Peak Performance Trainer (PPT^{TM}): Interactive Neuro-educational Technology to Increase the Pace and Efficiency of Rifle Marksmanship Training

Giby Raphael[1], Chris Berka[1], Djordje Popovic[1], Gregory K.W.K. Chung[2], Sam O. Nagashima[2], Adrienne Behneman[1], Gene Davis[1], and Robin Johnson[1]

[1] Advanced Brain Monitoring, 2237 Faraday Ave., Suite 100, Carlsbad, CA 92008
chris@b-alert.com
[2] UCLA/National Center for Research on Evaluation, Standards, and Student Testing: CRESST

Abstract. 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. Current training procedures rely heavily on conventional classroom instruction often with qualitative assessment based on observation (i.e. coaching). We have developed a novel device called the Peak Performance Trainer (PPT^{TM}) which can accelerate the progression from novice-to-expert based on automated inferences from neurophysiological measurements. Our previous work has revealed specific EEG correlates to stages of skill acquisition in simple learning and memory tasks. We have incorporated this knowledge as well as an array of other physiological metrics to develop a field-deployable training technology with continuous physiological monitoring in combination with simultaneous measures of performance, workload, engagement and distraction, accuracy, speed and efficiency. This paper outlines the features of the PPT and the preliminary results of its use in marksmanship training.

Keywords: EEG, Heart rate, Alpha, Theta, Haptics.

1 Introduction

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 [1-3]. 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 [4-5]. Transitions between stages can be assessed with 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 changes in EEG power spectra and event-related EEG can be identified as associated with stages of skill acquisition in simple and complex tasks [6-8].

D.D. Schmorrow et al. (Eds.): Augmented Cognition, HCII 2009, LNAI 5638, pp. 630–639, 2009.

Relationships between EEG parameters and proficiency in real world activities have been reported in golf putting [9], archery [10], and marksmanship [11-13]. 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” [9]. The pre-shot routine is characterized by a progressive increase of the power of EEG in the alpha bands (8-12Hz) particularly over the parietal-occipital regions, with decreased activation in cortical regions not relevant to skilled visuomotor tasks [14,15]. Alpha power in expert marksmen is particularly increased over the left central-temporal-parietal region during the seconds preceding trigger pull [14,16]. The magnitude of the increase in pre-shot alpha power has been positively correlated with the accuracy of the subsequent shot [15,17] n both experts and novices. Less EEG activation is observed across 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 [14]. The pre-shot period is also characterized by heart rate deceleration and a decrease in electrodermal skin conductance levels [18-20]. Heart rate changes are believed to reflect the focusing of attention and the skill-related aspects of sensory-motor preparation for performance [21]. Consistency and reproducibility of the successful pre-shot routine is a major feature that distinguished novice from expert [22, 23].

Our previous work has revealed specific EEG correlates of stages of skill acquisition in simple learning and memory tasks and in more cognitively complex and challenging test environments. Unique event-related EEG signatures detected during various stages of skill acquisition were evaluated to assess participants’ ability to reflect aspects of learning across tasks and environments. 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 [24-26]. EEG-engagement increased as a function of level of interest in a specific display (equally sensitive and specific for text or image-based presentations) 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 decreased as a function of increasing level of skill acquisition [26, 27].

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 [28, 29].

The Peak Performance Trainer (PPT) is a novel system that incorporates our knowledge about EEG signatures as well as an array of other physiological metrics that change during stages of learning. The goal of the PPT is to provide continuous psychophysiological monitoring and feedback (visual, auditory or haptic) on relevant changes in these measures to the trainee in real time. Our hypothesis is that we can characterize the psychophysiological profile of expertise, and provide feedback to shape the novice into the psychophysiological state of an expert. The laboratory-based

PPT was designed to offer multiple options for training including: sensor inputs (EEG, EKG, respiration, eye tracking), algorithms for deriving state changes (based on single or multiple sensor inputs, designed for shaping to an expert model) and feedback delivery (visual, audio, haptic or multimodality). Training can be customized to meet the needs of the investigators or the trainees. The training protocols can then be streamlined and optimized for field deployability. The mobile PPT is then designed for portability with fewer options for sensors and/or feedback.

2 Methods

In order to first assess the concept and effectiveness of using the PPT to accelerate learning, a PPT lab setup was designed, built, and pilot tested on a group of novice participants in a current marksmanship study.

2.1 PPT Apparatus

Shooting was untimed, completed indoors in the kneeling position, and simulated a 20” target at 200 yards distance. A demilitarized “airsoft” replica of the M4 was used as the instrumented weapon and an infrared laser-based training system from LASERSHOT [30] was used for target projection (via an LCD projector) and shot detection (via infrared camera). Psychophsysiological metrics associated with shooter performance were used to compare experts to novices, to examine the efficacy of interventions based on these metrics and to guide interventions leading to rapid skill acquisition. An overview of the recorded measures, with their respective source and usage is listed in Table-1.

All necessary sensors and associated electronics incorporated in the PPT setup were integrated into a portable package that provided both closed loop real-time feedback to the shooter as well as transmitted data to a remote computer for display, storage and offline analysis. A low power 32-bit ARM9 processor was used to interface the sensors, for software signal processing and for running the complex feedback algorithms. The sensors and data acquisition circuitry of a previously developed 9-channel wireless B-Alert® sensor headset were integrated to the microprocessor to acquire high quality physiological signals such as EEG from sensors placed at F3, F4, C3, C4, P3, P4, Fz, Cz and POz positions (according to the international 10-20 system) as well as EKG and EOG. The patented EEG sensor dispenses a small amount of conductive cream through the hair to make electrical contact, which eliminates the need for hair or scalp preparation. The sensors and the headset were attached to a comfortable porous cap. Analog circuits combined with EEG amplification close to the sensors allowed the shooter freedom to move without generating artifacts.

The acquired data was processed to identify and decontaminate artifacts using hardware filters as well as adaptive filters in the firmware. The filtered data was then used by the algorithms running in the microprocessor for real-time feedback and also transmitted to a remote computer via Bluetooth protocol for display, storage and analysis. The Bluetooth module was interfaced to the microprocessor via the serial port to transmit the data, and an off-the-shelf Bluetooth dongle plugged in to the USB

Table 1. Metrics recorded for analysis

Metric	Data Source	Usage
Cognitive overload Pre-Shot EEG Alpha and Theta	EEG	Used as an indicator of how well shooter is processing information and accommodating task demands. Used as an indicator of focused and relaxed ("in the zone") mental state
Anxiety	Heart rate variability	Used to measure degree of stress experienced by shooter.
Precision	Shots	Used to characterize the degree of dispersion of shots.
Accuracy	Shots	Used to characterize the distance of shots from the intended target.
Respiration	Breathing	Used to measure inhalations and exhalations.
Trigger break	Switch	Used to establish a synchronization point for all measures.
Trigger squeeze	Force pressure sensor	Used to examine quality of trigger squeeze - slow or rapid.
Muzzle wobble	Accelerometer	Used to measure the degree of movement in the muzzle of the weapon.

port of the computer was used to receive the data at the remote end. Our patented B-Alert software was used for display and analysis of the data on the computer. The B-Alert software provided capabilities for further processing of the data such as classifying the brain's electrical activity into validated measures of engagement, mental workload, and distraction/drowsiness. The package had multiple analog and digital input ports to interface external sensors. Three primary real-time feedback modalities were provided: i) audio feedback via a small speaker interfaced to the microcontroller as well as from the remote computer; ii) haptics feedback via two shaft-less vibration motors attached behind the neck; and iii) visual display on a projected screen and the remote computer.

Alpha power in expert marksmen has been shown to increase during the seconds preceding trigger pull [14, 15]. Preliminary studies suggested that a single EEG channel is sufficient for the measurement of alpha increase, and that alpha (as well as theta) levels in the two seconds preceding the shot were at least 10% higher than during inter-shot interval in experts. In order for the PPT to quantify pre-shot theta and alpha levels and provide that feedback to the shooter, band pass filters were used to extract theta (4-7Hz) and alpha (8-12Hz) bands from channels Fz and Cz of the EEG signal and the area under the curve (squared) was calculated to extract the energy per unit time of the bands. Individualized baseline alpha levels were calculated during a 30-second interval before shooting began, and real-time feedback of the current alpha levels during the shooting process was provided using audio as well as haptic vibrators. The alpha levels were classified as good (less that 5% above baseline), better (between 5% and 10% above baseline) and best (10% above baseline). Haptic feedback was provided using the potential feedback states: two vibrators were both switched ON when alpha levels were at or below normal; one stopped vibrating when alpha level increased to 5% above normal; and both stopped vibrating when alpha increased the at least 10% above normal – indicating to the participant that they were in an ideal state and ready to shoot the weapon. Some initial training was required for subjects to learn to increase their alpha levels and to rapidly move in and out of the desired pre-shot brain state.

Significant deceleration of HR was found in experts beginning about two seconds pre-shot and ending at around 0.5 seconds following shots. Heart rate (HR) and Heart Rate Variability (HRV) measures add the dimensions of stress, frustration, arousal and anxiety to the EEG-based cognitive metrics. In order for the PPT to provide HR feedback to the participant, missed beats and false detections due to movement artifacts in the EKG were corrected using software filters. A proprietary adaptive R-wave detection algorithm was employed to detect the R-waves in the EKG to provide real-time feedback of the heartbeat to the shooter. The haptic vibration pattern for the alpha feedback was triggered by R-wave detection (the haptic motors vibrated at an interval that was in synch with the heart beat) thus superimposing the alpha feedback over the heartbeat feedback. This reduced the need to memorize complex feedback patterns for the shooter.

Breath control is another significant factor in marksmanship; firing during the natural respiratory pause is accepted as the correct procedure. The expansion and contraction of the lungs during the breathing cycle can cause the rounds to be dispersed vertically on the target due to the displacement of the muzzle. A respiratory belt transducer containing a piezo-electric device that responded linearly to changes in length was used to measure changes in thoracic or abdominal circumference during respiration. The necessary circuitry for the amplification and filtering of the signal was implemented in hardware and the transducer was interfaced to the analog input of the microprocessor. The signal representing the respiratory pattern was transmitted to the remote computer and was stored and displayed in real-time.

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. The signal was amplified, filtered and transmitted to the remote computer for real-time display and storage. The respiratory and the trigger squeeze waveforms were superimposed to detect variations from the expert trigger squeeze profile which consists of a steady increase in trigger pressure during natural exhalation with the trigger break occurring at the end of the exhalation and before the beginning of the next inhalation (Fig. 1). We also provided audio feedback of the trigger squeeze profile by modulating the frequency of the sound with the amplitude of the pressure applied on the trigger.

Muzzle wobble can never be completely eliminated, however its magnitude was found to be considerably depressed in experts. An accelerometer was attached to the muzzle of the instrumented weapon to measure the degree of movement in the muzzle of the weapon. The signal from the accelerometer was amplified and transmitted to the remote computer for real-time display.

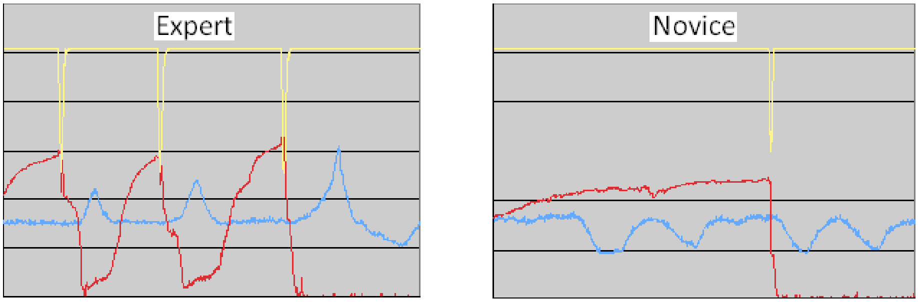

Fig. 1. Snapshots of the real time display from expert and novice shooters, showing trigger break (*yellow*), trigger squeeze profile (*red*), and breathing profile (*blue*)

Shots were recording using a LaserShot rifle simulation set-up. The target was projected on a screen and the laser "shot" was detected by a high-resolution infrared camera. The strike was interpreted by the system to yield x and y coordinates on the target projected on the screen. The main performance measure was the shot group precision. The "center of mass" of the first N shots was calculated initially and the shot group precision was defined as the mean dispersion across N shots to the center of the shot group. Two dimensional standard deviation (x & y axis) of each shot from the center was also recorded.

Incorporating all sensor inputs, the PPT setup provides direct, real-time haptic feedback to the shooter regarding their pre-shot alpha level (in relation to their baseline level) and HR, as well as real-time continuous measures of respiration, trigger pressure, and muzzle wobble in relation to shots. In this manner, the PPT setup is designed to provide feedback not only regarding the output of their comprehensive technique (shot performance), but also feedback on each element of technique that contributes to shot performance.

The PPT lab setup is currently being developed as a generic training/research platform that could be extended to many other activities requiring skill development. It is an ideal solution for indoor training; however the multiple display devices such as the computer and the LaserSoft rifle simulation make it bulky and not easily portable. Based on the results from the lab setup, the most relevant subset of features was implemented in a field-deployable version which we call the "PPT-mobile". We developed one such version that extracted EEG alpha level as well as EKG R-wave spikes in real-time and provided feedback on alpha level and heart rate via haptics and audio. The same ARM9 microprocessor that was used in the lab setup was also used in the mobile version, and the EEG / EKG sensors were interfaced to it. A Bluetooth module was also interfaced to collect data on a remote computer if required. The device was battery operated and was attached to the EEG sensor cap worn comfortably by the user. The device had a modular architecture allowing for easy addition of new features.

2.2 Pilot Study

We recruited 9 novice subjects (8 males, 1female; mean age 23.1 years; range 20-27) to evaluate the effectiveness of the real-time PPT when applied to marksmanship training. Three participants first completed the protocol without sensory feedback (no PPT) and then returned on a later day to complete the PPT protocol. The remaining six subjects completed the PPT protocol only. Preliminary studies suggested that sensor-based feedback is overwhelming to the novice shooter in the beginning training stages, and is more useful once the novice is familiar with the positional elements of marksmanship. For this reason, real-time feedback using the PPT during shooting was not delivered to the novice until the later trials of the study, after they had received computer instruction, individualized coaching, and modular training in EEG alpha, breath, and trigger control.

As a preliminary assessment of the efficacy of the PPT, performance improvements achieved using the PPT were compared to two other experimental groups of novices, and one group of marksmanship experts. All novice groups (Ground Zero, Tx2, and PPT) represented similar age and experience levels, completed the same number of trials and watched the same 15-minute introductory marksmanship video. All other factors being equal, each novice group completed marksmanship training with distinct conditions. The Ground Zero group received no individualized coaching, no offline (not while shooting) sensor-based feedback, and no PPT while shooting. The Tx2 group received individualized coaching and offline sensor-based feedback, but no PPT while shooting. The PPT group received individualized coaching, offline sensor-based feedback, and PPT while shooting. The expert group was comprised of 10 USMC marksmanship coaches recruited from USMC base Camp Pendleton, each of which qualified as expert on their most recent marksmanship qualification. Experts were given no instruction or other type of feedback during shooting.

3 Results

Preliminary analysis of performance data comparing the performance (mean distance of each shot from shot group center) at Baseline (Trials 1 and 2) and Final (two trials

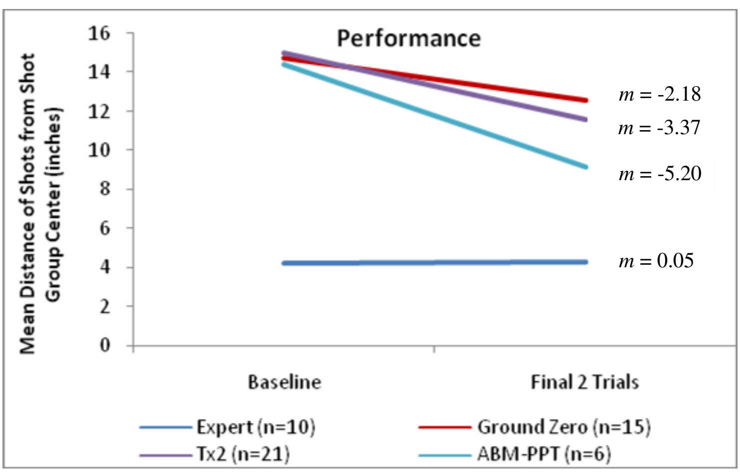

Fig. 2. Performance curve of groups trained with & without PPT

at or after Trial 7 that show best performance) of PPT protocol compared to the same measures for other experimental groups revealed an improved learning trajectory beyond that attained with the Ground Zero or Tx2 groups. The performance data (Fig. 2) is encouraging and suggests that providing offline, real-time physiological feedback through the PPT protocol is effective in improving the performance of novices at a greater rate than for other treatment groups.

4 Discussion

The PPT is a part of our effort to create a suite of Interactive Neuro-Educational Technologies (I-NET) that can be used in multiple training environments. I-NET covers four major themes: 1) integrating brain monitoring into paced instructional tutorials, 2) identifying psychophysiological characteristics of expertise using expert marksman as a model population, 3) developing sensor-based feedback to assist novices in acquiring marksmanship skills and 4) identifying neurocognitive factors that are predictive of marksmanship skill acquisition to allow early triage and interventions. While the entire PPT system is limited in its functionality due to the reliance on computer monitors and projectors to display visual feedback, the development of the PPT-mobile opens the door for incorporation of real-time neuro- and biofeedback for the first time into many psychomotor skill tasks performed outside of the laboratory setting.

Experiments are currently underway to begin to address the applicability of the PPT-mobile in scenarios that more closely approximate combat conditions. It will be necessary to introduce threat/fear stressors into the basic marksmanship training set-up to encourage a combat mindset, as being able to manage such stress is critical. One way in which this will be implemented is through the use of first-person shooter games. The psychophysiological profile of expert and novice shooters under stressful combat conditions is as yet undefined; mitigation is usually performance driven, and via intense reality-based training. Thus, developing neurophysiological metrics that drive sensor-based feedback is highly desirable. In the current (non-combat) training paradigm, the measure of shooter readiness that drives the PPT is based on high alpha + HR deceleration. How this measure relates to performance under more dynamic conditions is unclear, particularly when there is a threat component.

Multiple combinations of pre-training triage and interventions including relaxation and attentional training will be evaluated in addition to real-time feedback during simulated combat marksmanship. The psychophysiological profile of the expert USMC marksmen suggests a finely tuned level of control over physiology that appropriately allocates resources to meet task demands [31, 32]. I-NET are being designed to assess, characterize and further develop this psychophysiological control system. The acquisition of expertise in marksmanship can serve as a model of the key skills required for training in military and other educational environments and can be extended to other activities such as golf, archery and free throw shooting in basketball.

Acknowledgements

This work was supported by the DARPA program, Accelerated Learning, Dr. Amy Kruse Program Manager and by NIH grant MH078436.

References

1. Fisk, A.D., Schneider, W.: Memory as a function of attention, level of processing, and automatization. J. Exp. Psychol. Learn Mem. Cogn. 10(2), 181–197 (1984)
2. Schneider, W., Shiffrin, R.M.: Controlled and automatic human information processing I: Detection, search, and attention. Psychological Reviews 84, 1–66 (1977)
3. Schneider, W., Fisk, A.D.: Concurrent automatic and controlled visual search: Can processing occur without cost? Journal of Experimental Psychology: Learning, Memory, and Cognition 8, 261–278 (1982)
4. Anderson, J.R.: Acquisition of cognitive skill. Psychological Review 89, 369–406 (1982)
5. Anderson, J.R., Cognitive psychology and its implications. 4 ed. 1995, New York: Freeman.
6. Segalowitz, S., Wintink, A., Cudmore, L.: P3 topographical change with task familiarization and task complexity. Cognitive Brain Research 12(3), 451–457 (2001)
7. Klimesch, W.: EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res. Rev. 29(2-3), 169–195 (1999)
8. Chang, G., et al.: Practice-related EEG Changes during Simulated Flight. In: MIT Conference, MIT Press, Cambridge (2003)
9. Crews, D., Lander, D.: Electroencephalographic measures of attentional patterns prior to the golf putt. Medicine and Science in Sports and Exercise 25, 116–126 (1993)
10. Landers, D., Han, M., Salazar, W.: Effects of learning on electroencephalographic and electrocardiographic patterns in novice archers. International Journal of Sports Psychology 25, 313–330 (1994)
11. Kerick, S., Douglass, L., Hatfield, B.: Cerebral cortical adaptations associated with visuomotor practice. Medicine and Science in Sports and Exercise 36(1), 118–129 (2004)
12. Haufler, A., et al.: Neuro-cognitive activity during a self-paced visuospatial task: comparative EEG profiles in marksmen and novice shooters. Biological Psychology 53(2-3), 131–160 (2000)
13. Hillman, C., et al.: An electrocortical comparison of executed and rejected shots in skilled marksmen. Biological Psychology 52(1), 71–83 (2000)
14. Hatfield, B., et al.: Electroencephalographic studies of skilled psychomotor performance. Journal of Clinical Neurophysiology 21, 144–156 (2004)
15. Kerick, S., Hatfield, B., Allender, L.: Event-related Cortical Dynamics of Soldiers during Shooting as a Function of Varied Task Demand. Aviation Space and Environmental Medicine (in press)
16. Kerick, S., et al.: The role of the left temporal region under the cognitive motor demands of shooting in skilled marksmen. Biological Psychology 58(3), 263–277 (2001)
17. Loze, G., Collins, D., Holmes, P.: Pre-shot EEG alpha-power reactivity during expert airpistol shooting: a comparison of best and worst shots. Journal of Sports Sciences 19(9), 727–733 (2001)
18. Tremayne, P., Barry, R.J.: Elite pistol shooters: physiological patterning of best vs. worst shots. International Journal of Psychophysiology 41(1), 19–29 (2001)
19. Salazar, W., et al.: Hemispheric asymmetry, cardiac response, and performance in elite archers. Research Quarterly for Exercise and Sport 61(4), 351–359 (1990)
20. Kontinnen, N., Lyytinen, H., Viitasalo, J.: Preparatory heart rate patterns in competitive rifle shooting. Journal of Sports Sciences 16(3), 235–242 (1998)
21. Proctor, R., Dutta, A.: Skill Acquisition and Human Performance. Sage Publications, Thousand Oaks (1995)

22. Feltz, D., Landers, D.: The effects of mental practice on motor skill learning and performance: a meta-analysis. Journal of Sport Psychology 5, 25–57 (1983)
23. Hatfield, B., Hillman, C.: The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In: Singer, R., Hausenblas, H., Janelle, C. (eds.) Handbook of Sports Psychology, pp. 362–386. Wiley & Sons, New York (2001)
24. Berka, C., et al.: Objective Measures of Situational Awareness using Neurophysiology Technology. In: Schmorrow, D., Stanney, K., Reeves, L. (eds.) Augmented Cognition: Past, Present and Future, pp. 145–154. Strategic Analysis, Inc., Arlington (2006)
25. Stevens, R., Galloway, T., Berka, C.: Integrating EEG Models of Cognitive Load with Machine Learning Models of Scientific Problem Solving. In: Schmorrow, D., Stanney, K., Reeves, L. (eds.) Augmented Cognition: Past, Present and Future, pp. 55–65. Strategic Analysis, Inc., Arlington (2006)
26. Berka, C., et al.: Evaluation of an EEG-Workload Model in an Aegis Simulation Environment. In: Caldwell, J.A., Wesensten, N.J. (eds.) Proceedings of SPIE Defense and Security Symposium, Biomonitoring for Physiological and Cognitive Performance during Military Operations, pp. 90–99. SPIE: The International Society for Optical Engineering, Orlando (2005)
27. Berka, C., et al.: Real-time Analysis of EEG Indices of Alertness, Cognition, and Memory Acquired with a Wireless EEG Headset. International Journal of Human-Computer Interaction 17(2), 151–170 (2004)
28. Best, J.B.: Cognitive Psychology, 3rd edn. West Publishing Company, New York (1992)
29. Solomon, R.M., Horn, J.M.: Post-shooting traumatic reactions: A pilot study. In: Reese, J., Goldstein, H. (eds.) Psychological Services, in Law Enforcement, pp. 383–393. United States Government Printing Office (1986)
30. LaserShot, Military Skills Engagement Trainer. Stafford, Tx (2008)
31. Berka, C., et al.: Using Interactive Neuro-Educational Technology to Increase the Pace and Efficiency of Rifle Marksmanship Training. American Educational Research Association, New York (2008)
32. Pojman, N., Behneman, A., Johnson, R., Berka, C., Chung, G., Nagashima, S., Espinosa, P.: Identifying Psychophysiological Metrics of Expert Marksman. In: 13th International Conference on Human-Computer Interaction, San Diego (2009)