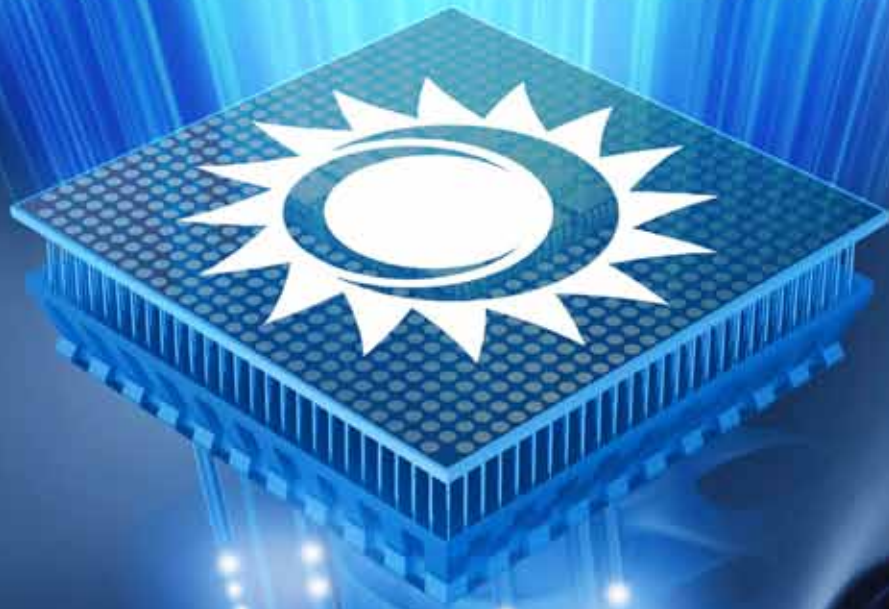




# OPERATIONAL NEUROSCIENCE APPLICATIONS



# Taking Neuroscience Out of the Lab... and Into the Real World, 4Z3 Wf Xb\_ 4;A B35

The measurement and interpretation of the brain's electrical activity to assess cognitive state, until recently, has been limited to laboratory investigations by academic researchers. Over the past eight years, Advanced Brain Monitoring and its collaborators pioneered the use of cognitive state analysis for real-world settings. These applications include: closed-loop performance monitoring and simulation training; HCI design assessment; situational awareness and team dynamics monitoring; tools for productivity and training enhancement; and fatigue management. Looking to the future, the company's goal is to expand the scope of its collaborations to further integrate and operationalize our technologies in defense, education, and health-care in the U.S. and worldwide. BIOPAC distributes the hardware & software ([www.biopac.com](http://www.biopac.com)).

Funding for the published research described herewith was directly or indirectly provided by one of the following institutions:

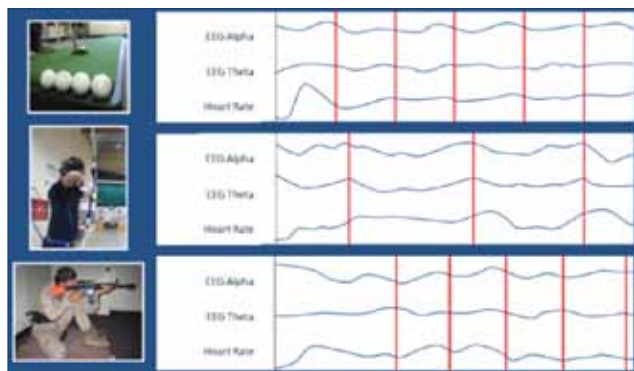


The published research described herewith was performed directly or indirectly at or in collaboration with investigators at the following institutions or entities:





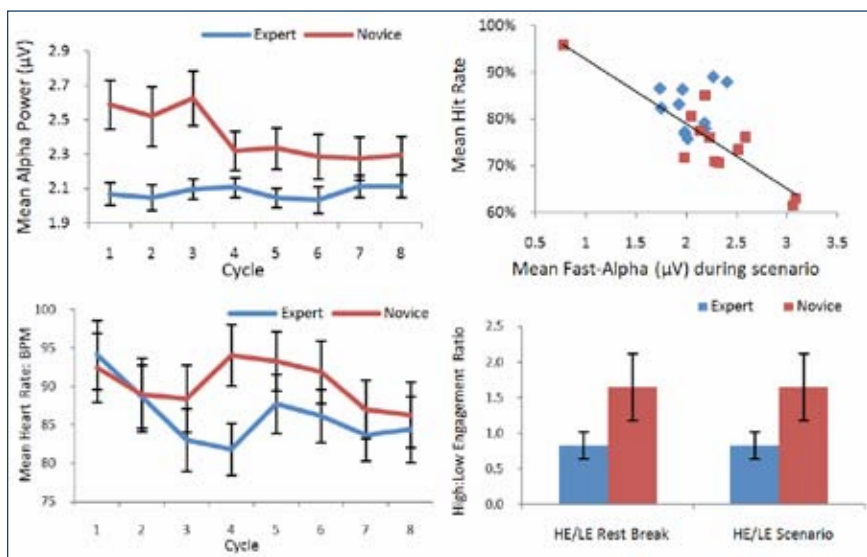
Accelerating proficiency in a novice is difficult when the acquired skill is dependent on consistently applying a well-defined set of sensory, motor and cognitive skills. Marksmanship, golf and archery are examples in which optimal performance is reliant upon motor preparation, focus and concentration. In this study the psycho-physiological profile of marksmanship was compared to archery and golf using 13 USMC active-duty marksman coaches, three archers on the U.S. Olympic team, and four PGA-certified golf professionals. Results showed that patterns of pre-shot alpha activity were similar across all three tasks, although pre-shot theta and heart-rate deceleration were not as pronounced during putting and archery. These findings suggest that marksmanship peak-performance training may be applicable to other sports which rely on motionless preparation and in which performance anxiety may be high (e.g., the “yips” in golf).



Berka, C., Behneman A., Kintz, N. (2010) Accelerated Training Using Interactive Neuro-Educational Technologies: Applications to Archery, Golf and Rifle Marksmanship. J Sports Society

## Combat Deadly-Force Judgment & Decision Making Performance

The decision of when to use deadly-force is one of the more challenging skills to train. Simulations must be sufficiently realistic to fully engage the trainees. Split-second life-or-death decisions require the decision maker to be optimally prepared mentally. The psycho-physiology of deadly-force judgment and decision-making (DFJDM) was evaluated in 12 experts (military and police) and 12 novices. Over the course of a day, each participant completed eight training cycles. Each cycle included three x two-minute life-size scenarios containing real world demographics and locations of domestic disputes, vehicle interventions, etc. Deadly force was justified in 17 of 24 (70%) of the scenarios.



with DFJDM skill. The next phase of this research is to assess the benefit of training novices to control EEG and heart rate during DFJDM.

Across subjects and scenarios, fast-alpha EEG activity (10 – 12 Hz) was significantly suppressed in experts vs. novices. The magnitude of alpha activity over the right parietal site explained almost 80% of the variance in correct use of deadly force (i.e., hit rate) across subjects. The high alpha activity exhibited by novices at the beginning of the study decreased as the study progressed (from cycle 1 to 8). Experts showed significantly lower levels of heart rate and cognitive engagement during the scenarios as well as at rest. These findings suggest lower alpha power in the right parietal region is associated

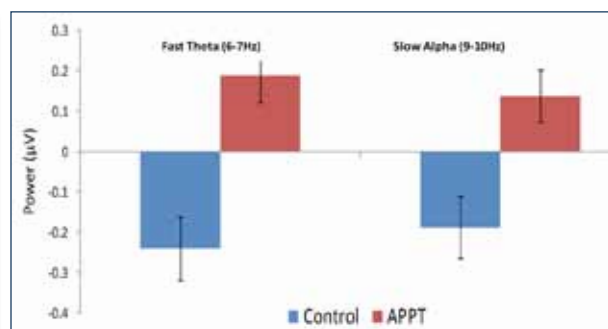
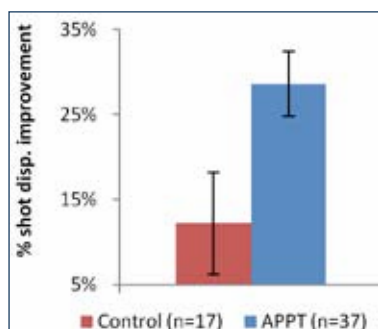
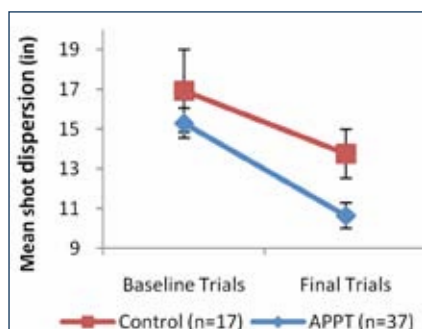
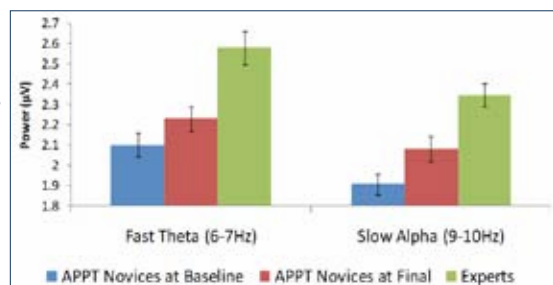
## Improving the Pace and Efficiency of Rifle Marksmanship

Rifle marksmanship is a core skill for the Army and Marine Corps, acquired through classroom learning and field practice. The speed and efficiency by which novices transition to expert is dependent in part on the acquisition of motor skills which involve physiological control (respiration, heart rate, etc.). For this study, the capability to accelerate marksmanship skill acquisition was assessed through the use of the Interactive Neuro-Educational Technology (I-NET). The I-NET is a suite of neuroscience-based evaluation and feedback systems that enhances the assimilation of well-defined sets of sensory, motor and cognitive skills.



To profile expert physiology, 13 off-duty qualified marksmanship trainers underwent a 45-min baseline physiological profiling session (physio-baseline) followed by 3 simulator trials of five shots. Marksmanship was studied in a kneeling position at simulated distance of 200m using a demilitarized “airsoft” replica of the M4 with an infrared laser-based training system for target projection and shot detection. Shot precision was defined as the mean distance of each shot from the center of the shot group, where lower values reflect better precision. Results showed that experts displayed a heart rate deceleration and a marked increase in EEG alpha and theta power three to four seconds preceding each trigger pull. This pattern suggested automated task execution performed with minimal conscious mental effort. The experts also exhibited significantly greater cardio- respiratory control when sitting quietly with their eyes opened or closed.

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Novices (n=54) underwent the same physio-baseline session as the experts followed by a 20-minute marksmanship instructional video. The group of 17 controls underwent up to eight marksmanship baseline trials of five shots. The second group of novices (APPT; n=37) underwent neuro-feedback training by completing four trials of five shots, five-minutes of alpha training, two trials of five shots, a second alpha training session, and the two final trials with neuro-feedback. The Accelerated Peak Performance Trainer (APPT) provided the neuro-feedback by delivering a vibrational pulse from a haptic motor taped to the neck triggered by each heart beat to assist the novice to learn how to control their cardio-respiratory function. Feedback was programmed to terminate when patterns of increasing EEG match those of the expert.

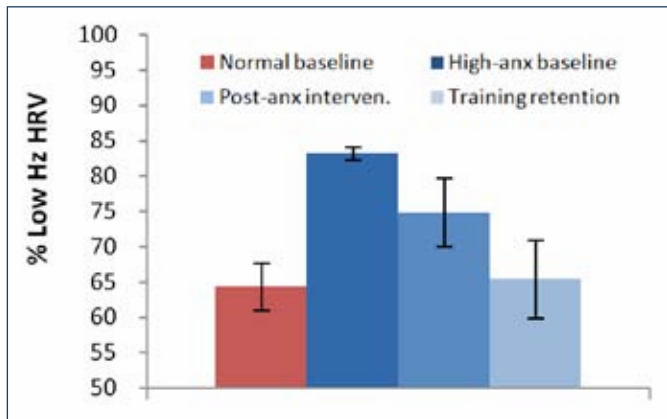
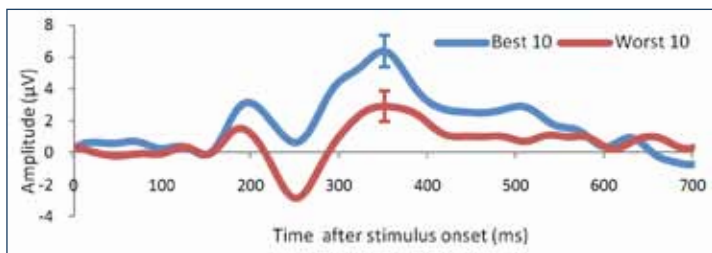
The upper-left graph above shows that APPT training improved the shot precision learning trajectory by 230% and contributed to a significant improvement in the percent change in shot dispersion. Over the course of training, the levels of pre-shot fast theta and slow alpha increased significantly for the APPT group (right), while the controls decreased in pre-shot fast theta and slow alpha power. Although one training session with APPT significantly improved marksmanship skill, it was not sufficient to bring the majority of novices to the expert level. Additional studies are planned to determine how to optimize the use of the APPT.

Berka, C., Behneman A., Kintz, N. (2010) Accelerated Training Using Interactive Neuro-Educational Technologies: Applications to Archery, Golf and Rifle Marksmanship . J Sports Society

Raphael, G., Berka, C. et al. (2009). I-NET: Interactive Neuro-Educational Technology to Accelerate Skill Learning. 31st Annual International IEEE EMBS Conference. Minneapolis, MN.

## Neuro-profiles that Predict Skill Competence

This investigation sought to define neuro-signatures useful in predicting marksmanship proficiency. Profiling was performed using baseline recordings from a 20-min 3-Choice-Vigilance-Test (3C-VT), and 5-min of eyes-open and eyes-closed obtained prior to marksmanship training.

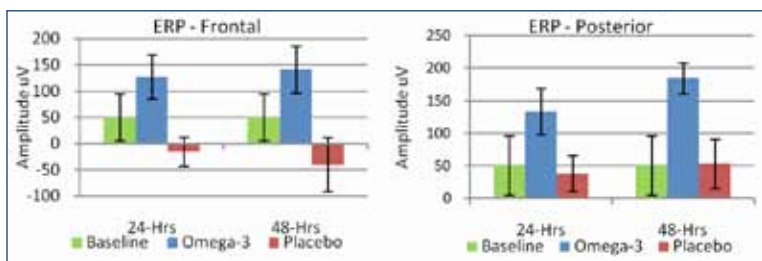
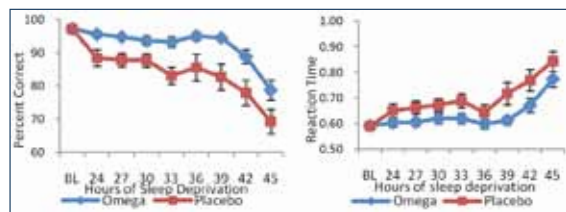


Results showed the amplitude of the “P300” component of the event related potential (ERP) of the best performers in a marksmanship training session were significantly greater than the poor performers during the 3C-VT. This finding suggests that EEG-based P300 amplitude recorded during a visual discrimination may be a predictor of marksmanship aptitude. High cardio-sympathetic activity as measured by power spectral analysis of heart rate variability during eyes-open and eyes-closed was a negative predictor for marksmanship performance. A training intervention was developed for

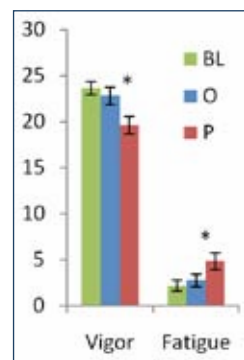
high anxiety individuals using a guided 18-min Relaxation Training video followed by a reassessment of heart rate/anxiety levels. Participants continued to marksmanship training once anxiety levels were within one standard deviation of the population mean or after two relaxation training sessions were completed. Ten of the 11 participants that completed the relaxation training exhibited decreased anxiety across training sessions.

## Mitigating Sleep Deprivation with Omega-3 Fatty Acids

The link between Omega-3 fatty acids and enhanced stress resiliency, memory, and performance was assessed in 30 subjects who completed two trials of 48-hour acute sleep deprivation. One arm of the double blind cross-over design was on high dose Omega-3 and the other on placebo. The Alertness and Memory Profiler was used to objectively assess outcomes. The graphs to the left show that performance, measured by percent correct and reaction time during a 3-choice vigilance task, was substantially better when the subjects were on high dose Omega-3. High performance was maintained for approximately 39-hours after the start of the sleep deprivation.



The amplitudes of the memory event related potentials (ERPs) across subjects and conditions in response to targets and non-targets were significantly greater while on high dose of Omega-3 as compared to



placebo. ERP memory components were more pronounced after 24- and 48-hrs of sleep deprivation compare to both baseline and placebo in the frontal (executive function) and the posterior (spatial working memory) regions. Subjects reported no difference in anxiety, depression, anger, or confusion resulting from sleep deprivation during their Omega-3 and Placebo sessions. While on placebo, subjects reported increased fatigue and decreased vigor. Additional studies are underway to assess the benefit of Omega-3 under chronic sleep deprivation conditions.

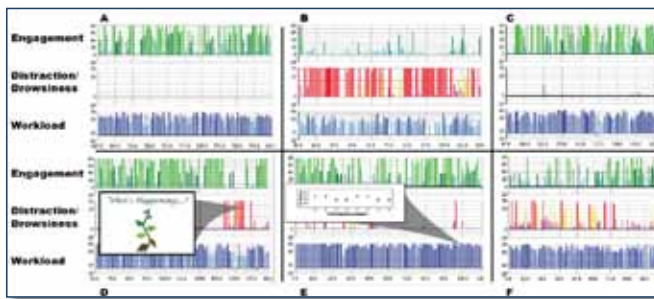
Johnson, R, Berka, C. et al. (2010) Mitigation of sleep deprivation through Omega-3 fatty acids: Neurocognitive inflammatory, EEG and EKG evidence, Neuroscience, San Diego, CA



## Psychophysiological Characterization of Learning and Skill Acquisition

Skill development occurs 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. During the transition from cognitive to associative stage, speed and accuracy increase as subjects become less reliant on declarative representations of knowledge.

Over a training session, a trainee's overall performance will be influenced by how rested and motivated they are, how familiar they are with the task, and the context of the environment that they are performing in (i.e. high vs. low stress). Over a series of inter-related tasks during the training session, performance is influenced by how well the trainee understands the content and contextual linkages between tasks. Sometimes these linkages are automatic, but on other occasions searching for additional information is required. These change as skills are acquired. Within a single problem solving task, event-related metrics can inform whether the trainee understood the task or recognized and encoded important pieces of information. The transitions between these 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 have demonstrated that quantification of information processing including attention, memory and workload through the application of in EEG power spectra and event-related EEG are associated with stages of skill acquisition in simple and complex tasks. Technically, EEG-based cognitive load measurement offers the advantage of extremely high temporal resolution. EEG is collected at the millisecond level, in contrast to the longer time intervals required for traditional measures such as mouse clicks or user responses. This permits effective monitoring of workload fluctuations in very rapid decision-making processes that are unobservable using traditional methods.

From a neurophysiologic perspective, complex learning events in simulations for training math and science skills span a long time. EEG measures are particularly relevant during the transitions across single problem solving tasks within a series of inter-related tasks. The key outcome related to depth of learning and skill acquisition is the eventual decrease in mental effort required to perform the task, not just 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.

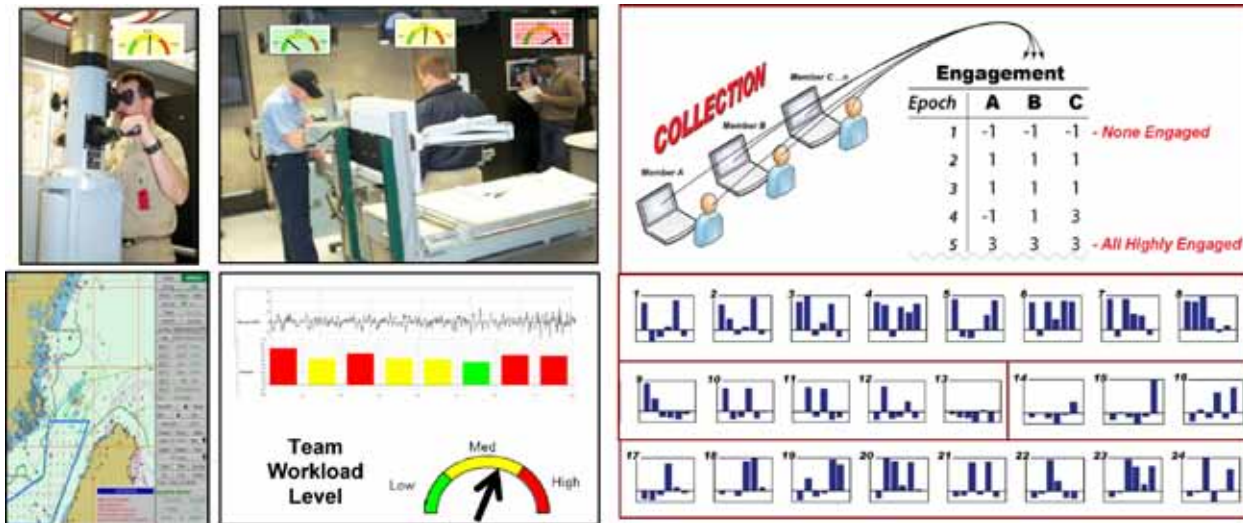
Empirical classroom studies have shown that dynamic changes in of EEG-based Workload, Engagement and Distraction identify different temporal levels that can help pace training activities in different ways. This can be accomplished using a closed-loop feedback system where the output of the cognitive state analyzer can be used to provide information to the trainee, the trainer or via an automated adjustment in a computerized training simulation test bed.

Stevens, R., Galloway, T. et al. (2007). EEG-Related Changes in Cognitive Workload, Engagement and Distraction as Students Acquire Problem Solving Skills. User Modeling Conference. Athens, Greece.

Raphael, G., Berka, C. et al. (2009). I-NET: Interactive Neuro-Educational Technology to Accelerate Skill Learning. 31st Annual International IEEE EMBS Conference. Minneapolis, Minnesota.

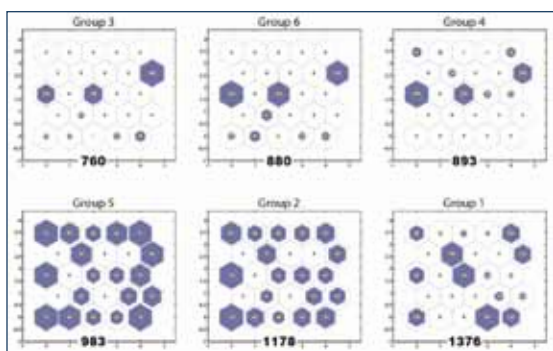
Stevens, R., Galloway, T. et al. (2007). Allocation of Time, EEG-Engagement and EEG-Workload Resources as Scientific Problem Solving Skills are Acquired in the Classroom. Augmented Cognition: Past, Present, & Future. D. Schmorow, Stanney, K., Reeves, L. Arlington, VA, Strategic Analysis, Inc.

Team performance is impacted by each member's level of attention, engagement, distraction, and cognitive workload relative to what they are responsible for at a particular time, the progress the team has made toward the task goal, and the composition and experience of the team. In this application, scenario-based group situational awareness was assessed in two, six-member submarine officer teams across four Submarine Piloting and Navigation (SPAN) sessions using neuro-physiological measures of cognitive engagement.



The framework for quantifying group neurophysiologic synchronies required the simultaneous acquisition, synchronization, and quantification of EEG-derived metric of engagement. Each individual's engagement values across the session were normalized to account for individual differences. A value of -1 was then assigned to any one-second epoch that fell into the lowest quartile of engagement values, a value of 3 was assigned to epochs in the highest quartile, and a value of 1 assigned to epochs that fell into the middle two engagement quartiles. A neural network was then trained using these nominal values with the order of the group pre-assigned (i.e., Officer of the Deck, Contact Coordinator, Navigator, Assistant Navigator, Quarter Master on Watch and Radar). The graphs above display the 25 unique combinations of engagement identified across the six team members.

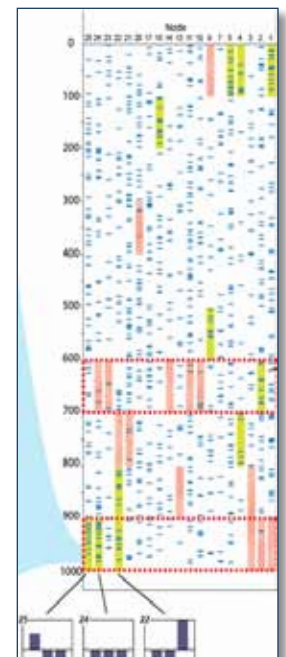
Previous work with 3-person teams showed patterns of neuro-synchrony could identify those teams that were most efficient and effective in reaching solutions to complex problems.



The graph on the left shows the contrast between NS patterns for the best (groups 1 – 3) and worst performing teams (groups 4 – 6). Optimal teaming as associated with consistent patterns of engagement during decision making. The graph to the right shows neuro-synchrony patterns which change over time as a result

of the complexity of the teaming environment and the frequency of decision making across members.

Preliminary evidence suggests that the interpretation of neuro-synchronies improve when the scenarios are controlled and comparisons are made relative to expert teams with patterns mapped for each role in the simulation. Novice data can then be compared to the experts to provide feedback with the goal of optimizing team performance.



Stevens, R., Galloway, T. et al. (2009). In the groove or Out of Synch?: Exploring a Neurophysiological Perspective of Teamwork. Society for Neuroscience, Chicago, IL.

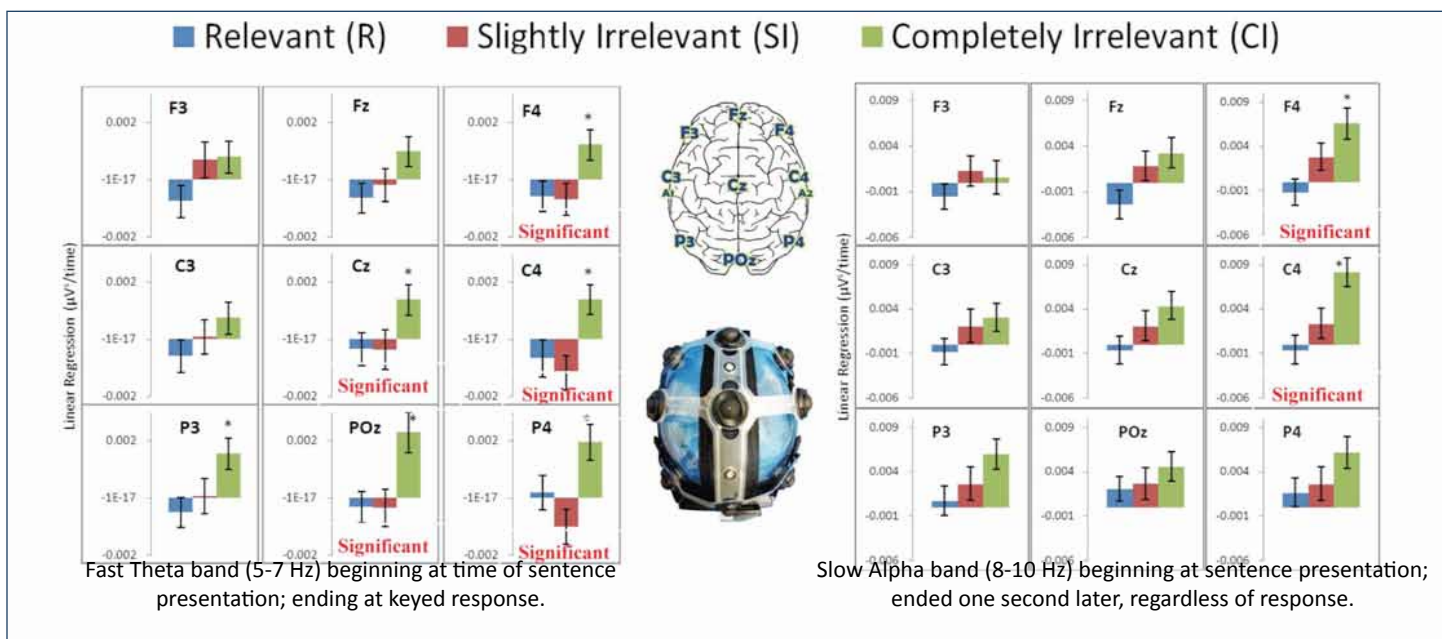
Stevens RH, Galloway, T. et al. (2010). A Neurophysiological Approach for Studying Team Cognition. I/ITSEC Conference Orlando, FL.

# Enhancement of Intelligence Analysts' Extraction of Text-Based Content

A closed-loop analysis system was developed to use intelligence analysts' neurophysiology to auto-extract text snippets relevant to the current analysis goal during processing textual data and associated decision making. The combination of EEG from a wireless headset and eye gaze from an eye tracker were used to identify and track sub-conscious elements of interest to ensure all relevant information was taken into consideration, while still allowing the analyst to also manually extract items they perceive as relevant. This approach was intended to reduce the effects of analyst bias and inattention and provides a faster, more accurate extraction of evidence.



The system was validated in study of 27 healthy subjects. Participants were first shown a short background story that provided the analysis scenario and a related one-sentence proposition (analysis question), and were then asked to view a series of 30 sentences to determine their relevance to the provided proposition. Ten of the sentences were relevant to the analysis question, 10 were totally irrelevant and 10 were irrelevant but contained key words found in the study topic. The figures below marked as "significant" identify the areas of the brain where the sub-conscious elements of interest can be recognized with fast theta and slow alpha EEG frequency bands.



The amount of EEG theta activity, adjusted to account for individual differences in theta generation, was linearly related to the assimilation of information within the reader's mental construct. When a reader began to read a sentence theta levels were high. As the reading of the sentence continued, if the information was consistent with the reader's belief system, theta levels gradually dropped. If the information was inconsistent or conflicted with the reader's mental model, theta values increased sharply. The results suggest that only EEG from the right hemisphere of the brain is needed for this text-based application. This study demonstrates how the number of sensors needed for a particular application can be reduced to improve the trade-off between increased speed and accuracy vs. user inconvenience when wide deployment is considered. Application of the automated linear theta scale has the potential to allow researchers to tailor content for desired outcomes.

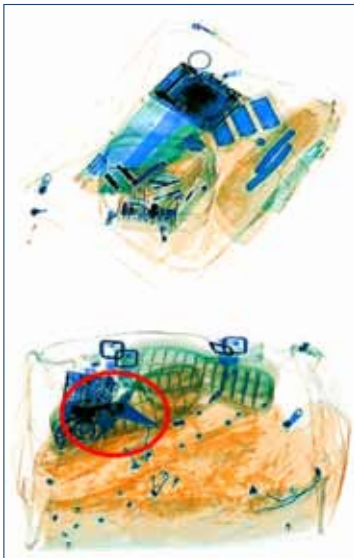
Behneman, A., Kintz, N. et al. (2009). *Enhancing Text-Based Analysis Using Neurophysiological Measures*. 13th International Conference on Human-Computer Interaction, San Diego, CA.



# EEG Correlates of Decision Making based on Mental Modeling

The role of an analyst includes scanning of imagery rapidly and accurately in order to identify operational threats. Indices which detect cognitive processing as the user matches their mental model of a threat/non-threat to the actual image could be used to accelerate learning and/or monitor performance.

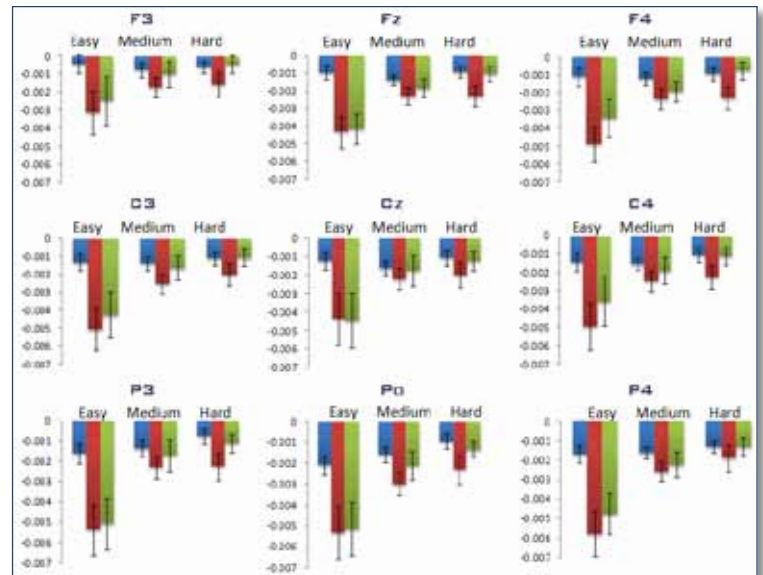
A study was conducted to assess the feasibility of integrating real-time analysis of EEG indices of workload, task engagement and attention into the human-computer loop for training new luggage screeners (n=23). X-ray imagery of non-treats and threats (sharp objects and hand guns) with varying degree of detection difficulty were used in the study design.



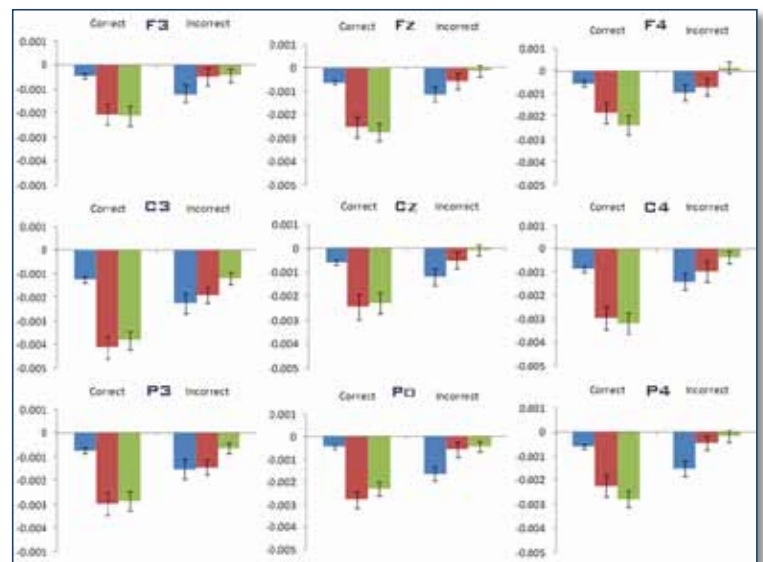
The results showed a distinct cognitive processing pattern was apparent in 90% of the subjects beginning with the presentation of the image and ending with the threat/non-threat decision. The magnitude of initial theta synchrony and the speed in which the theta activity desynchronized

related to the difficulty of the task, whether the image was a threat or non-threat and the region of the brain most activated by the encoding. The desynchronization of theta activity was followed by the synchronization of alpha power which was also influenced by and across stimulus difficulty and response type.

Given these patterns were strongest with easy or target stimuli, weakest with more difficult, non-target stimuli, these findings suggest that the EEG theta and theta synchronization is likely correlated with subject skill acquisition and indicative of the progressive development of the individual's cognitive mapping of their mental model. The relationship between EEG Alpha and correct vs. incorrect responses suggests a measure of efficient use of attention processes. Theta and alpha synchronization may also help to differentiate between hits, false alarms and correct rejections. The next phase of the research will be to reduce the number of scalp sites and provide a real-time assessment as to when the subject is guessing or actually believes to accurately recognize a target. Additional efforts will focus on neuro-cognitive signatures which profile those more likely to succeed in the role of a fast and accurate luggage screener.



Mean slope of EEG Theta (3-7 Hz) desynchronization from stimulus presentation to response averaged across Threat Type and Stimulus Difficulty

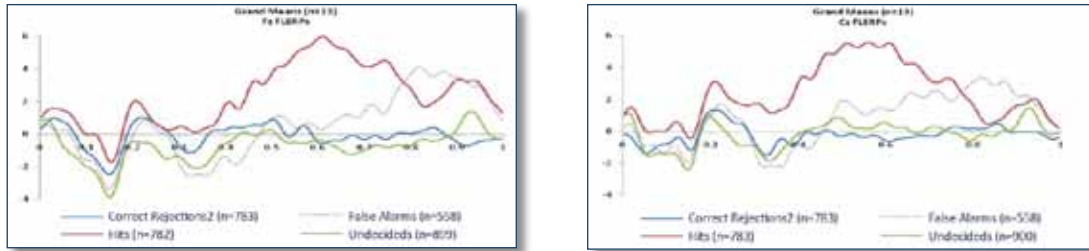


Mean slope of EEG Alpha (8-12 Hz) across stimuli type and response type from stimulus presentation to response

Raphael, G., Berka, C., (2009) "Interactive Neuro-Educational Technologies (I-NET): Enhanced Training of Threat Detection for Airport Luggage Screeners" Engineering in Medicine and Biology Society Annual International Conference of the IEEE

## Neuro-Patterns Associated with Viewing of Satellite Imagery

The ability to track salient targets is common to contemporary work environments ranging from airport security to imagery analysis. A neurotechnology platform was implemented for real-time EEG to monitor operator state during review of complex satellite imagery. Consistent, quantifiable stimulus-locked event-related potential (ERP) signatures for timed presentation of targets/non-targets were identified (right). A single trial classifier achieved accuracy approaching 80% across tasks, participants and test stimuli. An alternative approach maximizes accuracy of the time-locked analysis by integrating eye-fixations as triggers.

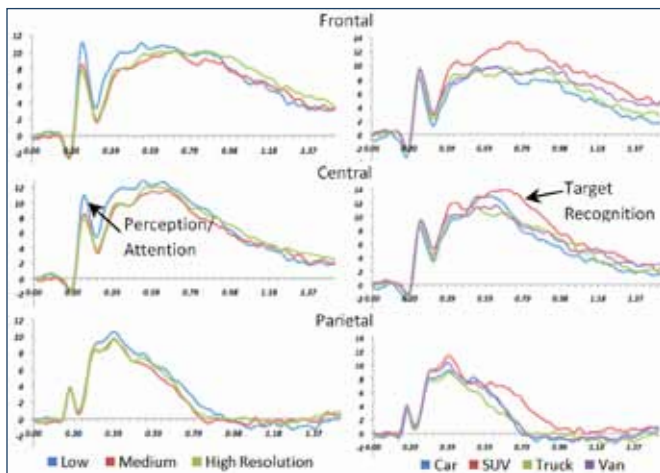


Given the review that intelligence data are more dynamically paced than conditions in which the presentation of the stimulus/data are carefully controlled, an ERP classifier was developed to trigger the EEG analyzer based on eye fixations defined by an eye tracker system. The preliminary evidence suggests that the waveshape characteristics of fixation-locked ERPs, “FLERPs” (left) resemble stimulus-evoked ERPs with distinct signatures associated with hits, correct rejections and misses. Single-event FLERP analysis requires millisecond time locking between the detection of the eye-tracker gaze and extraction of the EEG signature.

Berka, C., Hale, K. et al. (2008). Interactive Neurotechnology Platform: A Real-time Window on Human Information Processing at the Millisecond Level. Applied Human Factors and Ergonomics, Las Vegas, NV.

## Impact of Simulator Fidelity on Behavior and Neurophysiology

Visual fidelity is a critical element in the design of virtual training simulations. The cost benefit of enhanced fidelity in terms of improved immersion or training outcomes is compared to the associated development or procurement costs. This study used event-related brain potentials (ERP) to objectively assess differences in perception, attention, target recognition resulting from differences in vehicle type (van, SUV, car, truck), color (blue, red, white), orientation (east, northeast, southeast, etc.) and resolution (low, medium, high). Results showed that fidelity, vehicle type and orientation independently impacted correct recognition across the 432 stimuli presented to the 19 subjects. Increased vehicle resolution was found to positively impact reaction times for correct responses. Cars and vans were

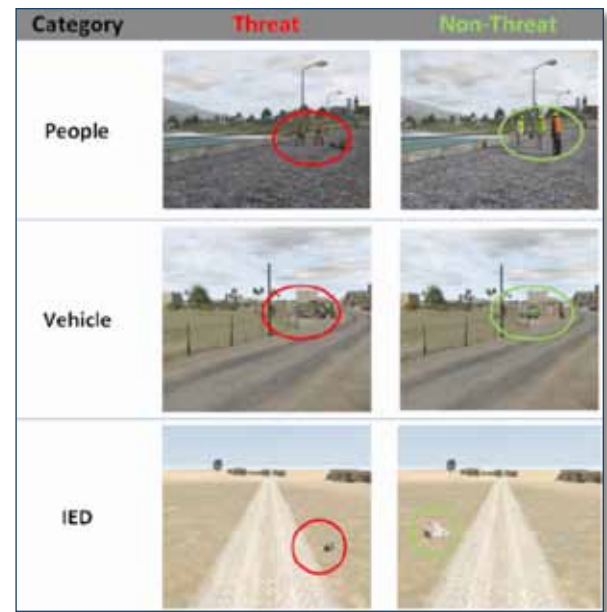


associated with significantly faster reaction times for correct responses; SUVs and trucks were associated with slower responses. Vehicle size did not impact detection accuracy, nor did the interaction across fidelity options (i.e., type, color, resolution, orientation). Patterns of increased attention were apparent in the midline ERPs for low resolution images while the amplitude of late target recognition component was distinctively greater for SUV. The ERP findings in combination with the performance measures suggest increased cognitive effort is required for lower resolution or difficult to interpret images

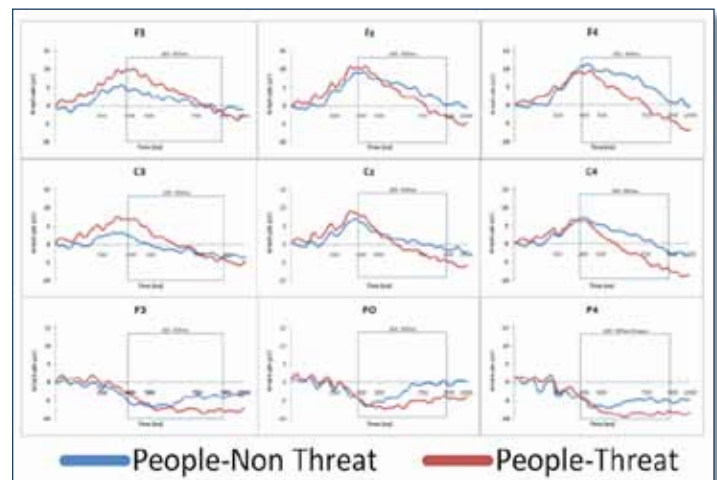
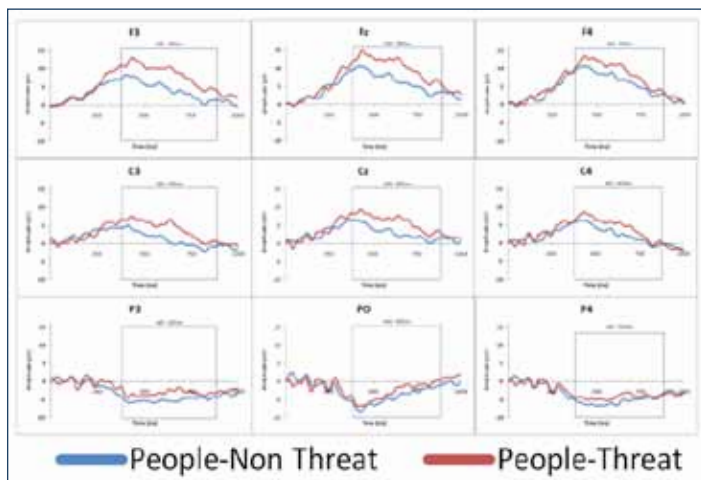
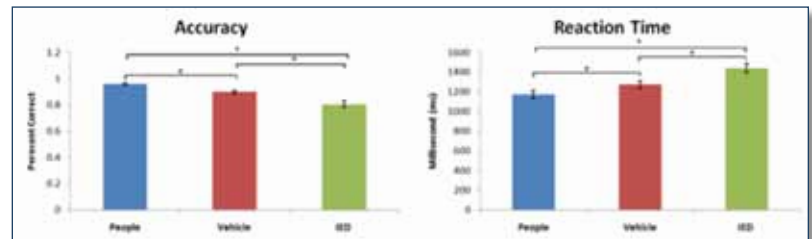
Skinner, A., Berka, C., et al. (2010) Impact of Virtual Environment Fidelity on Behavioral and Neurophysiological Response. I/ITSEC conference Orlando, FL

# Threat Identification in the Virtual Battlespace 2 (VBS2) Training

VBS2 is a complex and realistic training simulation platform that is widely used to train observation skills for military applications. In collaboration with NRL and UCF, ABM is developing an adaptive closed-loop interface with the VBS2 to allow EEG-derived cognitive and affective state metrics to drive the simulation scenarios. The goal is to accelerate learning with the simulation interactively adapted to individual's skill level by combining measures of performance (e.g., accuracy, speed, and efficiency), cognition (engagement, confusion, workload) and stress with intervention strategies including slowing or speeding the pace of the scenario; introducing alarms or prompts to direct attention; or changing the level or complexity of the task could be applied to accelerate learning.



An initial study was conducted to characterize neural signatures of threat detection using 10 threatening and 10 non-threatening virtual scenes depicting people, vehicles and IEDs were extracted from VBS-2. Fourteen participants made threat assessment on 60 images which were presented at 2-sec intervals. Result showed detection of IEDs was significantly more difficult than people or vehicles based on lower accuracy and longer reaction times. The differentiation between threatening and non-threatening people was easiest based on reaction time and accuracy.



Significant differences in the mean amplitude of the event-related potentials (EPRs) were observed by category and region of the brain. The plots below show that identification of an IED threat resulted in the largest and most consistent late positive target detection component in the frontal and central regions. A large amplitude late positive component in the left frontal and central hemisphere was associated with threatening people, while the detection of non-threatening people resulted in a substantially greater target detection component along the midline and in the right hemisphere.

These results show that unique neural signatures of threat detection can be identified in association with VBS2 imagery. These neural signatures form the foundation for mapping a highly detailed description of the brain's capability to identify and respond to both threatening and non-threatening imagery.

Berka, C., Pojman, N., et al. (2010) Merging Cognitive Neuroscience and Virtual Simulation in an Interactive Training Platform. 3rd Int'l Conference on Applied Human Factors and Ergonomics, Miami, FL



## HCI-Predicted Workload and EEG Indices of Workload and Engagement

Optimal Human Computer Interface (HCI) designs provide as much information as possible without overloading the operator. For training and simulation software, the pace of the application is optimized to maximize the experience without frustrating the novice user. Until recently, developers had to rely on subjective reports of operators and their own expert observations, neither are objective measures of workload. In addition, the ratings are often gathered at the end of a three-hour session, relying on the memory of the operator with no access to real-time metrics.



The DARPA “Improving Warfighter Information Intake under Stress” program allowed a study to be conducted to assess the HCI with a prototyped Tactical Tomahawk Weapons Control System (TTWCS). The scenario took approximately three hours from receipt of the strike package until the missiles impacted their target and required active duty Navy operators to redirect missile in flight. The scenario was segmented into 26 tasks and submitted to a Multimodal Information Design Support tool, which was based on the W/INDEX predictive workload equation, to produce a second-by-second total workload value for the entire scenario.

The correlations between the EEG indices and MIDS total and visual loads are presented in the table below. Excessive EEG Workload values were positively correlated with expected MIDS Visual workload. Excessive EEG Engagement has a high positive correlation with both Total Load and Visual Load. Excessive EEG Drowsiness values have a negative correlation with both Total Load and Visual Load values.

|                 | Correlation with     |                       |
|-----------------|----------------------|-----------------------|
|                 | Estimated Total Load | Estimated Visual Load |
| EEG Workload    | .85                  | .93                   |
| EEG Engage      | .77                  | .86                   |
| EEG Distraction | -.93                 | -.87                  |

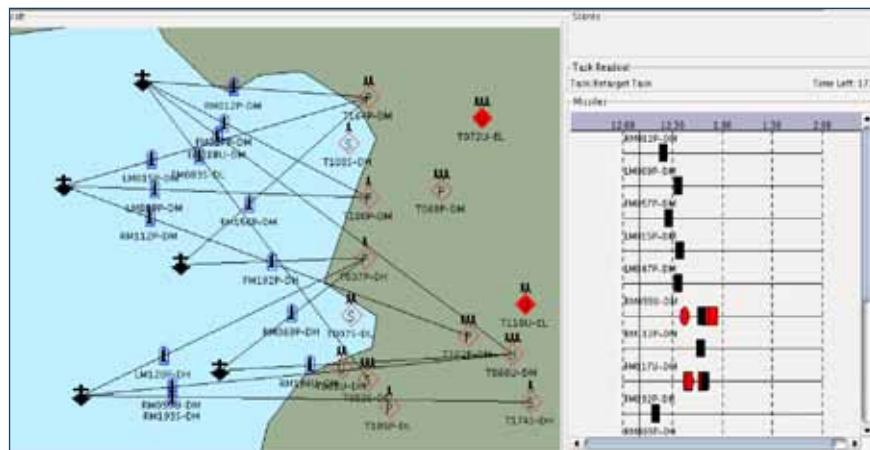
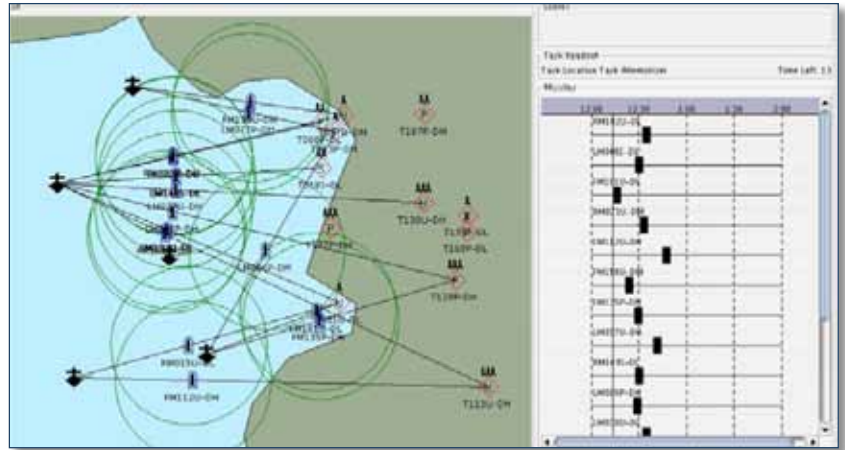
An expert’s review of the training scenario video recordings found periods of user confusion, performance mistakes, frustration and stress which were correlated with EEG measures of engagement workload and distraction. Current methods of evaluation including expert observations and self-reports from operators are subject to the biases of both parties and cannot provide the objectivity obtained by direct access to brain activity. Significant correlations between the MIDS values and the EEG indices suggest that consistent assessments of cognitive load can be obtained across subjects in an operationally valid test environment. The identification of these states provides important information for the HCI evaluator to assess bottlenecks in HCI design that is currently inaccessible by any other method.

| Task  | Condition   | Correlation with |               |                    |
|---|-------------|------------------|---------------|--------------------|
|   |             | High Engagement  | High Workload | Distraction/Drowsy |
| Execution of the strike package over 2 to 4 minute period | Confusion   | -0.78            |               | 0.68               |
|   | Mistakes    |                  |               |                    |
|   | Frustration | -0.77            |               | 0.64               |
|   | Stress      |                  |               | 0.65               |
| Bug in prototype caused unexpected behavior               | Confusion   | -0.66            | -0.64         |                    |
|   | Mistakes    |                  | -0.82         |                    |
|   | Frustration | -0.73            |               |                    |
| Engagement Control Officer standing over the operator     | Confusion   |                  |               | 0.84               |
|   | Frustration |                  |               | 0.84               |
|   | Stress      |                  |               | 0.84               |

Poythress, M., Russell, C. et al. (2006). Correlation between Expected Workload and EEG Indices of Cognitive Workload and Task Engagement. *Augmented Cognition: Past, Present and Future*. D. Schmorow, K. Stanney and L. Reeves. Arlington, VA, Strategic Analysis, Inc.: 32-44.

Working memory overload is one of the key contributors to operator errors during complex tasks. Recent investigations suggest that working memory capacity can be enhanced by utilizing verbal, spatial or alternative sensory modalities in a complimentary manner. Monitoring working memory load and delineating the verbal and spatial components would greatly enhance the speed and efficiency of the human-system interaction. In this investigation EEG data were first acquired while participants performed three simple working memory tasks. The auditory recognition task required a participant response as to whether a spoken Missile ID matched one of the previously presented missile ID sets. During mental addition, a series of sequentially presented numbers were supposed to be mentally tallied until prompted to report the total. In the “spatial-task”, participants were briefly presented a grid containing from three to five missiles. After 40 seconds, the grid reappeared and participants had approximately four seconds to identify the locations of missing missiles.

Two scenarios were developed to assess complex working memory demands. The “location” task was separated into three parts: encoding, rehearsal, and recall. During the encoding period, participants were given 15-seconds to relate targets with available missiles within the coverage zone. For the 45-second rehearsal period, participants were able to continue memorizing the target-missile relationships with the coverage zone circles removed. During the recall period, participants needed to identify targets which were not within missile coverage zones.



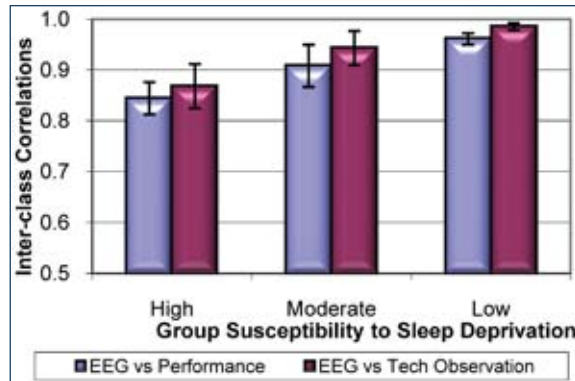
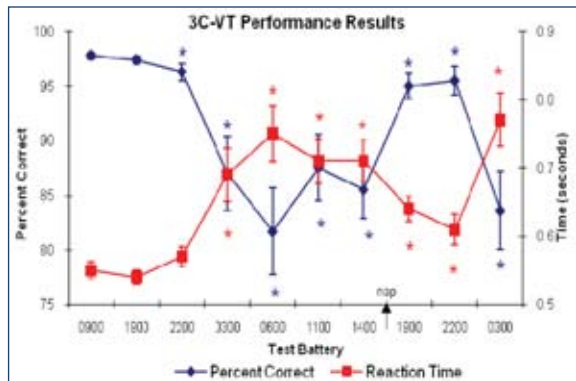
For the “Retarget” task, participants were provided 10 minutes to reallocate missile coverage to as many emergent targets as possible, while maintaining coverage on as many high and medium default targets as possible. The Task Readout, to the right of the missile-target map, provided information to the participant helpful in determining a retargeting strategy. This information included the amount of time from missile-target intercept and closest missile to emergent target.

To optimally discriminate verbal-spatial working memory, algorithms were fitted to each individual based on information obtained during two short baseline conditions (i.e., missile ID for the verbal and missile location for the spatial workload). When these algorithms were applied to the complex “spatial” working memory tasks, the mean percentage of epochs correctly classified as spatial workload with was 88% during encoding, 76% during rehearsal and 65% during recall. During the complex “verbal” task the mean percentage of epochs correctly classified was 76% during encoding and 81% during retargeting. These results demonstrate the potential for measuring verbal-spatial workload during a task similar to the Tactical Tomahawk Weapons Control System and suggest a way for building individualized models through the selection of easy to acquire baseline data.

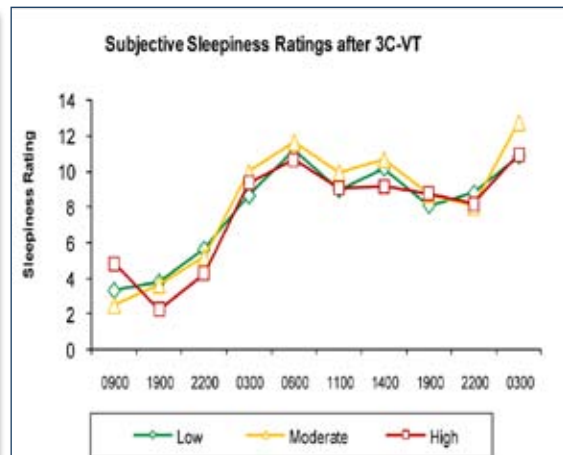
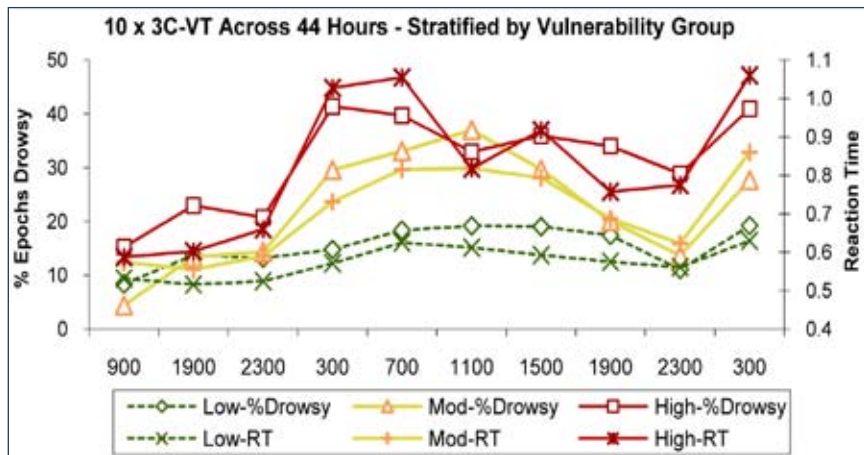
Berka, C., Levendowski, D. et al. (2005). EEG Indices Distinguish Spatial and Verbal Working Memory Processing: Implications for Real-Time Monitoring in a Closed-Loop Tactical Tomahawk Weapons Simulation. *1st International Conference on Augmented Cognition*. D. D. Schmorow. Las Vegas, NV.

## Identification of Individuals Most Susceptible to Sleep Deprivation

This investigation validated the use of the Alertness and Memory Profiler and B-Alert algorithms in objective measurements of drowsiness and the capability to identify those most susceptible to acute sleep deprivation. In this study 24 college-age healthy subjects were tested repeatedly during 44-hours of prolonged sleep deprivation to create changes in the level of alertness that permitted within-subject comparisons of alertness.



The graphs above show that percent correct and reaction time are inversely related measures of the impact of continuous sleep deprivation. The performance measures were very responsive to the 40-minute nap that was provided after 32 hours of sleep deprivation (at 1600 hours). Performance measures were independently used in a cluster analysis to categorize individuals into three groups based on susceptibility to sleep deprivation. The graph in the upper right shows the mean + SE of the canonical correlations between the B-Alert EEG drowsy classifications compared to performance measures (reaction time and percent correct) and technician-observed signs of drowsiness (eye closures, head nods) across the 10 time points. In the graph to the lower left, the percentage of epochs classified as drowsy are plotted with the associated reaction times (RT) for the three susceptibility groups. Note how well both measures relate across time for the three groups. The graph to the lower right shows that there was no difference in perceived sleepiness across the three susceptibility groups even though their performance was dramatically different.



These results indicate the B-Alert algorithms were capable of identifying fatigue resulting from a lack of sleep that leads to poor decision making. The combination of the B-Alert classifications and neuro-behavioral measures were demonstrated to be capable of identifying individuals whose performance is most susceptible to sleep deprivation. The fact that the subjective measures of sleepiness did not distinguish between the groups suggests that the subjects' perception of their own level of fatigue did not correspond to the objective measures.

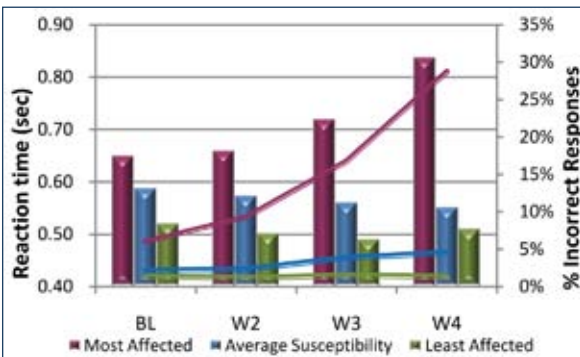
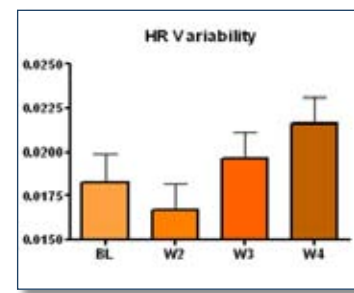
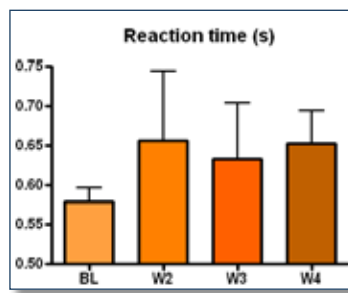
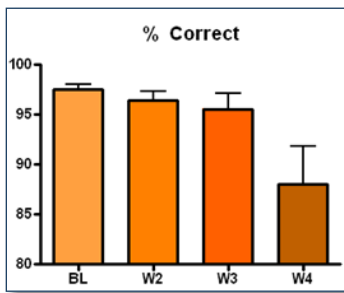
Berka, C., Levendowski, D. et al. (2005). [EEG Quantification of Alertness: Methods for Early Identification of Individuals Most Susceptible to Sleep Deprivation](#). Proceedings of SPIE Defense and Security Symposium, Biomonitoring for Physiological and Cognitive Performance during Military Operations, Orlando, FL, SPIE: The International Society for Optical Engineering.



U.S. Marine Corps troops experience combined stressors including sleep deprivation, physical exertion and threat of enemy fire that can impair vigilance and decision-making with potentially dangerous consequences. In this study USMC battalion/platoon leaders (n=17) were evaluated during a 28-day, continuous live-fire training exercise. Prior to the start of the exercise and then once a week wireless EEG and EKG were acquired in the field during a 20-minute, 3-Choice-Vigilance-Test (3C-VT). Physiological measures of engagement, distraction/drowsiness, heart rate variability, performance were assessed along with self-reported stress, fatigue and mood were assessed with Profile of Mood States, Stanford Sleepiness Scales, Brief Fatigue Inventory and Perceived Stress Scale.



Repeated measures analysis of variance revealed significant interaction effects ( $p < .0001$ ) across quartiles over time in the 3C-VT with increased Distraction/Drowsiness, decreased High-Engagement, decreased accuracy and increased reaction times across weeks of training. Heart rate variability, suggesting increased levels of stress, also increased significantly. Significant changes in self-report measures included only decreased POMS-Vigor.



This study confirmed the Marines also exhibit trait characteristics in susceptibility to sleep deprivation. The graph to the left shows a change in reaction times (histograms) and percentage of incorrect responses (lines) across weeks during the 28-day exercise. After normalizing the data to account for the fact that Marines as a group tend to be less susceptible to sleep deprivation than the general population, we found that speed and accuracy were highly affected in 11% of the Marines by the end of the training exercise. Conversely, performance in 35% of the group was minimally affected by sleep deprivation.

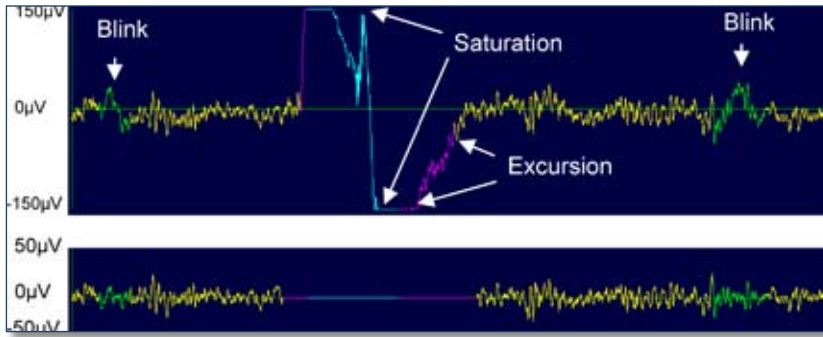


A closer investigation of the group with average susceptibility revealed a pattern that should be taken into consideration by those responsible for managing fatigue and situational awareness. The graph to the left shows that the speed of decision making (reaction time) increased during sustained operations which resulted in chronic sleep deprivation. The increase in decision making speed, however, contributed to a doubling in the number of incorrect decisions. Yet none of the questionnaire responses indicated that the Marines acknowledged the impact of the fatigue on their capabilities.

## Continuous Monitoring of Workload over 24-Hour Sustained Operations

For this application the EEG headset was modified so the sensors could be worn under a Kevlar battle helmet. The patented B-Alert artifact identification and decontamination algorithms were applied (e.g., eye blinks, gross head movement, etc.) to the signals and the decontaminated signals and associated power spectra density values were transferred in real time to a third party for their use in a proprietary measure of cognitive effort.

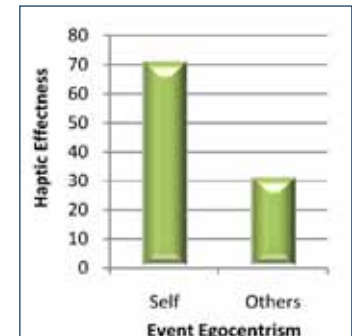
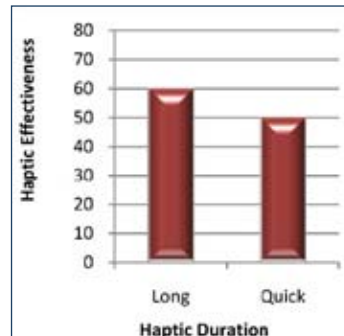
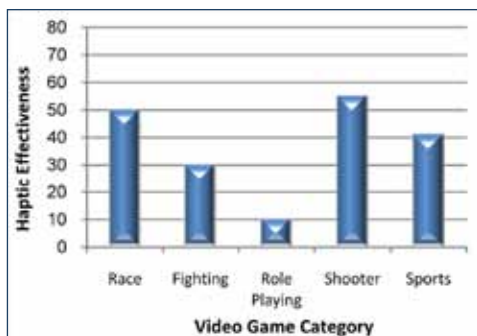
Six members of a 32-member National Guard platoon wore the EEG headset intermittently during a 24-hour sustained training operation at a United States Army training and testing facility. The platoon leaders, platoon sergeants and squad leaders were selected because of the expected variability in cognitive effort imposed as a function of their tactical combat activity and interaction with electronic communication technology. During exercises of entering and clearing buildings in an urban environment with simulated enemy forces and simunitions, approximately 75% of the data were acceptable for analyses using the B-Alert Headset and algorithms.



Mathan S., W. S., Dorneich, M. et al. (2007). Neurophysiological estimation of Interruptibility: Demonstrating Feasibility in a Field Context. *Augmented Cognition*. D. Schmorrow, Nicholson D., Drexler J., Reeves L. Arlington, VA, Strategic Analysis, Inc: 51-58.

## Impact of Visio-Haptic Feedback on EEG Alertness

The use of visio-haptic feedback is increasingly being used to augment and/or substitute for visual or audio cues. To assess the capability of haptic feedback on increased attention/engagement, a study was conducted using a PlayStation 2® gaming console with multiple video games. Game categories were selected based the use of vibrations that occur frequently throughout game and having events that caused different vibrations. Each game lasted between 20 and 30 minutes. The association between haptic events and peaks in the EEG-based high engagement were used to determine effectiveness. Results show that haptic feedback effectiveness was impacted by both game category and duration of the feedback. Haptic feedback was over 200% more effective during event involving an avatar or virtual player controlled by the user (self) vs. events that occurred in the environment or to another avatar not directly caused by the player (others). These results confirm that haptic feedback provides an effective condition-dependent modality for increasing attention or engagement in virtual reality or simulation training sessions.



Kahol K., French, J., et al. (2006). Evaluating the Role of Haptic Feedback in Multimodal Interfaces through EEG Analysis. *Augmented Cognition: Past, Present and Future*. D. Schmorrow, K. Stanney and L. Reeves. Arlington, VA, Strategic Analysis, Inc.: 289-296.

## Workload Detection in a Closed-Loop Aegis Simulation Environment

The Aegis command and control simulated environment is a combat system with advanced, automatic detect-and-track, multi-function phased array radar. The Aegis task involved monitoring multiple data sources (i.e., missile-tracks, alerts, queries, resources), detecting required actions, responding appropriately, and ensuring system status remains within desired parameters.

The B-Alert measures of workload were evaluated while individuals acted as identification supervisors during the Aegis command and control simulation. Periods with high or extreme EEG-workload occupied between 25-30% of the scenario total time and provided a detection efficiency approaching 100% for selection-identification and alert events, 77% for hooking-tracking and 70% for queries. High or extreme workload was identified in less than 5% of the time that wasn't occupied by high-difficulty events.

This man-machine integration demonstrates the potential for utilizing physiological monitoring for the real-time assessment of operator status. Intelligent feedback or closed-loop systems can facilitate active intervention to ensure the operator remains uninterrupted during high/extreme workload periods or to increase the cognitive demand level when periods of low workload are detected.



Berka, C., Levendowski, D. et al. (2005). [Evaluation of an EEG-Workload Model in an Aegis Simulation Environment](#). Proceedings of SPIE Defense and Security Symposium, Biomonitoring for Physiological and Cognitive Performance during Military Operations, Orlando, FL, SPIE: The International Society for Optical Engineering.

## Impact of Closed-Loop Drowsiness Feedback on Driving Performance



In this application, real-time EEG classifications of engagement and drowsiness were used to trigger feedback in a closed-loop time/performance-locked driving simulator training session. In a randomized cross-over design, partially sleep-deprived subjects performed four driving simulator scenarios over an eight-hour evening period. During two of the sessions, audio feedback was initiated when EEG metrics of extreme drowsiness were detected with the intensity and duration of the feedback modulated to match changes in the EEG. Six unique sounds were selected for the alarms; the feedback sounds became more urgent each time the alarm was triggered. Performance was monitored during the other two sessions without feedback.

When feedback was provided subjects showed statistically significant improvements in reaction times and correct responses to the driving simulator divided attention task. Although there was substantial variability in driving performance resulting from sleep deprivation, the number of drifts and veers and total accidents showed significant reductions when participants were most fatigued and feedback was provided. Most participants reported that the feedback alarms were beneficial in helping them maintain alertness.

Real-time closed-loop feedback based on EEG-indices holds the potential for a number of training or safety applications. Vibro-sensory motors are currently being explored as a means to provide tactile feedback, a novel alternative to audio or visual feedback that can be generated in a confidential, non-cognitive distracting manner.

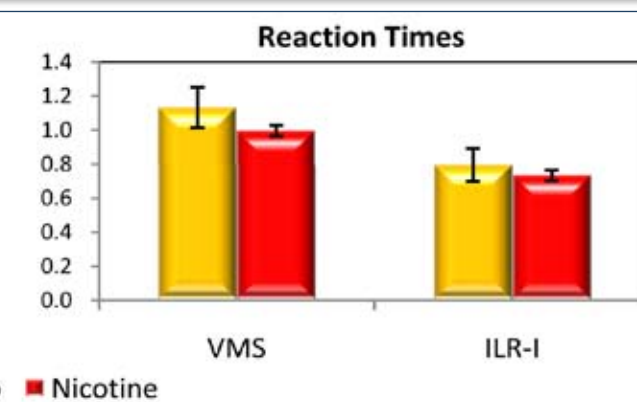
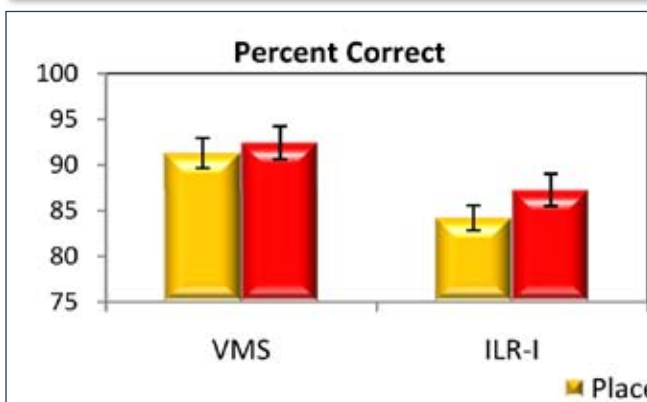
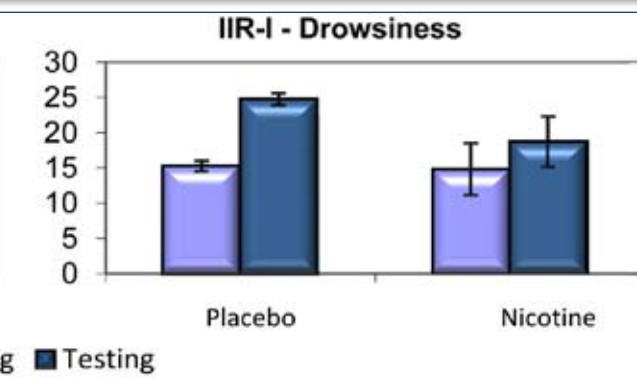
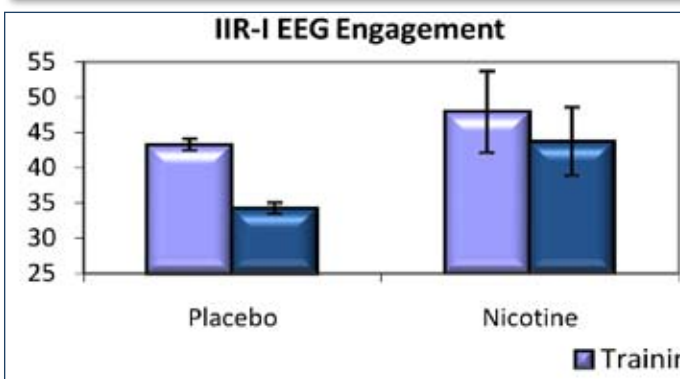
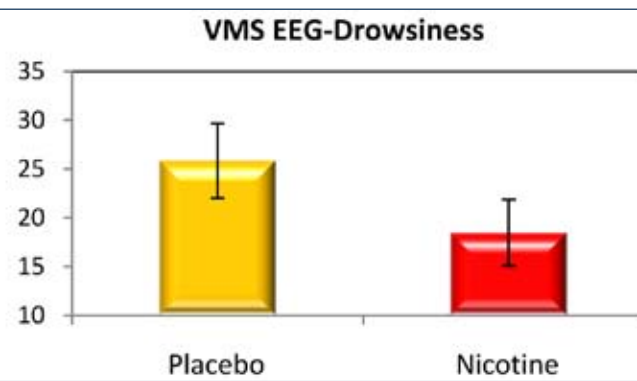
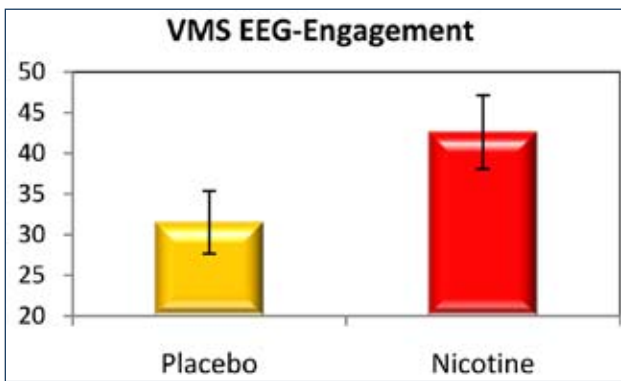
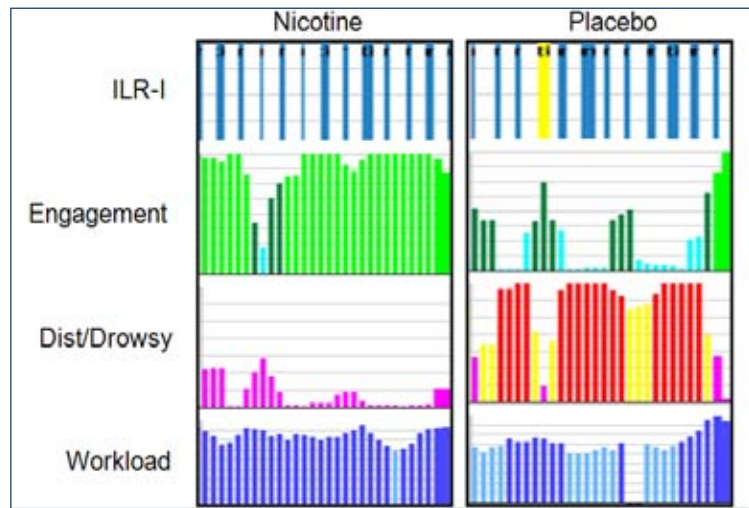
Berka, C., Levendowski, D. et al. (2005). [Implementation of a Closed-Loop Real-Time EEG-Based Drowsiness Detection System: Effects of Feedback Alarms on Performance in a Driving Simulator](#). 1st International Conference on Augmented Cognition, Las Vegas, NV.



## Effect of Nicotine and Withdrawal on Attention, Memory and Workload

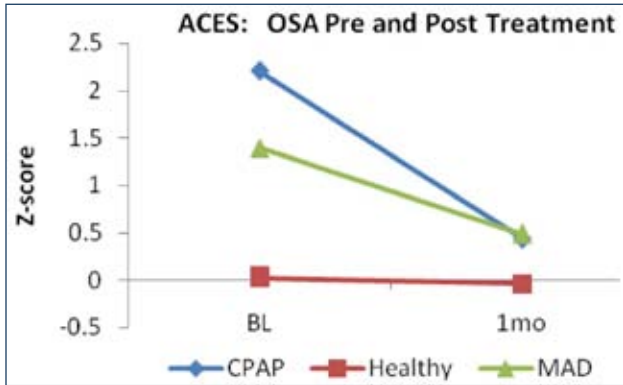
Despite the widely publicized health risks of smoking, an estimated 25% of the U.S. population and between 25% - 37% of military personnel continues to smoke. The use of nicotine as a fatigue countermeasure may be problematic in operational environments because the stimulant properties may increase speed while sacrificing accuracy.

In this randomized cross over design, the Alertness and Memory Profiler's Verbal Memory Scan (VMS) and, Image Learning and Recognition with Interference (ILR-I) tasks assessed neurophysiology and performance in cigarette smokers following 14 mg. transdermal nicotine administration vs. placebo nicotine patch. The results show that nicotine induces an excessive allocation of attentional engagement. After just 12 hours of nicotine withdrawal, fully-rested and otherwise healthy participants evidenced significant increases in EEG drowsiness and impaired performance on learning and memory tests.



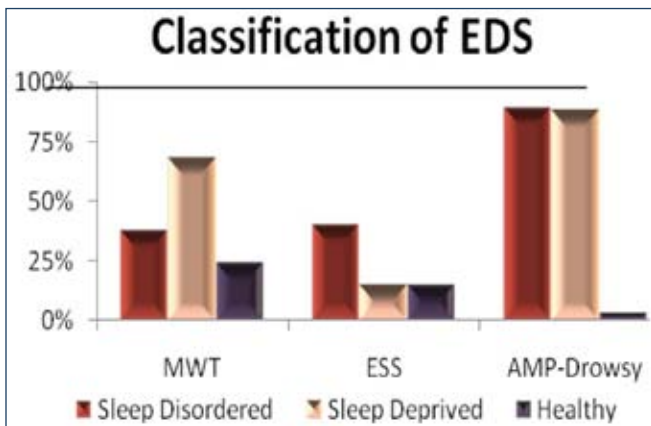
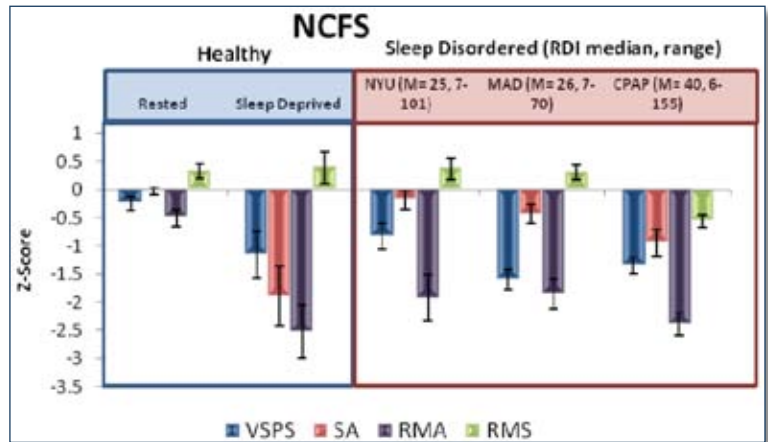
Berka, C., D. Levendowski, et al. (2006). Nicotine Administration and Withdrawal Effects on EEG metrics of Attention, Memory and Workload: Implications for Cognitive Resource Allocation. *Augmented Cognition: Past, Present and Future*. D. Schmorrow, K. Stanney and L. Reeves. Arlington, VA, Strategic Analysis, Inc.: 174-183.

The Alertness and Memory Profiler (AMP) provides assessment of physiological and neurocognitive factors using a non-invasive integrated and synchronized test battery (3-Choice Vigilance Test, Image Recognition (IR), IR with Interference, Verbal/Number-Image Paired Associate Learning, and Sternberg Verbal Memory Scan). This approach facilitates rapid data collection from any size population, enabling large scale epidemiological studies, disease diagnosis or treatment outcome evaluations. The AMP is sufficiently rugged and robust for studies to be conducted in operational environments (e.g., in the desert at 29 Palms) and its metrics have been proven useful in predicting susceptibility to sleep deprivation or marksmanship skill acquisition in US Marines.



One of the AMP metrics called the ACES score can be derived with less than one-hour of testing. It uses EEG and performance measures to discriminate healthy controls from obstructive sleep apnea (OSA) patients prior to treatment, providing a sensitivity of 0.88 and a specificity of 0.96 (n=396). Eighty-three percent of OSA patients had an ACES score of 7 or greater and 95% of the healthy subjects had a score of 4 or less. The graph to the left shows the change in ACES in OSA patients pre- and post-CPAP or Mandibular Advancement Device (MAD), and repeated testing in healthy subjects.

A 2-hour AMP test battery allows neurocognitive factors scores (NCFS) to be calculated for visual-spatial processing speed (VSPS), sustained attention (SA), recognition memory accuracy (RMA) and recognition memory speed (RMS). The graph to the right compares NCFS across Rested and Sleep Deprived Healthy subjects, OSA patients from MAD and CPAP studies and a third group of patients who underwent full polysomnography followed by Maintenance of Wakefulness Test (MWT) at the New York University School of Medicine.



The AMP Drowsy Detector combination of EEG, EKG, and performance indices from a four-task, one-hour battery to provide a highly sensitive and specific classifier to accurately discriminate daytime drowsiness due to sleep deprivation or sleep disorders. The graph to the left compares the AMP to the MWT and Epworth Sleepiness Score. The AMP is 20% more specific than the MWT in identifying fully rested healthy subjects, 20% more sensitive in identifying sleep deprived healthy subjects and 51% more sensitive in identifying patients sleep deprived as a result of sleep disordered breathing. These data show the ESS is insensitive as a measure to identify sleep deprivation.

Berka C., A. I., Burschtin O. et al. (2009). "High Throughput Brain-Behavior Assay: Quantification of EEG and Performance in Patients Referred for Assessment of Daytime Drowsiness." *Sleep* 32: A383.

Kintz, N., Johnson, R., et al. (2009). "Mandibular Advancement Devices Significantly Improve Neurocognitive Function for Patients with Obstructive Sleep Apnea." *Sleep* 32: A229

To learn more about operational neuroscience applications or for more information on B-Alert products or research, please visit BIOPAC [www.biopac.com](http://www.biopac.com) or speak to a representative at (805) 685-0066 or email [info@biopac.com](mailto:info@biopac.com).

