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I-NET®: Interactive Neuro-Educational Technology to Accelerate Skill Learning

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***Abstract*—The learning of a novel task currently rely heavily on conventional classroom instruction with qualitative assessment and observation. Introduction of individualized tutorials with integrated neuroscience-based evaluation techniques could significantly accelerate skill acquisition and provide quantitative evidence of successful training. We have created a suite of adaptive and interactive neuro-educational technologies (I-NET) to increase the pace and efficiency of skill learning. It covers four major themes: 1) Integration of brain monitoring into paced instructional tutorials, 2) Identifying psychophysiological characteristics of expertise using a model population, 3) Developing sensor-based feedback to accelerate novice-to-expert transition, 4) Identifying neurocognitive factors that are predictive of skill acquisition to allow early triage and interventions. We selected rifle marksmanship training as the field of application. Rifle marksmanship is a core skill for the Army and Marine Corps and it involves a combination of classroom instructional learning and field practice involving instantiation of a well-defined set of sensory, motor and cognitive skills. The instrumentation that incorporates the I-NET technologies is called the Adaptive Peak Performance Trainer (APPT®). Preliminary analysis of pilot study data for performance data from a novice population that used this device revealed an improved learning trajectory.**

I. 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]. 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[2]. 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 [3]-[5].

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 [6]-[7].

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 [8]-[10]. 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 [10]-[11].

The I-NET suite was developed to accelerate novice-to-expert transition in rifle marksmanship training and it addresses four major themes: 1) providing interactive and adaptive instructional tutorials with EEG-based closed loop paced training 2) characterizing the psychophysiological profile of expert marksmen by integrating our ABM wireless data acquisition system [26] to access EEG metrics and performance during laser rifle shooting 3) developing a novel device called the Adaptive Peak Performance Trainer APPT® that incorporates our knowledge about EEG signatures as well as an array of other physiological metrics to provide closed loop real-time feedback during shooting, and 4) identifying predictive factors such as aptitude for learning and anxiety levels to allow early triage and interventions. 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.

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II. METHODS

A. *Interactive and adaptive instructional tutorials*

Systematic interventions were designed to target three aspects of problem solving where the mental states (derived from EEG) of the individual are likely to reveal bottlenecks in skill acquisition. *i) The trainee not being ready to learn:* This situation could arise through sleep deprivation, excessive stress/poor stress management or through low priority of the learning task in a high workload situation. The intervention would be termination of the training session if deemed likely to be unproductive or if excessive errors in learning are likely to occur. *ii) Task-related lack of engagement:* This situation could arise where the task exceeds the individual's immediate ability to mentally model the problem due to the difficulty of the task. This would be evidenced by disengagement or 'thrashing', (acquiring excessive data while not engaged or while not processing it), and / or poor decision making. The intervention would be to shift the difficulty of the task to increase engagement or reduce discouragement. *iii) Excessive cognitive workload due to task and environment:* This situation could arise where constraints on the problem solving / decision making are imposed on an individual who otherwise would have no difficulty with the task. This would be evidenced by continuous high cognitive workload and high engagement. The intervention would be to closely monitor and shift the environmental factors to maximize learning.

B. *Characterizing psychophysiological profile of experts*

Relationships between EEG parameters and proficiency in real world activities have been reported in golf putting [12], archery [13], and marksmanship [14]-[16]. 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" [12]. 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 [17]-[18]. Alpha power in expert marksmen is particularly increased over the left central-temporal-parietal region during the seconds preceding trigger pull [17]-[19]. The magnitude of the increase in pre-shot alpha power has been positively correlated with the accuracy of the subsequent shot [18]-[20] in 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 [17]. The pre-shot period is also characterized by heart rate deceleration and a decrease in electrodermal skin conductance levels [22]. Heart rate changes are believed to reflect the focusing of attention and the skill-related aspects of sensory-motor preparation for performance [22]. Consistency and reproducibility of the successful pre-shot routine is a major feature that distinguished novice from expert [23]-[24]. For the current pilot studies, individual's alpha levels and basal heart rate were used as the reference point to provide feedback. Given the common finding that alpha power increases while heart rate decelerates in both our examination of experts and in prior studies [17]-[19]. [22], this was the state focused on in the current studies. There are potentially additional states that may include increases in theta power or other metrics, that will be addressed in future studies.

We used the lab-version of the Adaptive Peak Performance Trainer (described in the next section) to record psychophsysiological metrics associated with expert performance. An overview of the recorded measures, with their respective source and usage is listed in Table-1

TABLE I
METRICS RECORDED FOR ANALYSIS

Metric	Data Source	Usage
Cognitive overload	EEG	Used as an indicator of how well the shooter is processing information and accommodating task demands.
Pre-shot EEG alpha & Theta		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		Used to characterize the distance of dispersion of shots.
Respiration	Breathing	Used to measure inhalations and exhalations.
Trigger break	Switch	Used to establish a synchronization point for all measures.
Trigger squeeze	Pressure Sensor	Used to examine quality of trigger squeeze slow or rapid
Muzzle wobble	Accelerome ter	Used to measure movement in the muzzle of the weapon.

C. *Adaptive Peak Performance Trainer (APPT®)*

The Adaptive Peak Performance Trainer (APPT®) 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 APPT is to provide continuous psychophysiological monitoring and feedback (visual, auditory or haptic) on relevant changes in these measures to the trainee in real time. The laboratory-based APPT 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 in the mobile-version of the APPT.

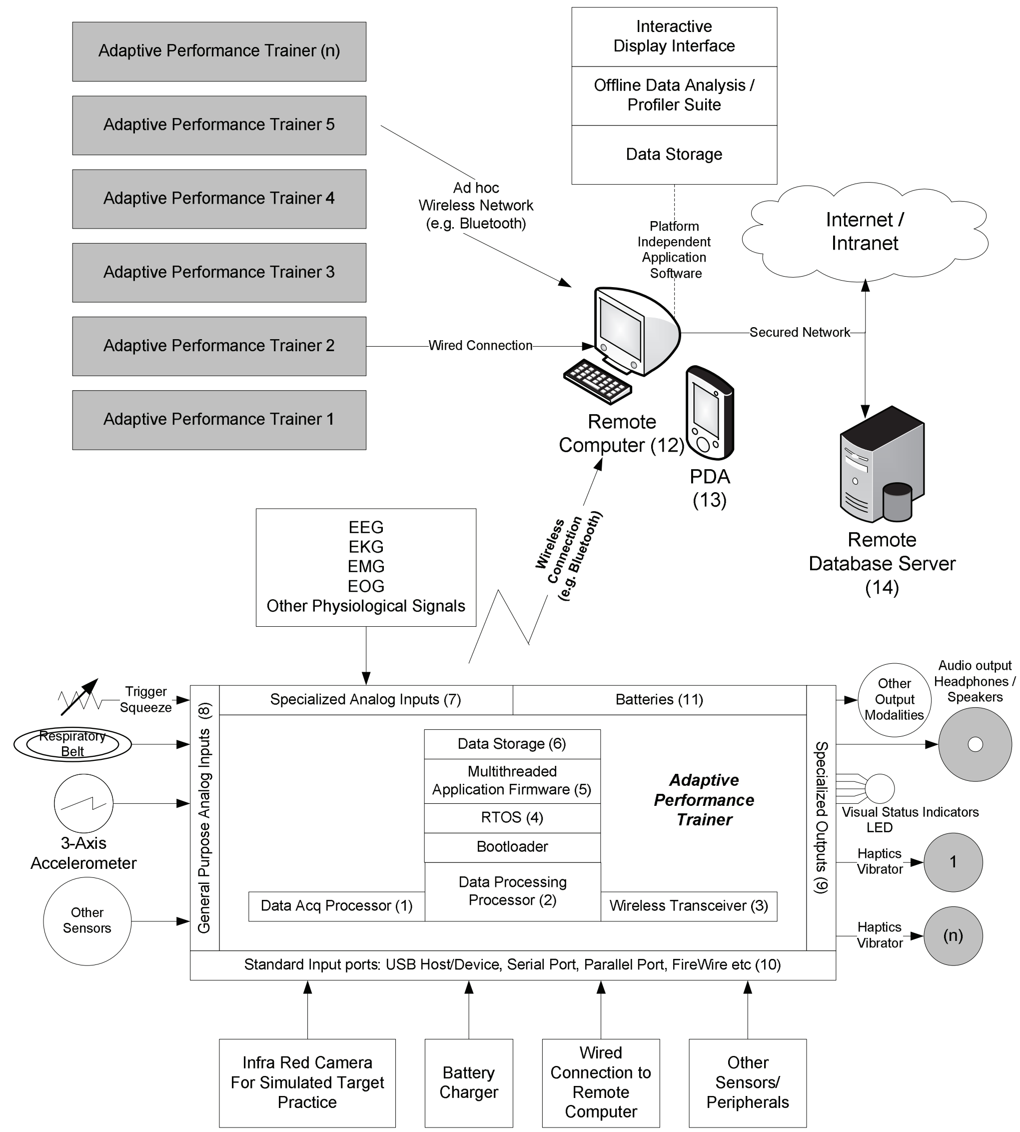

Figure 1. Block Diagram of the APPT

In the lab setup, a demilitarized "airsoft" replica of the M4 rifle was used as the instrumented weapon and an infrared laser-based training system from LASERSHOT [25] was used for target projection (via an LCD projector) and shot detection (via infrared camera). All necessary sensors and associated electronics were integrated into a portable package with a low power 32-bit ARM9 processor. Bluetooth protocol was used to transmit the data to a remote a computer for display, storage and offline analysis. The sensors and data acquisition circuitry of a previously developed 9-channel wireless B-Alert® sensor headset [26] 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. Three primary real-time feedback modalities were provided: i) audio feedback via a small speaker interfaced to the package and 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.

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. The alpha levels were classified as good (less that 5% above baseline), better (between 5% and 10% above baseline) and best (10% above baseline). Haptics feedback was provided corresponding to each alpha levels. 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 alpha and heartbeat feedbacks were superimposed in the haptics vibration pattern. Changes in thoracic or abdominal circumference during respiration were measured using a respiratory belt transducer containing a piezo-electric device. A force pressure sensor was attached to the trigger and the resultant pressure on the sensor measured over time. The respiratory and the trigger squeeze waveforms were superimposed to detect variations from the expert trigger squeeze profile. 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. An accelerometer was attached to the muzzle of the instrumented weapon to measure the degree of movement in the muzzle of the weapon.

D. Identifying predictive factors to allow early triage

The general aptitude of the trainee has been predictive of higher performance level outcomes during training. Our patented Alertness and Memory Profiling System (AMP®) [26] was used to better delineate the neurocognitive predictors of aptitude. The AMP was designed to simultaneously assess EEG and cognitive function using a multivariate approach integrating neurophysiological, neuropsychological, behavioral and subjective measures of alertness, attention, learning and memory into an easy-to-administer protocol. A database of over 1000 AMP sessions from healthy subjects (fully-rested & sleep-deprived) and over 200 patients with sleep disorders provided population statistics for comparison of AMP results. Four neurocognitive factors are derived from the AMP data: sustained attention, processing speed, verbal memory and visuospatial memory with a quantitative score applied to each factor. Alertness, attention, verbal/visuospatial learning and memory are also quantified using a combination of EEG and performance metrics. The recently integrated HR/HRV measures provide additional physiological metrics indicative of fatigue, overload, anxiety and stress levels. If aptitude is low, special on-line tutorials optimized to the individual was used to provide instruction.

E. Pilot study

We recruited 3 sets of novices to develop the APPT. The first set received only verbal coaching feedback (Ground zero, n=15). The next set of Novices were asked to use the APPT offline only to develop the ability to increase alpha (Tx2= 19), with various versions of the offline trainer. The final set of 9 novice subjects were used to evaluate the effectiveness of the full I-NET/APPT system when applied to marksmanship training. Three participants first completed the protocol without sensory feedback (no APPT) and then returned on a later day to complete the APPT protocol. The remaining six subjects completed the APPT protocol only. Preliminary studies suggested that sensor-based feedback is overwhelming to the novice shooter in the beginning training stages (the first portion of the Tx2 group), and is more useful once the novice is familiar with the positional elements of marksmanship. For this reason, real-time feedback using the APPT 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 APPT, performance improvements achieved using the APPT were compared to two other experimental groups of novices, and one group of marksmanship experts. All novice groups (Ground Zero, Tx2, and APPT) 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 APPT while shooting. The Tx2 group received individualized coaching and offline sensor-based feedback, but no APPT while shooting. The APPT group received individualized coaching, offline sensor-based feedback, and APPT while shooting. The expert group was comprised of 10 marksmanship coaches, each of which qualified as expert on their most recent marksmanship qualification. Experts were given no instruction or other type of feedback during shooting.

Figure 2. Experimental set-up.

III. RESULTS

Preliminary analysis of performance data comparing the pre/post intervention performance (mean distance of each shot from shot group center) at Baseline (Trials 1 and 2) and Final (two trials at or after Trial 7 that show best performance) of APPT 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. 1, Table 2) is encouraging and suggests that providing, real-time physiological feedback through the APPT protocol is effective in improving the performance of novices at a greater rate than for other treatment groups. Further evaluation is required, and currently being pursued with a more controlled experiment.

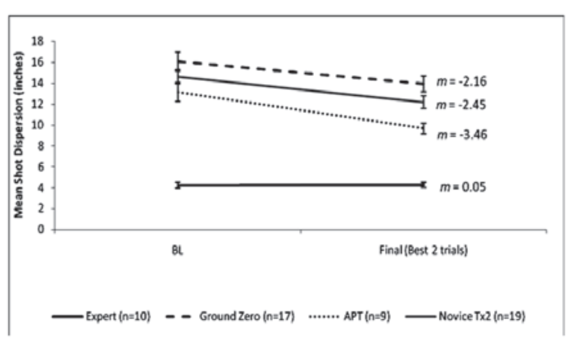

FIGURE 3: Pre-post intervention performance across each pilot test group and expert on shot dispersion.

TABLE 2.
DESCRIPTIVE DATA

Study group	Age +/-SD	M/F	Pre-Tx Shot Mean +/-SD	Post-Tx Shot Mean +/-SD
Experts	23.7 +/- 1.77	10/0	4.23 +/-2.7	4.28 +/-2.54
Novices				
Ground Zero	21.5 +/-2.61	13/4	16.08 +/-11.62	13.92 +/-9.71
Tx2	24.23 +/-5.34	14/7	14.98 +/-9.14	11.61 +/-8.11
APPT	22.89 +/-1.9	5/4	13.12 +/-8.6	9.66 +/- 6.6

IV. DISCUSSION

Experiments are currently underway to begin to address the applicability of the I-NET system in scenarios that more closely approximate combat conditions (including use with actual weapons). 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 marksmen suggests a finely tuned level of control over physiology that appropriately allocates resources to meet task demands. I-NET is 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.

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