Psychophysiological Measurements in Real Working Environments
Wireless EEG Study of the Operators' Vigilance

Pavle Mijović, Ivan Gligorijević, Evanthia Giagloglou and Ivan Mačužićand Branislav Jeremić
Faculty of Engineering Sciences, University of Kragujevac, Sestre Janjić 6, Kragujevac, Serbia

1 STAGE OF THE RESEARCH

The vigilance decrement and inability of the industry worker to sustain attention during a task can lead to errors in operating, which could further lead to dangerous situations including catastrophic events with fatalities. Therefore, measuring operators' vigilance level, while performing everyday monotonous repetitive task, is of crucial interest.

The current project is related to innovation through human factors in risk analysis and management at the work place (InnHF project, http://www.innhf.eu). The term innovation is justified by hypothesis that it is possible to obtain higher degree of operators' safety and workers well-being by on-line measurement of operators' vigilance state, using lightweight and wireless sensor systems. Extensive literature review in the fields of neuroergonomics, human factors and ergonomics (HFE), psychophysiology and biomedical signal processing preceded the current research in order to approach this problem in the most appropriate way. At this point, we believe that it is possible to obtain reliable measure of operators' vigilance state, while performing repetitive task, by continuous on-line recording of the brain signals using compact and lightweight wireless EEG system.

The initial experiments have been conducted, using novel and state-of-the-art lightweight wireless EEG system (SMARTING, made by mBrainTrain LLC, Serbia), which confirmed the ability of the device to obtain reliable, artefact-free recordings. The signal strength, judged by visual inspection of known eye-blink signatures and clearly visible alpha activity, proved strong enough for the proposed psychophysiological measurement of operators' vigilance state. These "entry" experiments were carried out using the open-source open ViBE software package (http://openvibe.inria.fr).

Further, we have created the experimental set-up of the improvised "lean" workplace, where the real-life example from one of our industry partners is authentically replicated. This serves to examine the psychophysiological correlates of the operators' vigilance state, while carrying out everyday repetitive jobs.

We have also identified research paradigms and the next step is to perform high-density EEG measurements in these realistic work conditions, identifying the physiological signatures of vigilance state of the operator and offer tools for their real-time detection.

2 OUTLINE OF OBJECTIVES

Neuroergonomics is the study of brain and behavior at work (Parasuraman, 2003). It is a novel and interdisciplinary area or research that merges the disciplines of neuroscience and human factors and ergonomics in order to maximize the benefits of each (Parasuraman and Rizzo, 2007).

With the recent technological advancements it became possible to move the EEG measurement from the strictly controlled laboratory conditions (movement-constrained behavior), to the real-life environments where subjects are allowed to naturally walk outdoor wearing wireless EEG device (Debener et al., 2012). Therefore, with these new wireless EEG systems it becomes possible to merge EEG measurements with the guiding principle of neuroergonomics, and examine how the brain carries out the complex everyday work tasks, and not just simple and artificial laboratory task (Parasuraman and Rizzo, 2007).

The first objective of our work is to examine the psychophysiological correlates of vigilance decrement in the improvised, but highly realistic workplace by using the wireless EEG system in or der to avoid any constrains to physical actions of the operators.

After the initial identification of these correlates, the next step is to develop and implement real-time vigilance estimation mechanisms.

Final stage assumes applying knowledge from the improvised workplace repeating the experiments in the real working environment featuring "lean" production procedures. This is planned in collaboration with the industrial partners from the InnHF project (FIAT Automobiles Serbia and Tetrapak Serbia). This brings twofold benefit: on the side of research, it will be possible to obtain useful information on the cognitive state of the operator without disrupting the everyday work routine; on the industry side, new guidelines and constrains for increasing the workers vigilance levels are expected to improve the ergonomic of the workplace and consequently, the operators' and equipment safety, bringing reduction in costs and maximizing production efficiency.

Another side objective is to upgrade the vigilance monitoring system to create a brain computer interface (BCI) that will allow the operators' safety action in cases that are critical from the safety point of view. Also, this system is to serve for control of robotic actions for the places hardly reachable by the hand of an operator. It is well known that in the industries with high production output it is not always possible to design the production line that is completely user-friendly, due to robustness of the machinery. Therefore, the BCI application for the safety actions would be a highly desirable solution: the operator would use comfortable, completely wireless EEG system that would not require any physical action.

Finally, we believe that we will be able to identify the optimal sensor positions using high-density recordings brought in by our current wireless EEG system. This is expected to enable reduction of the number of necessarily used electrodes, which could in turn offer guidelines for future industrial vigilance and BCI sensor system that is lightweight, comfortable, completely mobile and ready to be used by workers. Therefore, we aim to contribute to creation of the state-of-the-art on-line monitoring and interaction system for the operators' in the industry. This way, the operators' potential errors due to decrement of alertness level could be prevented, leading to decrease of the industrial accidents and incidents that are in the most cases caused by the operators' lapses in sustained attention.

The outline of the objectives of this work is graphically represented in Figure 1.

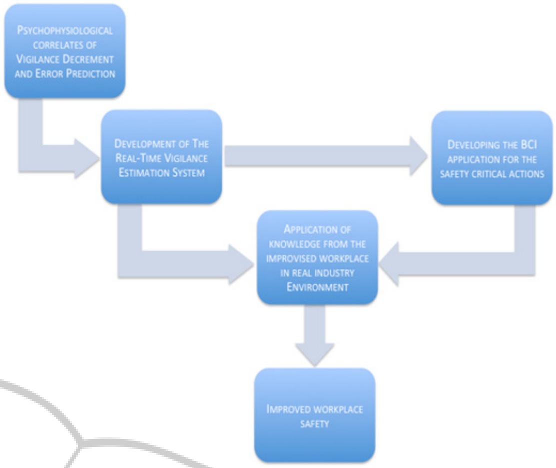

Figure 1: Outline of the research objectives.

3 RESEARCH PROBLEM

3.1 Vigilance Monitoring

Regarding safety assessment, HFE is concerned with the elimination, reduction, or mitigation of human error. Human error is typically categorized as slips (errors in actions), lapses (errors in memory), or mistakes (errors in applying knowledge; Reason, 1990) and is often cited as a factor in up to 80% of accidents (Wiegmann and Shappell, 2001).

The critical role that is assigned to HFE in design and safety assessment depends on the widespread use of automation and its impact on human errors (Cacciabue, 2004). The automation is often proposed as a method for removing or reducing human errors in a system and it shifted the roles of operators from active controllers to that of system supervisors who serve in fail-safe capacity only when problem arise (Sheridan, 1980). Even though automation can improve performance of routine operations by reducing the workload and reducing human error at behavioural level, it also introduces a variety of safety critical issues due to lapses in attention and errors of cognition. Therefore, vigilance became crucial component of human performance in many working environments where automated systems are ubiquitous (Warm et al., 2008), because lapses in attention and errors committed by the operator in industry can have catastrophic consequences.

Vigilance is a term that has been used in different ways by different scientist and therefore, it has various definitions (Oken et al., 2006). However, in cognitive neuroscience and psychology, the term of vigilance is used to refer ability of organisms to maintain their focus of attention and to remain alert over prolonged period of time (Warm et al., 2008). When studying vigilance, the neuroscientist often specifically refers to a vigilance decrement and lapses in the sustained attention over extended period of time, especially when repetitious, monotonous and continuous tasks are carried out (Oken et al., 2006; Warm et al., 2008). However, many studies of vigilance have shown that for most of operators engaged in attention and monotonous tasks, it is not possible to retain a constant level of alertness (Yu et al., 2007).

Various authors studied the physiological correlates of vigilance decrement. Hung et al. (2001) quantified alertness level by correct rates on auditory and visual vigilance task in an EEG study. According to them, in the auditory vigilance task, the relative spectral amplitudes in the alpha and theta bands as well as the mean frequency spectrum was found to be the best combination for predicting the alertness level. In visual vigilance task, the beta frequency band was the only feature for predicting alertness level (Huang et al., 2001). This was supported by the work of the Dockree et al. (2007). They confirmed that the subjects with higher tonic frequencies in the alpha range show a larger-amplitude late positive event-related potential (ERP) component that has previously been found to predict a good sustained attention performance. Bonnefond et al. (2010) showed in an ERP study that vigilance decline that is reflected by significant changes in performance and spectral power, is also accompanied by specific effect of time on the P2 and Late Positive LP1 component.

Jung et al. (1997) proposed a method for estimating operators' level of attention in near real time, by merging power spectrum estimation, principal component analysis and artificial neural networks. They confirmed that there is a close relation between changes in performance and in EEG power spectrum.

Pattyn et al. (2008) studied the mechanisms of sustained attention by targeting two modes of attention control, endogenous and exogenous attention. In their study, they did not use the EEG measurements, instead the reaction times (RT), error rates (ERs) and heart rate variability (HRV) were measured and it was found that performance decrement in the visual vigilance task appears after approximately 20-30 minutes.

Above mentioned studies almost exclusively agree on obtaining the information about vigilance from EEG signals. However, the optimal set of features for detecting it, as well as their applicability to on-line monitoring is still out of reach. Identifying measures that are intuitive, reliable and applicable for working environment would bring a huge benefit. These would then serve to tune the future industrial algorithms.

3.2 Problems regarding Real-life Vigilance Monitoring

As already stated before, continuous monitoring of the operators' mental state, in operational environment, could decrease potential for serious errors and provide valuable information concerning the ergonomics of the tasks being performed (Gevins et al., 1995). However, in order to achieve this kind of monitoring, specific requirements need to be fulfilled including the reliable measurements using inexpensive and highly mobile equipment. These are the necessary prerequisites for conducting brain activity monitoring outside the laboratory settings (Gevins et al., 1995). Therefore, the non-invasive, small in size and weight, and relatively inexpensive wireless EEG device that produces reliable results, seems like a promising solution for the above-mentioned problems. Even though mobile EEG represents a promising tool for the experiments to be carried outside the laboratory settings, it is far from being the only requirement for achievement of reliable psychophysiological results. In fact, it is necessary to carefully design and set up the experiment itself due to limitations of use of presentation software and other conditions contributing to realistic character of the improvised workplace.

Previously mentioned studies were conducted in the strictly controlled laboratory conditions using presentation software and obtaining the time-locked events in order to study, mostly, the ERPs and time locked power spectral densities. Further, apart from measuring the electrocortical brain activity, in most of these studies, the reaction time (to a stimuli) was one of the main parameters for measuring the vigilance level. At this point, it is important to outline the difficulty of obtaining the time-locked events in dynamic real working environment. We believe that if there is a requirement for operator to put additional effort for the button press, or any other action in order to obtain the time-locked events while performing actual task, the credibility of results will decrease as in that case the working environment is changing as the action that operator is carrying out is altered.

Therefore, one of the biggest challenges regarding EEG recording outside the laboratory settings, assuming the movement related artefacts already being suppressed, is to find a way to obtain the time locking events, without distracting the operator from performing his task in order to asses the information regarding the ERP components and time-locked spectral densities.

4 STATE OF THE ART

Recent studies indicated that it is possible to measure the human state of vigilance using EEG signals (Oken et al., 2006; Yu et al., 2007; Dockree et al., 2007; Huang et al., 2007; Bonnefond et al., 2010). It has been further reported that it is possible to estimate the vigilance level in near real-time (Jung et al., 1997). However, all of the mentioned studies have one common limitation, that is, all of them have been performed in laboratory conditions, with constricted movements and featuring bulky equipment.

Apart from the advantage that wireless EEG systems are small enough and allows the on-field measurement of the operators' vigilance state, this setting also allows to the operator to move naturally in the working environment, without causing huge instrumentation artefacts. This is supported by the fact that movement of electrode wires, a major source of instrumentation artefacts (Usakli, 2010), and electrode displacement are minimized and therefore, artefacts that are not physiologically related are suppressed (Debener et al., 2012).

Recently a few EEG studies were conducted in various areas, including the study of vigilance. However, the most of these studies were carried out in order to assess information regarding the drivers safety and safety of the pilots in aviation industry and not for operators that are working in industry sector. This is not surprising, since the most of the advances in HFE, including the early beginnings of this field, are coming from aviation industry (Canas et al., 2011). On the other hand, a large portion of the research in the field of mobile EEG is conducted in the scope of medical studies, example being the work of Lin et al. (2008) in which non-invasive neural prostheses was proposed for continuously monitoring high-temporal resolution brain dynamics using wireless EEG.

It is important to note, that while carrying out the above-mentioned studies for driver and/or pilot vigilance, virtual reality software was used. While it allowed replicating the real-life situations to a large extent, it still could not sufficiently mimic the real environment and all of ifs features.

Further, the majority of the previous studies were carried out using commercial wireless EEG gadgets with dry and non-contact electrodes that are becoming increasingly popular, mostly due to gaming purposes. The attractive side of these commercial devices lies in their comfortable and easy-to-use character, e.g. stemming from the fact that the traditional, gel electrodes are avoided. However, on the downside, they currently provide the limited signal strength and therefore, the results obtained with this equipment are not reliable. Debener et al. (2012), on the other hand, showed that it is possible to modify one of the consumer 14-channel wirelesses EEG in order to improve the signal quality, obtaining the state-of-the art device for further research. In the aforementioned study, wireless and mobile character of the consumer EEG device was combined with the research-grade electrodes allowing for high-quality recordings.

5 METHODOLOGY

5.1 Vigilance Monitoring

Measuring EEG in an unrestricted environment always gathered close attention of scientific community. However, high-quality, medical graded recordings were only recently demonstrated with fully mobile platforms (Debener et *al.* 2012). Company mBrainTrain recently provided a research tool for neurofeedback testing paradigms. We adapted their "SMARTING" device for vigilance research task mainly due to two features:

1) Small, lightweight and mobile character, and
2) Close to medical signal quality

Figure 2 portrays a close-up of "SMARTING" while being prepared for recording. This solution uses gel-based electrodes produced by the renown Easycap company (Germany), offering high-quality recordings mainly due to low impedance.

This system features 24 EEG channels with 24-bit resolution. The real-time data transmission is achieved using the Bluetooth 2.1 EDR that is able to communicate with a PC or Android based phones/tablets. In addition, electrode impedance information is continuously sent, together with the gyroscope readings.

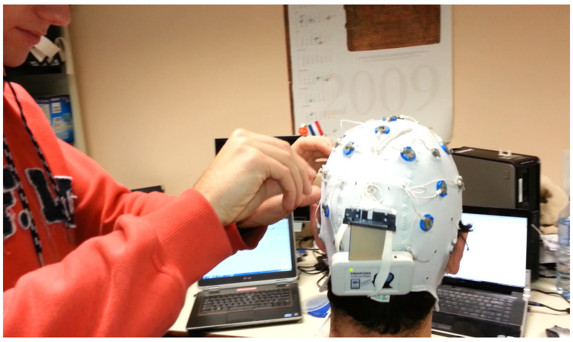

Figure 2: Mounting of "SMARTING": recording electrodes are filled with conductive gel.

Figure 3 shows a preview from our initial quality tests. A simulated "lean" factory work place was also created (Figure 4). Although still in the fine-tuning stage, it can faithfully replicate several common working places related to the targeted, repetitive factory tasks.

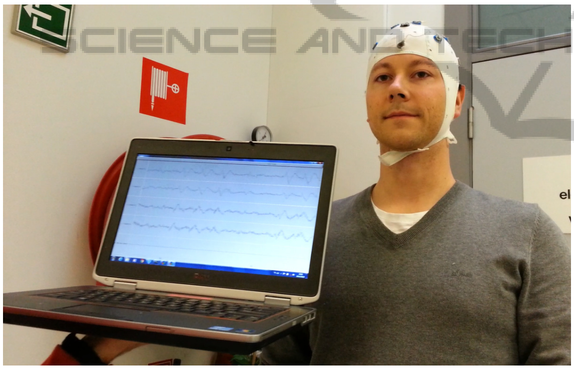

Figure 3: Signals with a moving subject exhibited almost no visual movement artefacts.

5.2 Signal Segmentation

For tracking of changes in vigilance, it is necessary to properly segment the signal according to the performed action. This is not an easy task taking into account the often vague beginning and the end of this process.

We decided to take a two-step approach to this:

1) Provide a sound signal, identical to the sound that is produced by the machine used by the operator at the real working environment, to mark a beginning of the operation (and also serve as a trigger signal for the EEG segmentation), or
2) Provide a signal, not notable for the operator but coinciding with the beginning of the operation.

While precise triggering is still a hard task, we believe that introducing a microphone device that would serve as a reliable reference can solve this problem.

The logic behind "notable" and "not notable" triggers is to eliminate (but also investigate) vigilance dependency on outside factors like this one.

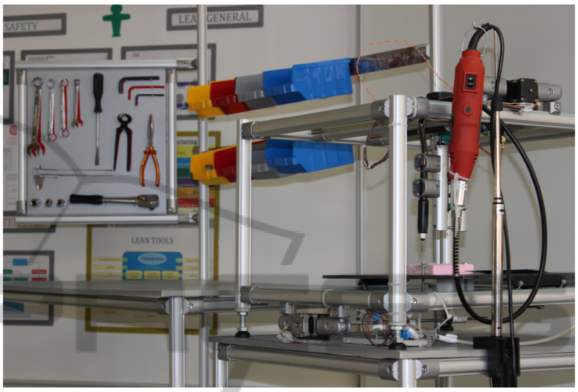

Figure 4: Realistic "lean" workplace, where simulated repetitive task is performed.

5.3 Signal Processing

The use precise triggering will enable the comparison between spectral EEG measures and the ERPs obtained after the signal segmentation. The rationale lies in the fact that ERPs, if proven sufficiently reliable compared to established spectral measures, can offer much faster detection of the decrease in vigilance. In this scope, the changes in the delay or amplitude of e.g. P300 can be related to the depth of cognitively processing the stimulus that further can be related to the level of attention (Murata et al., 2005).

In parallel, we plan to segment the continuous EEG signal, according to the duration of one complete operators' action, in order to investigate known frequency components of interest, theta (4-8 Hz), alpha (8-13) and beta (13-30 Hz) bands.. Further, due to the non-stationary nature of EEG signals and in order to achieve precise time-frequency resolution, we will use decomposition techniques including Wavelet transform and Empirical Mode Decomposition (Huang et *al.* 1998, Mijovic et al., 2010). Then, spectral correlates for vigilance monitoring will be traced and the delay in their detection used to assess their suitability as a real-time vigilance-tracking marker.

Temporal analysis of ERP- based vigilance detectors would be achieved by first training a classifier in case of the present audio stimuli.

Response time delays would most likely be used as a measure of decreased attention. Introducing another triggering system (e.g. precise enough, yet outside of the intentional human notice) would be used to assess how vigilance changes in presence/absence of distraction.

Also, training ERP and spectral methods for robotic control is going to take place as well to pinpoint the usefulness of industry BCI devices.

5.4 Real-time Implementation and Industry Solution Roadmap

Once the algorithms are developed to positively detect vigilance shift, they are going to be implemented online. Following this, the complete system is expected to be tested within the facilities of our partners, FIAT Serbia and Tetrapak Serbia.

Further, the minimal viable EEG system to perform these tasks can be identified from here. This means fewer sensors, on much fewer previously identified locations. This would serve as a guideline for future industry vigilance monitoring system.

6 EXPECTED OUTCOME

The proposed aim of this research is to pinpoint to routines used to attain close to constant vigilance level of operators performing industrial, repetitive tasks.

This is done in order to reduce and/or eliminate potential slips of sustained attention, which is desirable from both economic (production efficiency) as well as health related (work injuries) points of view.

We expect to deliver real-time algorithms for vigilance monitoring and notification from one hand, as well as guidelines for improvement of work routines taking into account the newly available vigilance monitoring data from the other.

We will use a high-density electroencephalographic (EEG) sensor to identify the limits of necessary "resolution" for vigilance monitoring. We expect to, following the success of this task, propose an industrial system that would reduce the costs and increase the work safety, while being of acceptable price and comfortable to use.

Attaining the individual privacy, we expect it will be possible to provide the operator with the information when his alertness level starts to decrease, which in turn can yield fewer errors committed and consequently, increase the overall industrial safety at the workplace and decrease the economical losses.

In order to achieve the objectives of this work, we will firstly conduct psycho-physiological measurements at the improvised, but authentically replicated workplace using the novel wireless EEG system. We will then bring these measurements to real factory conditions due to collaboration with our partner companies interested in this concept.

ACKNOWLEDGEMENTS

The presented study is fully funded by the European project framework FP7 InnHF.

REFERENCES

Bonnefond, A., Doignon, C. N., Touzalin, C. P., and Dufour, A., 2010. *Vigilance and intrinsic maintenance of alert state: An ERP study. Behavioural brain research,* 211(2), 185-190.

Cacciabue, P. C., 2004. *Human error risk management for engineering systems: a methodology for design, safety assessment, accident investigation and training. Reliability Engineering & System Safety*, 83(2), 229-240.

Canas, J. J., Velichovsky, B. B., Velichovsky, B. M., 2011. *Book chapter "Human Factors and Ergonomics", in* Martin, P. R., Cheung, F. M., Knowles, M. C., Kyrios, M., Littlefield, L., Overmier, J. B., &Prieto, J. M. (Eds.), 2011. *IAAP handbook of applied psychology.*Wiley.com.

Debener, S., Minow, F., Emkes, R., Gandras, K., and Vos, M., 2012.*How about taking a low□cost, small, and wireless EEG for a walk?.Psychophysiology*, 49(11), 1617-1621.

Dockree, P. M., Kelly, S. P., Foxe, J. J., Reilly, R. B., and Robertson, I. H. 2007. *Optimal sustained attention is linked to the spectral content of background EEG activity: greater ongoing tonic alpha (□ 10 Hz) power supports successful phasic goal activation. European Journal of Neuroscience,* 25(3), 900-907.

Gevins, A., Leong, H., Du, R., Smith, M. E., Le, J., DuRousseau, D., Zhang, J., and Libove, J. 1995.*Towards measurement of brain function in operational environments. Biological Psychology,* 40(1), 169-186.

Huang, N. E., Shen, Z., Long, S. R., Wu, M. C., Shih, H. H., Zheng, Q., Yen, N. C., Tung, C. C., and Liu, H. H., 1998.*The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences,* 454(1971), 903-995.

Huang, R. S., Tsai, L. L., and Kuo, C. J., 2001. *Selection of valid and reliable EEG features for predicting auditory and visual alertness levels. Proceedings-national science council republic of china part b life sciences,* 25(1), 17-25.

Jung, T. P., Makeig, S., Stensmo, M., and Sejnowski, T. J. 1997. *Estimating alertness from the EEG power spectrum. Biomedical Engineering, IEEE Transactions on*, 44(1), 60-69.

Lin, C. T., Ko, L. W., Chiou, J. C., Duann, J. R., Huang, R. S., Liang, S. F., Chiu, T.W., and Jung, T.P. 2008. Noninvasive neural prostheses using mobile and wireless EEG. *Proceedings of the IEEE*, 96(7), 1167-1183.

Mijovic, B., De Vos, M., Gligorijevic, I., Taelman, J., and Van Huffel, S. 2010. *Source separation from single-channel recordings by combining empirical-mode decomposition and independent component analysis. Biomedical Engineering, IEEE Transactions,*57(9), 2188-2196.

Murata, A., Uetake, A., Takasawa, Y., 2005. *Evaluation of mental fatigue using feature parameter extracted from event-related potential", International Journal of Industrial Ergonomics,* 35(8),,761–770.

Oken, B. S., Salinsky, M. C., and Elsas, S. M., 2006. *Vigilance, alertness, or sustained attention: physiological basis and measurement. Clinical Neurophysiology,* 117(9), 1885-1901.

Parasuraman, R., 2003.*Neuroergonomics: Research and practice. Theoretical issues in ergonomics science*, 4, 5-20.

Parasuraman, R., Rizzo, M., 2007.*Neuroergonomics: The Brain at Work*. Oxford University Press, Oxford.

Pattyn, N., Neyt, X., Henderickx, D., and Soetens, E., 2008. *Psychophysiological investigation of vigilance decrement: Boredom or cognitive fatigue?.Physiology&Behavior,*93(1), 369-378.

Reason, J. T., 1990. *Human Error.* Cambridge University Press, Cambtidge.

Sheridan, T., 1980. *'Supervisory Control' in Handbook of Human Factors*, ed G Salvendy, Willey, New York, pp. 1243-1268.

Usakli, A. B., 2010. *Improvement of EEG signal acquisition: An electrical aspect for state of the art of front end. Computational intelligence and neuroscience,* volume (*2010)*, article ID 630649.

Warm, J.S., Parasuraman, R., and Matthews, G., 2008.*Vigilance requires hard mental work and is stressful. Human Factors: The Journal of the Human Factors and Ergonomics Society*, 50(3), 433-441.

Wiegmann, D. A., and Shappell, S. A., 2001. *Human error analysis of commercial aviation accidents: Application of the Human Factors Analysis and Classification System (HFACS). Aviation, Space, and Environmental Medicine,* 72 (11), 1006-1016.

Yu, H., Shi, L. C., and Lu, B. L., 2007. Vigilance Estimation Based on EEG Signals. In *Proceedings of the International Conference on Mechanical Engineering 2007* (ICME2007).