International Journal of Advances in Image Processing Techniques– IJIPT
Volume 2 : Issue 2 [ISSN : 2372-3998]
Publication Date : 30 October, 2015

Experiments in Modelling Attention Fatigue

TOH CHIA MING, JAMES MOUNTSTEPHENS

***Abstract*— Keywords-component; formatting; style; styling; insert (key words) Knowledge of mental fatigue has been a mystery to the field of psychology and neuroscience as we still don't know the exact mechanism of mental fatigue. Mental fatigue can be caused by prolonged use of focus for any sustained attention task. When fatigued, human performance of task is affected and may cause discomfort and some tasks may have safety risk due to decreased performance. An underlying mechanic of attention has been identified and categorized into bottom-up mode and top-down mode where a fight between these 2 modes may cause Directed Attention Fatigue (DAF). DAF would appear due to the inability to inhibit cues of bottom-up mode in favor of top-down ones therefore leading to a drop in performance. An eye-tracking based research would be to verify this. This paper attempts to study this by using existing visual attention computational models together with human eye gaze data. By having human participants to perform a customized sustained attention task, their performance and eye gaze details can be recorded. The obtained data can be modeled and integrated into existing visual attention model to reproduce the results of human data. In order to achieve that, the model had to have the capability to reproduce human perception, recognition and also decision making. The model chosen to as the base of this project would be the Itti and Koch Model (IKM) and heavily modified to suit the purpose of this project. The human data yielded insights into the gaze characteristics of DAF and was used to test the predictions of the overall model, with encouraging results for the proposed DAF.**

Keywords—*Directed Attention Fatigue, Mental Fatigue, Visual Attention Computational Model, Eye Tracker*

I. Introduction

In our daily lives, we need to go through various tasks that require some degree of concentration. People could classify these tasks as trivial but can be also mortally dangerous if one is not concentrating while performing tasks such as driving. Some tasks require sustained concentration overtime and it is common knowledge that performance on task usually degrades over time and various factors such as motivation greatly affect the rate degradation. However, even with infinite motivation, the duration of sustained concentration is still limited to the human body and mind which will have produced negative outcomes such as tiredness and decreased performance on task which may prove fatal.

A state known as Directed Attention Fatigue (DAF) would appear after some time of continuous inhibition of bottom up cues and focusing on top down cues where it will cause the inability to inhibit bottom up cues anymore. The inability to inhibit irrelevant stimuli or focus on top down cues would have a negative effect on performance over time and DAF is still a mystery as not much study has been done its underlying mechanics and also its relationship with eye gazes. This is where computer models come in to help us to understand DAF in a much better way in order to adapt to DAF or even produce countermeasures for it. A variety of computational models of visual attention has being developed however no models available have the capability to fatigue.

The goal of this project is to develop a computer model that has the characteristic of DAF given a specific sustained attention task. This can be done by extending existing Itti and Koch model (IKM) as this model itself is famous for bottom-up mode of attention [5]. A top down feature will be integrated to IKM in order to create a functional mechanism for DAF. However, for this project to be human like and can respond to sustained attention task, modeling on sustained attention task from human subjects are required and the extended IKM model would require human like perception, object recognition and also decision making. Human data on DAF within a specially designed sustained attention task was collected using an eye tracker with custom software. This human data yielded insights into the gaze characteristics of DAF and was used to test the predictions of the overall model, with encouraging results for the proposed DAF mechanism.

II. Literature Review

A. *Visual Perception and Attention*

Attention and visual perception are closely related as it is impossible to attend to things that we can't see due to the structure of the eyes [8]. The fovea vision gives an important note to attention as our eyes' perception is generally blurry except at the point of gaze. Gaze control, or orientation, is also a function of both bottom-up and top-down influences. Attention is said to have a voluntary and involuntary aspect - a distinction going at least as far back as William James (1892) and one also recognised by modern cognitive science and computational modelling[5]. Salience is a concept used to describe those properties of visual stimuli that attract our attention in bottom-up fashion. Salience is conceptualised as local differences in visual properties such as intensity, orientation, and colour, and is detected by early visual areas. Saliency based models has been highly influential on computational modelling of attention, particularly on the model developed by Itti and Koch, and extended in this present work.

B. *Directed Attention Fatigue*

It has long been known that objective task performance deteriorates over time and is accompanied by negative subjective effects. This performance deterioration is a failure of basic ability and therefore "is distinguished from the effects of sleepiness, motivation, learning, and physical fatigue [1]. Boksem defined mental fatigue as "the effects that people that people may experience after or during prolonged periods of cognitive activity" [2]. Boksem did a test that has spatial elements on human participants but however did not collect any eye data while Berto performed restorative test using Sustained Attention to Response Test (SART) and the results correlated with the effect of DAF. One thing is for sure that DAF must be induced in challenging mental test in either hard test or a very long one.

C. *Computational Modeling of Attention*

It is said that modelling can use to prediction[8]. At a superficial level, a predictive model may be expressed as a mathematical equation directly relating external variables; data are collected and patterns are found that allow prediction. Therefore, a model with fatigue capability based on human data can set the base line in understanding DAF but yet no model has implemented fatigue into account because various reasons.

IKM is one of the models developed for this propose and is using the concept of the biologically inspired saliency map. Saliency map is created by calculating the difference between a center point with its surrounding in terms of basic visual features such as color, orientation and intensity. This allows IKM to recreate human gaze patterns in a free viewing or bottom up mode as we know it. Extended work was also done to include task based capability to the original model [6]. Overall, this made the IKM suitable as the baseline in this project as it is also freely available.

III. Methodology

On the general scale, the human data was first collected from 10 participants when doing a sustained attention task. Data collected were task performance, reaction time, and distance from target (positive stimuli). The data collected was analyzed and modeled into equations to be integrated into IKM. The newly integrated model would also be simulated with the same sustained attention task to provide equal similar output in order to be compared with the human data. The comparison would allow fair evaluation of the model's performance with respect to the human data. Below is the overall flow of the project:

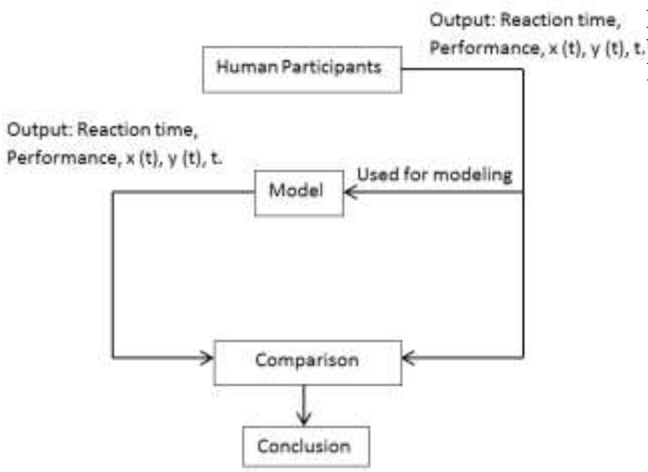

Figure 1. Flow of the Methodology

A. *Participants*

10 healthy participants (5 males), between 21 to 26 years of age, were recruited from the university population. They had normal vision or corrected to normal vision. None of the subjects used prescription medication of sorts. Participants were paid with base amount of RM10 and extra 10 cents for every correct answer. There was also a decrement of 10 cents per error. The maximum amount each participant can earn is RM 50 and decrement won't reduce below RM 10.

B. *Eye Tracking*

To obtain eye gaze data in real time, Mirametrix S2 was used to fulfill this purpose. The S2 is eye tracker that was placed under the monitor with a portable tripod and it utilized the reflection of eye glint with infrared reflection to detect the eye gaze. The S2 comes with an API that Java compatible and also with readymade calibration software. Basic raw data of the S2 is the x, y coordinates and timing of the eye gazes with respect to the screen. The S2 has accuracy of 0.5 to 1% range with data rate of 60Hz which is suited for this project.

C. *Software Used*

To administer the SAT test, Java was used to collect the human data in terms of performance and eye tracking because of the convenience in instrument interfacing. While Java was used to administer the test, the material of the test was created using MATLAB because of the capability to perform operations on images with more ease. The customized model too was programmed in MATLAB environment alongside with any data processing work.

D. *Sustained Attention Test*

1) Boksem's Test

Boksem's test was used in conjunction with event related potential (ERP) in order to learn about brain activity and mental fatigue[2]. The test originally administer with duration of 3 hours without rest. However, with this project, the test was shorten to 1 hour only with constrains such as physical discomfort because of the eye tracker. The goal of the test is memorized the correct cues and respond to Relevant Targets only. The flow of the test is as below:

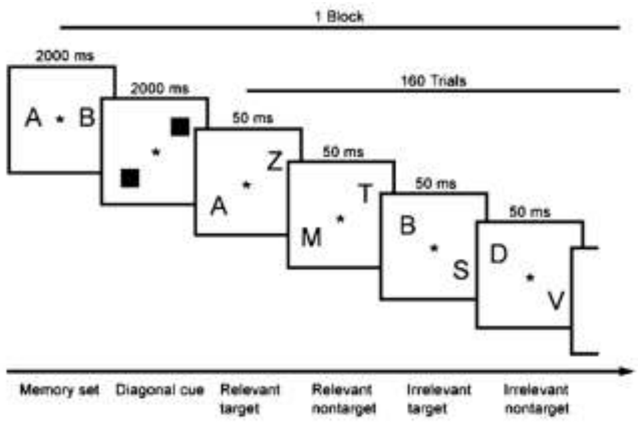

Figure 2. Flow of Boksem's Test [3]

Success on answering the correct target yields a true positive, β while wrong responds will earn the participants a false positive, α. The performance of the test is decided by this equation:

$$\text{Performance \%} = \beta / (\beta + \alpha) \quad (1)$$

2) Spatial SART

Spatial SART is a modified of the original SART test with the addition of spatial element. The SART test as stated in the literature review has been effective in producing results whereby the participants' were performance in the test were reduced over a short period of time (usually 4 to 5 minutes). However, to fit our purpose of research, SART has to be modified with spatial aspect. With randomly generating the position of numbers on the screen instead of just center point of fixation, we will be able to use the eye tracker to study the effect of fatigue related to the human gaze and participants' performance in the test.

This SART test is based on SART version 10. The number '3' was the target while all other digits are non-target. Digits were presented on the computer screen every 1250 ms and remained on the screen for 250ms. The digits size is 35 by 35 pixels with native screen resolution of 1080 by 1920. Participants had to press the spacebar on the keyboard any time they saw a non-target digit and to avoid pressing the spacebar when the target appeared. The performance of the test was also evaluated using the same equation as the Boksem's Test.

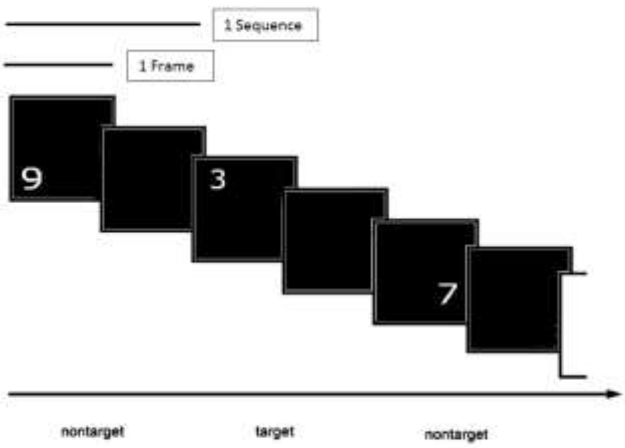

Figure 3. Flow of Spatial SART

E. *Environmental Set Up*

Participants were individually tested in the laboratory in the morning. Participants were informed few days earlier of the arrangement and were asked to get a good night rest before doing the test. A trial test of 5 minutes were administered to the participant so they will get used to the test and fully understand the rules of the test in practice. From there, the participant was tested for the full duration of the test.

To focus attention on the computer screen, the lights were dimly lit and there were no adjacent objects other than the eye tracker. The dim lights were also used to boost the sensitivity of the eye tracker by reducing luminance interference. The experimenter has a separate computer screen which has the information on the eye tracker and will give instructions to the participant if the eye tracker failed to detect the participant's eyes due to movement of head. After the test, the participants were asked for feedback in terms of how fatigue they were after the test. Results of Human Data

The results obtained from all the participants were averaged out and the data were also split into 10 time intervals where all the data in 1 time interval were averaged out for every participant respectively. This was done in order to see the big picture and obtain an overall trend of the results as shown below with smooth curve fitting.

F. *Results for Boksem's Test*

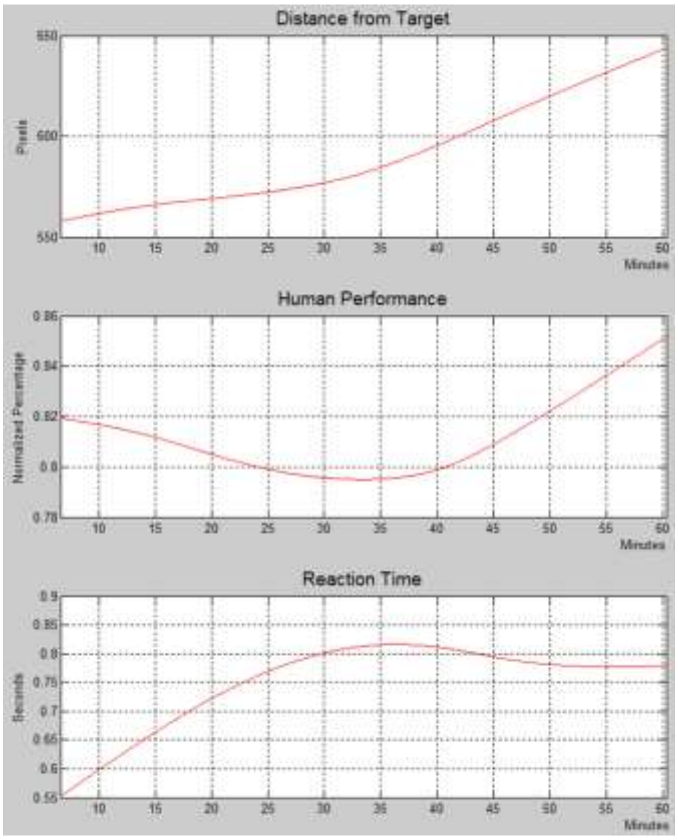

Figure 4. Results from Boksem's Test

In overall point of view, this test shows promising results in reaction time and distance from target however with failure of the terms of accuracy. Reactions time gradual increase overtime which meaning the participants were getting slower over time because of DAF. The accuracy of participants changed little over time and this was related to the distance over time which also related to the strategy used by the participants. Participants' explained that for this test that, it is possible to maximize accuracy without sacrificing too much mental resource. Due to the nature of the test, a strategy was utilized by most of the participants by looking only at the one of the cued point as there were only 2 cued points in this test. By doing so, they can focus less while still having good performance with the true positives.

As a conclusion, the result from Boksem's test was not good enough due to the minimal impact on performance with the exploit of certain loopholes. As the test was originally conducted for 3 hours, it is possible that a longer duration may remedy this.

G. Results for Spatial SART

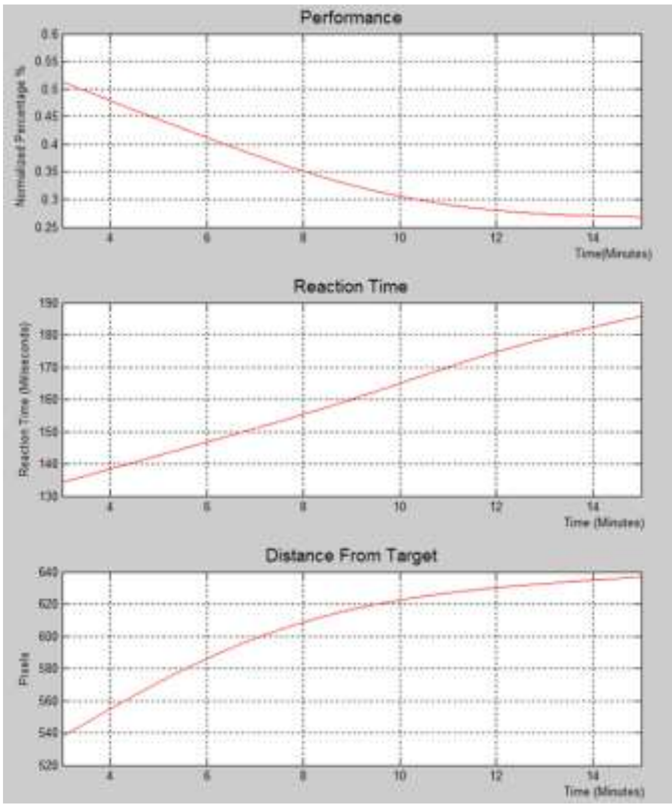

Figure 5. Results from Spatial SART

From the graphs, it can be seen there were drastic changes over time in all 3 variables. Reaction time increases which fit the findings of other authors [4][5]. Performance graph showed a drastic drop in performance which shows a reduction of around 30% over the course of the test and increase in overall distance to target. This shows that the participants managed to be under the influence of DAF after a certain point during the test. To analysis deeper for modelling purposes, a more detail analysis was done on the distance to target but breaking down it down to specific distance as average value doesn't provide the critical information needed. The breaking down was done as the following illustration to obtain a probability model that can be integrated into IKM:

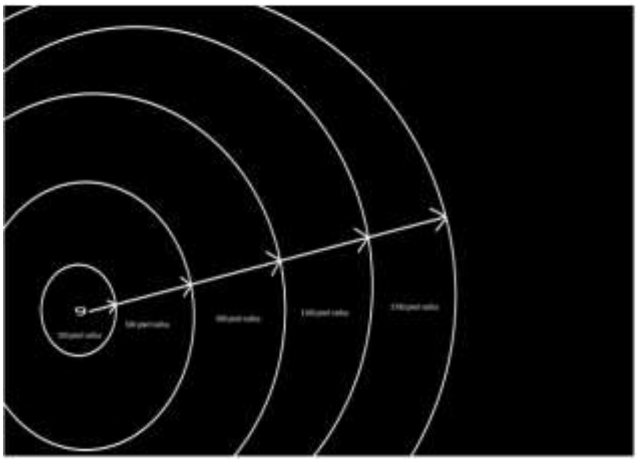

Figure 6. Illustration of the Breaking Down of Proability Distribution Model

IV. Modeling and Model Results

A. Model Flow

The flow of the model can be summarized as below:

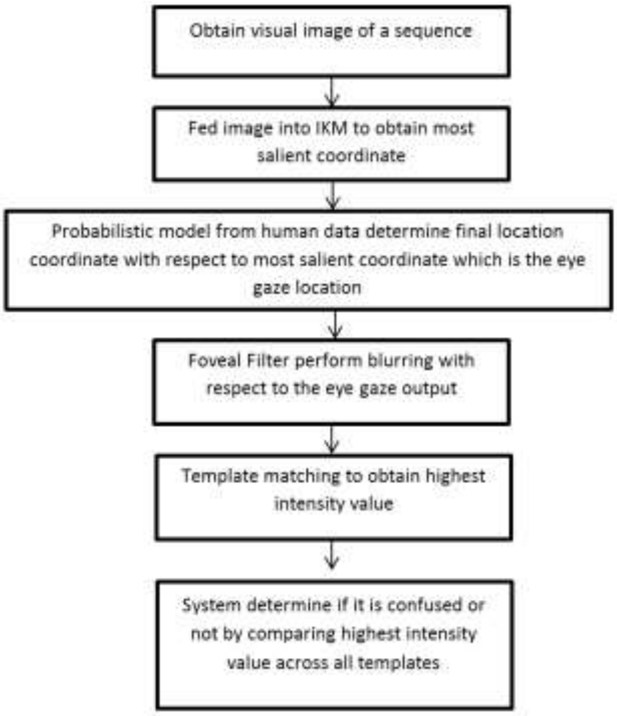

Figure 7. Flow of the Model

B. Results

The results of the model will be compared to human data in order to obtain a measure on the accuracy of the model. Variable that would be compared and analyzed are the accuracy on the correct responses and the accuracy on the eye gaze position. Method of analysis on individual variable will be same as the analysis done on human data to uphold consistencies. The experiment was done on workstation with Intel(R) Xeon(R) CPU E5-1650 @ 3.2 GHz and 16 GB Ram. One experiment approximately takes 6 hours to complete which the raw data has 13 minutes in terms of duration.

As recalled previously, 2 variable which was the reaction time (RT) and performance were obtained from human data. The reaction time was not included because RT is dependent not only human recognition and decision making, but also dependent on the motor skills which the model cannot replicate. Therefore, only the performance between the model and the human data was compared. On the hand, the eye tracker results will be compared with the model's eye gaze position result in terms of average minimum distance from target and the probabilistic model. A total of 10 trials of the model were done to mirror the 10 human participants for spatial SART.

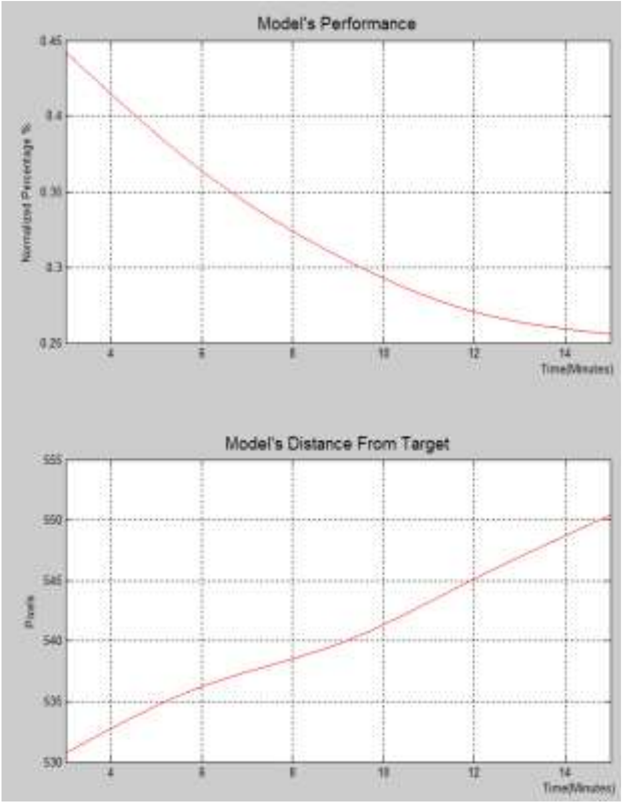

Figure 8. Results of the model

Overall, the result from the model matches very well the human data in terms of trend. However, it must be noted that the model performance is weaker compared to the human data in general while the distance from target isn't perfect either. Cross correlation was done between the human data's performance data and model performance data and 89.2% similarity was obtained.

V. Conclusion

Attention fatigue has always being a mystery in the world of neuroscience where knowledge of this field is scarce and there were still a lot of unknowns yet to be discovered. This project provided a certain insight on how attention fatigue works and how human performance on a sustained attention task varied with time. Literature review from the fields of neuroscience and psychology provided the basis for project where they described the nature of attention fatigue which was consistent with the results obtained from this project. The attempt to create a comprehensive and realistic model requires inclusion of human elements such as visual perception, learning, strategy and decision making.

Human elements has to come from human data, therefore initiating human data collection by using a modified well known sustained attention task known as SART. By adding spatial element to SART, human eye gaze and its behavior can be observed over time. Initial observation and human analysis provided a positive correlation between human eye gaze location and human performance result. In other words, the human performance degraded overtime pointing to attention fatigue while the human eye gaze behavior also changes overtime suggested that all these 3 variables can be linked together. What discovered was that the human mind was trying to use strategies in order minimized attention fatigue while trying to maintain the overall performance to a certain degree. This can be clearly seen from the eye gaze behavior changes where the eye gaze distance from the intended target increases with time. This allowed the human participant to reduce their mental resource usage while still maintain a reasonable performance.

Using the knowledge obtained from the human data, designing and modeling of the model was done. The basis of the model was based on the existing visual attention model IKM in MATLAB which already is a model that drew inspiration from biological process of the human visual system. IKM was customized to respond to spatial SART with addition of task relevance map. Other than that, the model was integrated with parts that are analogous to the human visual system such as recognition, learning and decision making with the modeled human data providing a coarse probabilistic approach on how eye gaze position changes over time.

The model was experimented for 10 times continuously and the average results were obtained. The model Correct Response Performance differed from the human data only by a small deviation. Overall, the model achieved the objectives in capturing the essence of human performance in a sustained task environment which has the capability to fatigue and varying performance over time.

Reference

[1] Leonard J. Trejo; Rebekah Kochavi; Karla Kubitz; Leslie D. Montgomery; Roman Rosipal; Bryan Matthews, "Measures and models for predicting cognitive fatigue" in Proc. SPIE 5797, Biomonitoring for Physiological and Cognitive Performance during Military Operations, (23 May 2005).

[2] Maarten A.S. Boksem, Theo F. Meijman, Monicque M. Lorist, "Effects of mental fatigue on attention: An ERP study" in Cognitive Brain Research 25 (2005) 107 – 116.

[3] R. Berto, "Exposure to restorative environments helps restore attentional capacity," in Journal of Environmental Psychology

[4] L. Itti, C. Koch, E. Niebur, A Model of Saliency-Based Visual Attention for Rapid Scene Analysis, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 20, No. 11, pp. 1254-1259, Nov 1998.

[5] L. Itti, N. Dhavale, F. Pighin, Realistic Avatar Eye and Head Animation Using a Neurobiological Model of Visual Attention, In: Proc. SPIE 48th Annual International Symposium on Optical Science and Technology, (B. Bosacchi, D. B. Fogel, J. C. Bezdek Ed.), Vol. 5200, pp. 64-78, Bellingham, WA:SPIE Press, Aug 2003.

[6] V. Navalpakkam, L. Itti, Modeling the influence of task on attention, Vision Research, Vol. 45, No. 2, pp. 205-231, Jan 2005

[7] Itti, L., Rees, G., Tsotsos, J.K. (Eds) (2005) Neurobiology of Attention. Academic Press.

[8] Gershenfeld, N. (1998). The nature of mathematical modelling. Cambridge University Press.

About Author (s):

Toh Chia Ming is a postgraduate student at Universiti Malaysia Sabah.

James Mountstephens is a Senior Lecturer at Universiti Malaysia Sabah.