Using Interactive Neuro-Educational Technology
to Increase the Pace and Efficiency of Rifle Marksmanship Training

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Abstract

Our research objective is to use neuroscience-based assessments to accelerate military skill acquisition and provide quantitative evidence of successful training by detecting, in real-time, cognitive and physiological states of the trainee under various conditions.

The research focuses on: (a) integrating brain monitoring capabilities into rifle marksmanship training; (b) identifying psychophysiological characteristics of expertise using expert marksman as a model population; (c) developing a sensor-based feedback system—information that would not be available under current training conditions—to accelerate novices in the acquisition of marksmanship skills, and (d) identifying neurocognitive factors that predict marksmanship skill acquisition.

The first step in developing the feedback system is to describe the neuro- and psychophysiological metrics associated with levels of skill acquisition and efficiency as participants progress from novice to expert in simple and complex task environments. Our previous work revealed specific EEG correlates of stages of skill acquisition in simple learning and memory tasks and in more cognitively complex and challenging test environments. Similarly, we will evaluate these metrics across tasks and environments. Physiological measures will include heart rate variability to measure stress and anxiety, a respiratory gauge to measure breath control, and an instrumented rifle (simulator) to record the movement of the muzzle, trigger pressure and trigger break. Performance data (hits, shot group precision and accuracy) will be time-synchronized with neurocognitive states, physiological states, and gross and fine motor movements.
Our long term goal in conducting this research is to determine whether feedback, based on participants’ cognitive, physiological, and motor states increases the pace and efficiency of rifle marksmanship training.
Introduction

Today’s military training procedures rely heavily on conventional classroom instruction often with qualitative assessment. Introduction of individualized tutorials with integrated neuroscience-based evaluation technologies could significantly accelerate military skill acquisition and provide quantitative evidence of successful training. This paper describes progress in the development of a suite of adaptive and interactive neuro-educational technologies that can be used in multiple training environments. The technologies are applied to identify characteristics of expertise using expert marksman as a model population and developing sensor-based feedback to assist novices in acquiring marksmanship skills.

The first objective is to characterize psychophysiological indices associated with levels of skill acquisition and associated efficiency metrics as subjects progress from novice to expert in simple and complex task environments. Previous work revealed specific EEG correlates of stages of skill acquisition in simple learning and memory tasks and in more cognitively complex and challenging test environments. The envisioned products will incorporate the EEG and other physiological metrics into systems with continuous psychophysiological monitoring in combination with simultaneous measures of performance accuracy, speed and efficiency.

Rationale for selection of marksmanship training as the field of application

Marksmanship training involves a combination of classroom instructional learning and field practice involving the instantiation of a well-defined set of sensory, motor and cognitive skills. The acquisition of expertise in marksmanship can serve as a model for many of the key skills required for training in military and other educational environments. Rifle marksmanship is a core skill for the Army and Marine Corp—every Marine must qualify annually. Training & qualification for marksmanship is generally a two-week program. Thus, the USMC training
requires ~352,000 person weeks making individualized instruction impossible. If technology can be designed that accelerates marksmanship instruction and simultaneously improves performance by a factor of two, the USMC will save precious time and resources and potentially improve the health and safety of the troops.

**Psychophysiological approaches to characterizing learning and skill acquisition**

Skill development is thought to occur in stages characterized by distinctive amounts of time and mental effort required to exercise the skill: the initial cognitive stage of assembling new knowledge, the associative stage where newly assembled procedural steps gradually automate as they are practiced, and the autonomous stage where the task execution is automated and performed with minimal conscious mental effort (Schneider and Shiffrin 1977; Schneider and Fisk 1982; Fisk and Schneider 1984). During the transition from the cognitive to associative stage, both speed and accuracy increase as subjects become less reliant on the declarative representations of knowledge (Anderson 1982; Anderson 1995). Transitions between stages can be assessed with performance metrics, expert observations and subjective reports, but these measures often lack precision and do not offer insight into the neurocognitive processes involved during learning.

Recent investigations suggest that monitoring neurophysiological parameters during learning offers the potential for precise quantification of key aspects of information processing including attention, memory and workload (Klimesch 1999; Segalowitz, Wintink et al. 2001; Chang, Brown et al. 2003). These studies suggest for example, that changes in power spectra of the electroencephalogram (EEG) and event-related EEG can be identified as characteristically associated with stages of skill acquisition in simple and complex tasks. EEG measures may be particularly relevant during the transition between stages two and three, because the key distinction at this point is a decrease in mental effort rather than a reliable difference in the accuracy of performance. If
performance alone is used, no distinction is made between people who perform well but expend a significant level of mental effort and people who perform well with minimal effort (Feldon 2004). The addition of the EEG-based metrics for workload and task engagement offers potential evidence of the progression from stage 2 to stage 3 (Berka, Levendowski et al. 2004; Berka, Levendowski et al. 2007).

Although previous EEG work has focused on laboratory-based learning and memory tasks (i.e. paired associate learning, n-back working memory and performance in the Space Fortress test), recent reports have extended the quantification of EEG to more complex simulation environments (Berka, Levendowski et al. 2005; Berka, Levendowski et al. 2006) and computerized tutorials (Stevens, Galloway et al. 2006). Relationships between EEG parameters and proficiency in real world activities have also been reported including golf putting (Crews and Lander 1993), archery (Landers, Han et al. 1994) and marksmanship (Hauffler, Spalding et al. 2000; Hillman, Apparies et al. 2000; Kerick, Douglass et al. 2004). In these real-world task environments, the most predictive data is acquired during the period of mental preparation (usually between 8-15 seconds in duration) before the skilled movements occur, referred to in sports medicine as the “pre-shot routine” (Crews and Lander 1993). Consistency and reproducibility of the successful pre-shot routine is a major feature that distinguishes novices from experts (Feltz and Landers 1983; Hatfield and Hillman 2001). Neuroimaging studies suggest that expertise is characterized by decreased activation of frontal cortical regions involved in planning and executive activities, accompanied by activation of the parieto-occipital regions suggesting a highly efficient allocation of attentional and cognitive resources during the pre-shot routine (Milton, Solodkin et al. 2003). In addition, novices show higher activation of the limbic region than experts suggesting higher levels of anxiety or stress (Vogt, Finch et al. 1992).
EEG studies reveal that the pre-shot routine period is characterized by a progressive increase of the power of EEG in the alpha bands particularly over the parietal-occipital regions with decreased activation in cortical regions not relevant to skilled visuomotor tasks (Hatfield, Haufler et al. 2004; Kerick, Hatfield et al. in press). In expert marksmen alpha power is particularly increased over the left central-temporal-parietal region during the seconds preceding trigger pull (Kerick, McDowell et al. 2001; Hatfield, Haufler et al. 2004). The magnitude of the increase in pre-shot alpha power is positively correlated with the accuracy of the subsequent shot (Loze, Collins et al. 2001; Kerick, Hatfield et al. in press) in both experts and novices. Less EEG activation is observed over all brain regions for experts compared to novices, suggesting that the neural networks of experts may be more efficiently organized than novices providing a relative economy in the recruitment of cortical resources in the expert brain (Hatfield, Haufler et al. 2004). The pre-shot period is also characterized by heart rate deceleration and a decrease in electrodermal skin conductance levels (Salazar, Landers et al. 1990; Kontinnen, Lyytinen et al. 1998; Tremayne and Barry 2001). Heart rate changes are believed to reflect the focusing of attention and the skill-related aspects of sensory-motor preparation for performance (Kontinnen, Lyytinen et al. 1998).

Transition from novice to expert requires practice. Repetition alone however, does not ensure success and a poor technique repeated can lead to performance deficiencies and/or stress injuries. Instructional strategies and feedback are believed to be critical to accelerating motor skill learning. Recent investigations have suggested that motor skill learning may be dependent upon the availability of cognitive resources including attention and working memory and that the speed and efficiency of learning may be affected by either state or trait differences in these cognitive capacities (Best 1992; Proctor and Dutta 1995).
Research Questions

The current study was designed to evaluate the utility of integrating the B-Alert wireless EEG system with a multi-sensor array and sensing apparatus platform to be used during marksmanship training. The initial goal of the study is to characterize the neuro- and psychophysiological metrics that distinguish expert marksmen from novices and to begin to identify changes in these metrics as participants progress from novice to expert. In addition to the physiological metrics, an instrumented rifle (simulator) recorded the movement of the muzzle, trigger pressure and trigger break. Performance data (shot group precision) were time-synchronized with neurocognitive states, physiological states, and gross and fine motor movements (Chung, Dionne, & Elmore, 2006).

The primary research questions were:

• To what extent do differences exist in the precision of shot groups, both at varying distances and across experts and novices?

• To what extent do breath control and trigger control vary differently between experts and novices?

• To what extent does the neurophysiological measure of anxiety, as measured by the Power Spectral Densities of Heart Rate Variability, vary between experts and novices?

• To what extent do EEG metrics (e.g. alpha level) vary between experts and novices?

Method

Participants

Three experts and five novices were recruited to participate in this study. All participants were consented according to protocols approved by UCLA IRB and the Biomed IRB. The three
experts were USMC Sergeants stationed at Camp Pendleton Marine Base. Two of the three experts were USMC rifle marksmanship coaches, and the third expert was a USMC trainer (i.e., trainer of coaches). A condition of coaching is to have qualified “expert.” As rifle marksmanship coaches, the experts had received training in how to coach, and how to diagnose and remediate shooter errors. All expert participants were experienced coaches and routinely trained Marine recruits on rifle marksmanship.

The five novice participants were comprised of UCLA graduate students and CRESST staff. Three novices had no prior weapons training, and so characterize ‘true’ novices. The two remaining novices had some limited previous weapons training, and so represent an intermediary skill level.

Design

Performance metrics and mental state metrics were developed using acknowledged experts (e.g., current combat marksmanship trainers and coaches). Novices were recruited from the local UCLA student population. The experimental work was conducted at UCLA in a laboratory setting.

Figure 1 shows an overview of the experimental data integration with rifle aim, shot performance, EKG and EEG, and trigger pull metrics.
Interactive Neuro-Educational Technology (I-NET)

Increasing the Pace & Efficiency of Marksmanship Training

OBJECTIVES

- Integrate systems
- Acquire data
- Select feedback options based on iterative experiments
- Automate feedback
- Field evaluation of new system
- USMC, Army, Air Force
- Decrease time spent on marksmanship training
- Increase marksmanship performance
- Improve health and safety of troops
- All classroom environments
- Maximize learning and accelerate transition from novice to expert

1. Compare psychophysiological profile of expert marksmen to novices at multiple stages of training.
2. Identify neurocognitive predictors for marksmanship skill acquisition to allow for early interventions.
3. Develop interactive, adaptive instructional tutorials with EEG-based closed loop paced training.
4. Develop psychophysiological-based feedback to guide novices into expert states.
5. Take the integrated portable system to demo in the field.

**Shot Accuracy**

- 8
- 2
- 3
- 4
- 5
- 6
- 7
- 1
- 1
- 7
- 6
- 5
- 4
- 3
- 2
- 8

![Shot Accuracy and Performance](image)

Figure 1. Overview of the experimental data integration with rifle aim, shot performance, EKG and EEG, and trigger pull metrics.
The testing protocol for both the experts and novices consisted of two trials of five shots each at a simulated 200m distance, and two trials of five shots each at a simulated 300m distance, all in a kneeling position. The target was scaled to these distances on a 1in-to-1yard scale. Table 1 describes the tasks carried out by each participant and the instruction given to each novice.

Table 1. Description of Tasks

<table>
<thead>
<tr>
<th>Participant</th>
<th>Description of tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts</td>
<td>Each expert fired two trials (5 shots per trial) at 200 yards, and two trials at 300 yards.</td>
</tr>
<tr>
<td>DP</td>
<td>An expert provided a brief 15-minute overview of the fundamentals of marksmanship. Then the expert provided one-on-one instruction as the participant practiced firing. After the participant demonstrated proper position and a reasonable shot group, the participant started the task. The task was two trials (5 shots per trial) at 200 yards, and two trials at 300 yards.</td>
</tr>
<tr>
<td>EE</td>
<td>An expert provided a brief 15-minute overview of the fundamentals of marksmanship. Then the expert provided one-on-one instruction as the participant practiced firing. After the participant demonstrated proper position and a reasonable shot group, the participant started the task. The task was two trials (5 shots per trial) at 200 yards, and two trials at 300 yards.</td>
</tr>
<tr>
<td>CL</td>
<td>A brief 10-minute overview of only the most important concepts in rifle marksmanship was provided. Then, one-on-one instruction for 1.5 minutes was provided by the expert to adjust the participant’s position. No other instruction was provided. The task was two trials (5 shots per trial) at 200 yards, and two trials at 300 yards.</td>
</tr>
<tr>
<td>LN</td>
<td>A brief 10-minute overview of only the most important concepts in rifle marksmanship was provided. Then, one-on-one instruction for 1.5 minutes was provided by the expert to adjust the participant’s position. No other instruction was provided. The task was two trials (5 shots per trial) at 200 yards, and two trials at 300 yards.</td>
</tr>
<tr>
<td>GC</td>
<td>Because this participant was familiar with the position, no instruction was provided. The task was two trials (5 shots per trial) at 200 yards, and two trials at 300 yards.</td>
</tr>
</tbody>
</table>
Apparatus

An instrumented weapon prototype was developed using off-the-shelf sensing components and a demilitarized “airsoft” replica of the M16/A2 (electric motor version). An accelerometer was attached to the muzzle of the weapon to measure movement. A force-pressure sensor was attached to the trigger to measure the amount of pressure on the trigger, and a respiration belt was used to measure participants’ respiration. To measure strikes, a laser-based simulation system was used (MD. 2006). The laser “shot” was detected by a receiver and the strike interpreted by the system to yield $x$ and $y$ coordinates on the target. EEG was recorded using the wireless B-Alert 6-channel differential EEG headset.

![Apparatus](image_url)
Measures

An overview of recorded measures, with their respective source and usage is recorded in Table 2. A discussion of each metric follows.

Table 2 Metrics recorded for analysis

<table>
<thead>
<tr>
<th>Metric</th>
<th>Data Source</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neurophysiological measures</strong></td>
<td></td>
<td>Used as indicators of how well shooter is processing and integrating sensory information and accommodating task demands. Prior work in this area has demonstrated the utility and feasibility of EEG as a measure of task engagement and mental workload (Berka, Levendowski et al. 2004; Berka, Levendowski et al. 2007). EEG-based pre-shot peak performance metrics are derived from the power spectral analysis.</td>
</tr>
<tr>
<td>Task Engagement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental Workload</td>
<td>EEG</td>
<td></td>
</tr>
<tr>
<td>Peak Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anxiety</td>
<td>Heart rate variability</td>
<td>Used to measure degree of stress experienced by shooter.</td>
</tr>
<tr>
<td>Instrumented (simulated) weapon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>Shots</td>
<td>Used to characterize the degree of dispersion of shots.</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Shots</td>
<td>Used to characterize the distance of shots from the intended target.</td>
</tr>
<tr>
<td>Respiration</td>
<td>Breathing</td>
<td>Used to measure inhalations and exhalations.</td>
</tr>
<tr>
<td>Trigger break</td>
<td>Switch</td>
<td>Used to establish a synchronization point for all measures.</td>
</tr>
<tr>
<td>Trigger squeeze</td>
<td>Force pressure sensor</td>
<td>Used to examine quality of trigger squeeze—slow or rapid. Trigger control is considered a fundamental skill in marksmanship.</td>
</tr>
<tr>
<td>Muzzle wobble</td>
<td>Accelerometer</td>
<td>Used to measure the degree of movement in the muzzle of the weapon.</td>
</tr>
</tbody>
</table>
**Trigger control.** Trigger control was measured by determining the force profile of the shooter’s trigger finger during the aiming period immediately preceding the shot (about 6 seconds) and immediately following the shot. Proper trigger control is important because yanking the trigger will cause the weapon to sway laterally. A force pressure sensor was attached to the trigger and the resultant pressure on the sensor measured over time. A ramp signal indicates a slow, steady squeeze and an impulse signal indicates a rapid squeeze. For slow-fire applications, the more desirable trigger control is reflected in the ramp signal.

**Shot group precision.** The main outcome measure was shot group precision. We defined shot group precision as the mean distance from the center of the shot group. Table 3 shows how the measures were computed.

**Breath control.** Breath control was assessed by measuring the respiratory response of a shooter during firing. Firing during the natural respiratory pause is the correct procedure. Firing while breathing can cause rounds to be dispersed vertically on the target due to the muzzle being displaced as the lungs expand and contract during the breathing cycle.

**Heart rate.** Heart rate was measured with a pulse-oximeter clipped on the ear and with two sensors placed over the left collarbone and under the lower right rib. The HR leads were plugged directly into the B-Alert EEG headset to allow ECG to be acquired and digitized with the EEG.

**EEG.** EEG was recorded using the wireless B-Alert 6-channel differential EEG headset. EEG signals were processed and visually examined in the EVA data presentation program. Additionally, Power Evoked Response Potentials (PERP) and Evoked Response Potentials (ERP) were analyzed to determine the pre-shot peak performance metrics and the cognitive...
metrics of Engagement (EEG-E), Distraction (EEG-DT) and Workload (EEG-WL) were derived (see Berka, 2004, Berka, 2007 for detailed methods for calculating the EEG metrics).

**Heart Rate Variability.** Missed beats and false detections due to movement artifacts were manually corrected from the heart rate. Heart rate variability (HRV) was calculated on a second-by-second basis. FFT was performed on the HRV for the entire session, and the power spectral density (PSD) was then computed from 0-0.5Hz with a 0.001Hz step. HRV PSD analysis provides a measure of sympathetic activation.

Table 3. Shot Group Precision Measures (Johnson 2001)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Symbol</th>
<th>Computation</th>
<th>Eqn.</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of shot group</td>
<td>$SG_x$</td>
<td>$\frac{\sum_{i=1}^{N} x_i}{N}$</td>
<td>1</td>
<td>“Center of mass” of $N$ shots, $x$ coordinate.</td>
</tr>
<tr>
<td></td>
<td>$SG_y$</td>
<td>$\frac{\sum_{i=1}^{N} y_i}{N}$</td>
<td>2</td>
<td>“Center of mass” of $N$ shots, $y$ coordinate.</td>
</tr>
<tr>
<td>Distance of each shot to the center of the shot group</td>
<td>$D_{SG}$</td>
<td>$\sqrt{(x_i - SG_x)^2 + (y_i - SG_y)^2}$</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Mean distance of $N$ shots to the center of the shot group</td>
<td>$R_{SG}$</td>
<td>$\frac{\sum_{i=1}^{N} \sqrt{(x_i - SG_x)^2 + (y_i - SG_y)^2}}{N}$</td>
<td>4</td>
<td>The mean dispersion across all shots with respect to the center of the shot group.</td>
</tr>
<tr>
<td>Standard deviation of shot group, horizontal component</td>
<td>$sd_h$</td>
<td>$\sqrt{\frac{\sum_{i=1}^{N} (x_i - SG_x)^2}{N-1}}$</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Standard deviation of shot group, vertical component</td>
<td>$sd_v$</td>
<td>$\sqrt{\frac{\sum_{i=1}^{N} (y_i - SG_y)^2}{N-1}}$</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Standard distance deviation, 2 dimensions</td>
<td>$sdd_{xy}$</td>
<td>$\sqrt{\frac{\sum_{i=1}^{N} (x_i - SG_x)^2 + (y_i - SG_y)^2}{N-2}}$</td>
<td>7</td>
<td>Standard deviation of the distance of each shot from the shot group center. This is the two-dimensional equivalent of standard deviation.</td>
</tr>
</tbody>
</table>
Results

We report on the results with respect to the research questions.

To what extent do differences exist in the precision of shot groups, both at varying distances and across experts and novices?

Figure 3 shows a visual comparison of an expert shot group to a novice shot group. Table 4 and Figure 4 show the descriptive statistics for the distance of a shot from the shot group center (Equation 3 in Table 3), across three experts and four novices at different distances. In general, experts’ shots are on average closer to the center of the shot group compared to novices, suggesting tighter shot groups. The standard errors of experts’ shots are also smaller, suggesting higher consistency of shots for experts than novices. Distance appears to matter for both experts and novices, with the shot group increasing in spread as the distance increases.

Figure 3. Image of target with shot locations (blue and pink) and calculated “shot group center” (red cross-bars).

Numbers inside blue and pink circles designate the order of each shot.
Table 4. Descriptive Statistics of Distance of Shot from Shot Group Center, by Type of Shooter and Distance

<table>
<thead>
<tr>
<th>Shot</th>
<th>Distance (yards)</th>
<th>Type of shooter</th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>Expert</td>
<td>6</td>
<td>1.53</td>
<td>0.80</td>
<td>0.33</td>
<td>6</td>
<td>1.90</td>
<td>1.05</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Novice</td>
<td>8</td>
<td>2.43</td>
<td>1.98</td>
<td>0.70</td>
<td>7</td>
<td>5.57</td>
<td>1.54</td>
<td>0.58</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>Expert</td>
<td>6</td>
<td>1.37</td>
<td>0.96</td>
<td>0.39</td>
<td>6</td>
<td>3.08</td>
<td>1.42</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Novice</td>
<td>8</td>
<td>2.46</td>
<td>1.18</td>
<td>0.42</td>
<td>7</td>
<td>5.13</td>
<td>2.85</td>
<td>1.08</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>Expert</td>
<td>6</td>
<td>1.68</td>
<td>0.71</td>
<td>0.29</td>
<td>6</td>
<td>2.78</td>
<td>1.99</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Novice</td>
<td>8</td>
<td>4.20</td>
<td>2.30</td>
<td>0.81</td>
<td>7</td>
<td>4.11</td>
<td>1.71</td>
<td>0.65</td>
</tr>
<tr>
<td>4</td>
<td>300</td>
<td>Expert</td>
<td>6</td>
<td>2.94</td>
<td>1.12</td>
<td>0.46</td>
<td>6</td>
<td>2.41</td>
<td>1.24</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Novice</td>
<td>8</td>
<td>4.06</td>
<td>1.63</td>
<td>0.58</td>
<td>7</td>
<td>4.83</td>
<td>5.39</td>
<td>2.04</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>Expert</td>
<td>6</td>
<td>1.86</td>
<td>1.38</td>
<td>0.56</td>
<td>6</td>
<td>1.79</td>
<td>1.37</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Novice</td>
<td>8</td>
<td>2.54</td>
<td>1.69</td>
<td>0.60</td>
<td>7</td>
<td>6.69</td>
<td>4.85</td>
<td>1.83</td>
</tr>
</tbody>
</table>

*Note.* The unit of analysis is the shot.
A 3-way mixed within (shot number and distance) and between (expertise level) ANOVA was used to determine if the observed effects were statistically different. Significant main effects for expertise level and distance were found, $F(1,23)=12.54, p<.001$ and $F(1,23)=5.52, p<.03$, respectively. Experts’ shots were much closer to the center of the shot group compared to novices. In addition, the distance of the shot to the center of the shot group increased over distance. No significant within-subjects effects were found among shots, suggesting that shooters’ shots did not vary considerably within a series of five shots regardless of expertise level or distance.

**Conclusion.** These pilot data results demonstrate that experts were more consistent in their shooting compared to novices, as measured by shot group precision. These findings also support the use of the shot group precision measure (Equation 3 in Table 3) as a performance metric.
To what extent do breath control and trigger control vary differently between experts and novices?

We examined plots of expert and novice shooters’ trigger control and breath control relative to the trigger break. At this point we are identifying patterns that may discriminate expert shooters from novice shooters. In the following plots (Figures 5-7), the x-axis is in units of 1/128s, and y-axis is in units proportional to volts (range is from 0 to 1023). The use of counts provides a common scale for the various sensor signals; however, the actual value is meaningless and it is the shape of the signal and the coordination among breathing, trigger squeeze, and the trigger break that is of interest. The plot shown in Figure 5 is of an expert. The expert is slowly squeezing the trigger (indicated by the slowly increasing trigger pressure) during the natural respiratory pause (the point in the breathing cycle where there is neither an inhale nor exhale).

The plot shown in Figure 6 is of a novice. While the trigger squeeze looks proper, the novice is firing while breathing. The plot shown in Figure 7 is also of a novice who is slowly squeezing the trigger, but over an excessive period of time.

The next step in analyzing trigger control will be to mathematically define a good trigger pull, using metrics such as length and acceleration of trigger pull. The team will also examine trigger control in relation to other physiological measures.
Figure 5. Expert, “textbook” profile.

Figure 6. Novice, poor breath control (firing while breathing).
Conclusion. The plots shown in Figures 5-7 are representative of distinct signals of expert and novices, suggesting that there are skill-based differences in how experts and novices approach the shooting task. It is important to note that coordinating trigger squeeze and breath control (i.e., firing during the natural respiratory pause) has been identified by coaches as something that novices have difficulty with. The provision of explicit feedback of the coordinated process as shown in the plots may be a simple but effective way to instruct novice shooters on proper trigger and breath control.
To what extent does the neurophysiological measure of anxiety, as measured by the Power Spectral Densities of Heart Rate Variability, vary between experts and novices?

To inspect differences in anxiety between experts and novices, power spectral density analysis was applied to heart rate. In the analysis conducted thus far, missed beats and false detections due to movement artifacts have been manually corrected. Heart rate variability (HRV) was calculated on a second-by-second basis for the entire shooting session. FFT was performed on the HRV for the entire session, and the PSD was then computed from 0-0.5Hz with a 0.001Hz step.

Compared to the experts, the novices had higher mean heart rates (novices: 97bpm, experts: 90bpm, p=0.03) and a decreased overall heart rate variability as measured with the standard deviation of HRV over 5 minute intervals (novices: 8.97bpm, experts: 11.64bpm, p=0.08). Heart rate modulation at frequencies lower than 0.15Hz was more pronounced in novices than in experts (Figure 8). Prominent respiration-induced peak at ~0.18Hz can be observed in experts but is absent in novices, which suggests that the regulation of heart and respiratory rate was better coordinated in experts.

Conclusion: Overall differences in HRV and the HRV PSD during shooting suggests a trend towards more sympathetic activation for novices than experts. These data suggest that experts are able to regulate their cardiorespiratory function and that the novices as a group evidence increased anxiety levels during shooting. One of the goals in accelerating training of marksmen is to reduce the level of anxiety as it is known to impair performance. Additional evaluations will explore the relationship of HRV to heart rate, EEG, and other measures in ABM’s EVA data viewing program.
Figure 8. HRV Power Spectral Data Analysis, where for n=3 for both experts and novices. Frequencies below 0.15Hz indicate sympathetic activation (increased anxiety level), whereas frequencies above 0.15Hz indicate parasympathetic activation.

To what extent do EEG metrics (e.g. alpha level) vary between experts and novices?

One of the goals of this investigation was to define EEG parameters in the pre-shot period that were associated with peak performance. Consistent patterns were observed in the EEG Power Spectral Densities related to trigger pull. Furthermore, there appears to be observable differences in the PSD patterns of experts and novices. The EEG characteristics related to the shot were similar across channels, suggesting multiple cortical regions are engaged in the preparation to take the shot. The EEG channel located over the sensorimotor region (“Central locations, C3C4”) was selected for visual presentation in Figure 9; however a more systematic analysis across channels is required to identify the optimal sensor sites selected as
indicators for peak performance. For experts, in the three to four seconds preceding each trigger pull there is a marked increase in power at the alpha frequency. This result confirms previous reports of increased alpha during the pre-shot period (Hatfield, Haufler et al. 2004; Kerick, Hatfield et al. in press). The “EEG alpha state” has been described as one of relaxed wakefulness where an individual maintains focused attention and control over extraneous or distracting sensory inputs. The alpha in experts likely indicates the level of skill acquisition where the task execution is automated and performed with minimal conscious mental effort (Milton, Solodkin et al. 2003).

Interestingly, the experts also evidenced an increase in power at the theta frequency in the inter-shot intervals followed by a decrease in theta at the time of the shot. This suggests mental activity that may be associated with either reviewing the elements of shot preparation (e.g. stance, trigger pressure, gaze focus and cardiorespiratory control) or visualization of prior successful shooting. This finding will be further explored in future experiments.

The data also revealed that experts typically do not blink during a trigger pull, although an eye blink response immediately following the shot is common. The next step in EEG analysis of expert data will be to look at coherence across channels (i.e. to what extent do different brain regions contribute to the overall increase in alpha prior to shot) and to closely examine the pattern of theta leading up to the shot, and its relation to pre-shot alpha as well as other measures. In addition, individual differences across experts and novices will be explored in a larger sample.
In order to quantify and compare the EEG metrics associated with peak performance, event-related synchronization (ERS) calculations were also applied to and compared for experts and novices, and are shown in Figure 10. EEG was band pass filtered, where theta equals 4-7Hz and alpha equals 8-12Hz. The Root Mean Squared (RMS) amplitude of the filtered signal was calculated on a 125 ms window that was shifted for 1/256 s. RMS values for five seconds before
and one second after each shot were normalized with respect to a previous base line, and are expressed as percentages. Shot-centered averages of the normalized RMS amplitudes were calculated for each subject and band of interest. ERS analysis shows a high percentage of theta synchronization at C3C4 at the time of the shot for the expert, a lower percentage for the novice, and an intermediary percentage for the intermediate. Alpha patterns are similar.

![ERS for C3C4 at theta and alpha frequencies. Graphs compare a novice, intermediate, and expert, and are an average across 10 shots for each subject.](image.png)

In addition to the power spectral results, EEG-derived cognitive metrics previously developed and validated by ABM were computed for Task Engagement (EEG-E) and Mental
Workload (EEG-WL) and compared for experts and novices. These measures were derived from the power spectra for each 1Hz bin (from 1-40Hz) using 30 model-selected variables used in quadratic and linear Discriminant Function Analysis (DFA). Delta(1-2Hz), theta (3-7Hz), and alpha (8-12Hz) and Beta (13-20) bins were included.

The EEG-engagement measure has been shown to correlate with the number and complexity of visual stimuli being processed and the allocation of attentional resources in simulation tasks including the Warship Commander, a simulated naval command and control task and in an Aegis radar operations simulation environment (Berka, Levendowski et al. 2004; Berka, Levendowski et al. 2005; Kahol, French et al. 2006; Poythress, Russell et al. 2006; Stevens, Galloway et al. 2006). The EEG-engagement and mental workload measures have been shown to be equally sensitive and specific for text- or image-based presentations. EEG-engagement increases as a function of level of interest in a specific display as well as during the encoding period of memory tasks and during review of instructions for completing a new task. EEG-engagement and workload levels decrease as a function of increasing level of skill acquisition (Berka, Levendowski et al. 2004; Berka, Levendowski et al. 2006).

Figures 11 and 12 present the averaged EEG-Engagement and Workload levels in the 3-second pre- and post-shot intervals for experts and novices. Increased High Engagement levels in novices in comparison to experts suggest high levels of visual and other sensory processing extraneous to the task. The Workload levels are relatively high and are similar to those observed previously in complex task environments such as the Tactical Tomahawk Weapons simulation, suggesting high cognitive load for planning and executing the shot (Poythress, Russell et al. 2006; Tremoulet 2007).
Discussion

The results of this preliminary investigation confirm expectations regarding performance metrics in expert marksman. Experts appear to have much higher precision in their shot groups than novices and are more consistent in their shots both within trial and across experts. The physiological metrics provided an intriguing perspective on the psychophysiological profile of an expert.
marksman. Objective evidence for highly invariant breath control and trigger control was obtained across shots for the experts. A consistent heart rate deceleration was observed prior to each shot accompanied by an increase in alpha power EEG and an overall increase in theta power EEG in the inter-shot interval. The combined pre-shot metrics for the alpha and theta power in the EEG will be used as the basis for defining a “pre-shot peak performance (PSPP)” metric that will be used to provide instructional feedback to novices in an effort to enhance the speed and efficiency of marksmanship training.

In addition, the B-Alert EEG metrics for assessing task engagement and mental workload revealed a characteristic pattern distinguishing experts from novices. EEG-Engagement levels were much lower in experts than in novices during the pre-shot period. This finding suggests that experts have developed the ability to screen out all extraneous and distracting sensory input to allow selective focus on taking the shot. The EEG-derived metric of Workload appeared to be higher in experts than in novices. The EEG-workload index was designed specifically to assess increases with verbal and spatial working memory load and during increasingly difficult problem-solving, integration of information, analytical reasoning. The finding of higher workload for experts suggests that the load on working memory is high as experts position, aim and fire the weapon. Experts appear to have lower sympathetic activation than novices during shooting, as observed in the PSD’s of Heart Rate Variability. The investigators plan future work incorporating feedback on the complete psychophysiological profile to accelerate acquisition of marksmanship skill.

Novices have much higher within and between variability in their shots and evidenced a range of performance on breath control and trigger control and much greater variability in heart rate surrounding each shot. Alpha and theta EEG power was also much more variable for the
novices. Thus, variability in any or all of the metrics can be used as an objective metric for assessing level of expertise.

**Introduction of feedback: Closing the loop**

Closing the loop remains a critical issue in considering design options for the prototype marksmanship training system. Feedback may be given directly to the trainee or alternatively to the teacher or coach. Furthermore trainee feedback could be real-time and continuous, or summarized at intervals such as pre- or post-shot. Feedback to the coach provides the added benefit of allowing the coach to efficiently monitor many students at once. The method of delivering feedback is also a pressing question. Feedback may be delivered visually, where a green light indicates that the trainee is in an appropriate state to shoot the weapon and a red light indicates that some measure should be adjusted. Feedback may also be auditory, such as a small speaker in the ear that delivers simple verbal commands.

**Generalization to alternative training scenarios**

There is ample evidence to suggest that marksmanship training will generalize across a variety of skill sets including sports such as golf, archery and basketball free throw shooting. Whether this type of neurotechnology-based feedback training will be transferable to other motor skill learning or useful in more complex training environments remains to be determined.

**Limitations of the preliminary study**

The major limitation of this study is that the findings are based on only a few participants; thus, there is the risk that the findings will not generalize over a larger sample.

The second limitation is that the sample was not true novices. Most of the participants had some experience handling the weapon, although no formal training. It is unclear how much this experience affected performance or acquisition of the instruction.
**Next Steps**

The next steps are to continue pilot testing with novices to test feedback protocols. Based on the pilot data, our design for the main study is a three-group design, with the between-subjects variables being (a) types of information used as the source of feedback and (b) the criterion benchmark used to determine adequate proficiency, and within-subjects variables being shooting trials. The types of feedback will be varied to compare the current state (i.e., observable by a coach) to feedback based on the use of information available through the EEG and sensor data sources.
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