**Closing Report NASA Grant # NAG 1 2273:**

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The focus of this current grant was to continue our work which focused on the manner in which psychophysiological markers can be used to index hazardous states of awareness and to explore the feasibility of developing on-line systems that utilize real time feedback to modify on-going behavioral processes. In this work we have incorporated a multifaceted approach which includes psychophysiological, subjective, and performance based measures. We have considered this from both an internal and external perspective as reflected in work from a variety of labs. The external perspective has emphasized the task demands or workload as reflected by time pressure or complexity of tasks. However, previous research has shown that task demand and complexity cannot be modeled in a simple linear fashion. Thus, examinations of internal factors which can be reflected in a variety of psychophysiological measures offers an alternative window in terms of cognitive processing. In addition to the task requirements, individuals are also sensitive to the needs of the organisms some of which are preprogrammed through our evolutionary history. In this sense, all individuals engage constantly in a variety of multitasking situations which must be taken into account in developing models that reflect circumstances in which individuals work at both optimal and suboptimal levels. Lapses of awareness has been an important theme in our work. In addition to creating

situations that vary in terms of task demands, we have also varied individual differences factors such as anxiety, dissociative tendencies, or hypnotic suggestibility to model situations of stress, spacing out, or increased suggestibility and narrowed focus. Since there exists a close connection between anxiety and stress responses as well as between anxiety and internal distracting thoughts, we emphasized the individual difference of anxiety in our current work. Further, given the lack of one to one mapping between most physiological measures and complex cognitive, emotional, and motor responses, we have conceptually sought to articulate cognitive primitives which reflect basic environmental-organism responses. These basic cognitive building blocks can also help us better understand the manner in which the organism internally is modulated by its own responses in complex situations. Using this understanding, we have considered the feasibility of using these internals processes to create an architecture of situational control. In this progress report, we describe work from three studies designed to develop and validate psychophysiologcial methods related to the detection of hazardous states of awareness and report on the development of a biocybernetic system.

## EEG Theta Activity and Error Detection

Frontal midline theta was initially noted during the performance of mental tasks such as mental arithmetic and that it increases with task difficulty. Theta has also been linked to an event related potential, that of error-related negativity or ERN that peaks approximately 100 ms after an individual makes an error. This activity appears related to error monitoring in relation to action regulation. In terms of its source, a variety of

studies suggest that the anterior cingulate is the source of this 4-7 Hz midline activity. Broca in the 1870s first described the "le grand lobe limbique" or limbic system with the dorsal part being the cingulated cortex. Papez in the 1930s saw this structure as the receptive organ for the experience of emotion. The anterior cingulate receives information from the amygdala which is assumed to be fear related as well as show neuronal activity in relation to performance reward and error. Currently, the anterior cingulated is seen to monitor performance, including errors and reward, and to adjust behavior to optimize payoff. The purpose of the 4-7 Hz theta activity appears to be that of fostering entrainment in an interregional manner that allows for limbic circuits to exert regulatory control on cortical networks and thus facilitate the reestablishment of executive control following an error condition.

In order to examine the feasibility of using theta activity to index performance, we used a video game to study electrophysiological markers associated with successful and failed performance. In this study individuals performed a visuo-motor task contained within the computer game, "Frustrated Maze". The basic task was to drag a ball using the mouse along a narrow mazelike path from the starting point to the goal without touching the "maze wall" and other obstacles. We had subjects play the game both under time pressure and non-time pressure conditions. During the games we recorded EEG activity from 15 electrode sites (Fp1, Fp2, Fz, F3, F4, Cz, C3, C4, Pz, P3, P4, T7, T8, O1, O2) referenced to linked mastoids. Comparing the successful with the unsuccessful trials, we found three major results. First, there was a widely distributed reduction of *fast* alpha (peak of approximately 10.5 Hz) over frontal-central and parietal areas and centrally localized reduction of "mu" over the somatomotor

cortex during successful trials. Second, there was localized enhancement of frontal midline theta (Fm theta) and midline gamma in conjunction with successful trials. And third, these findings were more pronounced in the time pressure condition. We assume that the reduction in alpha, especially during the time pressure conditions, reflects an increase in task demands and complexity as has been noted in other studies. Theta, on the other hand, showed an increase in power during successful trials. Overall, this research lends support to the idea of an index of engagement suggest by previous NASA research and suggests an additional formulation of this index using frontal midline theta.

**Tremor**

Tremor is defined as small involuntary fluctuations in limb position that accompany voluntary postural tasks, with and without load. Traditionally, tremor has been divided into physiological, essential, and Pathological types. Physiological tremor is a "normal" tremor that appears to be caused by a complex interaction between physical/mechanical and neural systems. In that evidence suggests that tremor may have a role in the timing of the initiation of voluntary movement, it is important for our purposes both as potential index of temporal processing and as an index of situational processes such as complexity and workload. Compared to other physiological signals, tremor can be easily measured using an accelerometer attached to the finger. Mathematically, physiological tremor is linear and stochastic. Interestingly, physiological tremor has been shown to have two dominant frequencies in the 8-15 Hz range and another around 26Hz. Since the predominant frequencies of tremor appear

similar to those of the EEG, we first considered the relationship between resting tremor and EEG. Next, we considered the possibility that tremor measurements might give us a simple window that would reflect task demands. Finally, we examined tremor is a population of individuals who varied in terms of anxiety.

The procedure for all of our studies used an accelerometer taped to the left index finger which was connected to a Coulbourn Instruments Transducer Coupler Type A (Strain Gage Bridge) S72-25. EEG was recorded with a ECI Electro-cap System and a 21-channel Nihon-Kohden electroencephalograph (Model 4321 B). EEG was recorded from the left and right frontal, central, temporal, parietal, and occipital sites ($F_3$, $F_4$, $F_Z$, $C_3$, $C_4$, $C_Z$, $P_3$, $P_4$, $P_Z$ $T_3$, $T_4$, $T_5$, $T_6$, $O_1$, and $O_2$) according to the international 10-20 system for electrode placement (Jasper, 1958) using a linked ear reference. Both horizontal and vertical eye movement was recorded. These physiological signals were then digitized and stored on a computer for later analysis. Participants were seated in front of a computer screen in a comfortable chair.

In the first study, we examined 9 health individuals during a baseline, mental math task, and a relaxation task which last for 2 minutes each. Tremor was measured from both the left and the right hand. We performed Fast Fourier analysis (FFT) on these tremor time series signals. We found the tremor frequency in the left and right hands to be similar with a peak at approximately 10.5 Hz and 15.5 Hz in each hand. During the three tasks the frequency of tremor remained constant with the amplitude increasing between the mental math and relax task. We next examined the coherence between the tremor time series of the left and right hands. There was a .2 coherence at 15.5 Hz between the two hands at baseline which decreased to .11 during relaxation

and .02 during mental math. As in previous research EEG hemispheric differences varied according to task. The important finding of this work is that tremor is reflective of the task requirement and appears to be influenced by different processes during different tasks.

Given that one characteristic that leads to accidents and inattention is the individual's internal state, especially in term of negative affect and stress, we replicated our tremor study using individuals who reported high level of anxiety in their everyday life. The basic rationale supported by a variety of studies is that one common characteristic of increased stress, anxiety, or workload is that of a reduced cognitive capacity. In this study we examined 6 anxious individuals and 5 individuals of similar age and background who reported normal levels of anxiety. As previously, a FFT was applied to both the EEG and tremor data to determine predominant frequencies. In both the anxious group and the non-anxious group, the tremor data showed frequency peaks at approximately 10Hz and 29 Hz. Looking at the data on an individual level showed a great consistency among individuals suggesting that the frequency of tremor is a basic physiological property of human physiology. We next examined the coherence between the tremor and the EEG. In examining the data on an individual subject level, it became apparent that non-anxious individuals show a much larger coherence between finger tremor and EEG at 11 Hz. than anxious individuals. Thus, on both an individual level as found in this study and a situational level as found in the previous study, there appears to be a reduction in coherence either between tremor in each hands or between tremor and EEG when there is a reduction in cognitive capacity. We are continuing to validate tremor as a means of indexing changes in task demands.

**Startle**

The startle reflex is a set of skeletomuscular contractions viewed as a behavioral interrupt which prepares the organism for action. It is elicited by an intense stimulus of sudden onset and generally measured by its eye blink component in humans. Animal research suggests that the neuronal pathway of the acoustic startle pathway is primitive and consists of only three synapses which connect the cochlear root neurons, neurons in the nucleus reticularis pontis caudalis, and motorneurons in the facial motor nucleus.

The startle response is amplified during negative experiences and reduced during positive ones. In the present study we build on this by presenting startle stimuli while individuals performed tasks that were associated with stress and effort (sympathetic activation) as well as tasks associated with relaxation and no cognitive effort (parasympathetic tasks). Since additional mechanisms such as attentional engagement have also been implicated in contributing to startle amplitude, we additionally sought to probe the attentional component by utilizing tasks that directly manipulate attentional focus. Thus, we had subjects perform sympathetic and parasympathetic tasks that varied in attention focus.

In our study startle was measured with two 4-mm Ag/AgCl electrodes filled with high conductivity electrode gel and placed over the orbicularis oculi muscle below the left pupil. The startle stimulus consisted of a 95db fast rise time 50 millisecond white noise signal presented biaurally through headphones. All startle probes were presented at random intervals within each task, with the constraint that (a) at least 30 seconds elapsed during any task before the presentation of the first probe and (b) a

minimum of 30 seconds always elapsed between startle probes. For data analysis digitized raw EMG signals from the orbicularis oculi were amplified at a constant level for all participants and sampled at a 1000hz rate 200 ms prior to and 800 ms following the startle stimulus. A high pass filter was used to remove slow wave activity. The EMG signal was half-wave rectified and integrated using Matlab software developed by our lab.

We had 9 anxious and 9 non-anxious individuals perform two sympathetic tasks, a mental math task, and the stroop color interference task, and two parasympathetic tasks, watching a relaxing video of birds flying over the ocean and imagining a pleasant meal. Of the four tasks, two required external focus and two required internal focus. To determine the effects of attentional focus and autonomic nervous system activation, a 2 (internal vs external focus-of-attention tasks) by 2 (sympathetic vs parasympathetic tasks) ANOVA was performed between the anxious and non-anxious groups. A main effect for group was found in which anxious individuals showed significantly larger startle amplitudes (.28 vs .17). There was also a significant main effect for type of attention tasks, but not for type of autonomic nervous system tasks activation. Larger startle responses were seen during the internal as opposed to external focus of attention tasks (.29 vs .16). We also asked subjects to rate their mental state during the initial baseline and found that the more negative they experienced their inner state, the larger the startles were during this period (r = .59). At this point, the startle response appears to be an appropriate measure to model internal negative affectivity but not the nature of the task in terms of stressfulness. Thus, it offers a unique method for differentiating task characteristics from individual state characteristics. Since the startle

is able to model internal states, we are currently following up this study and asking whether predictability or control in terms of stimulus presentation reduces internal negative states. Although we not the completed the final analysis, it appears as if individuals show less negative affect in situations in which they know what will happen (predictability) as opposed to control (they are in change).

## Developing a Biocybernetic System

In order to develop a biocybernetic system that would utilize psychophsyiological such as EEG, tremor and startle, we continued to review the existing literature on adaptive interfaces. The ultimate goal of this work is to improve performance in situations in which awareness is limited (e.g., "spacing out", drowsiness or other hazardous states of awareness), pathological (e.g., attention deficit disorder) or as an alternative for normal manual means of control. In terms of physiological approaches to human-computer interfaces, there have been two major approaches. First, there have been attempts to train individual operators to control various aspects of their physiology (e.g., eye movement, EEG) which in turn can be utilized for controlling various display characteristics. And, second, using various forms of signal processing, there have been attempts to identify physiological signals associated with various cognitive states (e.g., attention, drowsiness) and in turn to modify displays in terms of these inferred states. Three academic based labs that have been historically involved in this interface work in relation to EEG are Donchin and his colleagues at the University of Illinois, Birbaumer and his colleagues at the University of Tubingen, and Wolpaw and his colleagues at the New York State Department of Health (Wadsworth Center). At NASA Langley, this

work has been conducted by Alan Pope, Lance Prinzel and their colleagues. This work has focused on EEG index of engagement and has produced a varied of pioneering studies based on a closed loop system.

We sought to extend the previous work by examining more discrete markers of correct and incorrect responses. We initially examined markers associated with successful memory perform using traditional EEG Fourier markers. In the present grant we have extended this using more exact signatures with more temporally precise measurement techniques including wavelet analysis. In this situation, the subjects were not temporally aware that they would make a mistake. At present both EEG gamma and theta band activity appear to play an important role. We have also explored the EEG signature when subjects know that they are supplying erroneous information as might be case in situations of extreme stress. Further, we conducted a series of studies which tend to suggest that using EEG coherence to reflect phase angle and thus direction of flow, there are differentially different directional vectors in terms of brain activity that corresponds with internal state. We are current examining these data to determine if task requirements are likewise reflected in EEG coherence data.

In terms of a biocybernetic system, we developed an initial system using digital processing systems developed by Data Translation after long discussions with their engineers. We had difficulty programming this system in a manner that could analyze the EEG stream online and allow it to control stimulus presentations based on this information. It appeared that some of the features that we required had not been fully tested by the company when it was released to us. We have now moved to a MATLAB based system with utilizes National Instrument digital control cards in a real time

environment. This system allows for ease of programming and more compatible links with our existing acquisition and presentation systems. This flexibility has allowed us to modify analytic characteristics that are applied to the EEG and to be view in real-time the original and resultant signal. The current design is based on simple decision rules but we are exploring the use of fuzzy logic and other such techniques for signal identification. The future goal will include decision making procedures which can incorporate real time information from a variety of physiological signals and external characteristics of the tasks.

## Summary

Grant NAG 1 2273 continued to build on our previous work combining operator states and external task. In this progress report, we described work from three studies designed to develop and validate psychophysiologcial methods related to the detection of hazardous states of awareness and report on the development of a biocybernetic system. In specific, we describe three measures: EEG frontal theta; resting tremor; and the startle reflex which offer indexes of performance, task demands, and internal emotional state.