Cognitive Workload Estimation due to Vague Visual Stimuli using Saccadic Eye Movements

Indu P. Bodala[1]-*IEEE Student Member*, Yu Ke[1]-*IEEE Member*, Hasan Mir[2]-*IEEE Senior Member*, Nitish V. Thakor[1]-*IEEE Fellow* and Hasan Al-Nashash[1,2]-*IEEE Senior Member*

***Abstract*— Visual perception is affected by the quality of stimulus. In this paper, we investigate the rise in cognitive workload of an individual performing visual task due to vague visual stimuli. We make use of normalized average peak saccadic velocity to estimate the cognitive workload. Results obtained from 16 human subjects show that the mean of peak saccadic velocity increases with workload indicating that faster saccades are required to obtain information as the workload increases. This technique should find application in assessment of vigilance and cognitive performance in many demanding professional, industrial and transportation situation.**

I. Introduction

The quality of natural or environmental stimulus highly affects visual perception. Degradation of visual stimuli is often encountered when performing tasks which require visual attention like driving or flying, demanding industrial tasks, surveillance, etc. This may lead to a raise in the cognitive workload of the person who is performing the task.

Cognitive state or workload can be defined in different ways, including the effort during problem solving or the level of perceived effort during thinking, learning, perceiving or reasoning. It can also be the result of pressure on working memory during task execution. Humans differ in their ability to handle task-induced stress. Therefore estimation of subject dependent changes in the cognitive workload caused by various factors is of high importance in the areas where tasks requiring human mental effort or attention are very common. There are several studies investigating the factors affecting cognitive workload of a person. Several brain computer interface (BCI) systems based on psychophysiological measures like EEG, ERP, eye tracking metrics, etc. are being developed for the reliable estimation of cognitive workload [1, 2].

Studies have shown the effect of noisy stimuli on cognitive performance [3-5]. However, these studies largely used audio noise. In this paper, we investigate the influence of visual stimuli degradation, such as by additive noise or interfering visual objects, on the eye pupil activity variations and its relationship to cognitive workload. For this purpose, we make use of the normalized average peak saccadic velocity. The study is also supported by the analysis of subjective NASA TLX [6] collected during the experiments.

This Research is funded by the Singapore Ministry of Defense, Singapore. Grant Number: 9011103788.

[1]Singapore Institute for Neurotechnology (SINAPSE), Life Sciences Institute, National University of Singapore, Singapore (e-mail: indu.iitbbs@gmail.com, yukebme@gmail.com, sinapsedirector@gmail.com).

[2]Department of Electrical Engineering, American University of Sharjah, UAE (e-mail: {hmir,hnashash}@aus.edu).

Eye activity is broadly classified into Fixations, Saccades and Blinks. When the eye looks at an object, it makes certain angular movement, for certain duration and with a certain velocity. Fixations are relatively stable with less angular movement (~2 degrees), and less velocity (15-100 degrees/sec) for a minimum duration of 200 ms [7]. Saccades are the eye movements that occur between two fixations. These are again divided into different subtypes like micro-saccades, regular saccades and saccadic intrusions [14].They have higher angular displacements with higher velocities to make the transition from one point to another. Blinks are eye activities of short duration (100-300 ms) that occur randomly during a viewing task. During blinks, the eye pupil size reduces to zero. There are several metrics related to each of these activities like the pupil size, saccade length, saccadic velocity, mean fixation duration, blink rate, etc. that can be used for the estimation of induced cognitive workload [7, 8].

Researchers have shown that the pupillary response is a reliable psychophysiological measure of cognitive workload. When faced with challenging tasks, we experience pupil dilation. Beatty [8] proposed that these task evoked pupillary responses can be used in estimating cognitive workload. Index of Cognitive Activity (ICA) [9] and pupil diameter are commonly used to assess workload induced while performing visual tasks [10, 11]. However, the variation in pupil diameter is highly dependent on the variation in the light intensity of the stimuli as well [12] and cannot be reliably used to estimate workload in the situations where the ambient light intensity changes frequently like in the case of surveillance, driving, etc.

Saccades have been reliably used to estimate the changes in the workload as they are found to be less affected by the light intensity variations [13-15]. Here, we use the peak saccadic velocity to demonstrate the raise in cognitive workload when there is degradation in the visual stimuli.

II. Experiment Design

A. Apparatus

The recording system includes an image stimulus monitors shown in Fig. 1. This is a high resolution 24” screen and used for displaying still target and non-target images. The controller PC is used for executing the experimental paradigm and sending the events marker pulses to the eye tracker PC to synchronize the event pulses with eye tracker signals. The eye tracker subsystem consists of the head support, infra-red based video camera and eye tracker PC (EyeLink 1000, SR Research, Canada). The chin rest and head strap are used to minimize head movements. The infra-red camera allows data collection at the rate of 1000 Hz. The eye tracker subsystem is primarily used for the non-invasive recording of gaze direction, eye positions and pupil size while a subject is viewing images on the image stimulus screen. Subject will view the stimuli on the monitor at a distance of 57 cm corresponding to 40 x 30 degrees of visual angle. All visual stimuli are precisely synchronized to the eye tracking system. In addition, we also record the EEG signals from the subject's scalp while performing the task. However, eye tracker data will be discussed here. The EEG data will be used for further studies in the future.

B. *Participants*

The experimental protocol was approved by Institutional Review Board (IRB) at the National University of Singapore. The experiment was conducted on 16 healthy volunteers between 18-31 years as subjects (subjects were students at the National University of Singapore). All the subjects have perfect or corrected-to-normal vision. All the subjects were tested for color blindness and ocular dominance. None of the subjects were color blind and they could be either left eye or right eye dominant. The data from one subject is excluded because the subject's performance is very poor (from the percentage score).

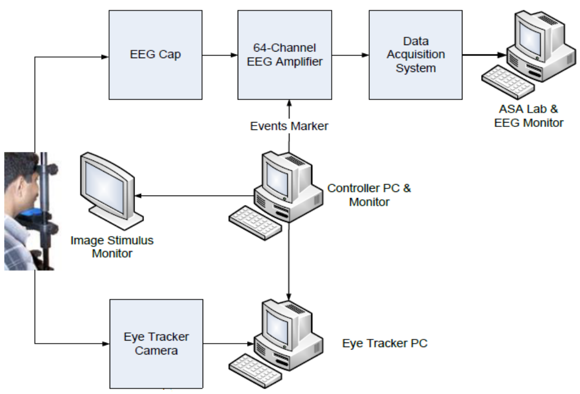

Figure 1: Experimental Eye Tracker Recording Setup

C. *Experiment Task*

The experiment was designed such that each participating subject went through four levels of visual task where he/she identified and distinguished target image sequences from non-target image sequences. The experiment was conducted in a quiet room with controlled level of luminance. At each cognitive workload level, the subject was shown image sequences as shown in Fig. 2, with all the images displaying at the center of the screen. Each image sequence consisted of a fixation cross (500 ms), Digit 1 (300 ms), Digit 2 (300 ms) and an image (300 ms). Digit 1 and Digit 2 are randomly chosen from 1 to 9. The image was also randomly drawn from a pool of images that contained several random human faces and random objects collected for this purpose. All the images shown were of the same resolution and were also displayed at the center of the screen. This set up is highly essential to nullify any effect on the eye tracker data due to the variations in the size of the image and the position of appearance of the image. Each sequence was followed by a blank screen for a maximum of 3 seconds which indicated the waiting time for user input. During this time, the user was expected to hit P on the keyboard if the image sequence was a non-target sequence and Q if it was a target sequence. Even though the maximum response time allowed was 3 seconds, the users were clearly instructed to respond as quickly and correctly as possible. Once the user input was given, the next image sequence is initiated. A total of 210 such sequences were shown for each level. The four cognitive workload levels are:

Level 1 – The subject was instructed to identify the sequence containing human face as target sequence. This level is used as a baseline for workload level classification.

Level 2 – The subject was instructed to identify the sequence containing human face preceded by either both even or both odd digits as the target sequence. This level was introduced to verify that the marker used to estimate workload is successful in representing the increased change in the workload introduced due to the working memory component.

Level 3 – The instruction for target sequence was the same as that in the level 2. But in this level, the displayed images are noisy with salt and pepper noise of magnitude 0.3 added to the image using MATLAB.

Level 4 – The target sequence is the same as in level 2 but the images are noisier than that in level 3 where salt and pepper noise of magnitude 0.5 added to the image using MATLAB.

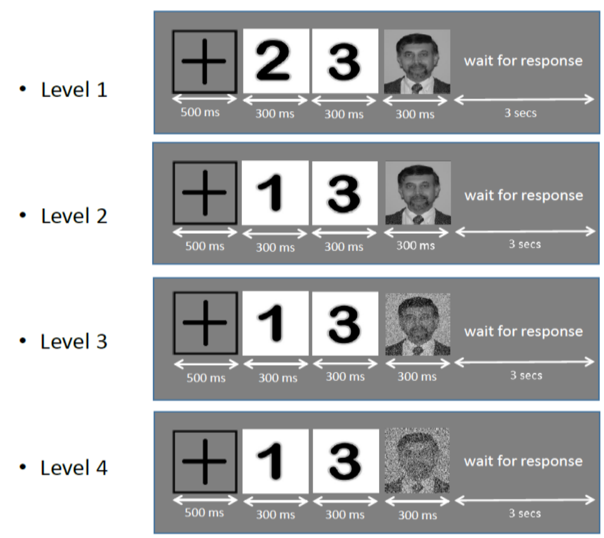

Figure 2: Sample target sequences for each level

D. *Procedure*

When the participants arrived, they were briefed about the experiment setup and procedure. They were then tested for color blindness and ocular dominance. After obtaining duly signed consent form, they underwent preparation for recording EEG signals using standard protocols. Then they were made to sit on a chair with comfortable back rest. The height of the chair was adjusted according to the chin rest of the eye tracker. A training session was first conducted where the participant went through all the four levels (with only 12 trials each) one after the other for the subject to understand

and get acquainted with the task. Then the original experiment was conducted, where the levels (with 210 trials each) were presented to the participant in a random order. This was done to make sure that the order effect on the fatigue was nullified. Eye calibration [11] was performed at the start of each level and the subjects were instructed not to move their heads from that point till the end of the level. The eye data were recorded for the dominant eye with a sampling frequency of 1000 Hz and stored for each level in a separate file. Sufficient breaks were given between each level for the participant to relax during which they were given NASA TLX form to get subjective feedback from them about the level of workload during the task that was just over.

III. Results

In this section, we present two types of results obtained from the analysis of variations in the cognitive workload during each level. First, we present the results of NASA TLX scale which is filled by each subject after the completion of each workload level. Then, we present the analysis of percentage change in the mean pupil diameter, a pupillometric measure to demonstrate the changes in cognitive workload during each level.

A. NASA TLX

As described earlier, each subject was asked at the end of each workload level experiment to fill in the NASA TLX questionnaire. The NASA TLX test includes 6 sources or demands of possible workload. They are mental demand, physical demand, temporal demand, performance, effort, and frustration. Each of these possible workload sources is rated by the subject under test at the end of each experiment on a scale 0 to 20. This is in addition to asking the subject to give a weight for each of the six dimensions ranging from zero allocated to the least relevant possible workload source and weight 5 to the most relevant workload source. The total score in each workload level is computed multiplying the weight by each source rating score and then summing across all the six sources. The tally score of all sources is then divided by 3 to produce the final workload score between 0 and 100. Fig. 3 shows the results of the ANOVA test on all subject data. ANOVA test results clearly show that the four workload levels used in this experiment are indeed different with p-value=9.9×10^{-5}. Even though NASA TLX can distinguish different workload levels accurately, it is to be noted that this is purely subjective in nature. Moreover this method cannot be used for the online estimation of workload, unlike psychophysiological measures. Therefore this index is used only to serve as a comparison for the psychophysiological methods used to estimate workload.

C. Saccadic velocity.

The eye tracking data obtained from Eyelink 1000 after the completion of the task are in .edf format. These data were converted to .asc format using Virtual EDF2ASC converter [14]. The converted data file consists of the pupil size at each sampling instant. This data file also consists of logs for different trials within the level and also the start and end markers for events like fixations, blinks and saccades within each trial. This file is processed using MATLAB® software to extract the necessary event or trial data.

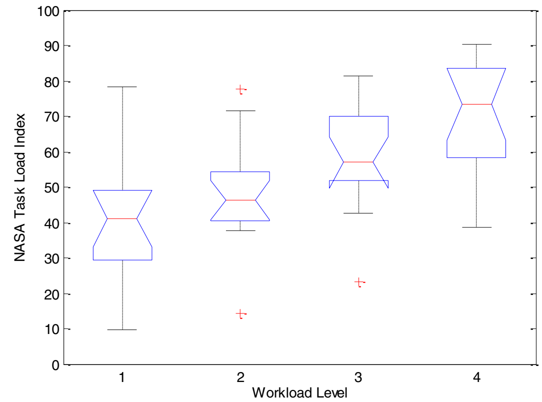

Figure3: NASA TLX Test Results

Using MATLAB, saccades during the period from the onset of the digits till the instant of user response (which is the sum of display time of digit 1, digit 2, image and the reaction time for that trial) are extracted from the event log file. The beginning of each saccade is indicated by the line starting with 'SSACC' and followed by the time stamp which indicates the starting point of saccade. The end of each saccade is indicated by the line starting with 'ESACC'. This line consists of the information related to saccade amplitude, duration and peak velocity during that particular saccade.

It is to be noted that the blinks are embedded inside a saccadic. So the saccades containing blinks are discarded as they actually correspond to blink events. Also, the saccades with amplitude greater 10 degrees are discarded as they correspond to the instant when the subject is moving his/her eyes out of the area of interest. These exclusions correspond to less than 2% of the total data. The average of normalized peak saccadic velocity for each trial of each level for all the subjects is shown in Fig. 4 to explain the variations in the peak saccadic velocity in each workload level.

The peak saccadic velocity for each trial of each level is obtained and averaged over all trials of that level. This has the units of degrees/msec. The mean of average peak velocity of all the levels is calculated. This is referred to as overall mean peak velocity. To minimize the subjective variations between subjects the average peak velocity of each level is normalized with respect to the overall mean peak velocity of that subject.

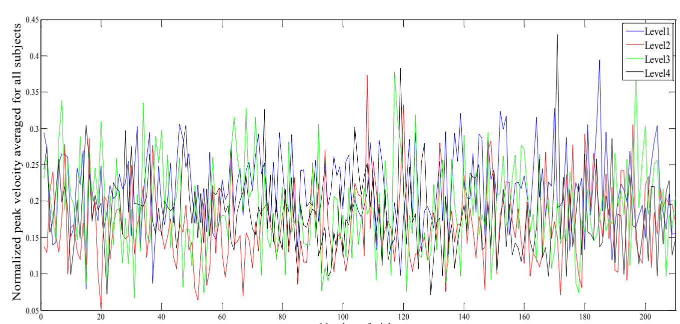

Figure 4: Peak Saccadic Velocity of all 4 levels averaged over all subjects

The equations below explain the steps in calculating normalized average peak velocity of each level for each subject

$$\text{Overall mean peak velocity}, M = \frac{1}{4}\sum_{i=1}^{4} APV_i, \quad (1)$$

where APV_i isaverage peak velocity of workload level i, for i=1,2,3,4.

$$\text{Normalized average peak velocity of level } i, NAPV_i = \frac{APV_i - M}{M}, \quad (2)$$

ANOVA analysis is performed on this normalized average peak velocity. The results shown in Fig. 5 indicate that the saccadic peak velocity increases for each level ($p<0.02$) indicating a positive correlation with the increasing cognitive workload.

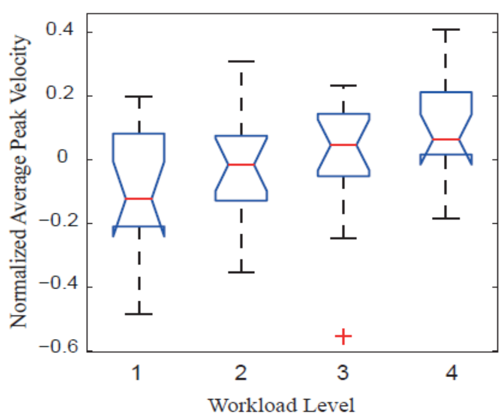

Figure **5**: ANOVA of normalized average peak saccadic velocity

From the above two analyses, we conclude that the degradation in the visual stimulus results in an increase in the cognitive workload of the subject. The saccadic velocity is found to increase with the increasing workload. This can be explained by the reason that as the cognitive workload increases in a viewing task; the subject tries to acquire more information in the same time by making faster saccadic movements.

IV. CONCLUSION

In this paper, we have demonstrated using peak saccadic velocity that the degradation of visual stimuli induces cognitive workload. The subjective results from NASA TLX demonstrate that the workload increases from Level 1 to Level 4. The normalized average peak saccadic velocity is found to correlate positively with the increase in workload. Hence, the level of vagueness or degradation is found to modulate cognitive workload of a person performing visual tasks.

This work can further lead to the development of useful techniques to monitor workload or the cognitive performance of a person who is performing visual tasks like driving [3] or military surveillance. With the development of advanced eye tracking apparatus which does not require the restriction of head movements and which is insensitive to ambient light, it is much easier to record and simultaneously monitor the cognitive performance of an individual in more naturalistic environments. In our future work, we intend to make use of these results indicating the change in cognitive workload due to vague stimuli to develop an application to enhance the cognitive performance of a subject performing tasks which require high degrees of visual attention. To better understand and evaluate workload, integration of both eye tracking and EEG is also necessary.

ACKNOWLEDGMENT

We would like to thank Prof. Yen Shih-Cheng and Esther Wu Xiu Wen of SINAPSE for providing their support in the use of EyeLink 1000 eye tracker.

REFERENCES

[1] Wilson G. F.“An Analysis of Mental Workload in Pilots During Flight UsingMultiple Psychophysiological Measures”, The Int. J. Aviation Psychol., 12:1, 3-18, 2002.

[2] Zarjam P., Epps J., Lovell N. H. and Chen F., “Characterization of memory load ing an arithmetic task using non-linear analysis of EEG signals”,*Engineering in Medicine and Biology Society (EMBC), Annual International Conference of the IEEE*: IEEE) pp 3519-22, *2012*.

[3] Blackwell P. J. and Belt J. A.,“Effect of differential levels of ambient noise on vigilance performance”, Perceptual Motor Skills 32 734. 1971.

[4] Davies D., Lang L. and Shackleton V.,“The effects of music and task difficulty on performance at a visual vigilance task”, British J. Psychol. 64 383-9, 1973.

[5] Warm J. S., Sustained Attention in Human Performance: Wiley New York, 1984.

[6] Hart S.G., and StavelandL.E.,“Development of NASATLX (Task Load Index): Results of empirical and theoretical research”,In“Human Mental Workload”, by Meshkati N. HancockP. A., 239–250. Amsterdam: North Holland Press, 1988.

[7] Ellis, K.andEdward K., "Eye tracking metrics for workload estimation in flight deck operations", Master's Thesis, University of Iowa.http://ir.uiowa.edu/etd/288, 2009.

[8] Di Stasi, L. L., Antolí, A., &Cañas, J. J., “Evaluating mental workload while interacting with computer generated artificial environments.” Entertainment Computing.Volume 4, Issue 1, February 2013, Pages 63–69.

[9] Beatty, J. “Task Evoked Pupillary Responses, Processing Load and Structure of Processing Resources”. Psychological Bulletin, 91(2): 276-292, 1982.

[10] Marshall, S.P. “The Index of Cognitive Activity: measuring cognitive workload”. Proc. IEEE Conf. on Human Factors Power Plants. 7-9, 2002.

[11] Palinko O., Kun A. L., ShyrokovA. andHeeman P., “Estimating Cognitive Load Using Remote Eye Trackingin a Driving Simulator ”. Proc. 2010 Symposium on Eye-Tracking Research & Applications, 2010.

[12] Wierda S. M., van Rijn H., Taatgen N. A., Martens S., “Pupil dilation deconvolution reveals the dynamics of attention at high temporal resolution”, ProcNatlAcadSci U S A. May 29;109(22):8456-60, 1982.

[13] Palinko O., Kun A. L., “Exploring the Effects of Visual Cognitive Load and Illumination on Pupil Diameter in Driving Simulators”. Proc. 2012 Symposium on Eye Tracking Research & Applications, 2012.

[14] Tokuda, S.; Obinata, G.; Palmer, E.; Chaparro, A., "Estimation of mental workload using saccadic eye movements in a free-viewing task," Engineering in Medicine and Biology Society,EMBC, 2011 Annual International Conference of the IEEE, pp.4523,4529, 2012.

[15] Di Stasi, L. L., Catena, A., Cañas, J. J., Macknik, S. L., & Martinez-Conde, S., "Saccadic velocity as an arousal index in naturalistic tasks." Neuroscience &Biobehavioral Reviews 37, no. 5 (2013): 968-975.

[16] EyeLink® User Manual. Copyright ©2005-2008, SR Research Ltd.