Characterizing the Psychophysiological Profile of Expert and Novice Marksmen

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Abstract. Marksmanship training includes a combination of classroom instruction and field practice involving the instantiation of a well-defined set of sensory, motor, and cognitive skills. 10 expert marksmen and 30 novices participated in a study that measured marksman performance during simulated ballistics shooting of a M4 replica infrared rifle. Participants' physiology and performance were quantified while they completed a battery of neurocognitive tests. Experts demonstrated consistent and more accurate shot performance across all trials. Compared to novices, experts evidenced lower levels of sympathetic activation as measured by heart rate variability during the neurocognitive tasks. Factor analysis identified experts as having above normal visuospatial processing speeds and sustained attention, reflecting experts as having better performance during vigilance neurocognitive tasks. Identifying physiological metrics of experts during neurocognitive testing opens the door to individualized novice instruction to help to improve specific areas flagged as below normal during or prior to novice marksmanship instruction.

Keywords: Electroencephalogram (EEG), Electrocardiogram (EKG), Marksmanship, Expert, Heart Rate Variability, Neurocognitive testing, psychomotor skill acquisition.

1 Introduction

Rifle marksmanship is a core skill for multiple branches of the armed forces; many members are required to qualify annually. Marksmanship training is generally a two-week program and includes a combination of classroom instruction and field practice involving instantiation of a well-defined set of sensory, motor, and cognitive skills. This translates into an estimated 352,000 person-weeks per year making individualized coach supervision and instruction difficult. Instruction and development of the fundamentals of marksmanship demands a large amount of resources from the military. Integrated neuroscience-based evaluation technologies coupled with targeted pre-training interventions could provide quantitative markers of successful learning

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and accelerate marksmanship skill acquisition, thereby saving military resources and potentially improving the safety and efficacy of troops. Furthermore, the rapid acquisition of expertise in marksmanship could serve as a model for aiding the instruction of other physical or mental skills required in military or other educational environments.

Marksmanship is a complicated psychomotor skill that demands high physical and mental coordination for proper execution, and can thus be conceptualized as a complex skill. Proper rifle shooting is accomplished through the synchrony of breathing; gross motor control of body positioning; fine motor control of muzzle wobble and trigger pull; and the processing of rear and front sight alignment with respect to a target. Psychomotor skill acquisition is commonly viewed as a progression from the initial cognitive phase in which new knowledge is assembled; intermediate associative phase where newly learned skills are slowly automated with practice; and a final autonomous phase in which task execution is automated and demands minimal conscious effort [1, 2]. Chung et al. (2006) used this phasic model of skill acquisition as a framework to identify five variables of rifle marksmanship that influence the development from early to final phases: perceptual-motor, cognitive, affective, equipment, and environment. Marksmanship expertise is accomplished through controlling these variables through the practice, development, and automation of fundamental marksmanship skills.

Previous EEG studies have revealed notable neurophysiological distinctions between expert and novices marksman during shooting [3-5]. EEG patterning of skilled marksmen during the preparatory shooting (pre-shot) period has identified distinct alpha and beta wave patterns between executed (fired) and rejected (non-fired, withdrawn) shots [6]. Several other studies have identified unique cortical activation patterns associated with successful shots in experts [7] and demonstrated distinct patterns between experts and novices [8]. Prior research comparing EEG during shooting to EEG during comparative novel visuospatial and visuo-analytic tasks found no significant differences between novices and experts during the two visual tasks to which neither group had been exposed before. However, researchers did discover unique alpha, beta, and gamma power differences during shooting. This unique EEG pattern has been theorized to be an indicator of experts' increased efficiency during only those visuospatial tasks in which they held expertise [9].

Heart rate is an additional physiological measure commonly analyzed in marksmanship studies. The preparatory period, or pre-shot period, is characterized by a heart rate deceleration and decrease in electrodermal skin conductance levels [10, 11]. Heart rate deceleration during the pre-shot period in experts may reflect the attentive and the skill-related aspects of sensory-motor preparation for performance [12]. These data indicate that both EEG and HR are measures that previous research has used to link physiological patterns to performance in experts marksmen. In addition to these factors, assessing physiological metrics during non shooting neurocognitive testing may provide reliable predictors of marksmanship expertise. Identification of cognitive and physiological metrics that distinguish expert from novice marksmen may prove useful in early identification of a novice psychophysiological state which may hinder or prevent progression towards expertise. This identification offers the possibility of early triage and potential intervention that may be tailored to meet the unique needs of each individual.

2 Methods

10 qualified expert marksmen (off-duty military) and 30 novices were recruited and screened for general health. Experts were all male, with an age range of 21-27 years (*M*= 23.7, *SD*=1.78). Novices were comprised of UCLA students and volunteers from the general population with no prior marksmanship experience. Novice participants (9 female, 21 male) ranged in age from 18 to 41 years (*M*=23.17, *SD*=4.80) and were screened to verify minimal shooting experience.

Ballistics simulation relied on a LaserShot rifle simulation set-up. A LaserShot M4 rifle trainer with simulated recoil replicates the weight (~ 8 lbs), sound, and kick of a real weapon using a CO_2 pneumatic recoil system. The weapon is fitted with an infrared (invisible) laser that “fires” upon trigger pull. Shooting performance was captured using the rifle’s built-in infrared laser, infrared camera, and a digital projector. Each laser “shot” was detected by an Ultra Series Laser detection calibrated using LaserShot Ultra Series Camera Software. The Ultra Series Camera generates a mouse-click using the location of an infrared laser strike on the projected screen. These clicks were interpreted by computer to yield x and y coordinates on the target screen. A data integration program, Fusion 4000, was developed by collaborators at UCLA-CRESST to allow for a streamlined data collection. This software scaled targets and captured shooting performance. Data was collected in rooms at least 8.3 yards (~300”) long. The digitally projected target was scaled by measuring the width of the projected screen and the screen’s distance to shooter using. Fusion 4000 then adjusted the displayed target to simulate a 20” target at 200 yards [13].

All participants were asked to shoot from the kneeling position, one of the four required qualifying shooting positions [14]. Expert participants were given no instruction or feedback and completed 5 trials of 5 shots. Novices completed at least 8 trials of 5 shots each. After each trial, novices were shown the locations of their shots on a computer monitor along with number indicators next to each shot so they could identify when each strike occurred. All shots were fired at the participants will with no time restraint imposed on either the Experts or Novices. The pacing of shots was not regulated for any trial. All novices received basic instruction on proper positioning, handling, and sight alignment of the weapon prior to trial 1. Initial instruction was given by the same researcher for all novices. Novice participants were asked to shoot from the kneeling position but were allowed to choose any of the three variations of the kneeling position: high, medium, and low kneeling positions. The researcher modeled each of these positions and used posters of right and left handed versions of each position for additional reference. After the first two trials, novices watched a 15 minute video of a qualified marksmanship coach providing further details regarding proper shooting and positioning techniques.

A second session for collection of the neurocognitive test battery was completed on a separate visit, either before or after the shooting visit. All participants were given a battery of neurocognitive tests using the patent-pending Attention and Memory Profiler (AMP^{TM}) system. The AMP test battery included 3-Choice-Vigilance-Test (3C-VT), Standard Image-Recognition (SIR), Image Recognition with Interference (IIR), Verbal Paired-Associate-Learning (VPA), Number Image Recognition (NIR), Sternberg-Verbal-Memory-Scan (VMS), Eyes Open timed vigilance task (EO), and Eyes Closed (EC) timed vigilance task. These tasks were completed by participants using a computer in an isolated room. Participants' EEG, EKG, and task performance were measured while they completed visual memory and vigilance tasks.

EEG was recorded during both the marksmanship and neurocognitive sessions using the wireless B-Alert® 6-channel differential EEG headset [Figure 1]. The headset was designed with fixed sensor locations for three sizes (e.g., small, medium and large) with placement determined according to the International 10 – 20 system coordinates. All participants wore a 6 channel headset with 6 electrode sites at F3, C3, C4, Fz, Cz, and POz. Heart rate (HR) was measured with two sensors placed over the left collarbone and under the fifth lower right rib. Four neurocognitive factors are derived from the AMP data: sustained attention, processing speed, verbal memory and visuospatial memory, each with a quantitative, normalized score (based on our database of over 300 healthy data sets). Alertness, attention, verbal/visuospatial learning, and memory are also quantified using a combination of EEG and performance metrics. HR is recorded and quantified using PSD [14] to explore the relationship of sympathetic activation during AMP tasks with marksmanship performance.

Heart rate variability (HRV) was computed by first detecting QRS complexes in the EKG, and using the distance between them to calculate heart rate (raw HR). The raw HR is interpolated so that instead of a grid defined by heart beats, the grid is defined by seconds (HR). Each 5 minute segment of HR signal is then modeled as a 25th order AR process, the coefficients of the process are estimated from the data and used to calculate the power spectra in the range from 0.001 - 0.05Hz in steps of 0.001Hz. Low frequency (LF) HRV is equal to the sum of power spectrum from 0.04 – 0.15Hz. High Frequency (HF) HRV is the calculated as the sum of power spectrum from 0.15 – 0.4Hz. These data were then z-scored to our healthy, fully rested database subjects.

The marksmanship performance measure was shot group *precision*. We defined shot group precision as the mean distance of each shot from the center of the shot group, where lower values reflect better precision. Use of shot group precision is a useful measure to assess shooter consistency as well as accuracy. In general, experts' shots were closer to the center of the shot group compared to novices, suggesting tighter shot groups.

Neurocognitive factor scores (NCFS) are comprised of four composite variables (factors): Visuo-Spatial Processing Speed (VSPS), Sustained Attention (SA), Recognition Memory Accuracy (RMA) and Recognition Processing Speed (RPS). The

Fig. 1. 6 Channel B-Alert® (*right*) system wirelessly records EEG and EKG. AMP set-up (*left*) measures performance and physiology during a battery of neurocognitive tests.

factors are derived from the measures of behavioral performance (i.e. mean reaction time, and percent of correct responses) during the various AMP^{TM} tasks: Verbal Memory Scanning test, standard PAL test, verbal PAL test, interference PAL, numbers PAL, whole 3CVT and quartiles (0-5, 5-10, 10-15 and 15-20min) of the 3CVT (a total of 20 primary measures). Each raw factor score is then z-transformed with respect to the mean and standard deviation of the same score in a large reference population of normal subjects. Negative values indicate poor performance whereas positive values indicate good performance, with scores less than -2 indicated severe deficits.

3 Results

Shooting performance was determined using shot group precision on a trial by trial basis. Novice trials were summarized at four time points to reflect improvement as novices had more practice and instruction [Figure 2]. The worst novice performance was seen at baseline (n=30 participants X 2 trials, *M*=16.63, *SD*= 14.97), which was calculated as the mean distance to shot group center from trials 1&2. Trial 3 (*M*=15.77, *SD*= 11.93) included only the trial immediately following video instruction (Trial 3). Final (*M*=12.59, *SD*=8.54) included trials 7 and 8 for novices and showed the greatest shot group precision, thus reflecting the best average performance for novices. Expert trials were grouped into two groups, baseline (trials 1 &2) and final (trials 4&5). Expert marksmen showed little change from baseline (*M*=4.23, *SD*=2.70) to final (*M*=4.28, *SD*=2.54) trials. The standard deviation (variance) of experts' shots is also smaller, reflecting a higher consistency of shots for experts than novices.

Mann-Whitney U-test was used to compare novices to experts at baseline and final, respectively, do to uneven n and unequal variance of the samples. This analysis found that the Novices were significantly worse both at baseline (*U*=9, Experts=9, Novices=30, $p < 0.0001$) and final (*U*=5, Experts=9, Novices=28, $p < 0.0001$) time points, see Figure 2. Novice's improvement over time was examined with RMANOVA comparing baseline trials to final. RMANOVA found a significant improvement over time for the novice subjects [F (1,27)= 5.953, $p < .05$). These data are shown in Figure 3. Expert performance did not change over time ($p > .05$).

Neurocognitive factor analysis revealed significant performance-based changes between expert and novice groups in VSPS and SA factors [Figure 3]. Novices were randomly down-selected from n=28 to n=15 for ANOVA comparison of VSPS, SA, RMA, and RMS between novice and expert participants in order to meet the parameters required for ANOVA. A t-test was used to compare the subject included in these analysis to those that were excluded and found no significant difference (p=.487). Expert marksmen had a mean VSPS (*M*=2.12,) nearly 2 *SD* greater than the AMP normative database. Our novice shooters also had higher VSPS (*M*=0.65,) than the normative database. While both groups had VSPS above normal, experts did show

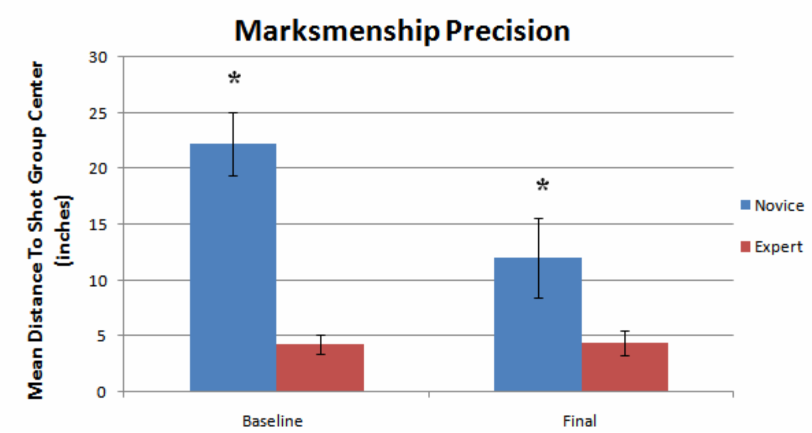

Fig. 2. Experts performed significantly better at both *Baseline* (Trials 1&2) and *Final* (Trials 7&8) compared to novices. Asterisk (*) indicates *p*<.01.

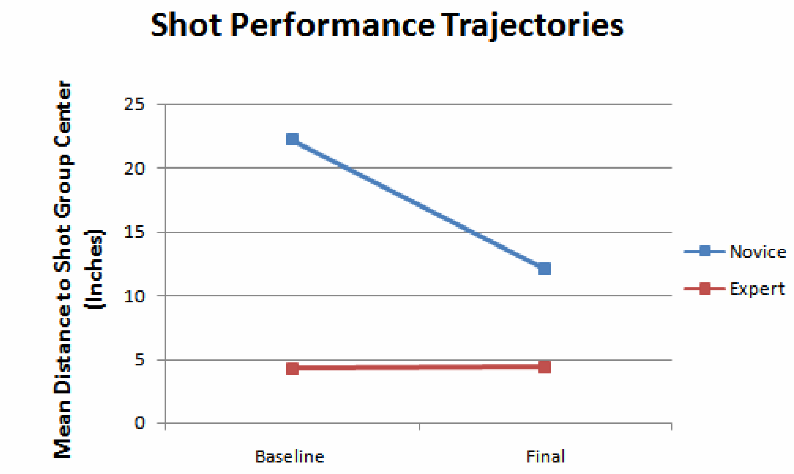

Fig. 3. Novice performance generally improved as they progressed through the trials. Mean distance to shot group center significantly improved from *Baseline* to *Final* Experts showed no change in performance from *Baseline* (Trials 1&2), to *Final* (Trials 4&5).

significantly higher VSPS as compared to novices according to ANOVA [*F* (1,23) = 6.13, *p* < .05]. ANOVA also found that experts had significantly higher SA [*F* (1,23) = 9.686, *p* <. 01] compared to novices although more than 1.5*SD* below the normative database.

Both experts and novices heart rate variability means were z-scored to a database of normal, healthy subjects. ANOVA analysis showed lower sympathetic associated (LF) HRV in the low demand tasks EO and EC for the experts compared to the novices; EO [*F* (1,23) = 5.061, *p* <.05], and EC [*F* (1,23) = 4.817, *p* <.05]. No group differences in HRV were found for any other tasks.

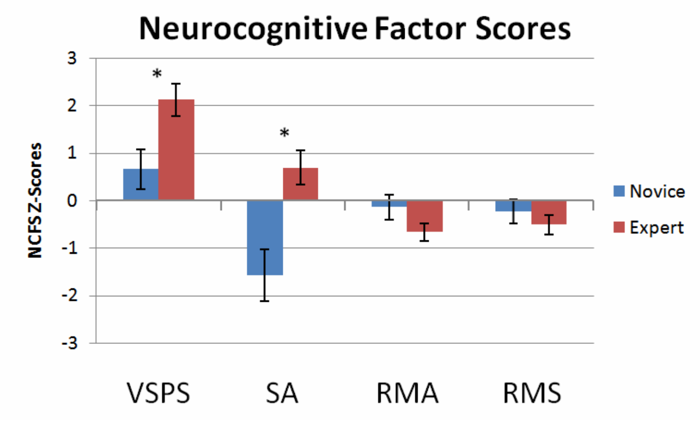

Fig. 4. Experts showed significantly higher scores for both Visuospatial Processing Speed (VSPS) and Sustained Attention (SA). No significant differences were seen in recognition memory accuracy (RMA) and recognition memory speed (RMS). Asterisk (*) indicates *p*<.05.

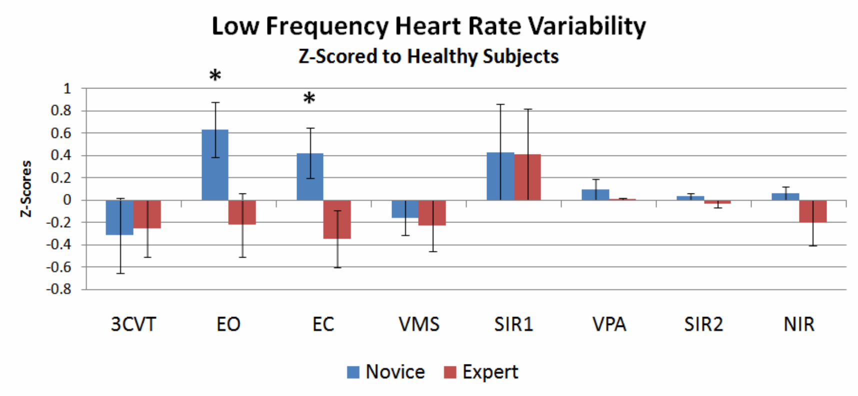

Fig. 5. Novices had significantly higher LF HRV compared to experts, reflecting higher anxiety in novices during timed vigilance tasks (3C-VT, EO, and EC). Asterisk (*) indicates *p*<.05.

4 Discussion

Assessment of shot group accuracy as measured by mean distance to shot group center shows that experts performed significantly better than novices across all trials. Experts showed no significant change from baseline to final shot trials reflecting the expert's controlled and consistent ability to replicate exceptional performance within and between trials. Consistent shot performance as indicated by no change across expert trials demonstrates that experts have the true ability to consistently apply the fundamentals of marksmanship. Neurocognitive factor analysis revealed experts as having VSPS more than 2 *SD* greater than normal levels and SA substantially above normal reflecting better performance on vigilance tasks. SA and VSPS neurocognitive factors are heavily derived from performance on the vigilance tasks (3C-VT, EO, and EC).

Experts had lower z-scored LF HRV for EO and EC tasks, compared to Novices. Greater LF HRV for novices may reflect increased sympathetic activation possibly indicating increased anxiety and mental stress during these neurocognitive vigilance tasks [15, 16]. It is important to note that HRV distinctions between experts and novices were only significantly different during the least cognitively challenging tasks in the AMP neurocognitive battery, the two timed vigilance tasks (EO and EC). This may indicate that experts are more able to regulate their cardio-respiratory function in a task specific/task appropriate manner. Further investigation comparing HRV during vigilance tasks and HRV during shooting may find distinct contrasts in HRV change between expert and novice group.

It is unclear whether this apparent ability to regulate expert's physiology is a genetically determined trait or a skill that can be acquired and refined with training. Our results highlight the need to investigate improving visuospatial processing speed, attention and cardiovascular regulation as a way to potentially improve novice marksmanship performance by early intervention designed to move novices toward the psychophysiological state observed in expert marksmen. Novices with below average VSPS may benefit from training using first person video gaming environments, which research has shown to improve visuospatial speed and attention [17]. Heart rate biofeedback or relaxation training may help novices develop control of sympathetic and parasympathetic activation to reduce anxiety and stress during vigilance tasks [15, 16, 18].

These results confirm research that asserts experts are capable of modulating their physiology to appropriately match task demands. Targeting physiological areas of weakness may increase novice's ability to automate the psychophysiological skills needed during shooting. Our results suggest the need for further research investigating whether pre-training interventions aid in the acceleration of learning for novices. These metrics may also have applications in other areas of psychomotor skill acquisition including additional military and education environments.

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