PROJECT COMPLETION REPORT

of

UGC (MRP) funded project

Submitted by

Dr. Rakesh Kumar Sinha

Discipline

BIOMEDICAL INSTRUMENTATION

Title of the Project

VOLUNTARY EVENT RELATED BRAIN SIGNAL CLASSIFICATION

BIRLA INSTITUTE OF TECHNOLOGY
MESRA, RANCHI- 835215
(August-2012)

ज्ञान-विज्ञान विमुक्तये

Annexure -III

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

Annual/Final Report of the work done on the Major/Minor Research Project.
(Report to be submitted within 6 weeks after completion of each year).

1. Project report No. 1st/2nd/3rd/Final **Final**
2. UGC Reference No. **F.No. 36-60/2008 (SR)**
3. Period of report: from **May, 2009** to **June, 2012**
4. Title of research project **Voluntary Event Related Brain Signal Classification**
5. (a) Name of the Principal Investigator **Dr. Rakesh Kumar Sinha**

   (b) Deptt. and University/College where work has progressed

   Dept of Biomedical Instrumentation
   Birla Institute of Technology
   Mesra, Ranchi-835215
6. Effective date of starting of the project **May, 2009**
7. Grant approved and expenditure incurred during the period of the report:

   a. Total amount approved **Rs.11,47,800.00 (Received Rs. 9,53,800.00)**

   b. Total expenditure **Rs. 9,26,547.00**

8. **Report of the work done: (Please attach a separate sheet)**

(i) **Brief objective of the project**

- Manual identification of voluntary events in brain signals.
- Power spectrum and wavelet analysis to identify the typical feature(s) for the particular event(s).
- Development of neuro-fuzzy artificial system for automated identification of events.
- With the aid of digital signal processing, soft computing as well as robotic tools, design of smart rehabilitation system for disabled person by means of processing and identification of brain signals for voluntary events.

(ii) **Work done so far and results achieved and publications, if any, resulting from the work (Give details of the papers and names of the journals in which it has been published or accepted for publication).**

The laboratory designed paradigms for recording the biosignals (EEG, EMG, ECG, EOG, EDA and PPG) for defined mental tasks has been used for the recording. The experiments were performed with variety of mental tasks such as, eye gaze, mental arithmetic and motor imagination. The recorded biosignals were processed and defined features for specific mental task were identified and classified with the help of acknowledge 4.0 software (Biopac Inc, USA) and MatLab programs on fuzzy C means clustering and Kohonen neural network. The obtained results showed that in response to mental effort, ECG and PPG alter and a rise in EDA has been observed with the onset of event. Further, the response of changes in ECG and PPG is similar and the EOG is recorded for observing the eye ball consistency. The results achieved in the classification of mental efforts were encouraging (98% accuracy) and we believe that these can be used to provide an alternate communication pathway with the machine.

- One M.Sc. dissertation entitled “EEG feature extraction for event related two-class motor imagery” has been completed under the project.
- Three Ph.D. students are enrolled under the Principal Investigator.
- One research paper published and one revised version is under review.

- The principal Investigator has visited and trained in the advanced brain-computer interface lab. at University of Ulster, UK under the leverhulme trust visiting fellowship for a period of one year.

(iii)**Has the progress been according to original plan of work and towards achieving the objective. if not, state reasons**

Yes, the progress is as per the plan of work.

(iv)**Please indicate the difficulties, if any, experienced in implementing the project**

Few difficulties have been faced as mentioned below.

- The second installment has not yet been received from the UGC. Therefore, the contingency and travelling expenses are not available to explore different research laboratories working in the same area.
- Three project fellows were appointed and they left the team before the completion of project. The fellowship amount was not enough to hold them in the project.
- More components are required to localize the brain events to get specific features from the scalp.

(v) **If project has not been completed, please indicate the approximate time by which it is likely to be completed. A summary of the work done for the period (Annual basis) may please be sent to the Commission on a separate sheet**

N.A.

(vi)**If the project has been completed, please enclose a summary of the findings of the study. Two bound copies of the final report of work done may also be sent to the Commission**

Summary of the findings as attached in Appendix 1.

(vii) **Any other information which would help in evaluation of work done on the project. At the completion of the project, the first report should indicate the output, such as (a) Manpower trained (b) Ph. D. awarded (c) Publication of results (d) other impact, if any**

- One M.Sc. dissertation entitled "EEG feature extraction for event related two-class motor imagery" has been completed under the project.
- Three Ph.D. students are enrolled under the principal investigator.
    - ✓ Mr. Nishant Singh: Electrooculogram and Brain Wave Assisted Brain-Computer Interface
    - ✓ Mr. Gauri Shanker Gupta: Multi-Class Brain Computer Interface
    - ✓ Mr. Anshuman Prakash: Design of Biosignal Controlled Prosthetic Device
- The principal Investigator has visited and trained in the advanced brain-computer interface lab. At University of Ulster, UK under the leverhulme trust visiting fellowship for a period of one year.
- One journal and one conference article have been published and for the other journal article revision has been submitted and is under review. One more conference article is under preparation. The list as follows:
    - ✓ *Aggarwal, Y., Singh, N., Sinha, R. K. (2012) Electrooculogram based Study to Assess the Effects of Prolonged Eye Fixation on Autonomic Responses and its Possible Implication in Man-Machine Interface, Health and Technology, 2: 89-94.*
    - ✓ *Aggarwal, Y., Ghosh, S., Sinha, R. K. (Revision submitted) Eye Gaze Modulated Heart Rate Variability Analysis to evaluate features for Man-Machine Interface, Medical Engineering & Physics.*
    - ✓ *Singh, N., Aggarwal, Y., Sinha, R. K. (2011) Eye fixation based pulse rate variability as switching signal for human-machine interface. ICBME-2011 held on 10-12 December, 2011, organized by Manipal Institute of Technology, Manipal.*
    - ✓ *One paper is under preparation to submit in the forthcoming conference (IHCI-2012) on 27-29 December, 2012, at IIT Kharagpur with the title "Classification of two-degree mental arithmetic task with the variation in heart rate variability".*

SIGNATURE OF THE PRINCIPAL INVESTIGATOR

REGISTRAR/PRINCIPAL

Registrar
Birla Institute of Technology
Mesra: Ranchi

ज्ञान-विज्ञान विमुक्तये

Annexure - IV

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

Utilization Certificate

Certified that the grant of **Rs. 9,53,800.00 (Rupees nine lakhs fifty three thousand and eight hundred only)** received from the University Grants Commission under the scheme of support for Major Research Project entitled **Voluntary Event Related Brain Signal Classification** vide UGC letter No. **F.No. 36-60/2008 (SR)** dated **27-03-2009 out of which Rs. 9,26,547.00** (Rupees **Nine lakhs twenty six thousand five hundred forty seven** only) has been utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission.

SIGNATURE OF THE PRINCIPAL INVESTIGATOR	REGISTRAR/PRINCIPAL	STAUTORY AUDITOR
	Registrar **Birla Institute of Technology** **Mesra; Ranchi**	A.K. Singhania & Co. RANCHI Chartered Accountants

ज्ञान-विज्ञान विमुक्तये

Annexure - V

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

STATEMENT OF EXPENDITURE IN RESPECT OF MAJOR/MINOR RESEARCH PROJECT

1. Name of Principal Investigator	**Dr. Rakesh Kumar Sinha**
2. Deptt. of University/College	**Department of Biomedical Instrumentation Birla Institute of Technology Mesra, Ranchi-835215**
3. UGC approval No. and Date	**F.No. 36-60/2008 (SR) and 27-03-2009**
4. Title of the Research Project	**Voluntary Event Related Brain Signal Classification**
5. Effective date of starting the project	**May, 2009**
6. (a) Period of Expenditure: From	**May, 2009** to **April, 2012**

h. Details of Expenditure

Sl. No.	**Item**	**Amount Approved Rs.**		**Expenditure Incurred Rs.**
		Sanctioned	**Received**	
1	Books & Journals	25,000.00	25,000.00	19,694.00
2	Equipment	7,00,000.00	7,00,000.00	6,98,607.00
3	Contingency	60,000.00	30,000.00	56,116.00
4	Field Work/Travel (Give details in the proforma at Annexure- VI).	40,000.00	20,000.00	27,715.00
5	Hiring Services	-----	-----	-----
6	Chemicals & Glassware	-----	-----	-----
7	Overhead	34,800.00	34,800.00	34,800.00
8	Any other items (Please specify)	-----	-----	-----

i. Staff

Date of appointment: **July, 2009 to October, 2011**

Sl. No.	**Expenditure Incurred**	**From to**	**Amount Approved Rs.**		**Expenditure Incurred Rs.**
			Sanctioned	**Received**	
1	Honorarium to PI (Retired Teachers) Rs.10,000/- p.m.	-----	-----	-----	-----
2	Project Associate Fellowship @ Rs. 8,000/- p.m.	-----	-----	-----	-----
3	Project Fellow consolidated salary @ Rs.6000/- p.m.	July, 2009 to October, 2011	2,88,000.00	1,44,000.00	89,615.00

1. It is certified that the appointment(s) have been made in accordance with the terms and conditions laid down by the Commission.

2. It as a result of check or audit objective, some irregularly is noticed, later date, action will be taken to refund, adjust or regularize the objected amounts.

3. Payment @ revised rates shall be made with arrears on the availability of additional funds.

4. It is certified that the grant of Rs. **9,53,800.00** (Rupees **nine lakhs fifty three thousand and eight hundred** only) received from the University Grants Commission under the scheme of support for Major Research Project entitled **Voluntary Event Related Brain Signal Classification** vide UGC letter No. F. **36-60/2008 (SR)** dated **27-03-2009 out of which Rs. 9,26,547.00** (Rupees **Nine lakhs twenty six thousand five hundred forty seven** only) has been utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission.

SIGNATURE OF PRINCIPAL INVESTIGATOR

REGISTRAR/PRINCIPAL

Registrar
Birla Institute of Technology
Mesra: Ranchi

ज्ञान-विज्ञान विमुक्तये

Annexure - VI

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

STATEMENT OF EXPENDITURE INCURRED ON FIELD WORK

Name of the Principal Investigator: Dr. Rakesh Kumar Sinha

Name of the Place visited	Duration of the Visit		Mode of Journey	Expenditure Incurred (Rs.)
	From	To		
Biopac Workshop on electrophysiology, New Delhi	06/12/2009	10/12/2009	Rail	5,063.00
BMBHRC, Kolkata	27/02/2011	01/03/2011	Rail	6,592.00
UGC, New Delhi	10/03/2011	12/03/2011	Rail	6,195.00
Conference, Manipal Institute of Technology, Manipal	07/12/2011	14/12/2011	Rail	9,865.00

Certified that the above expenditure is in accordance with the UGC norms for Major Research Projects

Rakesh

SIGNATURE OF PRINCIPAL INVESTIGATOR

REGISTRAR/PRINCIPAL

Registrar
Birla Institute of Technology
Mesra, Ranchi

ज्ञान-विज्ञान विमुक्तये

Annexure - IX

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

PROFORMA FOR SUBMISSION OF INFORMATION AT THE TIME OF SENDING THE FINAL REPORT OF THE WORK DONE ON THE PROJECT

1. **NAME AND ADDRESS OF THE PRINCIPAL INVESTIGATOR**

Dr. Rakesh Kumar Sinha
Associate Professor
Department of Biomedical Instrumentation
Birla Institute of Technology
Mesra, Ranchi-835215.

2. **NAME AND ADDRESS OF THE INSTITUTION**

Birla Institute of Technology
Mesra, Ranchi
Jharkhand-835215

3.	**UGC APPROVAL NO. AND DATE**	F.No. 36-60/2008 (SR) dated 27-03-2009
4.	**DATE OF IMPLEMENTATION**	May, 2009
5.	**TENURE OF THE PROJECT**	3 years
6.	**TOTAL GRANT ALLOCATED**	Rs. 11, 47,800.00
7.	**TOTAL GRANT RECEIVED**	Rs. 9,53,800.00
8.	**FINAL EXPENDITURE**	Rs. 9,26,547.00

9. **TITLE OF THE PROJECT** Voluntary Event Related Brain Signal Classification

10. **OBJECTIVES OF THE PROJECT**

Brief objective of the project

- Manual identification of voluntary events in brain signals.
- Power spectrum and wavelet analysis to identify the typical feature(s) for the particular event(s).
- Development of neuro-fuzzy artificial system for automated identification of events.
- With the aid of digital signal processing, soft computing as well as robotic tools, design of smart rehabilitation system for disabled person by means of processing and identification of brain signals for voluntary events.

11. **WHETHER OBJECTIVES WERE ACHIEVED (GIVE DETAILS)**

The laboratory designed paradigms for recording the biosignals (EEG, EMG, ECG, EOG, EDA and PPG) for defined mental tasks has been used for the recording. The experiments were performed with variety of mental tasks such as, eye gaze, mental arithmetic and motor imagination. The recorded biosignals were processed and defined features for specific mental task were identified and classified with the help of acknowledge 4.0 software (Biopac Inc, USA) and MatLab programs on fuzzy C means clustering and Kohonen neural network. The obtained results showed that in response to mental effort, ECG and PPG alter and a rise in EDA has been observed with the onset of event. Further, the response of changes in ECG and PPG is similar and the EOG is recorded for observing the eye ball consistency. The results achieved in the classification of mental efforts were encouraging (98% accuracy) and we believe that these can be used to provide an alternate communication pathway with the machine.

12. **ACHIEVEMENTS FROM THE PROJECT**

- One M.Sc. dissertation entitled “EEG feature extraction for event related two-class motor imagery” has been completed under the project.
- Three Ph.D. students are enrolled under the Principal Investigator.
- One research paper published and one revised version is under review.

- The principal Investigator has visited and trained in the advanced brain-computer interface lab. at University of Ulster, UK under the leverhulme trust visiting fellowship for a period of one year.

13. **SUMMARY OF THE FINDINGS (in 500 words)**

Sheet as attached in Appendix-1

14. **CONTRIBUTION TO THE SOCIETY (give details)**

HRV based man-machine interface system is proposed. However, the systems need to be revised with the help of the development of bioamplifier along with embedded system to provide real-time support to disabled.

15. **WHETHER ANY PH.D. ENROLLED/PRODUCED OUT OF THE PROJECT**

Two Ph.D. students are enrolled under the principal investigator.

- Mr. Nishant Singh: Electrooculogram and Brain Wave Assisted Brain-Computer Interface
- Mr. Gauri Shanker Gupta: Multi-Class Brain Computer Interface
- Mr. Anshuman Prakash: Design of Biosignal Controlled Prosthetic Device

16. **NO. OF PUBLICATIONS OUT OF THE PROJECT (please attach re-prints)**

- One article has been published and the other is under review.
    1. *Aggarwal, Y., Singh, N., Sinha, R. K. (2012) Electrooculogram based Study to Assess the Effects of Prolonged Eye Fixation on Autonomic Responses and its Possible Implication in Man-Machine Interface, Health and Technology, 2: 89-94.*
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4. *One paper is under preparation to submit in the forthcoming conference (IHCI-2012) on 27-29 December, 2012, at IIT Kharagpur with the title "Classification of two-degree mental arithmetic task with the variation in heart rate variability".*

(PRINCIPAL INVESTIGATOR)

(REGISTRAR/PRINCIPAL)

Registrar
Birla Institute of Technology
Mesra; Ranchi

Appendix-1

SUMMARY OF THE FINDINGS

The recording paradigm and the setup have been demonstrated in fig. 1 & 2, respectively. At first, the HRV/IHRV data have been analyzed for it's all the parameter and then the IHRV was used for the feature extraction and classification purposes.

Analysis of HRV: The summarized results of the HRV analysis are presented in table 1. The relatively higher mean RR interval and the lower SDNN has been observed for all the five subjects during the gaze duration as compare to the relax condition. However, for RMSSD, TI and TiNN lower values have been achieved during the eye fixation period. Although, marginal higher values have been obtained from S2 and S3 for TI and S2 shows little higher value for TiNN during the gaze period. Further, the spectral analysis of IHRV has been evaluated using the LS method and discrete wavelet transform in frequency and time-frequency domain, respectively, which shows almost similar findings. Three subjects (S1, S2 and S4) show decrease in LF and increase in HF power components, while reverse results have been observed for two subjects (S3 and S5) (table 1).

In Poincare analysis, subjects S1-S4 show reasonably lower values of SD1 and SD2 during the gaze period as compared to the rest period. Conversely, higher values for SD1 and SD2 are obtained from subject S5. Further, SD1/SD2 ratio shows lower value during the eye fixation except in subject S5, which shows higher value. Visual inspection of the Poincare graphs shows an elliptical shape lies at the center of the quadrant and are symmetrical both during the gaze as well as in relax period. The results are shown in fig. 3a,b. In DFA analysis, lower values of α_1 has been observed in subjects S2, S4 and S5 and higher in subjects S1 and S3 during the eye fixation. In long term fluctuation, subjects exhibit the higher values, except in subject S5, where marginally lower value during the eye fixation is observed. The graphical representation is illustrated in fig. 4a,b. Similar to the DFA, during the gaze period subjects S2, S4 and S5 shown higher values and lower values have been observed in subjects S1 and S3 for SE.

It has also been observed that heart rate and pulse rate decreases during eye gazing and tries to attain the baseline during relaxed condition (fig. 5 & 6). Although, the time corresponding to the maximum variation in these two signals are almost same (27.58 seconds for ECG and 22.44 seconds for PPG) during the trial. The consistency in variation in the PPG is not as good as it was obtained with ECG. The mean pulse rate variability showed sudden rise at 22.44 seconds due to which the result shows high variation in pulse rate (9.43 beats/minute) in comparison to the changes in heart rate (6.30 beats/minute). Based on the observations, it can be suggested that the non-stationary component in the PPG is more prominent than that of ECG signals.

Feature Extraction and Clustering**:** For the classification of HRV signal for gaze and relax conditions, two unsupervised methods *i.e.*, fuzzy C means clustering and KNN have been adopted. The feature extraction process for performing the classification has been carried out using FFT. As mentioned earlier, the frequency spectrum obtained from the FFT has been decomposed in three sub-bands. The area covered under each of these sub-bands is used to obtain the feature space. Fig. 7 represents the HRV (for both gaze and relax condition) by a point in three dimensional spaces. The entire data set (200 cases, 20 each for gaze and relax condition for five subjects) has been divided into completely different training and validation data sets of equal length. Care is taken to accommodate widely varying trails of all subjects.

The fuzzy C means process is initiated at randomly selected cluster centers. The two centers are updated iteratively till no changes in the clusters are observed between two successive iterations for all the data points of the training set. For the present case, the algorithm is found to converge after ten iterations at the cluster centers C_1 = [80.5006 5.3168 2.0182] and C_2 = [12.4344 6.6622 1.9486] for gaze and relax conditions, respectively. The data points of the validation dataset are grouped based on the degree of closeness to the cluster centers. On the validation dataset, except for two cases, fuzzy C means classifier is able to classify all the cases correctly, *i.e.*, a classification accuracy of 98%. The points corresponding to the arrow marker in fig. 7 denotes the data points and hence the HRV, which has been incorrectly classified (same for each classifier). Both this cases corresponds to the same subjects (S1). While, all the data points for the other four subjects are correctly classified. During the training of KNN, for a randomly selected weight vectors, the individual weights are iteratively updated with the aim of reducing the Euclidian distance between the vectors corresponding to the two classes and the associated data points. The iterative process of weight updating is carried out for 100 iterations, after which the weight vectors corresponds to W_1 = [80.5605 5.3141 2.0413] and W_2 = [12.5649 6.5596 2.0413]. The trained network is simulated with the validation dataset, resulting in two possible outputs depending on the distance of the weight vectors from the data points. Exactly similar classification accuracy is observed for both the classifiers *i.e.*, the same data points are classified/misclassified. From fig. 7, it is observed that high classification accuracy can be attributed to the high disparity in the feature corresponding to the lowest sub-band, which normally ignored for the HRV analysis as it is related to thermoregulatory processes and renin-angiotension system. The features for the other two sub-bands are not very distinct for gaze and relax condition. No change in the pattern of classification is observed when only the lowest sub-band is considered to that when all the three bands are taken. In other words, the low and the high frequency bands do not add any additional information for classification.

Table 1: Variations in the parameters for gaze/relax condition using different HRV analysis techniques.

			Subjects				
Sl. No.	**HRV Analysis**	**Parameter**	**S1 (Gaze/Relax)**	**S2 (Gaze/Relax)**	**S3 (Gaze/Relax)**	**S4 (Gaze/Relax)**	**S5 (Gaze/Relax)**
1	**Time Domain**	Mean RR Interval (ms)	709.8/700.6	776/767.5	833.6/808.4	871.3/861.1	901.8/865.6
		SDNN (ms)	66.6/86.6	86.3/108.3	57.7/85.4	68.6/124.9	89.3/115.7
		SDHR (bpm)	8.1/13.3	10.2/14.1	4.3/14.2	8.3/15.9	8.8/14.1
		RMSSD (ms)	65.1/109.5	101.2/146.2	67.8/112.1	75.8/152.6	100.4/148.2
		TI	4.7/5.2	3.8/3.1	3.6/3.2	3.4/2.8	4.5/5.1
		TiNN (ms)	230.6/279.7	230.6/239.1	193.6/185.6	165.0/186.3	319.2/347.3
2	**Frequency Domain**	LF (nu)	0.441/0.458	0.406/0.428	0.477/0.442	0.346/0.351	0.483/0.451
		HF (nu)	0.559/0.542	0.594/0.572	0.523/0.558	0.654/0.649	0.517/0.549
3	**Time-Frequency**	VLF (ms^2)	580.4/800.2	1405.1/955.4	518.7/697.8	858.5/3187.2	1406.6/1435.1
		LF (nu)	0.455/0.461	0.421/0.445	0.461/0.451	0.358/0.428	0.525/0.446
		HF (nu)	0.545/0.539	0.579/0.555	0.539/0.549	0.642/0.572	0.475/0.554
		LF/HF	0.835/0.855	0.727/0.801	0.854/0.822	0.559/0.748	1.105/0.834
4	**Poincare Analysis**	SD1 (ms)	46.0/77.6	71.6/103.6	48.0/79.4	53.6/108.1	71.1/18.8
		SD2 (ms)	82.2/94.8	98.8/112.9	66.1/9.0	80.9/139.7	104.4/31.8
		SD1/SD2	0.559/0.818	0.724/0.917	0.776/0.872	0.662/0.773	0.681/0.591
5	**Detrended Fluctuation Analysis**	α1	0.921/0.867	0.679/0.713	0.849/0.717	0.757/0.884	0.874/0.932
		α2	0.670/0.545	0.865/0.357	0.719/0.422	1.071/0.703	0.707/0.785
6	**Sample Entropy**	SE	2.225/2.232	1.990/1.591	1.648/1.927	1.819/1.605	2.522/2.216

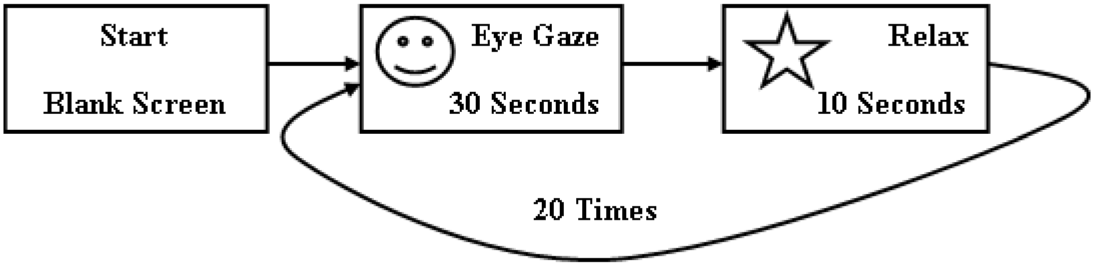


Fig. 1: The experimental paradigm used for the recording.

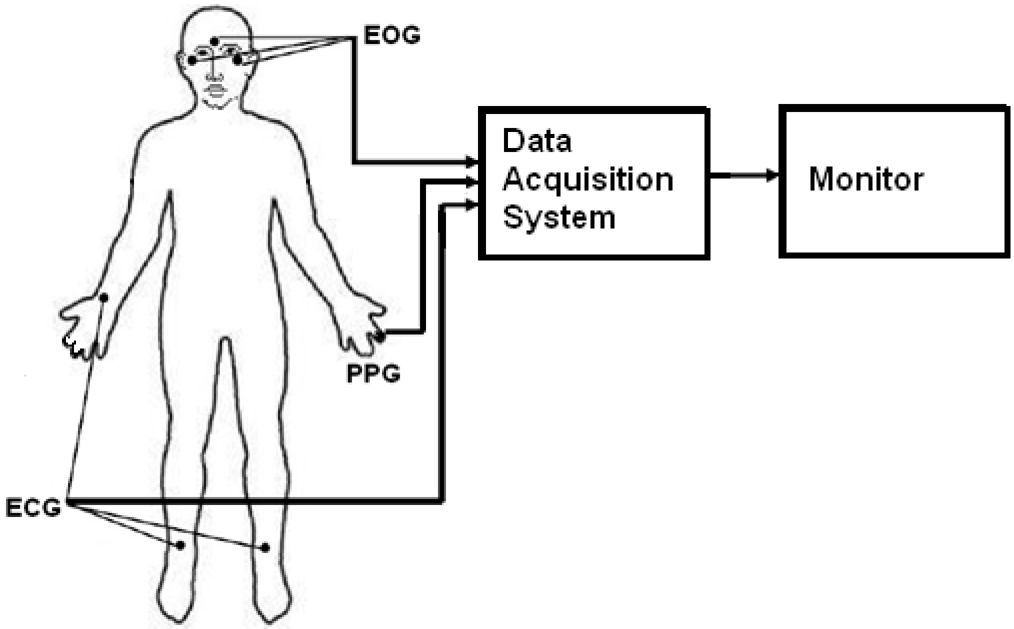
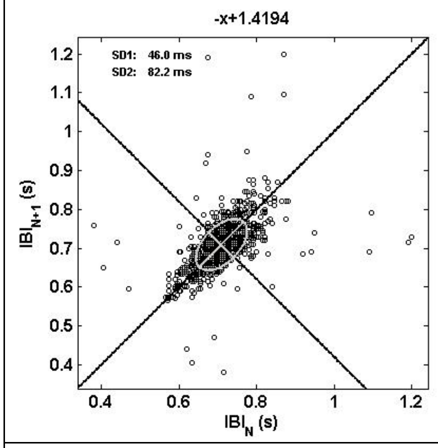
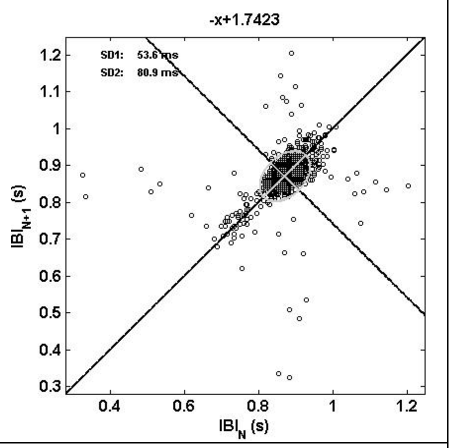


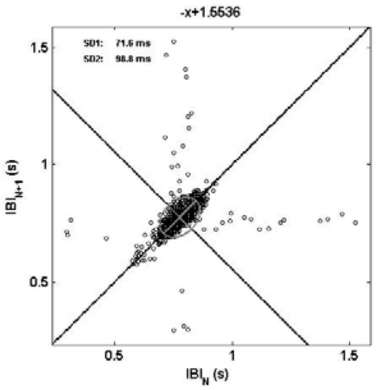
Fig. 2: Representative diagram of the electrode placement and recording setup.



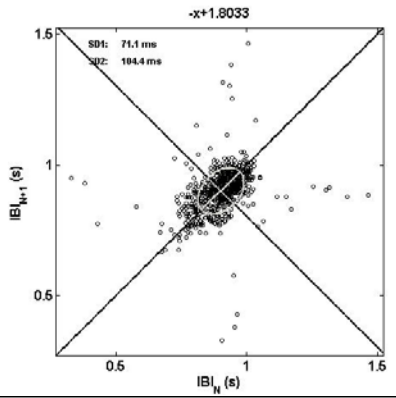
S1



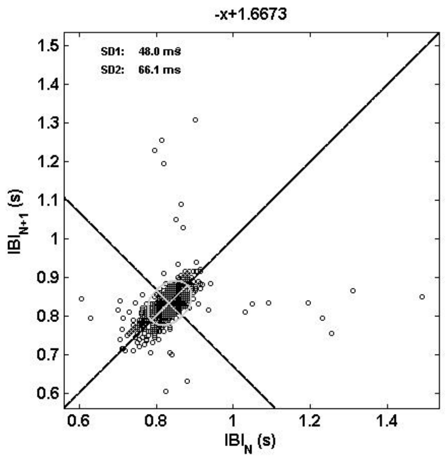
S4



S2

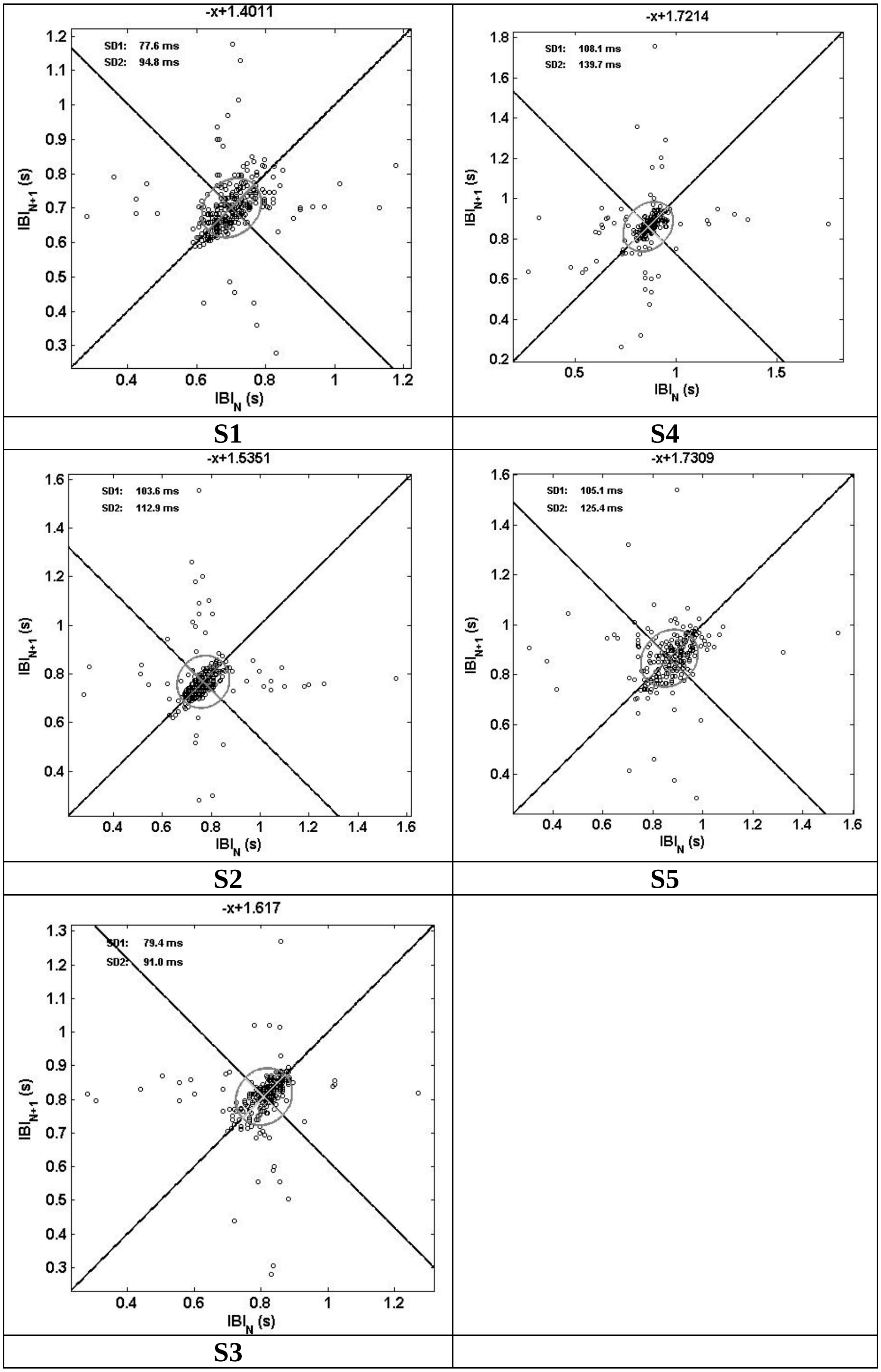


S5



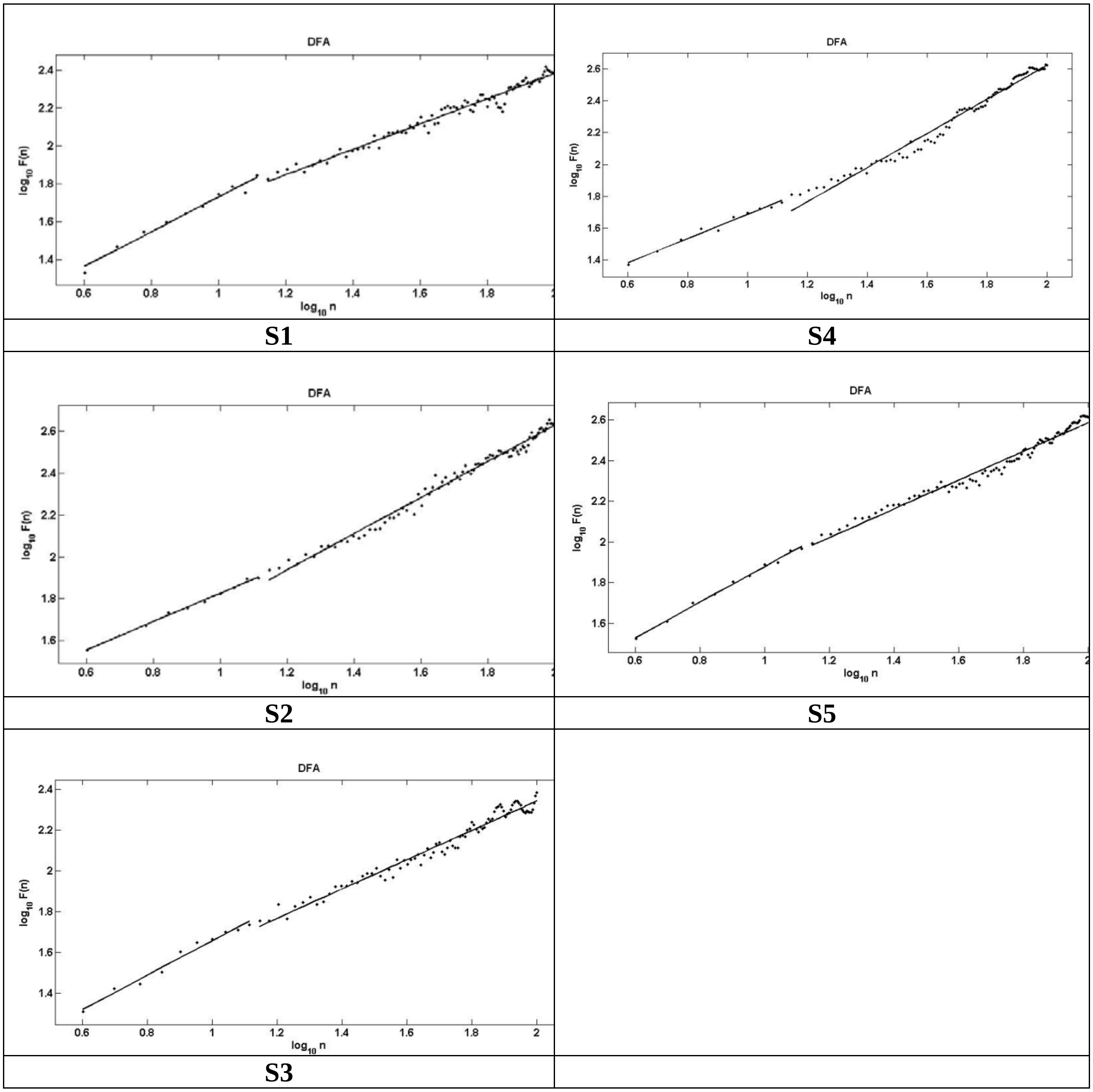
S3

(a)



(b)

Fig. 3: Poincare analysis during (a) gaze period and (b) rest period; where IBI is interbeat interval.



S1

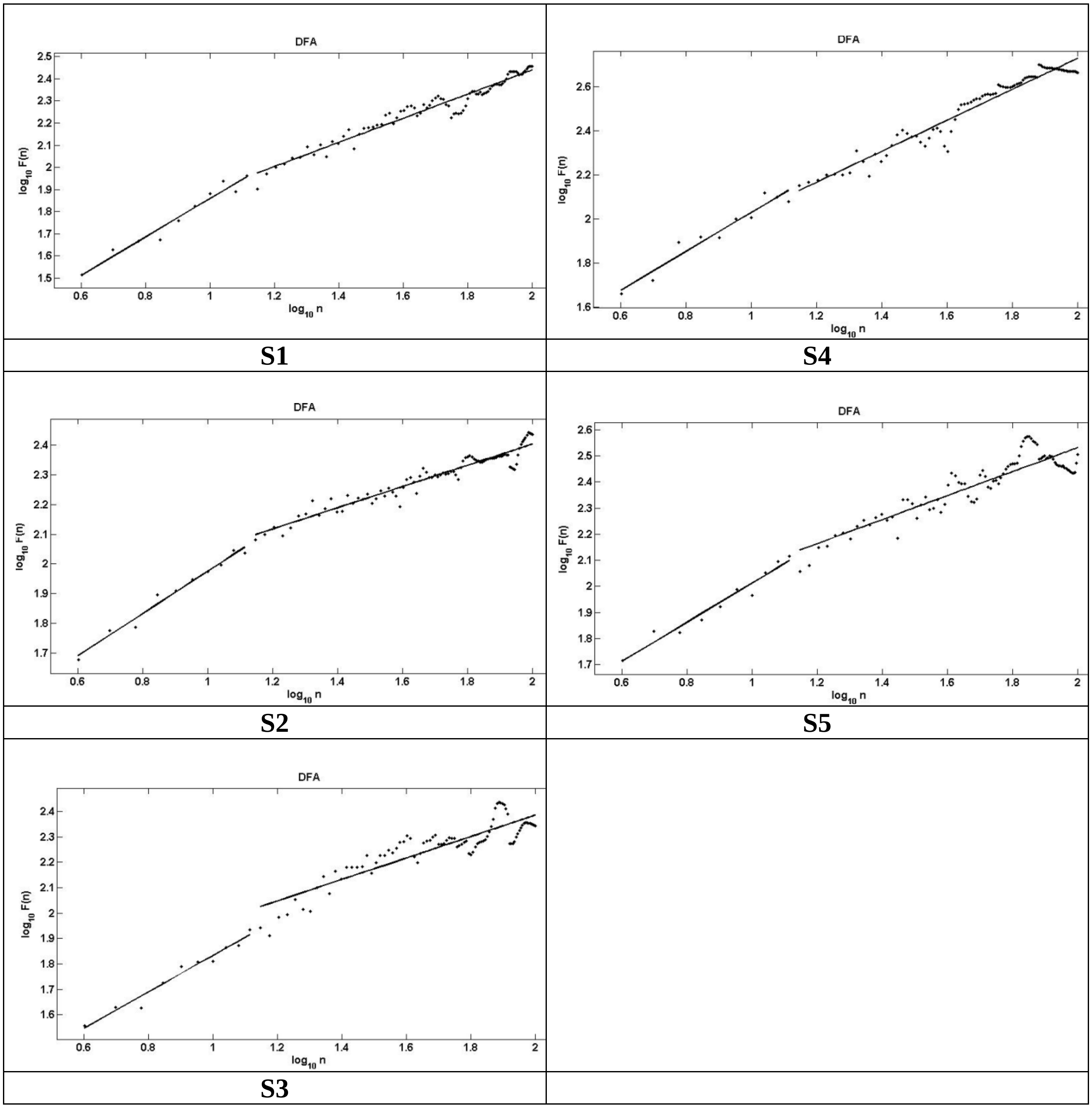
S4

S2

S5

S3

(a)



S1

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(b)

Fig. 4: Detrended fluctuation analysis during (a) gaze condition and (b) rest condition.

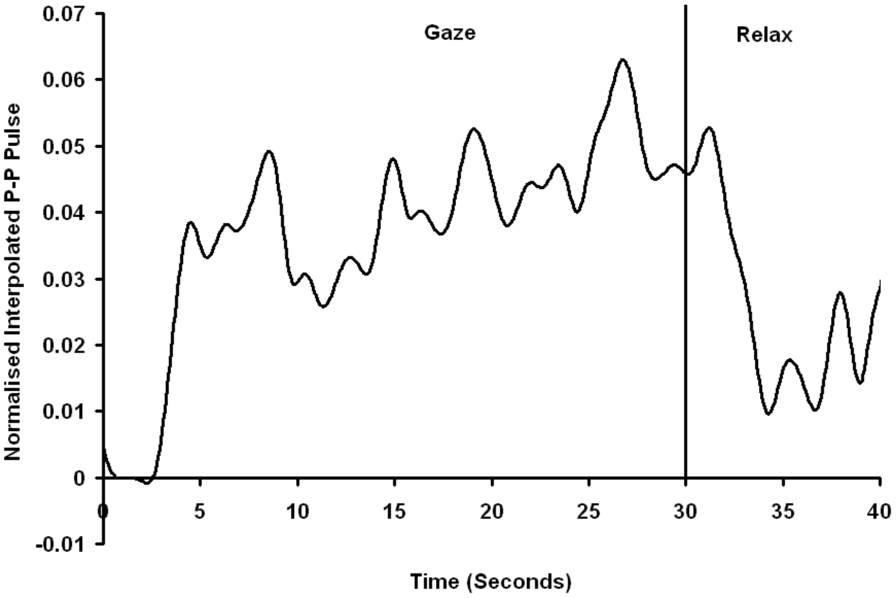

Fig. 5: Mean Pulse rate variability under eye gaze of 30 seconds followed by 10 seconds relaxation period (n=5, 100 trials).

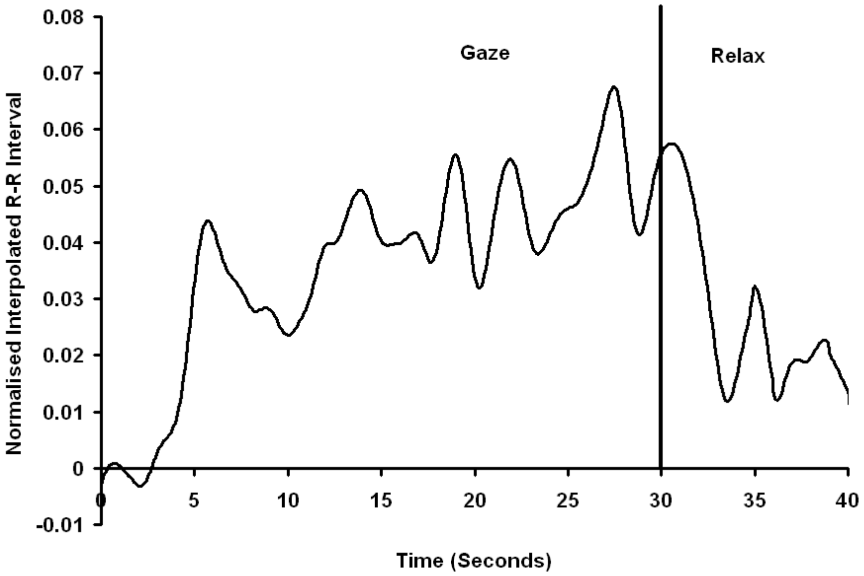

Fig. 6: Mean Heart rate variability under eye gaze of 30 seconds followed by 10 seconds relaxation period (n=5, 100 trials).

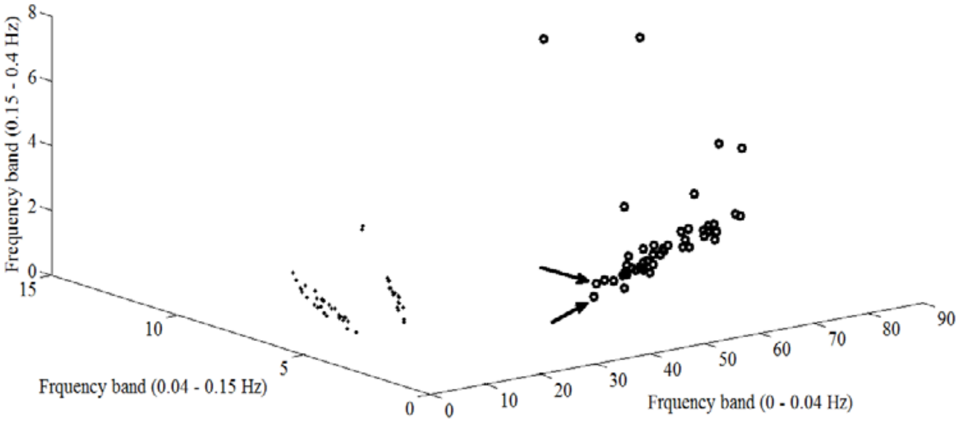

Fig. 7: Three dimensional features extracted from the Fourier spectrum of the HRV under different trials of eye gaze movement (circle) and rest condition (dot). The arrow refers to the feature vectors that have been misclassified using fuzzy C means clustering.

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SHORT COMMUNICATION

Electrooculogram based study to assess the effects of prolonged eye fixation on autonomic responses and its possible implication in man-machine interface

Yogender Aggarwal · Nishant Singh · Rakesh Kumar Sinha

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Abstract Need of an alternative method for communication has been seriously felt for man-machine interface (MMI) because of difficulties in the analysis of complex electroencephalogram (EEG). The proposed method analyses the alterations in autonomic responses due to prolonged eye gaze. The experimental paradigm was designed to include 20 trials of 30 s for eye gaze and 10 s for relaxation. Along with electrooculogram (EOG), electrocardiogram (ECG), pulse plethysmogram (PPG) and electrodermal activity (EDA) was recorded from the five male subjects. Results demonstrated that the eye gaze modulates heart rate, pulse rate and EDA signals that were too analyzed to occur with the latency of nearly 5 s, which is nearer to the EEG based brain-machine interfaces (BMI). The alterations in autonomic variables persist for longer duration and the maximum change in pulse rate was observed at 26.79 s (5.16 beats/minute) in comparison to the maximum change of heart rate (6.27 beats/minute) at 27.45 s, respectively. Further, the changes in EDA were found more at the onset of events. With the above findings, it can be suggested that the changes in autonomic responses with the mental effort produced by eye gaze were distinct and provides a good platform for the development of MMI.

Keywords Autonomic responses · Electrooculogram · Eye gaze · Man-machine interface

1 Introduction

Stroke is one of the largest killer identified in the human society. The impaired supply of oxygen and the communication breakdown from central nervous system (CNS) to the skeletal muscles are among the commonest indications of stroke. Some of the well known ailments, which have been resulted due to the stroke are, paraplegia, hemiplegia, tetraplegia and amyotrophic lateral sclerosis. In these pathological conditions, neuromuscular pathways are disrupted that leads to long-term motor disabilities. However, their sensorimotor cortices are activated during attempted movements. For such subjects to fulfill their day to day activities brain-machine interfaces (BMI) provide direct communication pathway between the brain and an external device to assist and augment the human sensorimotor functions [1–4].

So far, different techniques have been employed to implement BMIs [5–8]. However, the major difficulty lies in the method for extracting the features from acquired brain signals, which are highly non-stationary and uncomfortable to subjects due to the attached scalp electrodes. Recently, it has also been suggested that an alternative source of information can be identified from various other electrophysiological parameters. Apart from brain signals, electrooculogram (EOG) [9, 10] and autonomic variables [11–13] have also been used effectively for developing hybrid type of BMIs. It is generally understood that in most of the stroke cases, cognitive functions remains intact with capability of eye ball movements. Based on this hypothesis, Barea and coworkers [9] have developed the motorized wheel chair for disabled people, who could solely operate through the features extracted from the EOG. Further,

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Usakali et al., [10] also proposed the effective use of EOG in the development of man-machine interface (MMI). Though, the developments of assistive devices with EOG were more or less based on the gaze direction as well as on the controlled eye blink, the control of random eye movement is another challenging task.

Conversely, it is supposed that the unidirectional continuous eye fixation is enough to produce mental effort as it affects significantly the premotor cortex area [14]. It has been demonstrated that the activation of neurons in dorsal premotor area that encode the reach goal is relative to the eye fixation and irrespective of the hand position [15]. Simultaneously, these mental efforts may be able to produce autonomic activation similar to as demonstrated earlier [16]. Morata in 2005, confirmed that the mental efforts produced in their experiments modulated the autonomic responses [17], which were also considered as the components of the behavioral responses of CNS [18]. On the similar line of research in the area of BMI, researchers have already proposed the use of autonomic parameters in the development of command to control the external devices. However, no literature has been identified, which demonstrates the effects of eye gaze on autonomic responses.

Therefore, the aim of present study is to analyze the effects of mental effort produced by eye gaze on autonomic responses, so that the effects of eye gaze without any motor imagination (MI) on the autonomic variables can be evaluated for the ultimate target of proposal of new MMI system.

2 Materials and methods

Subjects and experimental paradigm This study involved five young male volunteers (S1 to S5, age 20–30 years and weight 55–65 kg) without any medical history. The experimental protocol was demonstrated to all the subjects and the consents were signed for their involvement in the study. The study was designed to record the lead-II electrocardiogram (ECG), pulse plethysmogram (PPG) and electrodermal activity (EDA) with EOG to observe the consistency of eye fixation. One animated power point presentation (Microsoft Office 2007, USA) was designed with 20 trials per subject. Each trial consists of 30 s eye gaze followed by 10 s relaxation period to the subject (Fig. 1). During the eye gaze period, a smiley appears at the center of the computer screen for 30 s. The subject was asked to gaze the smiley that constantly appeared on the computer screen. After the finish of gaze period, a star appears on the screen for 10 s to signal the subject to rest. During the relaxation period subjects were not advised to adopt a continuous eye closed condition, however, allowed for eye blink.

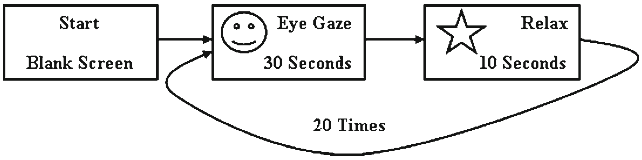


Fig. 1 The experimental paradigm used for the recording

Signal recording and processing With standard recording protocol, the biosignals (ECG, PPG, EDA and EOG) were recorded with the help of 4-channel bio-amplifier (Biopac Inc., USA) and Ag-AgCl disposable electrodes. Subjects were instructed to be seated on the armed rest chair and foot rested on insulated surface. Out of four, first channel was used for lead-II ECG, second for PPG, third for EDA and the fourth for EOG, and data were recorded as per the experimental paradigm. The PPG signal was recorded from distal phalanges of index finger of the left hand and EDA from proximal phalanges of the index and middle fingers of right hand of the subjects. For EOG, three electrodes were placed, one above the nasion, and two below the outer canthi of each eye, generating in a right-angled triangle (Fig. 2) as suggested by Scherer et al. [19]. All the digital recordings were performed with the sampling frequency of 200 Hz. The snapshot of the subject with all electrodes placed with running paradigm is shown in Fig. 3.

The mean heart rate and pulse rate changes across the trials were calculated over the paradigm period to confirm whether there occurred distinct variations in ECG and PPG during the eye gaze time. To analyze the heart and pulse rate variability, a methodology was adopted from Pfurtscheller et al. [11]. The R-wave of the ECGs and the peaks of pulse waves were identified and R-R and peak-to-peak intervals were calculated, respectively, with the help of software (Acknowledge 4.0, Biopac Inc. USA) using a modified Pan-Tompkins algorithm. The algorithm normalizes the wave data to 1 whereby the peak amplitude of the highest peak of the wave represents 1. The threshold level of 0.5 has been placed in the middle of the wave. The threshold level is used for the calculation of interpolated heart rate variability

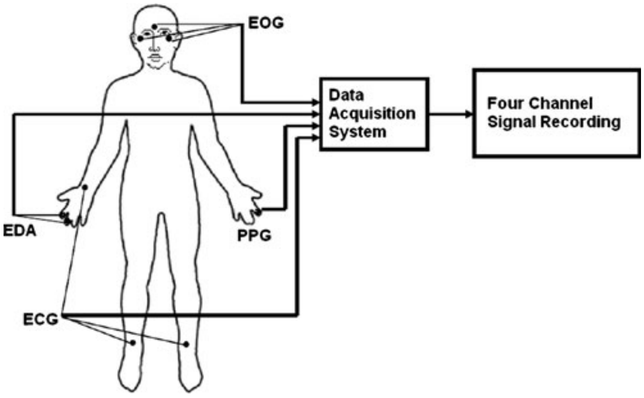


Fig. 2 Representative diagram of the electrode placement and recording setup

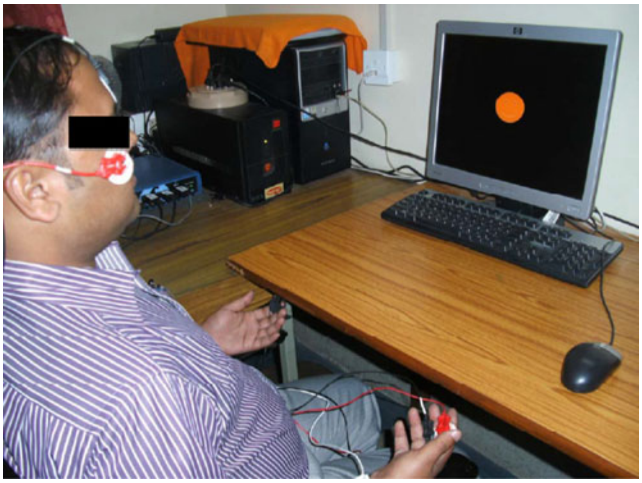


Fig. 3 Snapshot of running experimental paradigm with subject

(IHRV) and interpolated PPG (IPPG) from ECG and PPG signals at 8 Hz spline re-sampling frequency, respectively, by a cubic-spline interpolation method. The averaging was performed across 100 trials (from 5 subjects) obtained from all the five participants using MS Excel (Microsoft, Office 2007, USA). Further, to get the normalized variations, the relative changes in heart rate and pulse rate were calculated by subtracting the 5th digital value of each trial, respectively, in order to maintain the origin of each trial on the 5th data point as zero. The averaged and normalized data has been plotted for mean IHRV and mean IPPG analysis both for eye gaze (30 s) and relax condition (10 s). While on the other hand, before final calculation of average changes, EDA and EOG signals were band pass filtered at 0.01 to 0.5 Hz and 0.01 to 5 Hz frequency bands, respectively. The data of all 100 trails taken from all the subjects for EDA and EOG activity were taken to MS Excel Spreadsheet and mean for these parameters were calculated.

Statistical analysis All the statistical analyses were performed manually. Significance of changes in heart rate during relaxation and gaze period were calculated with the help of paired *t*-test. For the analysis, mean heart rate data of last 5 s of the eye gaze and relaxed condition were analyzed. Further, the Pearson's coefficient of correlation analysis (r) was also performed to evaluate the alterations in heart rate and EDA with eye gaze, if any, in these parameters. For the correlation analysis, mean data between 0–5 s, 25–30 s and 35–40 s (relaxation period) of the paradigm were considered. The brief description of the correlation analysis as described by Gupta [2000] is given below.

$$r = \frac{\sum xy}{\sqrt{\sum x^2 \times \sum y^2}}$$

The coefficient of correlation (r) is said to be a measure of covariance between two series. The covariance of two series X and Y is written as

$$Covariance = \frac{\sum xy}{N}$$

where, x and y stands for deviation of X and Y, respectively, from their respective mean.

$$x = \left(X - \overline{X}\right) \, and \, y = \left(Y - \overline{Y}\right)$$

3 Results

Analysis of autonomic responses With the analyzed EOG (Fig. 4) from 100 trials (n=5) of the assigned mental task through eye gaze and further relaxation period, a distinct alterations in recorded parameters have been observed. The analyses suggested distinct alterations in heart rate, pulse rate and EDA during eye fixation.

It has been observed that heart rate and pulse rate decreases during gaze period and tries to attain the baseline during relaxation condition (Fig. 5). Conversely, the analysis of the data of IHRV and IPPG shows reverse changes in comparison to their respective heart and pulse rate changes (Fig. 6). With the help of these results, remarkable and consistent increase in peak-peak interval has been revealed that also suggests the decrease in mean heart and pulse rate during the fixation period. Further, the time point for getting maximum difference in these two signals are almost same (27.45 s for ECG and 26.79 s for PPG) during the trials, the consistency of the variation was also observed very much similar in these two parameters. The mean pulse rate variability showed maximum rise at 26.79 s with a shift from the baseline of 5.16 beats/minute in comparison to the changes in heart rate, 6.27 beats/minute (Fig. 6). It is very important to analyze that the changes in EDA during the eye gaze and further in relaxation period follows the similar pattern as the

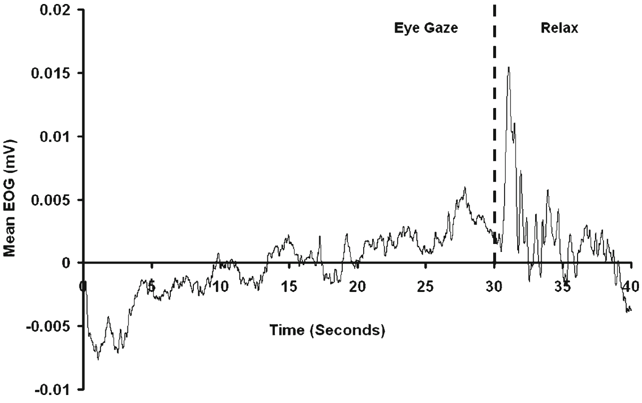


Fig. 4 Mean electrooculogram activity under eye gaze period of 30 s followed by 10 s eye relaxation period (5 subjects, 100 trials)

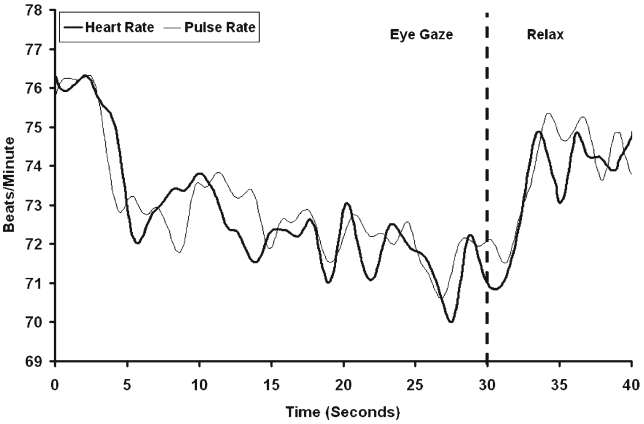


Fig. 5 Mean heart rate and pulse rate analysis under eye gaze period of 30 s followed by 10 s eye relaxation period (5 subjects, 100 trials)

heart and pulse rate. However, this parameter shows sudden jump just after the onset of task and then slowly attain its initial position (Fig. 7).

Correlation analysis between autonomic parameters Based on these results, HRV during the maximum change period (25th to 30th s) and the last 5 s of relaxation period for all the 5 subjects was evaluated for the significance of alterations. With the paired *t*-test, changes between the mean values of heart rate for gaze and relaxation period were found to be significant ($t=2.95$, $P<0.05$). Subject wise as well as averaged heart rate changes have also been presented in Fig. 8.

The correlation analyses were performed between data sets of the heart rate and EDA. The time points selected for the evaluation were the first 5 s of the gaze period (within the latency period), last 5 s of eye gaze (maximum deviation period in the heart rate) and the last 5 s of the relaxation period. For each of the mentioned 5 s period, mean for heart rate and EDA for all the 5 subjects were calculated and taken for the correlation analysis. A positive correlation was analyzed between heart rate and EDA variations during the first 5 s of gaze duration ($r=0.614$) and the last 5 s of relaxation period ($r=0.567$), while negative correlation was calculated during the maximum deviation period of the heart rate of the gaze time ($r=-0.194$).

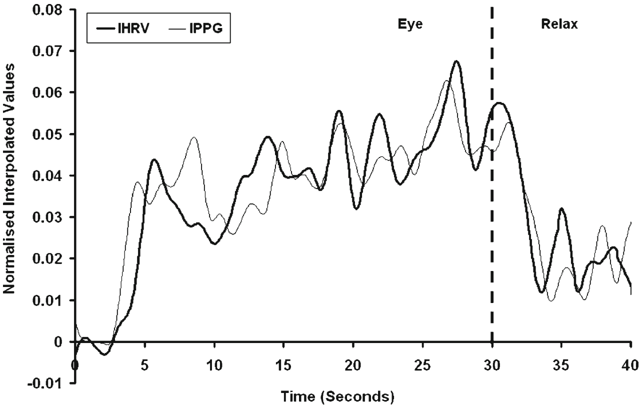


Fig. 6 Mean interpolated heart rate variability (IHRV) and interpolated pulse rate variability (IPPG) analysis under eye gaze period of 30 s followed by 10 s eye relaxation period (5 subjects, 100 trials)

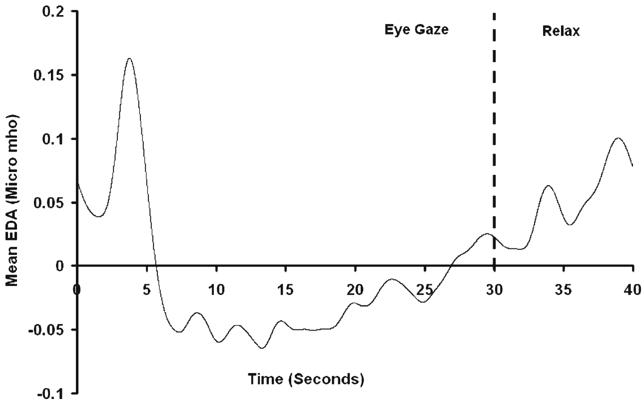
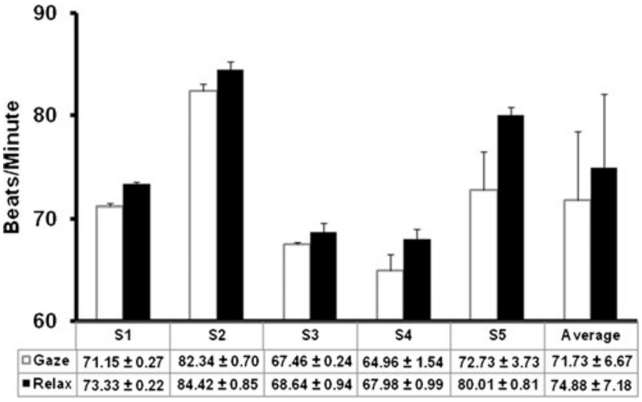


Fig. 7 Electrodermal activity produced due to prolonged eye gaze period of 30 s followed by 10 s eye relaxation period (5 subjects, 100 trials)

4 Discussion

In the present work, effect of prolonged eye fixation on three parameters viz. heart rate, pulse rate and EDA have been evaluated. The observed results have shown the gradual decrease in heart rate and pulse rate during gaze period and tries to attain the baseline during relaxed condition. The consistency of the alterations was observed to be very much similar in these two parameters (Figs. 5 and 6). The statistical analyses also suggested a significant difference between heart rate at the time of eye fixation and relaxation ($t=2.95$, $P<0.05$). Considering the findings of this pilot experiment, it is understood that prolonged eye fixation



	S1	S2	S3	S4	S5	Average
☐Gaze	71.15±0.27	82.34±0.70	67.46±0.24	64.96±1.54	72.73±3.73	71.73±6.67
■Relax	73.33±0.22	84.42±0.85	68.64±0.94	67.98±0.99	80.01±0.81	74.88±7.18

Fig. 8 Subject wise (20 trials) as well as mean±S.D. variations (5 subjects, 100 trials) of heart rate during the maximum deviation period (25th to 30th s) of eye gaze period and the last 5 s of eye relaxation period

certainly produce some mental effort that influences the autonomic nervous system to alter cardiac responses, which is similar to the past hypothesis [17]. The obtained findings were also found to be in accordance with the results and hypothesis as suggested by Pfurtscheller et al. [11] in which they demonstrated that decrease in heart rate with MI in a normal environment during preparation for a voluntary movement. However, in contradiction to above findings, Oishi et al. [16] suggested a significant increase in heart rate, but with different mental task.

As eye gaze being the first step in reaching the visual goal, the accurate goal-directed reach typically rely on the eye gaze and motor action [20]. On the other hand, it has been revealed that the unidirectional extended eye fixation is enough to produce the mental effort as it affects significantly the premotor cortex area [14]. Further, it has also been demonstrated that the activation of neurons in dorsal premotor area that encode the reach goal is relative to the eye fixation and irrespective of the hand position [15]. Therefore, the designed paradigm with constant fixation without any motor movement (or MI) to produce mental effort is justified. Further, Collet et al., [18] supported that the mental effort produced alterations in autonomic responses, which were also considered as the components of the behavioral responses of CNS.

The results indicate that there is covariance between measures of heart rate, pulse rate and EDA recorded during the eye gaze produced mental effort. The Pearson's correlation analyses suggested that deceleration of the heart rate is negatively correlated ($r=-0.194$) with the EDA at the peak of mental effort (25–30 s), otherwise it is positively correlated ($r=0.614$ at the start of mental effort and $r=0.567$ during the relaxation). Similar to the results obtained, literature has also revealed that in activation phase EDA increases and decreases in relaxed condition [18]. During the mental effort skin conductance level increases [16], which is measured as the function of activation of eccrine sweat glands those are innervated by the sympathetic chain of autonomic nervous system [21]. In the line of research hypothesis suggested by Oishi et al. [16], it can also be shown that when MI is performed, many physiological responses are activated, which may produce a low level efferent leakage effects on several autonomic variables [22]. The autonomic activation in this case is greater than the required during MI, occurs due to enhanced metabolic demand and have central origin [23, 24]. With these findings, it can be suggested that the prolonged eye gaze modulates both cardiac as well as eccrine system.

On the similar line of research in the area of BMI, researchers have already proposed the use of autonomic parameters in the development of command to control the external devices [13, 19]. However, no literature has been identified, which demonstrates the effect of prolonged eye gaze on autonomic responses. For the analysis of changes in autonomic variables, EOG signals have been considered as standard for the present experiment. It was identified that the EOG provides the standing corneal-retinal potential of the eye and proportional to the rotational angle of the eye [9, 25]. With the analyzed EOG from 100 trials of the assigned mental task through eye gaze and further relaxation period, a distinct variation in autonomic parameters have been observed, which can be useful for actuating a device for the purpose of MMI. Further, it was very interesting to note that the latency of changes (onset of response) in autonomic parameters lies nearly on 5th s of the start of trial, which is not far from the results obtained with the EEG data used for the BMI systems [26, 27].

5 Conclusion

The findings of the experiment suggest distinct changes in autonomic parameters such as ECG, PPG and EDA during the eye gaze trial. It was observed that the changes in these parameters start nearly on 5th s of the start of trial. It means the latency of separability between the eye gaze and relaxation are obtained just after 5 s of the trial, which is more or less similar with the results obtained with standard EEG data in BMI systems. Further, it is very interesting to note that the separability in these slow autonomic responses (ECG and PPG) with the relaxation persist for longer duration and reached on the maximum level between 25th to 30th s of the trial. Thus, it can be suggested that eye gaze modulated HRV provides better opportunity for the design and development of MMI in comparison to conventional BCI system.

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Analysis of Electrodermal Activity during Performance of Two-Leveled Mental Arithmetic Task and Its Possible Implications in Man-Machine Interface

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Abstract

There are limited practical methods available for communicating with the people who are in a locked-in state. This experiment is designed to examine the changes in Electrodermal activity (EDA) in young individuals in the performance of two levels of arithmetic mental calculation tasks. Seven Male and five Female participants had performed the two levels of mental arithmetic (MA) calculations, *i.e.*, 15 easy and 15 calculative. Each task was for 10 seconds, for both easy and calculative and presented in a random manner, and digital data of EDA was acquired. EDA from the easy MA task showed higher values in when compares to that obtained during the calculative MA task. With increased complexity in MA assignments, EDA decreases that are influenced by the autonomic nervous system under increased complexity of the mental arithmetic task and a pattern of separation at just before the 6th second from the onset of MA task has been identified. This study demonstrates the potential of using mental arithmetic based mental exercises to examine their influence on EDA of the performers.

Keywords: Autonomic Nervous System; Electrodermal Activity; Mental-Arithmetic task; Man-Machine interface.

Introduction

Physical disability is characterized by the inability to make use of body parts at will either partially or wholly. In many instances, mental blockade or a locked-in condition turns out to be the cause of such disability [1, 2]. In such circumstances the individual loses his/her ability to speak and reaches a complete paralytic condition, thus being deprived of any means of communication with the people around him. There is intactness of conscious mind, and the individual is able to feel and understand everything but lacks ways of interacting with the environment [3]. There may be an exhibition of certain voluntary functions such as yawning tearing or drooling, but these activities do not serve the purpose of communication effectively.

Development that have been made the area of brain-computer interface has provided efficient alternative for communicating with the disabled, making use of the technologies such as electroencephalography via either surface or brain-implanted electrodes [4, 5, 6]. Although much research has been done to improvise their usability, these modes are still in their development stage [6, 7, 8]. It is the lesser readiness to use, expense and real-time analytical integration of brain-computer interface that has lead to encouragement of research for alternate modes of communication.

Studies of autonomic physiological changes for the differentiation of mental states can serve as an alternative approach to communicating with such subjects. There are a number of physiological signals which can be correlated with an individual's mental states, namely electrodermal activity, heart rate, blood pressure and respiration rate [9, 10]. Electrodermal activity (EDA) comprises of the changes in electrical properties of the skin caused by sympathetic stimulation of the sweat glands. Skin conductance is a widely studies property and can be quantified by the application of an electric potential between two points of skin contact and measuring the resulting current flow between them. EDA has also been recorded from patients where sweating is entirely absent [11].

The purpose of this study is to determine the possible distinction in the EDA of individuals during the performance of two levels of Mental Arithmetic (MA) tasks, namely Easy and Calculative. Effects of such mental activity have been addressed prominently in previous studies showing variation in autonomic activity with MA tasks. As the EDA has a link with the autonomic variations of an individual, such identified patterns of changes may be unique and affirmative. These may be proposed to have direct application in Human-Machine Interaction.

Materials and Methods

For signal acquisition, 12 subjects (7 Male and 5 Female) had participated strictly on a voluntary basis; all lying within the age group of 18-25 years. All the subjects were explained and demonstrated a sample paradigm and the care was taken that every query of the volunteers regarding the experimental procedure was answered to their satisfaction. They were required to fill up and sign a consent form including a small health questionnaire before the experiment. All the subjects were having a normal vision or corrected-to-normal vision and hearing.

Task Design:

The task assigned in this study was MA calculation. An instruction paradigm for the task was designed using Superlab 4.5 (Cedrus, USA). It is a cue-based paradigm, worked in real time with the signal acquisition system MP35 (Biopac Inc, Goleta, California, USA). There were two sets of mental calculation instructions designed for the experiment, *i.e.,* easy and calculative; each set consisting of 15 questions. The easy mental calculation tasks consisted of easy level questions (e.g. 2+2.9; uses simple summation or subtraction); the higher calculative level questions (e.g. 4.65×7.82)/41.9; uses multiple arithmetic operators) as shown in figure 1. Two computers were used for the work that was connected in real-time for the paradigm part. One of the monitors displayed the MA instructions and on the other, the signals, which were being recorded with the cue applied, were displayed.

Recording Procedure:

The easy and the calculative tasks appeared in a random manner on the computer screen. The subjects were provided with a response sheet, where they were required to calculate and write down the answers to the MA calculations. The paradigm started with a blank screen (black in color) and remains for 2 seconds; followed by a fixation cross for 1 second. This fixation cross served as an indicative signal for the subject that the task (easy or calculative) was about to begin. The time allotted for each MA calculation for every individual task was 10 seconds after that a response time of 3 seconds was allotted during which the subjects were supposed to write their responses. The paradigm is illustrated in figure 1. Before the beginning of the recording session, the subjects were instructed well and were made to perform a similar task of short duration for making them well acquainted with the task to be performed.

The EDA was recorded from the middle and the ring fingers of the left hand of the subjects. Single session continuous recording of the subjects was done throughout all the 15 easy and 15 calculative tasks appearing randomly on the screen as shown in figure 2. It was a single subject single session recording. Acqknowledge 4.0 (Biopac Inc, Goleta, California, USA) was used for all the preprocessing and processing of the signals. For both easy and calculative arithmetic assignments, the EDA responses were evaluated and averaged. Both averaged tachogram and EDA were further normalized to maintain the baseline.

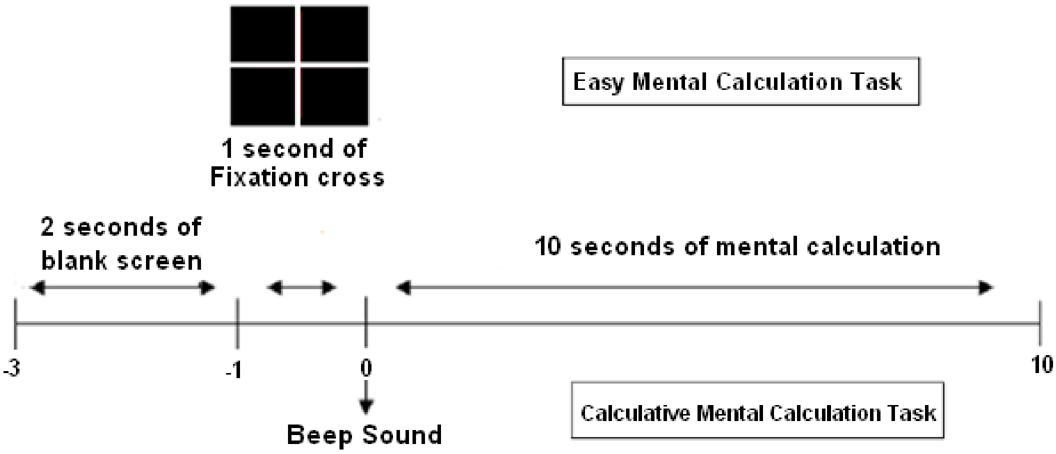

Figure 1: Schematic representation for the paradigm design.

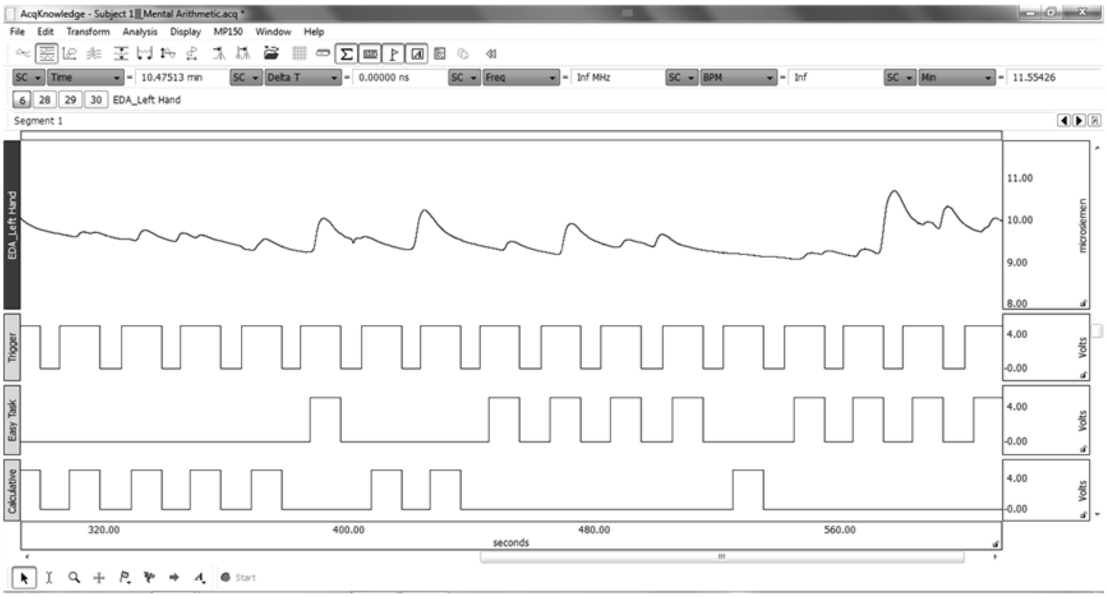

Figure 2: Representation of Recorded Signal along with the cue.

Statistical Analysis:

The statistical analyses were performed on MS Excel (MS Office 2007, Microsoft Inc) and also verified manually. Significance of the changes in EDA during the easy mental arithmetic task and the calculative mental arithmetic task were calculated using the Student's *t*-distribution. For analysis the mean EDA of the averaged subjects for both the easy and the calculative tasks were analyzed. A brief description of the Student's *t*-distribution analysis is given below.

The "*t*-statistic" is defined as:

$$t = \frac{\bar{X} - \mu}{S} \times \sqrt{n} \qquad (1)$$

Where,

$$S = \sqrt{\frac{\sum(X - \bar{X})^2}{n-1}} \qquad (2)$$

The t-distribution has been derived mathematically under the assumption of a normally distributed population.

It has the following form

$$f(t) = C\,(1 + \frac{t^2}{v})^{-(v+1)/2} \qquad (3)$$

Where

$$t = \frac{(\bar{X} - \mu)}{S} \times \sqrt{n}$$

C = a constant required to make the area under the curve equal to unity
v = *n – 1,* the number of degrees of freedom.

Results

Analysis of Electrodermal Activity:

A total 45 trials each of easy and calculative MA tasks were used for the analysis of outcomes. For getting the results of the Easy task, the subjects did not take more than 5 seconds. However, for the calculative task, the subjects remained busy during the entire trial period. This was also confirmed from the subjects by getting their responses in answering the assignments.

Raw EDA signals recorded for the easy and the calculative MA tasks can be seen as in figure 3. The comparative results for the calculation of EDA for both Easy and Calculative MA are presented in figure 4 & 5, respectively. The figure 4 depicts relative plot for all the 12 subjects along with their averaged graph. A similar representation has been shown in figure 5 for the Calculative MA task. The EDA of all the twelve subjects is showing almost the same results. During the calculative MA tasks, fall in EDA is evident in all the twelve subjects, but at the same time, it was showing elevation just after the start of easy tasks. A similar trend in the graph can be seen in the raw EDA signal also as depicted in figure 3.

Further close visual analysis of the graph in figure 4 clearly illustrates a pattern being followed by the EDA of twelve subjects, and this is in close association with their average signal that is represented by a dashed line. Here it can be seen that the EDA for all the subjects maintained a proximity to the baseline to the 6th second and swayed away above the baseline after that. However, 9 out of 12 subjects have followed a particular pattern; 9 subjects can be seen to move below the baseline after 6th second from the onset of the task, whereas one subject does so after the 8th second. The average of the 12 subjects for the calculative tasks maintains proximity to the baseline till 4 seconds and gradually moves below to the lower side after that. This gradual descent is continued till the 8th second and after that it moves away from the baseline in quick successions.

A comparison between the averaged Easy and the averaged Calculative tasks for all the 12 subjects has been shown in figure 6. Here it can be clearly seen that there is a latency of 2 seconds in the EDA signals after the start of tasks (both easy and calculative). The separation of the signal begins just before the 6th seconds which is in agreement with the pattern shown by the individual subjects. All the 12 subjects showed significance in the *t*-test. The overall average obtained for all the subjects was significant for $P<0.01$.

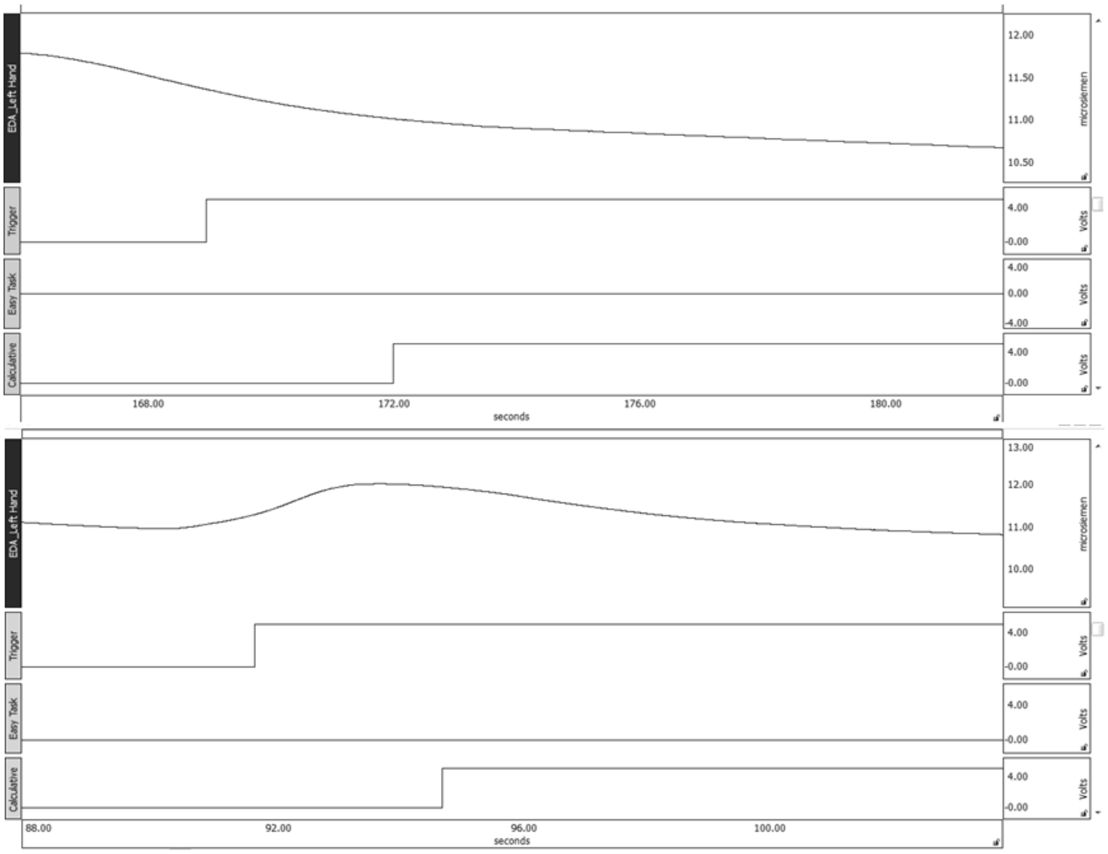

Figure 3: Raw EDA signal of Easy vs. Calculative Mental Arithmetic tasks.

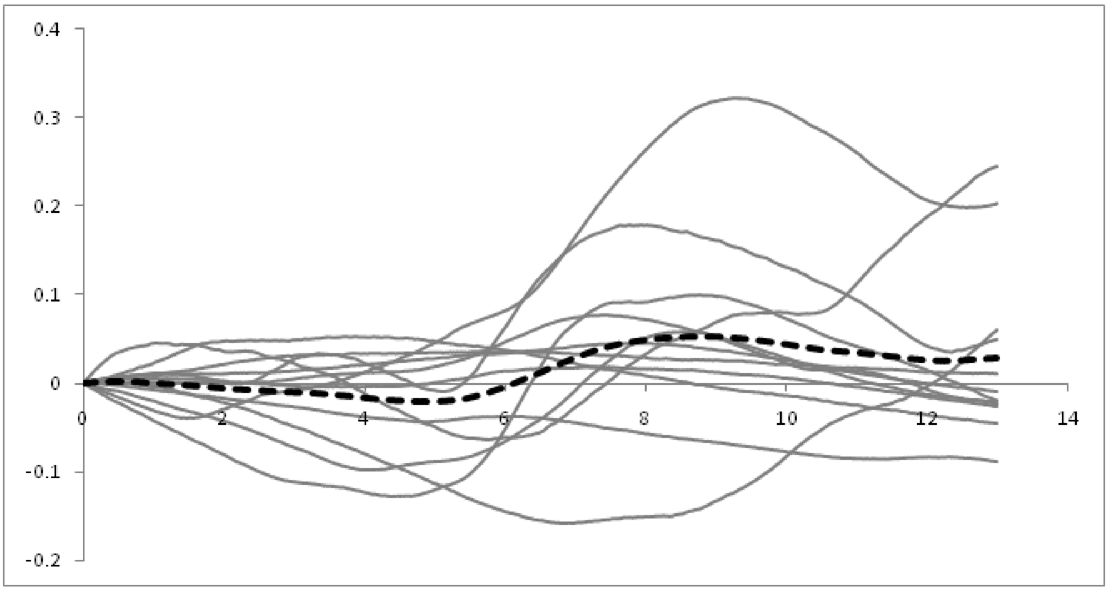

Figure 4: Significant changes during performance of easy MA task of 12 subjects along with their averaged result (dotted line).

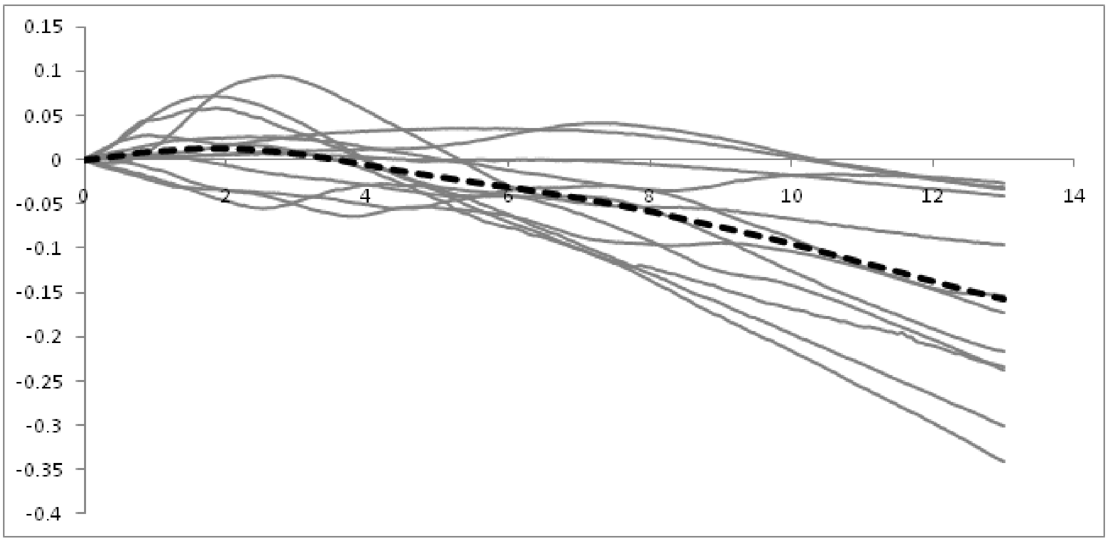

Figure 5: Significant changes during performance of calculative MA task of 12 subjects along with their averaged result (dotted line).

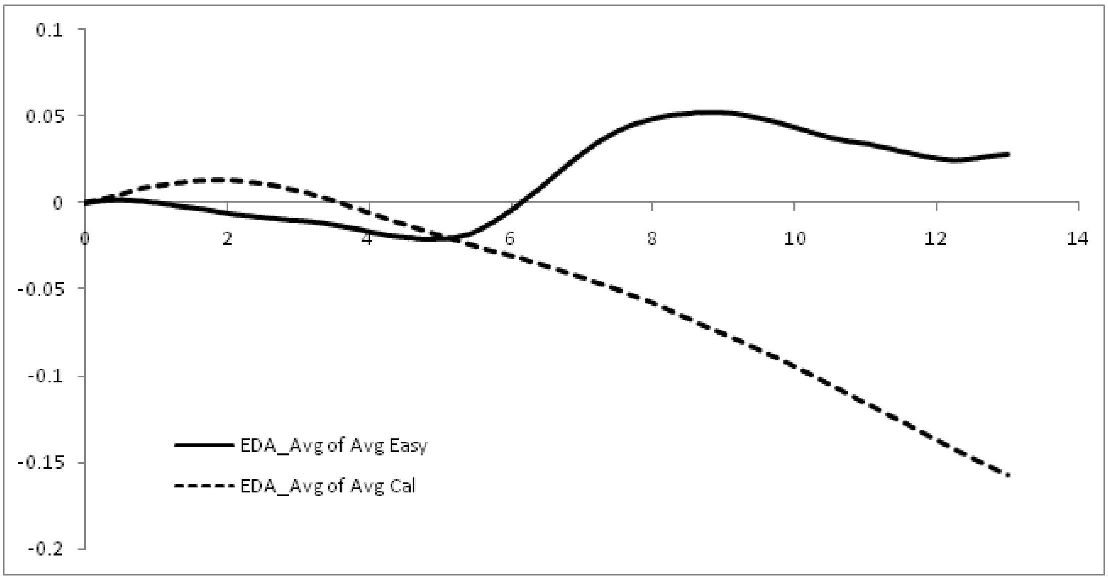

Figure 6: Comparison of the average of 12 subjects on performance of Easy and Calculative MA tasks.

Discussion

In this study, the variations caused in EDA upon subjection to two levels of MA tasks, *i.e.*, easy and calculative, have been analyzed. A clear pattern of separation can be identified among the two different tasks in EDA signals. During the time when the brain is focused on task performance, there is a decrease in EDA response and vice-versa when the task is complete. This can be clearly understood from the fact that the easy task took about 4-5 seconds for the subjects, and there is a variation in the signals that were observed only after easy task performance time. Whereas, the calculative task kept the subjects focused and the entire time was spent in task performance; the signals maintained a proximity to the baseline. It was observed that upon statistical analysis using *t*-test, the average of all the 12 subjects gave a significant result for $P<0.01$.

The Electrodermal Activity (EDA) has shown an increase in the EDA response for easy tasks in comparison to the calculative tasks which depicts sympathetic suppression in response to the cognitive suppressor that is mental arithmetic here. This result is in contrary to that obtained in some of the previous studies [12, 13]. As EDA is solely defined by the sympathetic branch of ANS, which is seen here in this experiment to be of a lesser value in increased task difficulty situation, thus it can be said that there is a decrease in the sympathetic activity of the ANS during the calculative task when compared to the easy MA task. Based on the results obtained, the MA can also be advocated as a suitable alternative to motor imagery for implication in Brain-Computer Interfaces.

Conclusion

In the present study, dual levels of mental tasks have been analyzed. The results show that there is a clear separation of the EDA signal of all the subjects for the easy and calculative MA tasks. This separation occurs in a definite initial period of task propagation and can be used as an important feature in the application for MA-based Brain-Computer Interface system. Further studies in using MA-based systems using EDA need to be carried out and it has the potential for development of a communication device who are in a locked-in state through a binary switch governed by changes in the skin potentials of such individuals.

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Eye Fixation Based Pulse Rate Variability as Switching Signal for Human-Machine Interface

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Abstract

In the condition of declining mental health the effect is usually visible with skeletal muscles being the most common in getting effected. Various studies on biosignals are being carried out, but because of the volume of data being very large the application of processing tools such as the Artificial Neural Network (ANN) are rapidly increasing. In the present work, the recording of pulse plethysmogram (PPG) and Electrooculogram (EOG) has been carried out here on five healthy subjects. Further, analysis of interpolated PPG (IPPG) has been done and backpropagation ANN applied on the processed data for studying the eye gaze and the resting periods. Upon testing and analysis, 75–60–1 is found to be the optimum ANN frame among others. Also, the IPPG analysis showed slow decline in the pulse rate on the onset of gaze period followed by a rise in pulse rate on the onset of relax period.

Introduction

1. Brain-machine interfaces have been established to be the counterparts who are playing an important role in providing a direct communication pathway between brain and external devices which can assist the human sensory-motor functions [1].
2. Seminal, native methods are also being adapted and bio-signals apart from electroencephalogram (EEG), such as electrooculogram (EOG) are being given importance for the development of a hybrid system, human machine interface.
3. Studies have shown artificial neural network (ANN) to be an accurate and reliable method for diagnosis and prediction of results [2].
4. Encouraged with the significant results obtained in past on the biosignal classification with the ANN, this work being presented here is aimed to show the effect of the mental efforts on photoplethesmogram, if any, developed due to prolonged eye-gaze. Furthermore, an ANN based model has also been proposed for the prediction of eye-gaze modulated outcome.

Materials and Methods

Subjects and the Experimental Paradigm:

Subjects: Five young and healthy volunteers took part in the study as subjects, without being paid (age: 20-30 years; weight: 55-66 kg**)** and the whole study was made in compliance with the Helsinki declaration.

Signals: Electrooculogram (EOG); Electrocardiogram (ECG); Pulse plethysmogram (PPG); Galvanic skin response (GSR).

Setup and Paradigm: Four-channel BIOPAC MP35 ultimate system with BSL 3.7 software has been used for signal acquisition with the assistance of a paradigm designed on Microsoft Office PowerPoint 2007 (Figure 2).

Electrode Placement: The PPG signal was recorded from the distal phalanges of the index finger of left hand and EOG was recorded by using three electrodes, one above the nasion, and two below the outer canthi of each eye, making a right-angled triangle as explained by Scherer *et al* [3] (Figure 1 & 3).

Classifier: A back-propagation ANN simulation program written in C++ programming language is used for differentiating the PPG data between the gaze and the resting period [5].

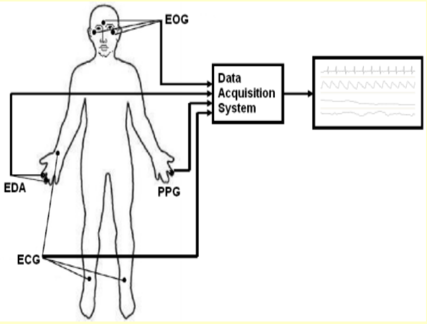


Figure-1: Electrode positions and data acquisition**.**

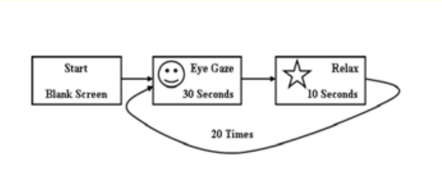
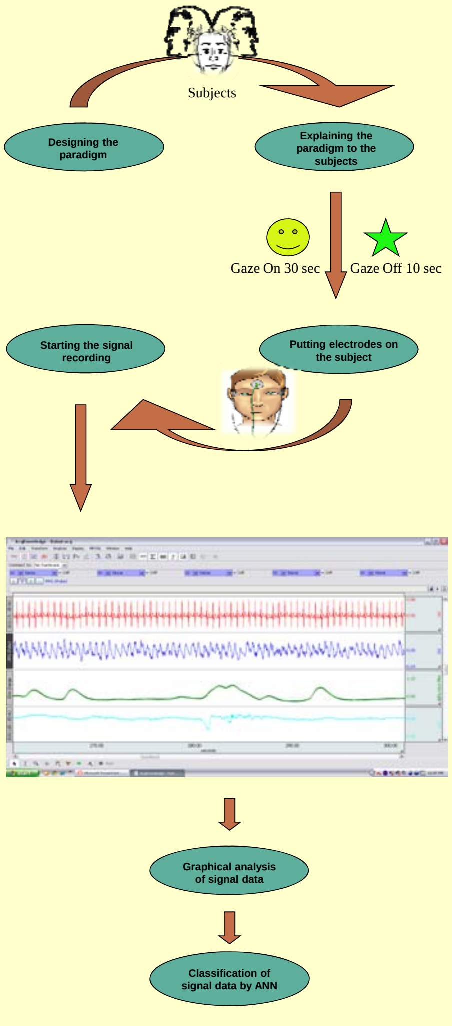


Figure-2: Experimental paradigm showing gaze and relax period.


Subjects

Designing the paradigm

Explaining the paradigm to the subjects

Gaze On 30 sec

Gaze Off 10 sec

Starting the signal recording

Putting electrodes on the subject

Graphical analysis of signal data

Classification of signal data by ANN

Figure-3: Flow diagram depicting the experimental procedure.

Results

1. A decreasing trend in pulse rate has been observed during the gaze period of 30 seconds, which comes to normal during 10 seconds of relaxation period (Fig. 4).
2. The obtained results suggested the role of autonomic responses under mental effort as demonstrated earlier [4].
3. The single hidden layered neural network was tested for differentiating PPG data between Gaze and Relax conditions with varied learning rate (0.01 to 0.7) and number of nodes in hidden layer (2 to 60) (table I & II) which gave the best accuracy of 61.66% in pattern classification at the learning rate of 0.1 and with ANN architecture of 75-60-1, respectively.

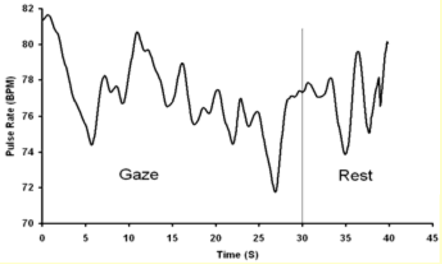


Figure-4: Variation of pulse rate (beats per minute) with respect to time during 30 seconds of gaze followed by 10 seconds of rest.

Table-I. Effect of learning rate on classification accuracy

Learning Rate	Accuracy % test pattern
0.01	60.85
0.1	61.66
0.2	60.85
0.4	57.10
0.6	60.75
0.7	58.98

Table-II. Effect of Hidden layer nodes on classification accuracy

Hidden Nodes	Accuracy % test pattern
2	56.42
5	60.85
10	60.32
20	57.64
30	60.85
50	58.98
60	61.66

Conclusion

1. The findings of this experiment suggest that the mental stress produced by constant and prolonged eye gaze influences the changes in the changes in pulse rate and mean interpolated pulse peak to peak interval which can be suggested to have occurred due to changes in the autonomic responses.
2. Upon classification the % accuracy of 61.66 was not good for simulation; however, the accuracy can further be improved with enhanced statistical analysis and with defined pattern that can be achieved by further experimentation.
3. With these findings it can be proposed that the present system may be used for development of rehabilitative and assistive devices for the stroke people.
4. Also, it can be suggested that variations in autonomic responses with mental effort can be used for the switching command for MMI (Man-Machine Interface).

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