Olaf TRUSZCZYŃSKI[1], Grzegorz NOWICKI[2], Jerzy ACHIMOWICZ[1]

NEW TELEMEDICAL APPROACH TO PILOT AND ASTRONAUT PSYCHOPHYSIOLOGICAL STATUS MONITORING AND IMPACT OF AUGMENTED COGNITION ON FLIGHT SAFETY

Military Institute of Aviation Medicine, Warsaw, Poland
[1] Department of Flight Safety
[2] Clinical Center

ABSTRACT: *A critical review of recently implemented methods for remote monitoring of psychophysiological status of operators performing complex tasks with high workload (information stream) in adverse physical environment (noise, acceleration), typical for aerospace operations is presented. The passive role of subject being monitored typical for telemedical system is compared with biofeedback based system where the pilot is aware of his/her physiological status. The negative impact of automation is stressed together with the weakness of augmented cognition and adaptive systems approach aimed of reducing the information load of the operator. The importance of monitoring the emotional status of the subject which has great impact on team coordination and efficacy is stressed. The need for development of a new synthetic measures (indexes) of psychophysiological pilot status for remote monitoring is discussed. The linear (coherence) and nonlinear (bicoherence) measures of phase coupling between ANS (Autonomic Nervous System) and CNS (Central Nervous System) ultradian rhythms is proposed as new descriptor of integrative physiological processes as a predictor for high performance in complex flight tasks. Possible implications for flight safety are presented*

KEY WORDS: *psychophysiological pilot status, remote monitoring, ANS, CNS, coherence, bicoherence, ultradian rhythms*

Correspondence to: dr n. hum. Olaf Truszczynski, Zakład Bezpieczeństwa Lotów WIML, 01-755 Warszawa, ul. Krasińskiego 54/56, email: otruszcz@wiml.waw.pl

Introduction

The aim of this paper is to stress a new approach in the monitoring of the psychophysiological status of pilots during military aviation training. The current most sophisticated technologies available for patient status monitoring are derived from telemedicine and augmented cognition systems developed by DARPA. These two systems represent extreme cases as far as the information flow is concerned. In the telemedical system a remote medical expert is provided with the information regarding the medical and psychological status of the subject. The decision is then made regarding the assignment of the tasks to the subject or his withdrawal from the operational environment.

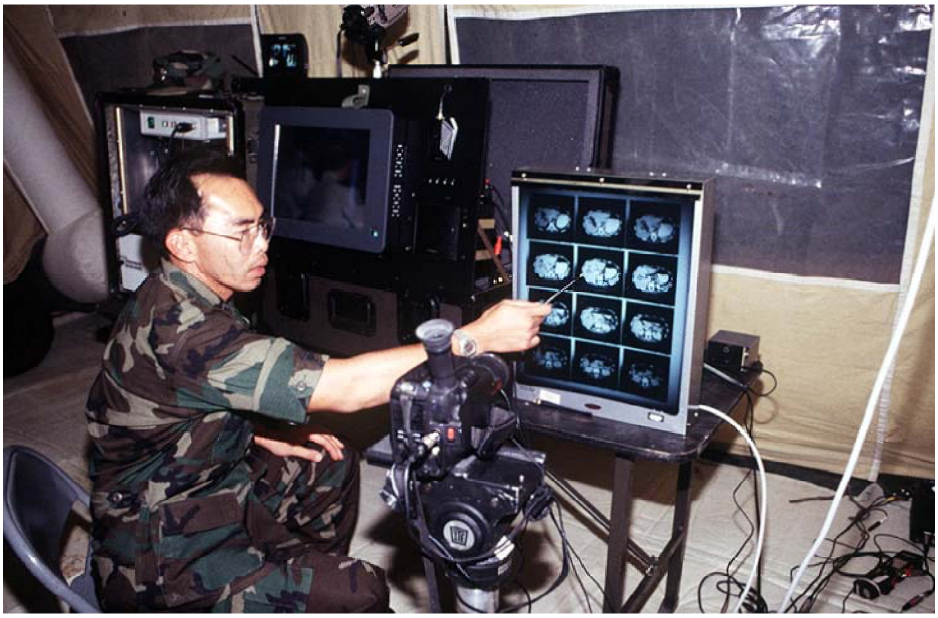

Fig.1. Use of telemedicine on the battlefield in the implementation phase. source: http://armymedicine.army.mil

In the augmented cognition system, a complex brain-computer interface (BCI) is used to monitor the workload of the subject and the information stream is reduced or changed in modality if the pilot (for example) is not capable of monitoring the environment/plane status and taking optimal decisions due to information overload or fatigue.

Ad Fig. 2. Among possible applications from research on augmented cognition is one in which sensors would be developed to detect when a pilot is immersed in conversation and allow the plane's in-board computer to display key information visually, source: Clancy, Frank, AT MILITARY'S BEHEST, DARPA USES NEUROSCIENCE TO HARNESS BRAIN POWER, Neurology Today, 17 January 2006; Volume 6(2); Pp 4,8-10, http://aan.com.

Ad Fig. 3. Brad Allenby in The Techno-Human Condition, What Is To Be Done,Why today's policies regarding human enhancement don't work, Psychology Today, published on May 23, 2011, http://situatedresearch.com.

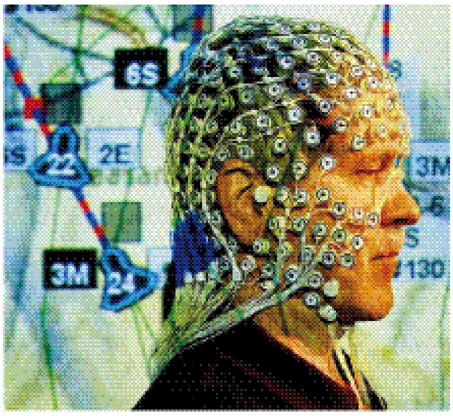

Fig. 2.

Fig. 3.

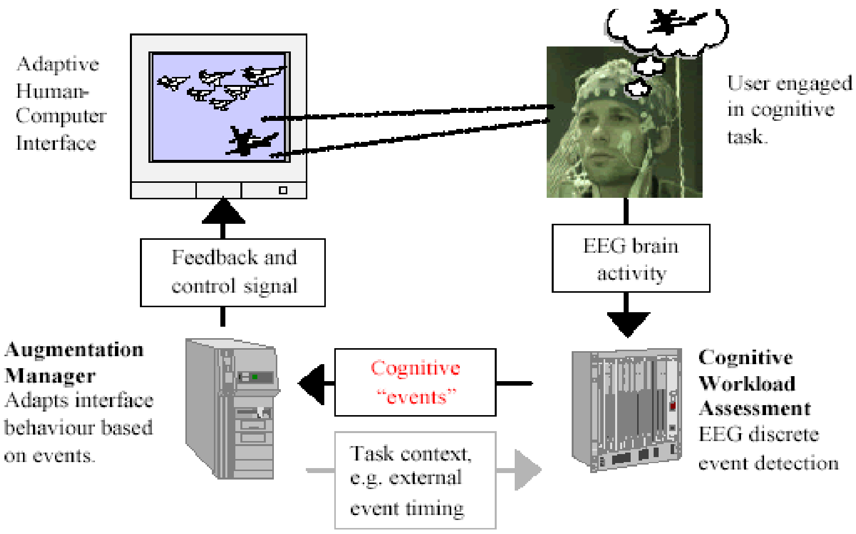

Fig. 4. Real-time brain computer interface system for augmented cognition and action requires an extensive digital signal processing in real time. The only solution is to design more effective data reduction techniques based on novel DSP algorithms for evaluating workload and emotion objective measures. Source: The Laboratory for Intelligent Imaging and Neural Computing (LIINC) , founded in September 2000 by Paul Sajda. http://www.liinc.bme.columbia.edu

Significant breakthrough in computer assisted performing of difficult tasks in aviation or space flight might be possible due to the application of biofeedback approach where the pilot is presented with the information about his psychophysiological state. A simple example of this approach is biofeedback assisted execution of respiratory exercises aimed at coping with short high acceleration episodes during the dogfight maneuvers. As already stressed during this workshop, the adaptive learning approach to the training of pilots and adaptive type closed loop systems are the most effective. However, the majority of this kind of psychophysiological research and applications concentrates on workload issues [17]. In the opinion of the authors of this paper, the most neglected field of research is the role of emotions (relaxed versus aroused state) and attention [5,18] (focused versus exploratory). These psychophysiological states are not easily and objectively recognised by automatic systems. The authors propose to apply certain, synthetic physiological measures , sensing the interactions between autonomic and central nervous systems (ANS-CNS coupling).

An even more important factor as far as the flight safety implications are concerned is the neglected role of the so called "social brain" approach where the social integration between team players (e.g. pilot, navigator, ATC, command) is important. The lack of coordination and proper emotional involvment of team members involved in the operational task, like target detection or emergency landing, results in the deterioration of inter-group communication. Such communication is a prerequisite for proper balancing of information load distribution/assignment to the multiple task crew [11,12,13,14].

The role of emotions is specially important in the early stages of aviation training or in acquiring the skills to perform extremely critical operations like docking in orbit, in-flight fueling , air carrier landing or landing in the minimal weather conditions. The basic problem in effective operational applications of recent advances in neuropsychology, especially so called cognitive neuroscience, is the need for development and operational verification of new synthetic measures of operator psychophysiological status. Recently published data by Shelly Carson from Harvard University confirmed the old theories about the role of rhythmic electric phenomena like alpha and gamma waves in problem solving processes . Our experiment on inflight recording and longitudinal analysis of autonomic nervous system activation (arousal reaction) in aviation academy cadets also revealed that the emotional component due to pilot-instructor communication is a good predictor of future pilot skill development.

There is, therefore, a need for the development of synthetic measures which are capable of detecting such CNS and ANS coordination which provides high and safe performance scores at the same time. Here are same examples of such measures:

Cardio-respiratory rhythms coupling

Exploratory study on the relation between coordination of rhythmic activities and performance on the centrifuge (linear onset rate profile) tests have shown [1], that there is a consistent difference between good performers (high G tolerance) and bad performers (low G tolerance) when the threshold was determined by loss of peripheral vision an/or drop of ear lobe blood circulation. The coupling was first evaluated by linear spectral analysis where transfer function and coherence function were estimated with FFT (Fast Fourier Transform) method.

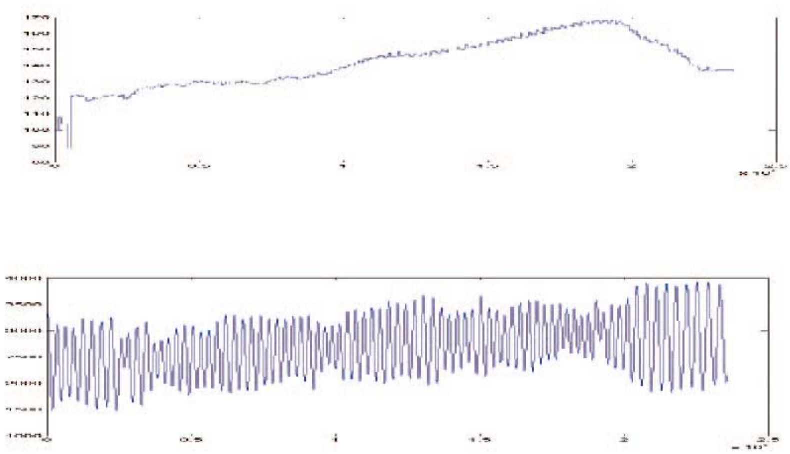

Fig. 5. The time trend of heart rate (upper plot) and respiration wave (air flow) during the classical acceleration tolerance test with linear +Gz onset rate. The threshold (acceleration tolerance limit) was determined by the drop in peripheral vision and/or decrease in the ear lobe blood flow measured by infrared plethysmography.

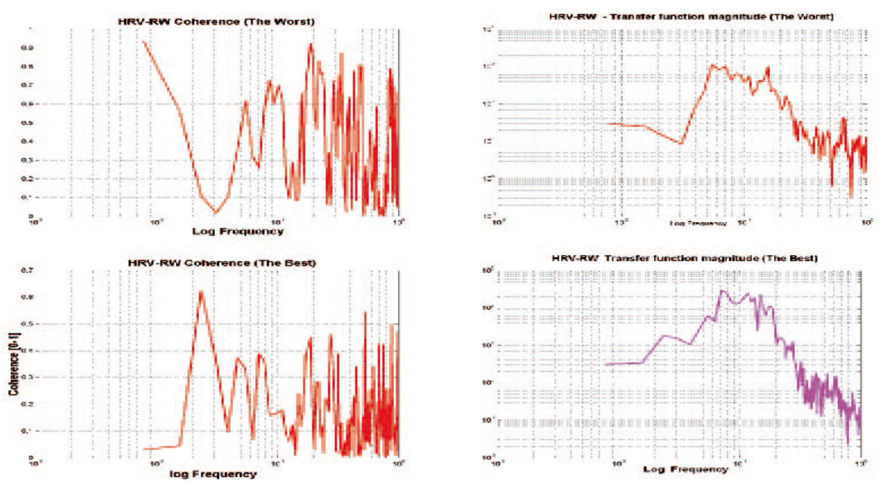

Fig. 6. The cardio-respiratory systems coupling strength estimated by coherence between HR and respiratory wave (two left plots) respectively for the pilots with low and high acceleration tolerance. On the right the corresponding transfer function amplitudes are shown. Notice very low phase synchrony (coherence) of low frequency rhythms in low tolerance group accompanied by low transfer function values. The peaks related to RSA (respiratory sinus arrhythmia) and Mayer waves, corresponding to blood pressure fluctuations can be observed. Frequency is plotted in logarithmic scale [8,10,16].

Much more informative and sensitive psychophysiological status synthetic indexes can be derived from the nonlinear spectral analysis where phase and amplitude relations (phase coupling) can be measured between rhythms of different frequencies by estimation of bispectra and bicoherences [2,7,9]. These techniques introduced in 1997 by the authors [4] for the assessment of the dynamics of CNS functions in various states of consciousness is now well recognized and used, for example as a basic indexes of wakefulness (anesthesia) level. However, the major inspiration for the investigation of phase synchrony of brain rhythms for the evaluation of brain functional state came from studies on the efficacy of TM relaxation techniques used by NASA for astronaut training. The authors performed validation studies on TM effects on brain state using hybrid methods (analog and digital analysis of rhythmic activities dynamics) known in literature as CSA (Compressed Spectral Arrays). Also the phase coupling was found between slow fluctuations of rhythmic EEG activities amplitudes (envelopes) and ultradian rhythms in autonomic nervous system (ANS).

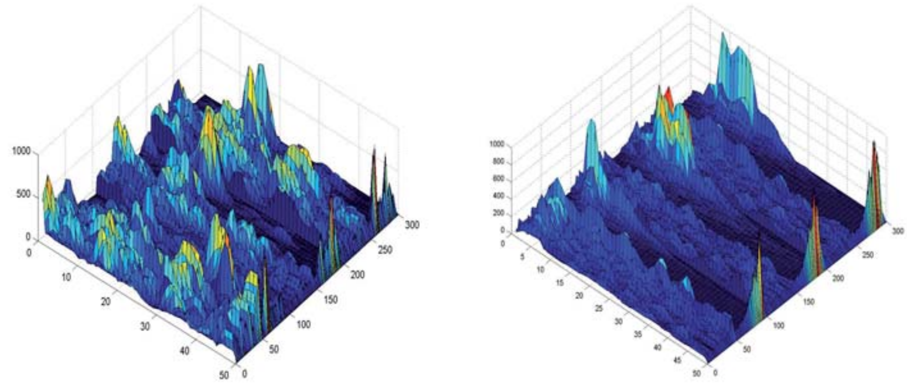

Fig. 7. Comparison of nonlinear coupling of slow rhythms in cardio-respiratory system. The base plane corresponds to the the frequency pairs (f1,f2) in the range from zero to 0.5 Hz.

The amplitude of bicoherence is unit-less and similar to coherence (0-1.0) range. The larger the bicoherence the more consistent phase coupling between the different frequencies rhythms is observed. The diagram on the left represents the average values of bicoherence for high G tolerance group and the one on the right the group with low G tolerance respectively.

Conclusions

The spectral phase properties of ultradian rhythms observed in the coupling of cardiovascular and respiratory systems (Mayer waves and RSA) are very sensitive indicators of the functional status of neural regulatory systems (sympathetic-parasympathetic balance) responsible for human organism response to stress factor. Phase coupling of these rhythms, as evaluated by linear (coherence) and non-linear (bicoherence) spectral methods, is highly time variable (non-stationary) hence the application of parametric signal modelling is necessary for the studying of physiological response dynamics. As the dynamic properties of neural regulatory systems are subject specific (idiosyncratic); hence the approach proposed by the authors based on the longitudinal studies of the autonomic and central nervous system (CNS) dynamics and flight performance measures may serve better as the indexes of flying skills then just performance sores alone. Specifically the discovered ANS-CNS rhythms phase coupling may be a new and sensitive index of integration between CNS and ANS and serve as the synthetic measure of the psychophysiological status of the operator.

Augmented reality and biofeedback

It is a well accepted fact that the training procedures in aviation and astronautics should be adaptive to provide optimal stimulation of the operator to avoid boredom or fatigue in case of information overload. However, the augmented cognition approach in aviation places too much attention on avoiding high workload by selecting the modality or even reducing the information stream. This automation may also lead to hazardous situations as the pilot may underestimate the need for the control of the aircraft relying excessively on automatic procedures.

The authors' opinion is that the information load can be reduced by proper distribution of tasks among the flying team members and ground control personnel backup. On the other hand, the pilots/astronauts and the ATC/mission controllers should perform in an augmented reality computer generated environment where the vital information about psychophysiological status of all team members would be visualized or vocally provided in addition to flight and weather/terrain data [6,15].

For example, the use of HUD for visualizing of the synthetic measures of the pilot's state on the scale of vigilance/awareness/attention with additional emotions measures/indexes may be crucial for adequate self-control by biofeedback approach and may improve the decision making processes during the critical phases of flight/mission assignments with significant positive impact on flight safety [3,5].

References

1. Achimowicz, J.Z., Kłossowski, M., Tkaczuk, W., Mikuliszyn, R., Drapiński, R. (2001). On the new method for evaluation of nervous system type in pilot candidates by linear and quadratic phase coupling of rhythms in autonomic nervous system, Accepted for ICASM 2001, Geneva, September 2001.

2. Achimowicz, J.Z., Bullock, T.H. (1993). Nonlinear properties of local field potentials in brain: Implications for biological neural network modeling., Proceedings of the Annual Research Symposium, Institute for Neural Computation, University of California in San Diego, USA, 14,3, 29-49.

3. Balk, I. (2003). Bio-feedback based simulator for mission critical training. Lecture Notes in Computer Science 2659, 1074-1080.

4. Bullock, T.H., Achimowicz, J.Z., Ducrow, B., Spencer, S., Iraqui-Madoz, V.J. (1997). Bicoherence of intracranial EEG in sleep, wakefulness and seizures. *Electroencephalography and Clinical Electrophysiology*, 103, 661-678.

5. Endsley, M.R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors,* 37(1),32–64.

6. Entin, E., Serfaty, D. (1999). Adaptive team coordination. *Human Factors*, 41(2), 312–325.

7. Elgar, S., Guza T., (1988). Statistics of Bicoherence, *IEEE Transactions on Acoustics, Speech and Signal Processing*, 36,10, 1667-1668.

8. Hamner, J.W., Morin, R.J., Rudolph. J.L., Taylor, J.A. (2001). Inconsistent link between low-frequency oscillations: R-R interval responses to augmented Mayer waves. *Journal of Applied Physiology*, 90, 1559-1564.

9. Huber, P.J., Kleiner B., Gasser,T., G. Dumermuth,G. (1971). Statistical methods for investigating phase relations in stationary stochastic processes, IEEE Transactions, Audio Electroacusic, 78-86.

10. Kłossowski, M., Drapiński, R., Achimowicz, J.Z., Mikuliszyn, R. (2001).Idiosyncratic relations between physical fitness, +Gz tolerance and phase properties of cardio-respiratory rhythms in selected population of Polish Air Force Academy candidates, ICASM 2001, Geneva.

11. MacMillan, J., Entin, E., Serfaty, D. (2004). Team Cognition Understanding the factors that Drive Process and Performance, chapter Communication Overhead: The Hidden Cost of Team Cognition. Salas and Fiore, 1st edi., 61-82.

12. Mandryk, R.L., Inkpen, K.M. (2004). Physiological indicators for the evaluation of co-located collaborative play. Proc. 2004 ACM Conference on Computer Supported Cooperative Work, New York, USA., ACM Press, 102-111.

13. Salas, E., Fiore, S.M., (2004). Team Cognition Understanding the factors that Drive Process and Performance. APA, 1st edi.

14. Serfaty, D.E., Entin, E.E., Volpe, C. (1993). Adaptation to stress in team decision-making and coordination. Proc. Human Factors and Ergonomics Society. 37th Annual Meeting, 37, 1228-1233.

15. Tarnanas, I., Tsirgogianni, A. (2003). A virtual reality as a self-efficacy boost for high demanding emergency planning and preparedness. Proc. International Workshop on Virtual Rehabilitation.

16. Terziotti, P., Schena,F., Gulli, G., Cevese, A. (2001). Post-exercise recovery of autonomic cardiovascular control: a study by spectrum and cross-spectrum analysis in humans., *European Journal Applied Physiology*, 84,187-194.

17. Wilson, J., Glenn, F. (2002). Psychological and Psychophysiological Models of Pilot Performance for Systems Development and Mission Evaluation. I*nternational Journal of Aviation Psychology*, 12,1-951.

18. Pomeroy, D.E. French, H.T., Clarke, E., Seymour, M., Clark, C.R. (2003). Psychophysiological measures of situation awareness, Australasian Society for Psychophysiology, Inc. Conference, 12-14 December 2003, Tasmania, Australia, Land Operations Division, DSTO External Publications, http://hdl.handle.net/1947/2602.