34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Preliminary Results of Mental Workload and Task Engagement Assessment using Electroencephalogram in a Space Suit

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***Abstract*—In this paper, we present preliminary results of subject's mental workload and task engagement assessment in an experimental space suit. We have quantified the mental workload and task engagement based on changes in electroencephalogram (EEG). EEG signals were collected from subjects scalp using a commercial wireless EEG device in two experimental conditions – when subjects did not wear space suit (control condition) and when subjects wore space suit. Brain state changes were estimated and compared with the direct responses for different tasks and different conditions. We found that the spacesuit experiment introduced a greater mental workload where subject's stress levels were higher than control experiment.**

I. INTRODUCTION

Modern operational environments such as driving a vehicle demands maintaining high level of performance by the operator for a longer period of time [1]. A reliable interface between human and machine is therefore would be useful ensuring operator's performance and security [1]. Real-time monitoring of the operator's status is now made possible by means of a human-computer interface system which can be used to monitor operator's performance as well as to alter the level of automation through a closed-loop feedback mechanism [2]-[4]. Such a system is useful in the intervention of undesirable situations, thus improving the efficiency, productivity, and safety [2]-[4].

Electroencephalogram (EEG) is the recording of brain's electrical activity. EEG can be recorded non-invasively using surface electrodes from the scalp. Numerous physiological parameters such as cardiovascular indices and galvanic skin response (GSR) have been used in previous studies to determine the changes in cognitive states [5]-[7]. EEG signals have been shown to be capable of revealing subtle changes in attention and mental workload [5]-[7]. EEG signals can identify and quantify dynamic changes in brain states on a segment by segment based analysis [5]-[9]. Previous studies have reported EEG measures of mental workload and task difficulty of air traffic controllers, pilots, drivers, and participants performing neuro-cognitive tasks [5]-[9]. Correlations between the subjective measures of human performance and the indices of cognitive state changes were found significant in earlier studies [10]-[11].

One of the methods to analyze EEG involves decomposing it into four fundamental power spectral bands, i.e., delta (0-12 Hz), theta (4-7 Hz), alpha (7-12 Hz), and beta (12-30 Hz) [9]-[11]. These spectral band powers of EEG or the ratios between them are highly correlated with changes in cognitive states [12]. Prinzel and colleagues have reported improved performance in vigilance task using an EEG engagement index [13]. The EEG index for task engagement was computed by dividing the beta band power (12-30 Hz) by the sum of the alpha band power (7-12 Hz) and the theta band power (4-7 Hz) [13]. EEG power spectral density (PSD) values were used as inputs into a classifier model so as to be able to identify and classify cognitive states such as attention, engagement and workload (mental demand) [5]. Both linear and non-linear classifier models such as linear discriminant analysis (LDA), artificial neural networks (ANN), quadratic and logistic function analysis have been used in earlier studies to classify EEG signals [4]-[13].

In another study, Pope et al. developed a biocybernetic system and used several indices derived from EEG for evaluating operator's task engagement [14]. The index computed by the ratio of alpha power to the sum of alpha and theta power was found to best reflect the task engagement [14]. Lin et al. proposed a system to estimate auto driver's drowsiness using EEG [15]. They have designed their experiment using a "virtual-reality-based driving simulator" and estimated the driver's mental performance quantitatively [15]. Berka et al. described a hardware and software system for real-time monitoring of alertness and mental workload using EEG indices [9]. They showed that across participants, engagement decreased over a twenty-minute vigilance test whereas the workload did not increase [9]. Workload was found to increase linearly as task difficulty increase for the "forward digit span", "backward digit span", "grid recall" and "mental addition test" [9]. This study suggested that the EEG engagement reflects "information gathering", "visual processing", and

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Manuscript received March 15, 2012. This work was supported in part by the North Dakota Space Grant Consortium and ND EPSCoR under Grant #EPS-0814442.

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978-1-4577-1787-1/12/$26.00 ©2012 IEEE

"allocation of attention" [9], [16]. Also, it showed that the EEG measures correlate with subjective and objective performance metrics [9], [16].

In this paper, we have studied the changes in EEG activity by computing an EEG index in response to a set of neurocognitive tasks performed in a space suit [13]-[14]. The results were compared to the same tasks performed in a control experiment where subjects were provided with a normal environment. We also compared the EEG activity with the direct responses.

II. METHODS AND MATERIALS

A. Experimental Design

Our study was approved by the institutional review board (UND IRB-201003-285). Five healthy subjects were recruited in a strictly voluntary manner; all of them were males within the age range of 21-45. Subjects were briefed about the space suit by an aerospace engineer (one of the co-authors of this paper). The time required for each subject for each experiment was approximately 70 minutes. However, for this study we have used first three tasks with duration of 23 minutes as shown in Table 1. The space suit experiment and the control experiment for each subject were carried out on separate days but at the same period (morning or afternoon) of day. No other intentional efforts were made to counter balance the two experiments. A consent form was presented to the participant and the participant was allowed to review the form before signing. Each participant was given a questionnaire to fill out before and after the experiment. At the end of each experiment, the EEG data was inspected for verification purposes.

In this study, we designed an experiment as a part of testing of the NDX-1 (North Dakota experimental space suit first generation) space suit. This planetary space suit has been developed in the Space Suit Laboratory of The University of North Dakota. Though space suit testing goes through different phases such as performing routine tasks by an astronaut as well as space walk simulations, we primarily focused on subjects performing routine tasks while wearing the space suit. This minimizes the movement related artifacts and other challenges in acquiring EEG data in a simulated space walk.

B. Data Acquisition

We used a commercially available EEG acquisition system for this study. The wireless EEG acquisition system consists of the head set and the B-Alert®/AMP (attention memory profiler) software [16]. The headset consists of the cap, head strip holding the sensors, and RF (radio frequency) wireless transmitter. Data were collected from six EEG scalp sensors (POz, C3, C4, Cz, F3 and Fz) and one electrocardiogram (ECG) electrode placed on the subject's chest. The signal was transmitted wirelessly to a host computer. Data were transmitted from the head set transmitter to the computer through six channels; five of these channels acquire EEG and one for ECG. EEG data were acquired by differential measurements through these channels. These channels are: FzPO (between Fz, Poz), CzPO (between Cz, Poz), FzC3 (between Fz, C3), C3C4 (between C3, C4), and F3Cz (between F3, Cz). The signal sampling frequency was 256 Hz. The analysis presented is for a single channel.

C. Neurocognitive Tasks Battery

The Attention Memory Profiler (AMP) of the B-Alert® software system [16] comprises a set of neurocognitive tasks used to estimate human performance. In this study, three of those tasks were used. These tasks are three basic tasks which represent different brain states, for example, alertness ("Eyes open", task # 1), relax state ("Eyes closed", task # 2) and vigilance ("Three choice vigilance task", task # 3).

TABLE I
SUMMARY OF ATTENTION AND MEMORY PROFILER TASKS [17]

Task no.	Task name	Task time (minute)
1	Eyes Open (EO)	5
2	Eyes Close (EC)	5
3	Three Choice Vigilance (3CVT)	13

For the EO task (task 1), the subject was presented a flashing red object on the computer monitor at varying time intervals. The subject was required to respond by pressing the spacebar on the computer keyboard immediately after the object was presented. The EC task (task 2) was similar to the EO except that a sound pulse was presented instead of a flashing object. The subject (with eyes closed) was required to press the spacebar on the computer keyboard following the stimulus (sound). For the 3-CVT (task 3) task, the subject was presented three flashing objects at varying time intervals. These objects were: a triangle pointing up, a triangle pointing down and a diamond. The subject pressed the left arrow key or right arrow key on the keyboard in response to the triangle pointing up and the triangle pointing down (or diamond) respectively [16]. For our experimental scenario, EO and EC are of low task difficulty level while 3CVT is of moderate difficulty.

D. Preprocessing and Feature Extraction

During the space suit experiment condition we had to consider the artifacts and noise issues which could badly contaminate the data. Some of those artifacts are due to eye blinks, movement related artifacts. In addition to the power line noise, high frequency noise from the oxygen supply could affect the data. The B-Alert® software consists of eye blinks detection and filtering algorithms which filtered out the eye blinks from raw EEG. Further, we used a 0.5-30 Hz fourth order Butterworth band-pass filter in order to reduce the high frequency noise and obtain the signals of interest. The band-pass filtering also reduces low frequency muscle and movement artifacts.

After the preprocessing, the EEG signals were segmented into overlaying 256 data point segments (50% overlapping). Fast Fourier Transform (FFT) was then applied to each segment (1 second duration) of the filtered EEG signals to determine the relative Power Spectral Density (PSD) for: delta (0-4 Hz), theta (4-8 Hz), alpha (8-12 Hz) and beta (12 – 30 Hz) frequency bands. We chose these features for our experiments as previous studies have shown that the relative power of the fundamental EEG bands strongly correlates with the human neurocognitive states. Finally, an EEG index was computed as the ratio of beta power to the sum of alpha power and theta power [13]-[15].

III. RESULTS

The direct responses to the three baseline tasks were available for further analysis. We used this information to compare the performances for the tasks for both the control and space suit experiments. Fig. 1 shows the percentage correct of the answers for three tasks for all five subjects.

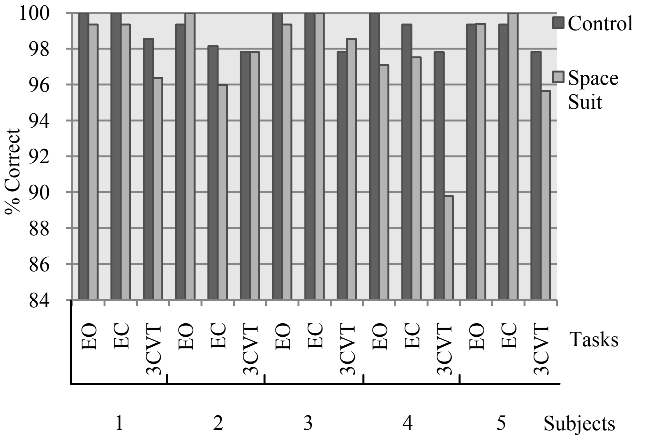

Fig. 1. Comparison of direct responses during three baseline tasks for two experimental conditions.

To further investigate the EEG index (the ratio of beta power to the sum of alpha power and theta power) changes with the task difficulty, we computed the mean index across the subjects for these three tasks as shown in Fig. 2.

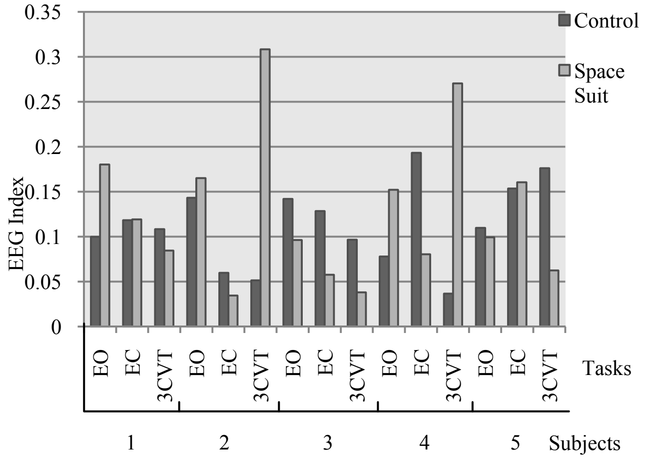

Fig. 2. Normalized brain index (EEG Index) variations during three baseline tasks for two experimental conditions.

We found a trend of decrease in performance with time as well as the increase in task difficulty. The EO and EC tasks could be identified as having low task difficulty and the 3CVT as having moderate task difficulty level. Percentage correct was highest in the EO task whereas it falls during the 3CVT task. The Fig. 1 and 3 also show the decrease in percentage correct during the space suit experiment. Fig. 3 and 4 compare the direct responses and the mean EEG index. Fig. 3 shows the degradation of performance with the increases in task difficulty in time as subjects tend to lose engagement and experience fatigue. Though it was inconclusive of finding a similar trend from the EEG index, it revealed the differences observed in task engagement for two experimental conditions. The subjects were found to be more engaged in performing EO and 3CVT tasks wearing space suits whereas loosely engaged in EC. During EC subjects might have been in a more relaxed state due to the added complexity of a space suit environment. Two subjects were found highly engaged during 3CVT in space suit compared to their task engagement during the same task in control environment (subject 2 and 4 in Fig. 2).

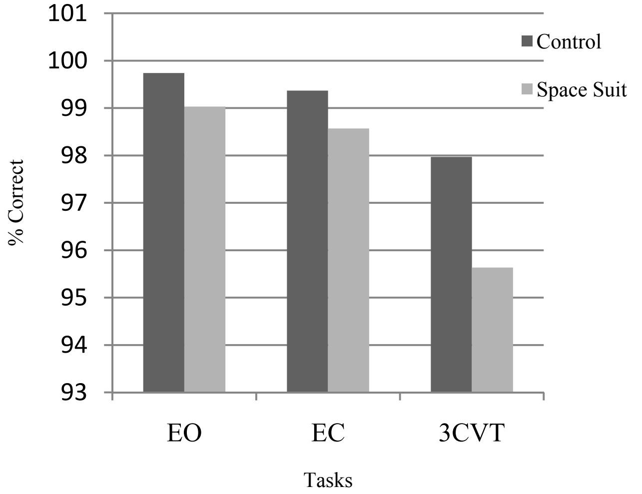

Fig. 3. Comparison of direct responses (mean percentage correct answers) variations during three tasks.

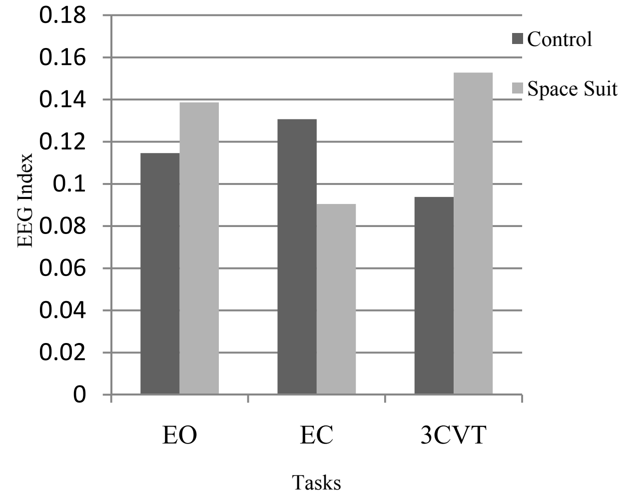

Fig. 4. Comparison of normalized brain index (mean EEG index) variations during three tasks.

IV. DISCUSSION

All of the subjects were found to have an overall, increase in beta activity for most of the tasks except the EC task. The increase in beta activity for both the space suit and control experiments suggests increased alertness (active or busy brain state) and this was expected as reported in a previous study [17]. The beta activity for the control experiment was generally found to be higher than that of the space suit experiment. As expected, the alpha band activity was relatively low except for the EC task where it is predominated. Previous reports [18] also showed that the alpha wave predominates during relaxed, EC tasks.

Alertness, as measured by the beta band activity (when compared to alpha band activity) was remarkably high for most of the tasks both spacesuit and control. This was expected because, the battery of neurocognitive tasks was designed for continuous attention, and beta wave (low amplitude wave) was predominant during active/alert/busy brain states whereas the alpha band activity was predominant only during the eyes closed task as expected.

V. CONCLUSION AND FUTURE STUDIES

Considering the conditions of the simulated operational environment, we expect a rapid decline in the beta activity, and such a system could be very critical in brain state analysis in a real operational environment where the operator could spend significantly long periods performing mentally demanding tasks. In the future, we would focus on designing a closed-loop neurofeedback system that could effectively reduce the risk of working as well as maintaining good health by providing a feedback to the subject as an indication of his performance specifically when the performance level fall below a specific standard.

Since the astronauts have to perform mission related tasks which require constant vigilance, the preliminary results from our experiment could provide an insight on the increase in mental workload with time, the chance of having fatigue and the decrease in attention as task difficulty increases.

In future studies, we will perform analysis of all the nine tasks in the AMP task battery. We will also investigate the significant difference and affect of three fundamental EEG band powers and the EEG index for the different tasks within subjects using repeated measure ANOVA with two factors: control vs. space suit and electrodes location. The statistical analyses will provide a detail insight into the experiment assessing mental workload and task engagement of subjects in our unique experiment.

ACKNOWLEDGMENT

The authors thank the test subjects for their voluntary participation in the experiment. Thanks also to Nicholas Pojman for his support with the B-Alert® equipment.

REFERENCES

[1] R. Molloy, I. L. Singh R. Parasuram, "Performance consequences of automation induced "complacency".," *International Journal of Aviation Psychology*, vol. 3, pp. 1-23, 1993.

[2] M. E. Smith A. Gevins, "Assessing fitness-for-duty and predicting performance with cognitive neurophysiological measures," in *Proceedings of SPIE Defense and Security Symposium, Biomonitoring for Physiological and Cognitive Performance during Military Operations*, Orlando, 2005, pp. 127-38.

[3] M. C. Moore-Ede, *The Twenty-four-hour Society: Understanding Human Limits in a World That Never Stops.* Reading, MA: Addison-Wesley, 1993.

[4] T. Bahri, J. E. Deaton, J. G. Morrison, and M. Barnes R. Parasuraman, "Theory and design of adaptive automation in adaptive systems," Naval Air Warfare Center, Aircraft Division, Warminster, Research NAWCADIWAR-92033-60, 1992.

[5] D. J. Levendowski, and C. K. Ramsey C. Berka, "Evaluation of an EEG-workload model in Aegis simulation environment," in *Proceedings of the international society for optical engineering*, Orlando, 2005, pp. 90-99.

[6] M. Inlow S. Makeig, "Lapses in alertness: coherence of fluctuations in performances and EEG spectrum," *Electroencephalography and Clinical Neurophysiology*, vol. 86, pp. 23-35, 1993.

[7] T. P. Jung S. Makeig, "Changes in alertness are principal component in variance in the EEG spectrum," *Neuroreport*, vol. 7, pp. 213-216, 1995.

[8] T. P. Jung S. Makeig, "Tonic, phasic, and transient EEG correlates of auditory awareness in drowsiness," *Cognitive Brain Research*, vol. 4, pp. 15-25, 1996.

[9] D. J. Levendowski, R. E. Olmstead C. Berka, "Real-time analysis of EEG indices of alertness, cognition, and memory with wireless EEG headset," *International Journal of human computer interaction*, vol. 17, pp. 151-170, 2004.

[10] D. J. Levendowski, M. N. Lumicao, A. Yau, G. Davis, V. T. Zivkovic, R. E. Olmstead, P. D. Tremoulet, P. L. Craven C. Berka, "EEG correlates of task engagement and mental workload in vigilance, learning, and memory tasks," *Aviat Space Environ Med.*, vol. 78, no. 5, pp. B231-44, May 2007.

[11] D. Levendowski, M. Cvetinovic C. Berka, "Real-time analysis of EEG indices of alertness, cognition, and memory with a wireless headset," *International Journal of Human Computer Interaction*, vol. 17, pp. 151-170, 2004.

[12] S. Makeig, M. Stensmo, T. J. Sejnowski J. Tzyy-Ping, "Estimating alertness from EEG power spectrum," *IEEE Transactions on Biomedical Engineering*, vol. 44, no. 1, pp. 60-69, January 1997.

[13] F. G. Freeman, M. W. Scerbo L. J. Prinzel, "A closed-loop system for examining psychophysiological measures for adaptive task allocation," *International Journal of Aviation Psychology*, vol. 10, pp. 393-410, 2000.

[14] A. T. Pope, E. H. Bogart, D. S. Bartolome, "Biocybernetic system evaluates indices of operator engagement in automated task," *Biological Psychophysiology*, vol. 40, pp. 187-195, 1995.

[15] R. C. Wu, T. P. Jung, S. F. Liang, T. Y. Huang C. T. Lin, "Estimating driving performance based on EEG spectrum analysis," *EURASIP Journal of Applied signal processing*, vol. 19, pp. 3165-3174, 2005.

[16] ABM, Inc. website. [Online]. Available: http://ww.b-alert.com/resources/EEG_Technology_Review_JAN_2007.pdf.

[17] S. N. Baker, "Oscillatory interactions between sensorimotor cortex and the periphery," *Motor systems: Neurobiology of behavior*, vol. 17, no. 6, pp. 649-655, 2007.

[18] W. Klimesch, P. Sauseng S. Hanslmayr, "Alpha phase reset contributes to the generation of ERPs," *Cerebral Cortex*, vol. 17, no. 1, pp. 1-8, 2007.