What can modern neuroscience technologies offer the forward-looking applied military psychologist? – Exploring the current and future use of EEG and NIR in personnel selection and training.

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ABSTRACT

Accurate assessment of psychological capabilities is central to the selection, training and retention of military personnel. Towards this end, a large battery of psychological exams have been developed, most sharing the general property of measuring mental function from "outside of the brain." While a great deal of information can be gained through these traditional tests, we believe that new and vital metrics can be obtained through the direct monitoring of brain activity itself. Over the last decade, investments in the field of neuroscience have resulted in substantial advancements in the non-invasive and minimally intrusive activity monitoring technologies of EEG and NIR (near-infrared spectroscopy). This presentation provides a brief review of these technologies followed by a description of their potential applications in the psychological assessment of military personnel during selection and training phases. We believe that these technologies will provide new insight and metrics for assessing the operators' ability to handle stress, uncertainty, adaptability to change - as well as the operator's capacity ability to maintain attention and focus during critical tasks.

1.0 Background

There are many tools available to the military psychologist for assessing the performance, fitness and suitability of personnel. The accurate measurement of psychological state is crucial for the success of military readiness and retention in the 21st century. The most modern methods of assessment currently in use are administered using Computer Aided Testing (CAT). Computer aided testing has the advantage of the rapid measurement of multiple parameters in a relatively short period of time. Some advantages include:

- Registration of reactions and answer times on the item-level
- Timing of measurements down to milliseconds
- Quick, error-free evaluation immediately after examination
- Results available in a database for easier statistical analysis

However, even in the best testing situations CAT only measures mental function from "outside of the brain". This is suitable for the measurement of some functions, but requires significant inferences for other mental processes that can be more directly measured through other means.

Some of the "inside of the brain" functions that can be measured include:

- Attention
- Arousal
- Vigilance
- Emotional reactiveness
- Error detection
- Cognitive effort/overload

All of these measures may be assessed through the direct monitoring of brain function.

2.0 Technological Developments

There are several technologies that hold promise for the measurement of brain function in military psychological testing settings. One of these technologies – electroencephalography (EEG) has been around for decades, but is beginning to find new usefulness outside of hospital and academic environments. EEG uses surface scalp electrodes to detect electrical activity originating from the brain below. A variation of this technique looks for patterns of electrical activity that are uniquely associated with specific stimuli or actions. The resulting record is called an evoked response potential (ERP).

EEG and ERP both measure electrical brain activity in real-time (millisecond resolution). However, both are confounded by the rapid spread of electrical signal by the fluids and tissues that lay between the brain and the surface of the scalp. As a consequence, the raw data obtained has very low spatial resolution. Fortunately, years of intensive efforts to deal with these issues via computational processing has resulted in reliable spatial localizations on the order of 1-2 cm. This resolution is more than adequate for extraction of many forms of useful information on the underlying brain activities as described below.

In addition, newer emerging technologies – such as functional near infrared imaging (fNIR) – offer similar levels of spatial resolution and may offer even greater promise for truly portable brain imaging devices.

As the name implies, this technology projects harmless infrared light through the scalp and underlying tissues and into the surface layers of the brain. Light sources are attached to scalp via fiber optic cables, and returning signals – in the form of scattered NIR light – are received through similarly mounted detectors.

Current technology NIR systems can detect changes in blood flow (like fMRI) and metabolic activity because these physiological processes affect the scattering of NIR light. Changes in blood flow usually trail neural activity by a few seconds, and so the temporal resolution of fNIR (like fMRI) is also limited to this time frequency. Furthermore, the activity detected through fNIR is restricted to the cortical levels of the brain, because NIR light does not penetrate into deeper structures.

Future developments in NIR technologies, however, promise to improve both the temporal resolution and the depth of signal detection. Recent studies indicate that NIR light is also scattered by the activity related movement of ions and water in and out of neurons, thus offering a more direct and real-time measurement of neuronal activity. Also, lower frequency infrared light (in the THz range) can penetrate more deeply into biological tissues. Until very recently, low cost sources that could generate THz infrared light were not available, new efforts incorporating these new light sources will hopefully extend the useful range of this promising brain imaging technology.

3.0 Applications to Psychological Testing

EEG provides an ongoing, real-time indication of arousal, vigilance, and stress levels in subjects. To the trained observer, these cognitive features can be assessed directly from the wave activity apparent in the raw EEG signals. Furthermore, detection of specific wave frequencies can be accomplished through the application of simple real-time analysis techniques (such as Fast Fourier Transformation processing). This approach makes specific rhythms even easier to identify and quantify. Such EEG signals are present independent of external stimulation or behavioral responses, and thus do not require complex testing or assessment paradigms. These types of measurements can be used to assess the overall state of a subject during a general task or combined with another assessment technique.

Some specific associations with EEG rhythms include:

- increased fast theta wave activity (6 – 7 Hz) from frontal (forehead area) electrodes during deliberate sustained concentration,
- increased global/posterior slow wave theta rhythms (4-5 Hz) as the subject becomes drowsy or enters light sleep,
- decreased alpha activity over posterior regions as task demands increase (decreased alpha activity is associated with the recruitment of more neurons for task-related processing).

An alternative application of EEG monitoring involves the processing time-specific events for stimulus or action evoked response potentials ERPs. Evoked responses can provide information on a number of additional cognitive functions. Based on the polarity of the waveform, the evoked response is generally assigned a negative (N) or positive (P) name. One waveform that may be of particular interest to the psychological assessment community is the Event Related Negativity or ERN.

The ERN is indicative of the emotional reactiveness of the subject and their assessment of the negative consequences of their choices. At the extreme, for example, pathological subjects exhibit little to no ERN, while Obsessive-Compulsive patients exhibit an unusually large ERN. In contrast, the P_e is found in ERP traces shortly after the ERN, and appears to be a more objective measure of the awareness of errors made.

Other processed waveforms may reveal additional information about cognitive workloads, or might be used to make more informed inferences related to selection testing. Specific questions that might be of interest include:

- Can subjects maintain arousal and attention during the more tedious tasks related to their post?
- Can they manage stress levels during more demanding task simulations?
- Is a subject slow to answer questions because they are confused or because they are being overly cautious?
- Are they too emotionally reactive?
- Are they cognitively overloaded?

In addition to applications for selection testing, daily assessments could be made to confirm readiness for duty. Is the air traffic controller coming on duty sufficiently focused to carry out his/her responsibilities? Can she/he sustain attention and arousal sufficiently for the task at hand? At what point during the day does her/his capacity slip below tolerable limits?

4.0 Future Directions/Predictions

In the near future, coordinated advances in three key areas (EEG and NIR technologies, the computational processing power of computers, and in the identification/understanding of the cognitive processing centers of the human brain) will create a new suite of sophisticated tools for cognitive and applied psychologists.

Advances in THz NIR, for example, will permit real-time imaging of deeper brain structures, including those associated with memory formation and emotional processing. The ERN, for example, is believed to originate from the anterior cingulate cortex, a structure implicated in both attention and emotional processing. This structure is too deep to be unambiguously monitored by current EEG/NIR systems. Advanced NIR technology should permit the direct detection of activity in this structure, eliminating issues of potential signal contamination by overlying or neighboring regions.

On a second front, automation and incorporation of real-time (EEG/NIR-based) cognitive assessment into the human-computer interface is a central goal of the Augmented Cognition program of the Defense Advance Research Projects Agency (DARPA). The efforts of this program will enable closed-loop systems, where computers read the user's cognitive load and adjust both the level and form of information presentation to maintain maximal performance levels. The development and use of such systems will both rely upon models of cognitive processing and will likely become a driving force for the development of newer, more sophisticated models.

Finally, as a spinoff of efforts like DARPA's Augmented Cognition program, fully portable, wireless EEG and NIR systems will soon be developed. These systems will be integrated into a wide variety of as yet unexplored human environments and will provide a radical shift in the form, quantity, and sophistication of real-world cognitive/psychological data.

5.0 Conclusions

In this presentation, we have explored several potential, practical applications for two cutting-edge neuroimaging technologies: EEG and NIR. Both of these technologies create novel opportunities to assess personnel from "inside of the brain." Such an approach will offer direct insights into a subject's aptitude and affinity for specific duties. These technologies also create opportunities to monitor mental capabilities in real-time in order to continuously assess fitness for duty. Future applications of these technologies will enable the development of closed-loop "augmented cognition" systems, where performance levels are maximized through the continuous assessment of mental function combined with an adapting human-computer interface.

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