. Significant group-specific bivariate correlations between shot variables and reaction time are listed in table 7. Significant reaction time correlates for both groups reflected those that were significant for all shooters; however, on average, skilled shooters demonstrated stronger shot variable-reaction time correlations than less-skilled shooters. While AimPath was a very strong correlate of tReact for both groups (the longer the aim path, the longer the shot reaction time), MaxTrigPress, DurTrigPress, PitchMax, and PitchAvg were stronger tReact correlates among skilled shooters than less-skilled shooters. This stronger correlation suggests that these factors have more of an impact on shot reaction time (or vice versa) as shooters become more consistently accurate. The indirect correlation between PostShotSpeed and tReact became a direct correlation when analyzed within skilled shooters only. Pooled shot correlations demonstrated a significant indirect relationship between PostShotSpeed and tReact, which indicated that the slower the speed of the aim point immediately following the shot, the longer the duration of the overall shot reaction time. This longer duration suggests that slower aim point movement is leading to longer shot times. However, when looking at group-specific correlations, PostShotSpeed is significant only for skilled shooters and becomes a significant direct correlation. Among all shooters, a slower post-shot aim point speed correlated with higher overall reaction times. However, when only analyzing skilled shooters, a higher post-shot aim point speed correlated with higher overall reaction times (table 7).

Table 7.
Significant shot variable correlations with reaction time by skill level group.

Skilled shooters			Less-skilled shooters		
Variable	Coefficient	Significance	Variable	Coefficient	Significance
OffRad	0.080	.047	OffRad	0.228	.000
PreShotSpeed	-0.213	.000	PreShotSpeed	-0.298	.000
PostShotSpeed	0.147	.000	PathRatio*	0.336	.000
PathRatio*	0.401	.000	AimPath**	0.602	.000
AimPath**	0.714	.000	MinTrigPress*	-0.317	.000
MinTrigPress*	-0.491	.000	MaxTrigPress*	0.430	.000
MaxTrigPress**	0.550	.000	DurTrigPress*	0.443	.000
DurTrigPress**	0.640	.000	CantMax	0.130	.008
CantMax	0.087	.032	CantAvg	0.133	.006
CantSD	0.124	.002	PitchMin	0.238	.000
PitchMin*	0.315	.000	PitchMax*	0.489	.000
PitchMax**	0.598	.000	PitchAvg*	0.486	.000
PitchAvg**	0.569	.000	PitchSD	0.240	.000
PitchSD*	0.345	.000			

*Medium effect size (Cohen, 1988)
**Large effect size (Cohen, 1988)

Significant correlates of OffRad for skilled and less-skilled shooters are included in table 8. As with the tReact correlates, group-specific accuracy correlations were relatively similar to significant correlates for all shooters pooled together. While the correlation strength differences between the two groups appeared to be less pronounced than those for reaction time correlations, skilled shooters seem to demonstrate a slightly higher number of significant OffRad correlates than less-skilled shooters. PreShotSpeed and PathRatio were significant direct correlates for skilled shooters, but not for less-skilled shooters (table 8). As expected, for more consistently accurate shooters, as PreShotSpeed increased, and as the aim point movement became less efficient, the distance of the hit from target center also increased.

Table 8.
Significant shot variable correlations with offset radius by skill level group.

Skilled shooters			Less-skilled shooters		
Variable	Coefficient	Significance	Variable	Coefficient	Significance
tReact	0.080	.047	tReact	0.228	.000
PreShotSpeed	0.132	.001	PostShotSpeed	0.191	.000
PostShotSpeed	0.176	.000	AimPath	0.245	.000
PathRatio	0.115	.004	MinTrigPress	-0.157	.001
AimPath	0.187	.000	MaxTrigPress	0.190	.000
MinTrigPress	-0.134	.001	DurTrigPress	0.151	.002
MaxTrigPress	0.150	.000	PitchMin	0.142	.004
DurTrigPress	0.136	.001	PitchMax	0.227	.000
PitchMin	0.105	.009	PitchAvg	0.240	.000
PitchMax	0.132	.001			
PitchAvg	0.124	.002			

Considering the numerous differences in coefficient values between skilled and less-skilled shooters for both reaction time and accuracy, a Mann-Whitney U test was conducted on coefficient values between the two groups to determine whether the difference in relationship strengths was significantly different. Results from this analysis are included in table 9. Less-skilled shooters had a significantly stronger relationship between tReact and OffRad than skilled shooters. As less-skilled shooters' reaction time increased, their shot distances from target center increased at a significantly higher rate than that of skilled shooters. Conversely, skilled shooters had stronger relationships between MinTrigPress and tReact and DurTrigPress and tReact. Lower trigger pressure readings and longer durations of trigger pressure correlated significantly more powerfully with higher shot reaction times for skilled shooters than less-skilled shooters. The correlation between PitchAvg and OffRad was significantly higher in less-skilled shooters than skilled shooters. Higher-tilted rifle angles resulted in shots significantly further from target center for less-skilled shooters than their skilled counterparts (table 9).

Table 9.
Significant differences in variable correlation strengths by skill level group.

Reaction time correlates		
Variable	Mann-Whit U	Sig (p = .05)
OffRad	109.000	.010
MinTrigPress	120.500	.023
DurTrigPress	127.000	.036
Offset radius correlates		
Variable	Mann-Whit U	Sig (p = .05)
tReact	109.000	.010
PitchAvg	125.000	.031

Discussion

The findings demonstrated significant differences between skilled shooters and less-skilled shooters in not only the number of accurate shots made during the shooting task (which was the classification variable to determine group membership), but also shot reaction time, number of accurate shots per second, and shot distance from target center. Skilled shooters were consistently and significantly faster and more accurate than their less-skilled counterparts. In order to better understand what specific actions and behaviors contributed to these overall differences, an analysis of 18 shot variables related to rifle handling, trigger pressure, and target acquisition was completed between the two groups. A correlation analysis for reaction time and distance from target center (used as a measure of accuracy) for all shooters was conducted to establish a normative pattern of correlation among all of the shooters, and group-specific correlation analyses were conducted to see how skilled shooter and less-skilled shooter correlations differed from the pooled model and from each other. Relatively consistent patterns of shot variable correlations with reaction time and accuracy – regardless of shooter skill – suggest that EST shot variables have the potential to be a useful measure of highly-precise marksmanship performance across multiple populations.

In addition to significant differences in performance variables (e.g., number of accurate shots, mean reaction time, accurate shots per second) between the two groups, there were a number of specific shot variables that differed significantly between skilled and less-skilled shooters. While many of the differences were expected between shooters of varying skill levels, significance and consistency of the differences highlight potential areas of interest for future research attempting to better classify the nature or possible causes of marksmanship differences. Even in an analysis of exclusively accurate shots, OffRad was significantly lower in skilled shooters than less-skilled shooters, which suggests that skilled shooters were able to hit their targets significantly closer to center than less-skilled shooters. This increase in precision did not appear to come at the expense of reaction time. Skilled shooters had significantly lower mean reaction times than less-skilled shooters, for all pooled shots ($\bar{x}$ = 2977.82 ms versus $\bar{x}$ = 3489.84 ms) and for accurate shots only ($\bar{x}$ = 2947.33 ms versus $\bar{x}$ = 3312.10 ms). Both groups demonstrated lower mean reaction times for accurate shots than their respective overall mean reaction times (when accurate and non-accurate shots were pooled), suggesting that for the shooting task used in this study, there was no speed-accuracy trade-off, contrary to what is often observed in timed shooting tasks (Walmsley and Williams, 1994). This contradiction may be explained by the high level of variance in the shot-accuracy ratio between shooters, which would make a trade-off difficult to identify. A more controlled study design would be useful in future studies to identify other possible explanations for why the speed-accuracy trade-off was not present.

Rifle cant during accurate shots was also significantly different between skill level groups, with skilled shooters demonstrating more of a left-tilted rifle handling pattern and a significantly attenuated range of cant rotation when compared to less-skilled shooters. Additionally, path ratio for accurate shots was also significantly lower in skilled shooters than less-skilled shooters, which indicates that skilled shooters' aim path during target acquisition was more efficient. The smaller range of rifle rotation may be related to the efficiency of motion during target acquisition, as both share links to the steadiness and fine motor control that have been identified as hallmarks of skilled marksmanship performance (Humphreys, Buxton, and Taylor, 1936; Malone and Rasch, 1964; Chung et al., 2006).

Since the shot data included in this analysis were not normally distributed, regression models were not possible, and analysis was limited to rank transformations and nonparametric differences and correlations. In general, reaction time had a larger number of significant shot variable correlates compared to accuracy (as measured by OffRad), regardless of shooter skill level. This can be most likely explained by the more linear relationships between many of the shot variables and the reaction time of the shot (e.g., longer duration of pressure on the trigger before the shot will directly increase the overall reaction time of the shot), and the very nature of reaction time as a variable. Shooters are able to maintain awareness of shot reaction time throughout the process of the shot and have more direct control over how long the shot takes; while control over accuracy is less certain for shooters and the placement of the shot is only known after all other factors have been accounted for. Therefore, the correlations between shot variables and accuracy are far more unidirectional than the correlations between shot variables and reaction time, which may impact their power.

Reaction time correlations overall appeared to be stronger for skilled shooters as compared to less-skilled shooters. A Mann-Whitney U test between correlation coefficient values for both groups indicated that, specifically, the correlations between reaction time and MinTrigPress and DurTrigPress were significantly stronger for skilled shooters, while less-skilled shooters had a significantly stronger correlation between reaction time and OffRad. Of particular interest was the correlation between PostShotSpeed and reaction time for skilled shooters. Although correlations among all shooters indicated that a slower PostShotSpeed was related to higher overall reaction times, correlations among skilled shooters demonstrated the opposite effect. Less-skilled shooters had a higher PostShotSpeed mean than their skilled counterparts ($\bar{x}$ = 758.67 versus $\bar{x}$ = 690.83); however, PostShotSpeed was not related to reaction time in less-skilled shooters. Higher post-shot aim point speeds are tied to shooters jerking the trigger rather than squeezing it gradually, which may suggest that while less-skilled shooters jerked the trigger more often than skilled shooters in general, skilled shooters may have been more conscious of their longer shot reaction times, causing them to rush the trigger pull in an attempt to make up time. This is consistent with the significantly stronger correlation between reaction time and MaxTrigPress for skilled shooters. Further research on skilled shooter performance in a timed shooting scenario is recommended to determine if time pressure may eventually have a significant effect on skilled shooter accuracy as a result of jerked triggers and other rushed shooting practices.

As previously stated, correlates of accuracy (as measured by OffRad) were less common and much weaker for both groups than the correlates of reaction time. Skilled shooters did demonstrate a slightly larger number of significant correlates than did less-skilled shooters, although the correlation strengths were consistently weaker. This suggests that the accuracy of less-skilled shooters is impacted by a smaller number of shot variables preceding and during the shot. The strongest correlates of OffRad in less-skilled shooters were tReact, AimPath, PitchMax, and PitchMin. The correlation between accuracy and reaction time was significantly higher in less-skilled shooters, indicating that the longer the shot took to execute, the tendency of the less-skilled shooters was to hit the target further from center. This correlation may be an effect of lower fine motor control and less muscle steadiness causing the shooters difficulty in acquiring and maintaining a target over longer periods of time, which is consistent with the high positive correlation between AimPath and OffRad. Previous studies investigating the effects of fatigue, anxiety, and postural instabilities in novice shooters' performance support this interpretation (Torre, Maxey, and Piper, 1987; Chung et al., 2005). Less-skilled shooters also demonstrated a significantly stronger correlation between PitchAvg and OffRad than skilled shooters. This suggests that, for less-skilled shooters, holding the rifle at an angle above level more often resulted in a shot further from target center than it did for skilled shooters; however, the effect size for the correlation in less-skilled shooters was small.

Overall, shot variable data from the EST 2000 indicates that skilled shooters tend to have less, more efficient rifle motion (less extraneous movement of the aim point and the rifle itself), as indicated by lower PathRatio values and attenuated weapon cant rotation values. The impact of less-controlled target acquisition and rifle handling may be a significant contributor to the high correlation between shot reaction time and shot distance from target center in these less-skilled shooters. While skilled shooters demonstrate more control of the weapon, they appear to be more affected by reaction time than their less-skilled colleagues, and may attempt to "make up" time during shots by rushing critical shot processes (as indicated by data suggesting that skilled shooters were more likely to jerk the trigger during shots with longer reaction times). Data from the study also provided an initial normative model for EST shot variables in a normal, uninjured military population for shooters of varying skill levels.

Limitations

The de-identified data used in this study contained no information on shooter rank, military occupation specialty, age, length of military experience, or any other important and potentially confounding variables. Future studies would benefit from the inclusion of such critical shooter characteristic data as covariates in the analysis of shot data. Marksmanship was assessed on the EST 2000 for this study, and therefore did not take into account a number of external/environmental variables that may impact marksmanship performance. Additionally, experimental analysis of EST 2000 shot data confirmed that the data is highly variable within subjects, and not normally distributed. These characteristics made parametric analysis of the variables impossible, therefore limiting multivariate analysis to comparisons of data ranks only. Data measurements, especially for the more precise rifle movement and trigger pressure variables, were limited by the processing power available within the EST system during any given task, and were often collected incorrectly (as indicated by values of "9999" or "-9999" in the EST data) or not at all. As a result, a number of shots had to be excluded from the final analyses of the study. The uneven distribution of shooters within the two groups was also a limiting factor during analysis. Future studies would benefit from a more experimental design, with the same number of shots taken by each shooter and the same number of shooters in each skill level group.

Recommendations

A more systematic study of marksmanship among Soldiers of varying skill levels would address a large number of limitations incurred in the present study, while allowing for more control of conditions and assessment procedures. Findings from this study support previous research determining that repetitive shooting practice appears to be the most practical and effective solution for improving performance in less-skilled shooters. Further study on repetitive shooting tasks may offer more specific directions for improving performance, especially in the area of fine motor control during target acquisition. Including a number of shooter-level conditions in the analysis and determining how they impact shot variable measures would also be of great interest, as the specific shot variable differences may shed light on the nature of marksmanship differences between different shooter groups. Findings from the present study suggest that skilled shooters would be best served by shooting practice that incorporates a time limit, highlighting performance deficits related to rushed shots and forcing shooters to practice accurate and controlled shots under time pressure. The task used in this study did not incorporate a time limit; conducting research on trigger control and rifle handling patterns for skilled shooters in a timed task would help determine performance thresholds and isolate what specific behaviors are most detrimental to accuracy based on EST shot variables. This information could provide a great deal of foundational information for advanced and tactical marksmanship training.

Conclusions

Analysis of EST shot variables established that skilled and less-skilled shooters differ not only in shot reaction time and the number of accurate shots made during the task, but also in the relationship between variables related to rifle handling, trigger pressure, target acquisition, reaction time, and accuracy. Less-skilled shooters demonstrated less weapon control and less efficient target acquisition than skilled shooters, and their accuracy appears to be more influenced by other shot variables (e.g. weapon pitch, aim path length). Skilled shooters demonstrated high levels of fine motor control, target acquisition, and overall performance; however, skilled shooter shot variables appeared to be more related to reaction time than those of less-skilled shooters, and data suggested that skilled shooters were more prone to rushing their trigger pulls when reaction time was high (although they were often still able to make an accurate shot during the shooting task used in this study). Overall, EST shot variable correlates of reaction time and accuracy were relatively consistent across all shooters (although the magnitude of correlation varied with skill), making EST shot variables a potentially useful tool in assessing precise aspects of marksmanship performance in populations of interest (e.g., Soldiers who have incurred a traumatic brain injury). Assessing marksmanship with the current binary score (hit versus no hit) simply identifies that a performance deficit exists. Inclusion of specific EST variables in future research may help in providing a greater level of specificity, and potentially sensitivity, in classifying the nature of skill differences between shooters, and eventually developing more efficient means of improving marksmanship in less-skilled shooters.

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Appendix A.

EST 2000 variable extraction list.

Data are exported from an EST file to an Excel spreadsheet with all of the de-identified variables included in the table below:

Variable Name	Description	Scale
START_SCEN	Time (ms) that the shooting scenario begins	
TARG_PRESENT	Time (ms) of target presentation, Target # (consecutive), Target distance (m)	Time: Interval Target #: Descriptive Distance: Interval
IMP_PT	x- and y-coordinates of rifle aim point, collected approximately every 33ms	Interval
SENSORS	Pitch and cant of rifle (deg), and pressure registered on the rifle trigger (%) collected approximately every 33 ms	Pitch: Interval Cant: Interval Trigger Pressure: Interval
BTN_REACT	Idle time (ms) between beginning of scenario and presentation of first target	
TRIGGER_PULL	Time (ms) between presentation of the target and the pull of the trigger	Interval
SHOT_RESULT	x- and y-coordinates of the shot, and whether the shot was a hit or miss	x-value: Interval y-value: Interval Shot Result: Binary
END_SCEN	Time (ms) that the shooting scenario ends	
Lane #	Lane # of shooters and targets – used for multiple shooter scenarios. Included data do not include multiple shooter scenarios, so no lane # information will be used in analyses	

Appendix B.

EST application variable extraction list.

Additional data are collected from a USAARL-developed application that applies a number of algorithms to extracted EST data. While these variables differ from EST 2000 extraction data, no additional data are included in the table below – these only represent mathematical calculations of the raw EST data.

Variable Name	Description	Scale
FileName	Name of the data file	Descriptive
Subject	Subject name (e.g. Subject 07 Ketamine)	Descriptive
Weapon	Weapon type/serial number	Binary (M7/M9)
Lane	Lane number	Descriptive
Target	Target number	Descriptive
Distance	Distance to target (m)	Interval
tReact	Shot reaction time (ms)	Interval
OffX	Shot x-offset (m)	Interval
OffY	Shot y-offset (m)	Interval
OffRad	Shot Radius offset (m)	Interval
HitMiss	Shot Result string, Hit or Miss	Binary (Hit/Miss)
PreShotTime	User-defined time (ms) before the shot for analysis	Descriptive
PostShotTime	User-defined time (ms) after the shot for analysis	Descriptive
AcqStartTime	Time at first point on target (ms)	Interval
PreShotSpeed	Average speed (mm/sec) during PreShotTime	Interval
PreShotRadius	Average radius (m) during PreShotTime	Interval
PreShotRMS	RMS radius (m) during PreShotTime	Interval
PreShotSD	Standard deviation of the radius (m) during PreShotTime	Interval
PostShotSpeed	Average speed (mm/sec) during PostShotTime	Interval
TargUpTime	Time at target pop up	Descriptive
AcqDuration	Total time on target ending at the shot	Interval
PathRatio	Path on target divided by radius of first point on target	Interval
AcqX	x-coordinate of first point on target (m)	Interval
AcqY	y-coordinate of first point on target (m)	Interval
AcqPath	Path length (m) from first point on target to shot	Interval
MinTrigPress	Minimum logged pressure (%) on trigger	Interval
MaxTrigPress	Maximum logged pressure (%) on trigger	Interval
DurTrigPress	Duration (ms) of time pressure on trigger was registered	Interval
CantMin	Minimum angle (deg) of rifle cant	Interval
CantMax	Maximum angle (deg) of rifle cant	Interval
CantAvg	Average angle (deg) of rifle cant	Interval
CantSD	Standard deviation (deg) of rifle cant	Interval
PitchMin	Minimum angle (deg) of rifle pitch	Interval
PitchMax	Maximum angle (deg) of rifle pitch	Interval
PitchAvg	Average angle (deg) of rifle pitch	Interval
PitchSD	Standard deviation (deg) of rifle pitch	Interval

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