EEG Indices to Time-On-Task Effects and to a Workload Manipulation (Cueing)

A. T. Kamzanova, G. Matthews, A. M. Kustubayeva and S. M. Jakupov

Abstract**—**The aim of this study was to evaluate the sensitivity of a range of EEG indices to time-on-task effects and to a workload manipulation (cueing), during performance of a resource-limited vigilance task. Effects of task period and cueing on performance and subjective state response were consistent with previous vigilance studies and with resource theory. Two EEG indices – the Task Load Index (TLI) and global lower frequency (LF) alpha power – showed effects of task period and cueing similar to those seen with correct detections. Across four successive task periods, the TLI declined and LF alpha power increased. Cueing increased TLI and decreased LF alpha. Other indices – the Engagement Index (EI), frontal theta and upper frequency (UF) alpha failed to show these effects. However, EI and frontal theta were sensitive to interactive effects of task period and cueing, which may correspond to a stronger anxiety response to the uncued task.

Keywords**—**brain activity, EEG, task engagement, vigilance task.

I. INTRODUCTION

THE WELL-KNOWN construct of attention resources is critical to the modern cognitive-psychological theory of vigilance [1], [2]. The resource theory of vigilance decrement states that during performance of high-workload signal detection tasks, resources become depleted, leading to decrements in perceptual sensitivity. In operational settings, it may be important to monitor workload and resource depletion.

Resource depletion may also be expressed in subjective state changes and in psychophysiology. Recent work links cerebral bloodflow velocity to resource utilization [3]. The study showed bloodflow velocity declined during performance of the vigilance tasks.

Task Engagement is a subjective state linked to vigilance, which includes energetic arousal, intrinsic motivation, motivation for success and concentration. Levels of task engagement predict perceptual sensitivity on a range of vigilance tasks [3]. Task Engagement is seen as an index of availability of attentional resource availability. It may also serve as an indicator of cognitive-adaptive processes such as task-focused coping, and mobilization and direction of resources to task processing. Subjective task engagement tends to decline during vigilance. EEG research especially links increased slow wave activity (e.g, delta, theta) to vigilance decrement. Previous studies of EEG have suggested a variety of indices of task load and operator engagement (see Table I).

TABLE I
EEG INDICES

Index	Notes	Source
ratio of beta to (alpha+theta)	“Engagement index” Can be measured by separate “montages”: frontal (F3, F4, F7, and F8), temporal, and parietal pooled over four sites (Cz, P3, Pz, P4): Hockey et al. -2009.	Freeman et al. (2000)
Ratio of theta activity at frontal midline sites to alpha at parietal sites [theta/alpha]	“Task Load Index”	Gevins and Smith (2003)
Frontal theta	“effort”: anteriorfrontal, frontal and fronto-central	Gevins et al. (1997)
Lower alpha suppression	“Alertness and expectancy”: frontal, central, parietal, occipital, temporal	Klimesch (1999)
Upper alpha suppression	“task processing”: frontal, central, parietal, occipital, temporal	Klimesch (1999)

A number of EEG researchers [4], [5] have revealed that both beta and alpha or theta rhythms negatively correlated with alertness and task engagement. They suggested an EEG engagement index with the following formula: β/θ. Freeman, Mikulka, Prinzel, Scerbo [6] and Pope, Bogart, Bartolome [7] suggested the inclusion of the alpha rhythm in any index of engagement. According to these authors an improved EEG engagement index defined by the new formula $\beta/(\alpha+\theta)$ enables not only the systematization of the psychophysiological data, but also allows definition of the EEG parameters signaling cognitive processes such as information processing and attention resources. An EEG study of cognitive task performance confirmed efficiency of the using "EEG engagement index" [8]. The task load index (TLI) identified by Gevins and Smith [9] may also be promising as an

A. T. Kamzanova is with the Department of Psychology, Al-Farabi Kazakh National University, Almaty 480078, Kazakhstan as PhD student (phone: +7(727)246-28-28; e-mail: kamzanova@ gmail.com).

G. Matthews with the Department of Psychology, University of Cincinnati, Cincinnati, OH 210376 USA as professor (Fax: (513)556-1904; e-mail: matthegl@ucmail.uc.edu).

A. M. Kustubayeva is with the Department of Psychology, Al-Farabi Kazakh National University, Almaty 480078, Kazakhstan as Associate Professor (phone: +7(727)267-43-83; e-mail: almkust@gmail.com).

S. M. Jakupov is with the Department of Psychology, Al-Farabi Kazakh National University, Almaty 480078, Kazakhstan as professor (phone: +7(727)267-43-83; e-mail: Satybaldy.Zhakupov@kaznu.kz).

indicator of task engagement. TLI is defined by increased frontal theta and reduced parietal alpha during demanding task performance, i.e., the ratio of theta activity at frontal midline sites to alpha at parietal sites [theta/alpha]. Similar results have been revealed by Fairclough et al. [10], Holm [11], and Nassef et al. [12]. Other indices may also be used to define cognitive responses to mental demands. Increased theta activity from frontal sites indicates increased demand and a state of focused attention [13]. Lower and upper alpha suppression measures have been found to index separate functions relating to attention and task processing respectively [14]. However, few studies have compared the various indices directly, and there is also little evidence on which index is most effective for detection of the loss of alertness associated with the vigilance decrement in performance.

Aims of study

To verify that cueing vigilance influences resource demands [brief description of Hitchcock findings] [15].

To compare a range of EEG indices in relation to their sensitivity to task parameters.

II. METHODS

A. Subjects

The participants were 100 students from Kazakh National University aged 18 to 29 years old (50 males, 50 females). Participants were required to be free of psychiatric and medical diseases at the time of the study. All were right handed, with normal or corrected-to-normal vision. Participants were randomly assigned to one of two groups. One group performed a cued vigilance task, the second group performed with no cue. The experiment design was accepted by the local ethics committee.

B. Task

Participants performed target detection on a simulated air-traffic control display during 40 minutes. The target represented two aircraft aligned on a potential collision course. Signals were presented for 80 ms followed by blank screen for 1875 ms. Signal probability was approximately 3%. Programming was achieved by means of Super Lab (v2.0) and Microsoft Excel software.

Task engagement was measured by the Russian version of the Dundee Stress State Questionnaire (DSSQ; Matthews et al. 1999). We also used “The Pittsburgh Sleep Quality Index (PSQI)” and “Cognitive failure Questionnaire”. Participants completed a pre-test form of the DSSQ, then performed the vigilance task, and then immediately completed a post-test version of the DSSQ. The simulated air-traffic control display was adapted to a Russian speaking population; DSSQ was translated into Russian and adapted. All scales of Russian DSSQ showed adequate alphas, ranging from 0.694 to 0.925.

C. EEG Measurements

EEG was recorded by using an electroencephalograph “Neuron-Spectrum-1” monopolarly from symmetrical frontal, central, parietal, occipital, and temporal lobes with the indifferent joint ears electrodes (Fp1A1, FzA1, F3A1, C3A1, P3A1, PzA1, O1A1, CzA2, Fp2A2, F4A2, C4A2, P4A2, O2A2, T3A1, T4A2) in the following situations: baseline with closed/open eyes, lasting four minutes, and four consecutives periods of the vigilance task, lasting 10 minutes each, for a total of forty-four minutes. The Spectral Power Density of EEG rhythms was analyzed in seven bands (Delta “0.5-3.9 Hz.”, Theta “4-7.9 Hz.”, Alpha-1 “8-10.9 Hz.”, Alpha-2 “11-13.9 Hz.”, Beta-1 “14-19.9 Hz.”, Beta-2 “20-29.9 Hz.”, Gamma “30-35 Hz.”).

III. RESULTS

Effects of task parameters on three performance indices – correct detections, false positives, mean RT for correct detections – were analyzed using 2 x 4 (cue x task period) mixed-model ANOVAs. False positive percentages were log-transformed prior to analysis to correct positive skew. Box’s correction was used in applying F tests, where appropriate, because of violations of the sphericity assumption. For correct detections, the main effects of cue, $F(1.90)=9.47$, $p<0.01$, partial $\eta 2= 0.095$, and period, $F(2.479, 223,124)=11.27$, $p<0.01$, partial $\eta 2= 0.111$, were significant, but the interaction between these factors was not. The only significant effect in the analysis of false positives was the main effect of cue, $F(1,90)=8.31$, $p<0.01$, partial $\eta 2= 0.870$. The false positive rate was higher in the no cue condition (8.46%) than in the cued condition (3.66%). The analysis of RT showed a significant cue x period interaction, $F(2.841, 252.889)=2.92$, $p<0.05$, partial $\eta 2= 0.032$, but no main effects of these variables. A vigilance decrement in correct detections was evident; across periods, detection rate tended to decline in both participant groups. Correct detections were higher in the cued condition but a trend towards greater performance decrement in the no cue condition was non-significant. RT was fairly stable across time in the cued condition, but increased monotonically in the no cue condition.

To test whether groups were initially matched for subjective state, we conducted a 2 x 11 (cue x scale) mixed-model ANOVA, using the data for the 11 DSSQ scales measured pre-task. Neither the main effect of cue nor the cue x scale interaction was significant, confirming that there was no systematic difference in initial state between the two participant groups. Next, we conducted a series of 2 x 2 (cue x pre- vs. post-task) ANOVAs to test for effects of task performance on subjective state, for each DSSQ scale. For each scale, the effect of pre- vs. post-task was significant at $p<0.01$, except in the case of task-relevant cognitive interference (NS). F values (df=1,90) were 36.94 (energetic arousal), 8.82 (tense arousal), 68.20 (intrinsic motivation), 10.95 (success motivation), 14.39 (self-focus), 22.23 (concentration), 33.07 (confidence and control) and 24.22 (task-irrelevant interference). In addition, significant cue x pre- vs. post-task interactions were found for energetic arousal ($F(1,90) = 5.64$, $p<0.05$), tense arousal ($F(1,90) = 6.25$, $p<0.05$), and self-esteem $F(1,90) = 4.12$, $p<0.05$).

There were no significant effects of the task factors on upper alpha. For the remaining indices, the main effect of period was significant for TLI, $F(2.517, 226.496)=3.29$, p<0.05, partial η2=0.035, for lower alpha F(2.116, 190.483)=16.91, p<0.01, partial η2=0.158, and for frontal theta , F(2.814, 253.256)=3.16, p<0.05, partial η2=0.034, but not for EI. The effect of cue was significant for TLI, F (1, 90)=4.18, p<0.05, partial η2=0.044 and lower alpha F (1, 90)=4.40, p<0.05, partial η2=0.047, but not for the other indices. The period x group interaction was significant (or nearly so) for EI, F(2.175, 195.745)=2.92, p=0.052, partial η2=0.031 and for frontal theta, F (2.814, 253.256)=3.05, p<0.05, partial η2=0.033, but not for other indices.

Thus, different EEG indices showed different patterns of response to the task parameters (see Figure 1-4). TLI and lower alpha showed complementary responses. Time-on-task decreased TLI and increased alpha power, whereas providing the cue elevated TLI and lowered alpha.

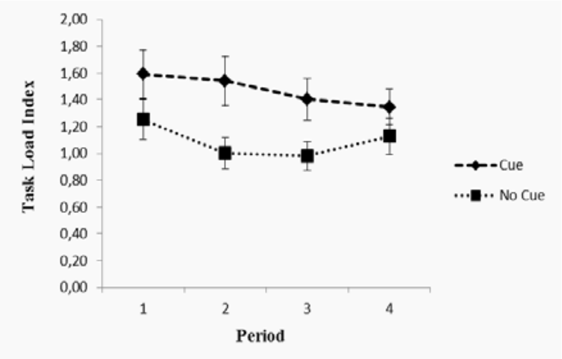

Fig. 1 TLI index of vigilance task

By contrast, effects of task parameters on EI and frontal theta were interactive, not additive. In the final period of work, EI was higher but frontal theta was lower in the cue group.

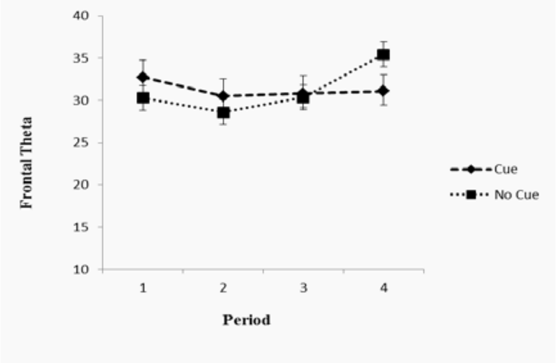

Fig. 2 Frontal Theta index of vigilance task

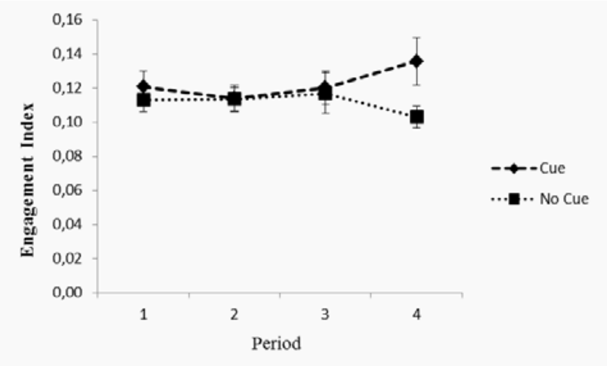

Fig. 3 EI index of vigilance task

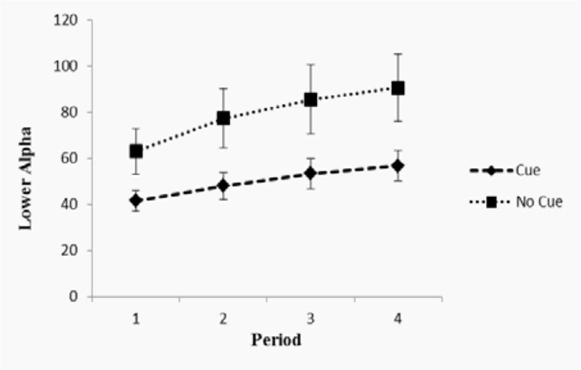

Fig. 4 Lower frequency alpha index of vigilance task

IV. CONCLUSIONS

Performance data were consistent with the assumption that both the absence of a cue and time-on-task may lead to resource shortfalls, as evidenced by declines in correct detections, findings similar to Hitchcock, Dember, Warm, Moroney, See [15]. In this study, however, RT but not correct detections showed an interactive effect of cuing task period. The profile of change on the DSSQ suggested decreasing task engagement and increasing distress: a pattern typical of high workload vigilance tasks. There was also higher TLX workload for uncued condition. The EEG data suggested that TLI and lower frequency alpha were most diagnostic of loss of vigilance. These indices were sensitive to both the cueing manipulation and to task period. Generally, it seemed that lower TLI and higher lower frequency alpha were diagnostic of attentional resource insufficiency. These findings contrast with previous TLI results from multi-tasking studies which link *high* TLI to potential performance breakdown and strain [16]. The significance of TLI may depend on the nature of task demands. The frontal theta and engagement indices showed no general sensitivity to the task manipulations, and may not be diagnostic of resource utilization. The elevation of frontal theta, and depression of the engagement index in period 4 of the uncued task may be linked to the greater stress of the uncued task, evidenced by high tense arousal, and lower self-esteem in the DSSQ data.

REFERENCES

[1] M. S.Humphreys, W. Revelle, “Personality, motivation and performance: A theory of the relationship between individual differences and information processing,” in *Psychological Review*, 91, pp. 153-184, 1984.

[2] J.S. Warm, W.N. Dember, “Tests of a vigilance taxonomy,” in “*Viewing psychology as a whole: The integrative science of William N. Dember*” R.R. Hoffman, M.F. Sherrick & J.S.Warm Ed. Washington, DC: American Psychological Association, 1998, pp. 87-112.

[3] L.E. Reinerman, G. Matthews, J.S. Warm, L.K. Langheim, K. Parsons, C.A. Proctor, T. Siraj, L.D. Tripp, & R.M. Stutz, “Cerebral blood flow velocity and task engagement as predictors of vigilance performance,” in *Proceedings of the Human Factors and Ergonomics Society*, 50, pp. 1254-1258, 2006.

[4] J.F. Lubar, M.O. Swartwood, J.N. Swartwood, P.H. O’Donnell, “Evaluation of the effectiveness of EEG neurofeedback training for ADHD in a clinical setting as measured by changes in T.O.V.A. scores, behavioral ratings, and WISC-R performance, ” in *Biofeedback and Self-Regulation*, 20, pp. 83–99, 1995.

[5] K. Offenloch, G. Zahner, “Computer aided physiological assessment of the functional state of pilots during simulated flight,” in *NATO Advisory Group for Aerospace Research and Development—Conference Proceedings,* vol. 490, pp. 1–9, 1990.

[6] A. Pope, E. Bogart, D. Bartolome, “Biocybernetic system evaluates indices of operator engagement,” in *Biological Psychology*, 40, pp. 187–196, 1995.

[7] F.G. Freeman, P.J. Mikulka, L.J. Prinzel & M.W. Scerbo, “Evaluation of an adaptive automation system using three EEG indices with a visual tracking task,” in *Biological Psychology,* 50, pp. 61–76, 1999.

[8] C. Berka, D.J. Levendowski, M.N. Lumicao, A. Yau, G. Davis V.T., Zivkovic, R. E. Olmstead, P. D. Tremoulet, P.L., Craven, “EEG Correlates of Task Engagement and Mental Workload in Vigilance, Learning, and Memory Tasks,” in *Aviation, Space, and Environmental Medicine*, vol. 78, no. 5, pp. 231-244, May 2007.

[9] A. Gevins, M.E. Smith, L. McEvoy, D. Yu, “High-resolution EEG mapping of cortical activation related to working memory: effects of task difficulty, type of processing, and practice,” in *Cerebral Cortex,* 7, pp. 374–85, 1997.

[10] S.H. Fairclough, L. Venables, “Tattersall The influence of task demand and learning on the psychophysiological response,” *International J of Psychophysiology*, 56, pp. 171– 184, 2005.

[11] A. Holm, K. Lukander, J. Korpela, M. Sallinen, K.M.I. Müller, “Estimating brain load from the EEG,” *TheScientificWorld J*, vol. 9, pp. 639-651, 2009.

[12] A. Nassef, M. Mahfouf, D.A. Linkens, E. Elsamahy, A. Roberts, P. Nickel, G.R.J. Hockey, G. Panoutsos, “The Assessment of Heart Rate Variability (HRV) and Task Load Index (TLI) as Physiological Markers for Physical Stress,” in *2009 IFMBE Proc.*, pp. 146–149.

[13] F. Yamada, “Frontal midline theta rhythm and eyeblinking activity during a VDT task and a video game: useful tools for psychophysiology in ergonomics,” in *Ergonomics*, vol. 41, no. 5, pp. 678-688, 1998.

[14] W. Klimesch, “EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis,” in *Brain Research Reviews*, 29, pp. 169-195, 1999.

[15] E.M. Hitchcock, W.N. Dember, J.S. Warm, B.W. Moroney, J.E. See, “Effects of cueing and knowledge of results on workload and boredom in sustained attention,” in *Human Factors*. vol. 41, pp. 365–372, 1999.

[16] G.R.J. Hockey, P. Nickel, A.C. Roberts, M.H., “Roberts Sensitivity of candidate markers of psychophysiological strain to cyclical changes in manual control load during simulated process control,” in *Applied Ergonomics,* 40, pp. 1011–1018, 2009.