Defence Life Science Journal, Vol. 6, No. 3, July 2021, pp. 197-204, DOI : 10.14429/dlsj.6.15616

Using Functional Near Infrared Spectroscopy to Assess Cognitive Workload

D. Ravi*, K. Ramachandran, Pushpendra Kumar Singh and Mistu Mahajabin

DRDO-Defence Institute of Psychological Research (DIPR), Delhi - 110 054, India

**E-mail: dravi@dipr.drdo.in*

ABSTRACT

Quantification of mental workload is a significant aspect of monitoring and adaptive aiding systems that are intended to improve the efficiency and safety of human–machine systems. Functional near Infrared (fNIR) spectroscopy is a field-deployable brain monitoring device that provides a measures of cerebral hemodynamic within the prefrontal cortex. The purpose of this study was to assess the cognitive load by using Performance (reaction time), Behavioral metrics (NASA TLX) and Neuro-Cognitive Measures (Hemodynamic response). To observe the activation in prefrontal cortex, we employed Functional Near Infrared (fNIR) Spectroscopy with a Standard Stroop task. A total of 25 healthy participants (*N* 18 Male and N 07 Female, *M* Age 25.5 *SD* 7.6), participated in the study. For statistical analysis, a repeated measure t-test was computed to compare the Oxy (Δ[HbO2]) and De-Oxy (Δ[hHb]) changes under Congruent and In-Congruent task conditions. For Classification, Binary logistic regression model applied to identify how accurately classifying the varied workload conditions. The finding shows that fNIR measures had adequate predictive power for estimating task performance in workload conditions. In this paper, we have found evidence that fNIR can be used as indicator of cognitive load which is important for optimal human performance.

Keywords: fNIRs; Stroop task; Prefrontal cortex; Hemodynamic responses; Cognitive work load

1. INTRODUCTION

Since 1960s several studies have been started on mental workload when the human-machine systems evaluation had begun[1]. Mental workload may be viewed as the difference between the capacities of the information processing system that are required for task performance to satisfy performance expectations and the capacity available at any given time[2]. In the neuro-ergonomic research, mental workload (MWL) is one of the vital concepts which have been invoked special attention[3-4]. Several studies have been reported that due to high workload conditions leads to dramatically decrease of human performance and/or an increase in the error[5].The vital reason for quantifying mental workload is the prediction of the operator performance and it will ultimately lead to the improvement of working conditions[6].

With the advent of new technologies (Electroencephalography, Magneto-encephalography, Positron Emission Tomography and functional Magnetic Resonance Imaging) one can recognise the neuro-physiological markers. These non-invasive methods allow us for monitoring brain activity during human performance. Particularly EEG and Event related potentials (ERPs) are the strong candidates for accurate, objective measures of operator workload. EEG has excellent temporal resolution for monitoring mental workload, but, it is limited in its capacity for spatial resolution and easily susceptible to electromagnetic artifacts. Other physiological measures like fMRI, PET and MEG are contributing a lot to understand the neural basis of mental workload. However in real world tasks it is limited because it is not portable and are expensive. They are very sensitive to motion artefact, participants are needed to be in confined positions, exposed to loud noise and potentially harmful materials. Apart from this, to measure the perceived workload self-reported measures helps to quantify the workload, stress and demand a task places in an operator such as Subjective Workload Assessment Technique (SWAT) Crew Status Survey, NASA Bipolar Rating Scale, Modified Cooper-Harper Scale, Subjective workload dominance (SWORD), self-reported mental effort, Malvern Capacity Estimate (MACE) and NASA Task Load Index. These measures are easy to administer, economical, and widely accepted. Moreover it has certain inherent limitations over other methods because of the subjectivity in it.

In this study, we utilised functional near Infrared spectroscopy (fNIRs) as an optical measure of neural activity, to detect hemodynamic variation in the cortex in responding to motor, cognitive or sensory activation[7]. It's a better measure for mental workload under varied field conditions and it is resilient to movement artefact. It is a portable, safe, affordable and negligibly intrusive neuro-imaging tool, which enables the study of cognition-related hemodynamic changes of cortical brain areas in various field conditions[8]. fNIR can be deployed for the hemodynamic response, particularly in dorsolateral prefrontal cortex[7,9]. It provides relative changes in hemoglobin levels when there is an increased neuronal activation. In relation to cognitive workload, existing studies demonstrates

Received : 20 March 2020, Revised : 02 March 2021
Accepted : 24 March 2021, Online published : 27 July 2021

that fNIRs can be used to gauge the changes on oxygen concentration in the prefrontal cortex in relation to the demand placed upon individuals. The metabolic state of the brain associated with cognitive state could be measured through NIR based functional optical brain imaging sensor[10]. Lots of studies were conducted to assess cognitive workload using functional infrared spectroscopy under controlled complex mental task[11]. Outcomes revealed that fNIR were sensitive to increased task difficulty especially at left inferior frontal gyrus[7,12]. Research efforts underway to apply fNIR technology to monitor mental workload towards field applications particularly in aviation sector to increase the safety of air travel and other high-risk activities[13.]

The present study is to ascertain the sensitivity of fNIRs to estimate the cognitive load of an individual. Existing studies administered N back task to study the working memory load of an individual. But not much research has utilised Stroop task as an index of cognitive load. In this task individual's speed of cognitive processing, attention and their level of cognitive control (otherwise known as their executive function) will be assessed. Its effective index of cognitive load by the assumption that naming the color is difficult than reading the word when there is an incongruence with word and color. Further to ascertain this we measured both behavioral and self-reported measures along with fNIRs. This kind of study helps the application of fNIRs in neuro-ergonomic research.

2. METHODOLOGY

2.1 Objective

To estimate the cognitive workload through optical brain monitoring.

2.2 Participants

A total of 25 healthy participants, 18 males and 7 females, participated in the study (*M* 25.5 *SD* 7.6). Participants had normal vision and no history of any physical, mental, or psychological disorder. The experiments were conducted in agreement with verbal consent was acquired from all the participants after explaining the experimental protocol. To avoid the learning effect, the participants who were selected had no previous experience with the Stroop task and Perceived Task Load index (NASA TLX).

2.3 Apparatus and Materials

2.3.1 Functional Near Infrared Spectroscopy

The prefrontal cortex of the participants is monitored throughout the experiments, using a continuous wave fNIR system. It comprised of three modules such as 16 Optodes flexible sensor pad, which has light emitting diodes (LED) and detectors, a control box for managing hardware and acquisition software for data analysis(COBI studio).The fNIR system operated with a sampling frequency of 2Hz. The LEDs were triggered one light source at a time and the four surrounding photo detectors around the active source were sampled. The positioning of the light sources and detectors on the sensor pad yielded a total of 16 active optodes (channels) and was designed to monitor dorsal and inferior frontal cortical areas underlying the forehead[14]. Data gathered is calculated on the principles of Beer–Lambert Law. Acquiring, processing and visualising fNIR signals were possible through COBI (Cognitive Optical Brain Imaging) Studio.

2.3.2 NASA-TLX (Hart, S.G 2006)

It's a subjective workload index during or after the performance of a task. It consists of six subscales such as mental, physical, temporal demands, frustration, effort, and performance. The first three of the subscales indicates demands on the subject and the last three is indicates the interaction of the participant with the task. Since the scale consist of different dimensions of workload, the subjects could select among the variables to represent the workload experienced on the task[15]. Each dimension is rated on score between 0 and 100 (Twenty-step bipolar scale with each step has a value of 5).Combination of these six dimensions gives the overall workload of the subjects.

2.3.3 Stroop Task (John Ridley Stroop 1935)

The stroop effect is basically the interference that occurs to the naming of the color by the word written. There are several versions for stroop tests. However, the basic principle is the same that compares the performance on the basic task such as reading names of colors with analogous task (naming the ink color that incongruously named color words are written in). There are 3 types of stimuli in stroop test: congruent, incongruent and neutral. When the ink color and the word are same, it is called congruent stimuli. Incongruent stimuli are the word and ink color doesn't match. When only text is there, it is called neutral stimuli[3]. In this version, there are two tasks with 112 words written in 4 columns in each task. The color and name of the word are non-congruent in both tasks. There are four colors namely RED, BLUE, GREEN and TAN. In the first task, the subject supposed to read the word irrespective of the color in which it is written ("word" is important). For example, read as 'RED' if the word written as 'RED' even if the color in

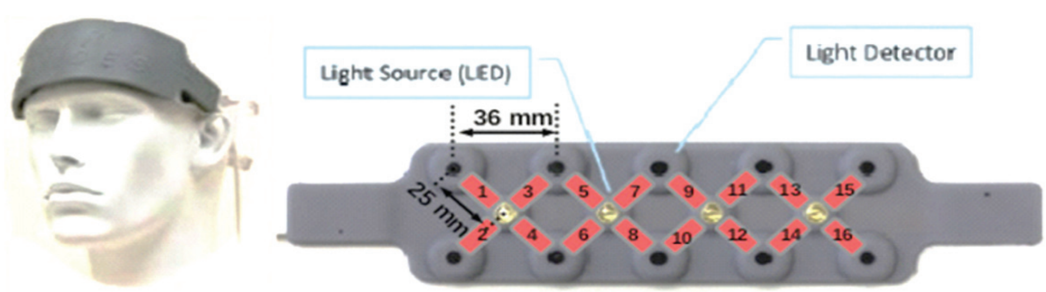

Figure 1. 16-Channel fNIRs System.

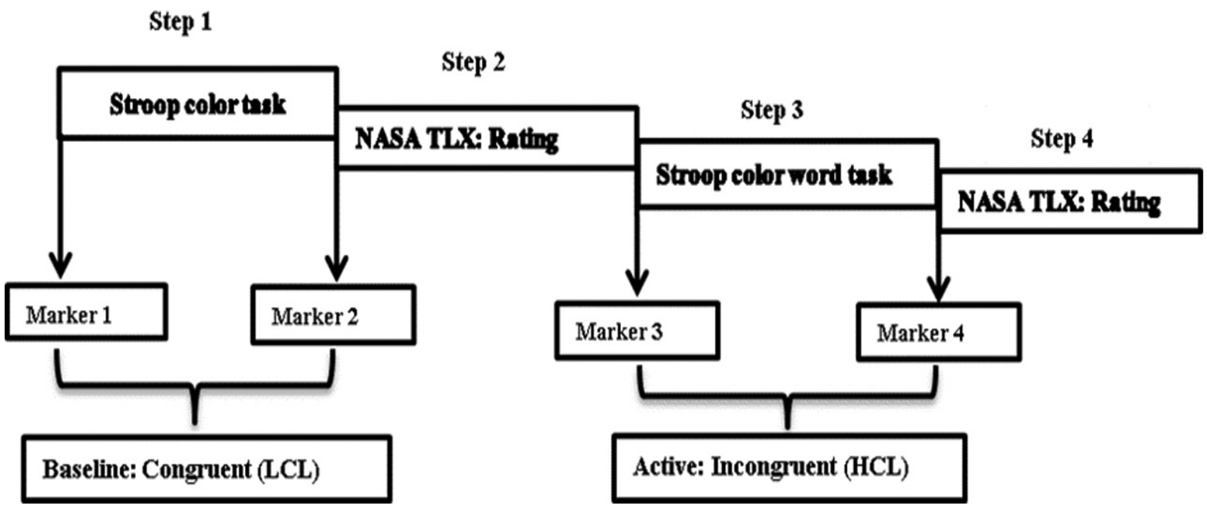

Figure 2. Schematic diagram of experimental procedure.

Table 1. Mean, standard deviation and significance level between congruent and incongruent conditions in response latency (milliseconds).

		M	N	SD	SEM	t	Df	p
RT(ms)	In Congruent	117443.4 ms	25	4291	796.8	44.9	28	0.00**
	Congruent	56716.5 ms	25	7412	1376			

Note: RT: Response Latency *** $p < 0.00$** $p < 0.01$ and * $p < 0.05$

which it is written as 'BLUE''. In the second task the subject need to name the color of the word regardless of the word in which it is written ("color" is important). The maximum time required to conduct stroop task is only 5minutes. Performance is assessed based on the time taken to complete the task and the total number of correct responses.

2.4 Procedure

Participants were seated in a quiet room on a comfortable chair in front of a computer monitor and were asked to restrict their motor motions before the start of the experimental paradigm. The duration of the tests ranged from 15 min. to 30 min. depending upon the time taken to calibrate the fNIRs device. Primary steps to acquire the noise free data are to fix the sensor pad appropriately and it shouldn't create artefacts. Further to get the proper signal hold the sensor pad with the palm of our hands to place onto the subjects' forehead. To ensure that all 10 sensors have adequate contact with the subjects' forehead or else change the tightness of the headband. Subsequently, instructed the subject to perform the stroop color naming tasks and NASA-TLX.

2.5 Experimental Protocol

Block paradigm (Fig. 2) was adapted to study the Stroop effect. In the first block Stroop color task(CT) is administered and the subject has supposed to read the words on the form as quickly as they can. The subjects are given for 120 seconds to complete the task. After the completion of the color task, the color-word task (CWT) is administered here the subject has to name the color of the ink (red, blue, green, or tan) in which the word is printed. The other regulations are same as of Stroop color task. Further to quantify the performance, response latency, was calculated from the two levels (color task &color-word task). Each participant's oxy and de-oxy changes were recorded and data were segmented through manual markers. Further subjective workload measures (NASA TLX) administered after each tasks.

2.6 Data Analysis

Data was analysed statistically using both descriptive and inferential statistics. For each participant, raw data (16 Optodes ×2 wavelengths) were filtered (low-pass) into a finite impulse response, linear phase filter and cut-off frequency of 0.1 Hz to attenuate the high frequency noise, respiration and cardiac cycle effects[11,16]. Using Modified Beer Lambert Law, Oxy and De-oxygenation hemoglobin changes for all the 16 optodes were calculated. In the preliminary analysis, the noisy data from Optodes 2, 11, and 13were discarded due to head motion or improper fixing of fNIR sensors. Remaining signals from 13 optodes were pre-processed and analysis for 13 optodes (features) and all the raw data was transformed in to standardised Z score. Normality and heteroscedasticity were assessed for that Kolmogorov-Simonov tests were applied. For data analysis paired – sample t-test were applied to compare the Oxy (Δ[HbO 2]) and De-oxy (Δ[hHb]) changes under different experimental conditions. For classification, Binary logistic regression was applied to classifying the workload conditions. Data analyses were performed in R studio.

3. RESULTS AND DISCUSSION

3.1 Behavioral Measure

Results (Table 1) showed that the mean response latency of incongruent condition (*M* 117443.4, *SD* 4291) was higher than congruent condition (*M* 56716.5, *SD* 7412) and it was

Table 2. Mean, standard deviation and significance level between congruent and incongruent conditions in NASA TLX

Parameters		N	Mean	SD	95 % CI		t	df	Sig.
					LL	UL			
Mental Demand	Congruent	25	31.1	21.6	-12.6	-3.05	3.41	24	**0.00*****
	Incongruent	25	39.0	23.6					
Physical demand	Congruent	25	12.0	12.4	-8.11	1.16	1.56	24	0.13
	Incongruent	25	15.5	16.2					
Temporal Demand	Congruent	25	30.8	24.1	-8.6	5.98	0.38	24	0.70
	Incongruent	25	32.1	24.7					
Operational Demand	Congruent	25	30.5	25.1	-11.6	11.68	0.00	24	1.00
	Incongruent	25	30.5	25.3					
Effort	Congruent	25	30.3	23.7	-10.8	1.11	1.69	24	0.10
	Incongruent	25	35.2	25.2					
Frustration	Congruent	25	20.9	24.2	-8.87	10.20	0.14	24	0.88
	Incongruent	25	20.2	21.1					

Note: *** p < 0.00

Table 3. Mean, standard deviation and significance level of oxy hemoglobin (Δ[HbO 2]) under congruent and incongruent conditions

Parameters		Mean	N	SD	95% CI		t	df	Sig
					L	U			
Opt 1: HbO2	Congruent	0.34	25	0.15	-.171	-.031	2.97	24	0.00***
	Incongruent	0.44	25	0.22					
Opt 3: HbO2	Congruent	0.33	25	0.22	-.243	-.015	2.32	24	0.02*
	Incongruent	0.46	25	0.28					
Opt 4: HbO2	Congruent	0.34	25	0.18	-.196	-.020	2.54	24	0.01**
	Incongruent	0.44	25	0.28					
Opt 5: HbO2	Congruent	0.22	25	0.10	-.141	-.023	2.88	24	0.00***
	Incongruent	0.30	25	0.21					
Opt 6: HbO2	Congruent	0.29	25	0.17	-.200	-.049	3.39	24	0.00***
	Incongruent	0.41	25	0.24					
Opt 7: HbO2	Incongruent	0.33	25	0.15	-.155	-.042	3.62	24	0.00***
	Congruent	0.43	25	0.20					
Opt 8: HbO2	Incongruent	0.36	25	0.15	-.210	-.048	3.27	24	0.00***
	Congruent	0.49	25	0.22					
Opt 9: HbO2	Incongruent	0.51	25	0.09	-.148	-.022	2.79	24	0.01**
	Congruent	0.60	25	0.19					
Opt10:HbO2	Incongruent	0.36	25	0.15	-.268	-.108	4.85	24	0.00***
	Congruent	0.54	25	0.23					
Opt12:HbO2	Congruent	0.37	25	0.08	-.158	-.029	3.01	24	0.00***
	Incongruent	0.47	25	0.17					
Opt14: HbO2	Congruent	0.35	25	0.15	-.164	-.017	2.53	24	0.01**
	Incongruent	0.44	25	0.21					
Opt15: HbO2	Congruent	0.41	25	0.13	-.212	-.099	5.69	24	0.00***
	Incongruent	0.57	25	0.18					
Opt16: HbO2	Congruent	0.36	25	0.14	-.143	-.029	3.12	24	0.00***
	Incongruent	0.45	25	0.20					

Note: Opt: Optodes, HbO2: Oxy Hemoglobin, Sig: *** p < 0.00, ** p < 0.01 and * p < 0.05.

Table 4. Mean, standard deviation and significance level of de-oxy hemoglobin (Δ[hHb]) under congruent and incongruent condition

		Mean	N	SD	95 % CI		t	df	Sig
					L	U			
Opt 1HbR	Congruent	0.61	25	.08	0.05	0.20	3.59	24	0.00***
	Incongruent	0.48	25	.22					
Opt 3HbR	Congruent	0.81	25	.08	0.06	0.23	3.77	24	0.00***
	Incongruent	0.66	25	.22					
Opt 4HbR	Congruent	0.64	25	.10	0.03	0.17	3.19	24	0.00***
	Incongruent	0.53	25	.20					
Opt 5HbR	Congruent	0.63	25	.10	0.02	0.16	2.88	24	0.00***
	Incongruent	0.53	25	.18					
Opt 6HbR	Congruent	0.50	25	.10	-0.04	0.12	0.95	24	0.34
	Incongruent	0.46	25	.23					
Opt 7HbR	Congruent	0.59	25	.08	-0.01	0.13	1.61	24	0.12
	Incongruent	0.53	25	.22					
Opt 8HbR	Incongruent	0.60	25	.15	0.03	0.19	2.88	24	0.00***
	Congruent	0.48	25	.23					
Opt 9HbR	Incongruent	0.46	25	.08	0.01	0.16	2.33	24	0.02*
	Congruent	0.37	25	.23					
Opt 10HbR	Incongruent	0.47	25	.11	0.02	0.18	2.72	24	0.01**
	Congruent	0.37	25	.20					
Opt 12HbR	Congruent	0.78	25	.10	0.05	0.17	4.01	24	0.00***
	Incongruent	0.66	25	.19					
Opt 14HbR	Congruent	0.73	25	.09	0.09	0.25	4.64	24	0.00***
	Incongruent	0.55	25	.20					
Opt 15 HbR	Congruent	0.59	25	.05	0.03	0.15	3.01	24	0.00***
	Incongruent	0.49	25	.17					
Opt 16HbR	Congruent	0.59	25	.15	0.06	0.20	3.81	24	0.00***
	Incongruent	0.45	25	.19					

Note: Opt: Optodes, HbR: De-Oxy Haemoglobin, Sig: *** $p < 0.00$, ** $p < 0.01$, * $p < 0.05$

statistically significant, t (28) = 44.9, P 0.00. It shows added time required to cognitively processing the details of task irrelevant condition (Incongruent) and they have to filter or inhibit their automatic processing and it requires selective attention to do the task.

3.2 Self-Reported Ratings of Workload

Subjects' rating of NASA task load index, shows (Table 2) that the mean score of Mental demand in incongruent condition (M 39, SD 23.6) was higher than congruent condition (M 31.1, SD 21.6) and it was statistically significant t (24) = 3.41, P < 0.00. It reveals that incongruent condition the subject has to cognitively control or inhibit their automatic process i .e reading to engage in color naming needs additional cognitive demands like cognitive control and selective attention to do the task. Remaining facets of workload other than mental demand was relatively higher in incongruent condition, but not statistically significant. Eventually both behavioral (response latency) and self-reported measures (NASA-TLX) stated that stroop inference task has induced certain extent of cognitive load to a person. Further to find out that fNIRs has applied to estimate the cognitive load.

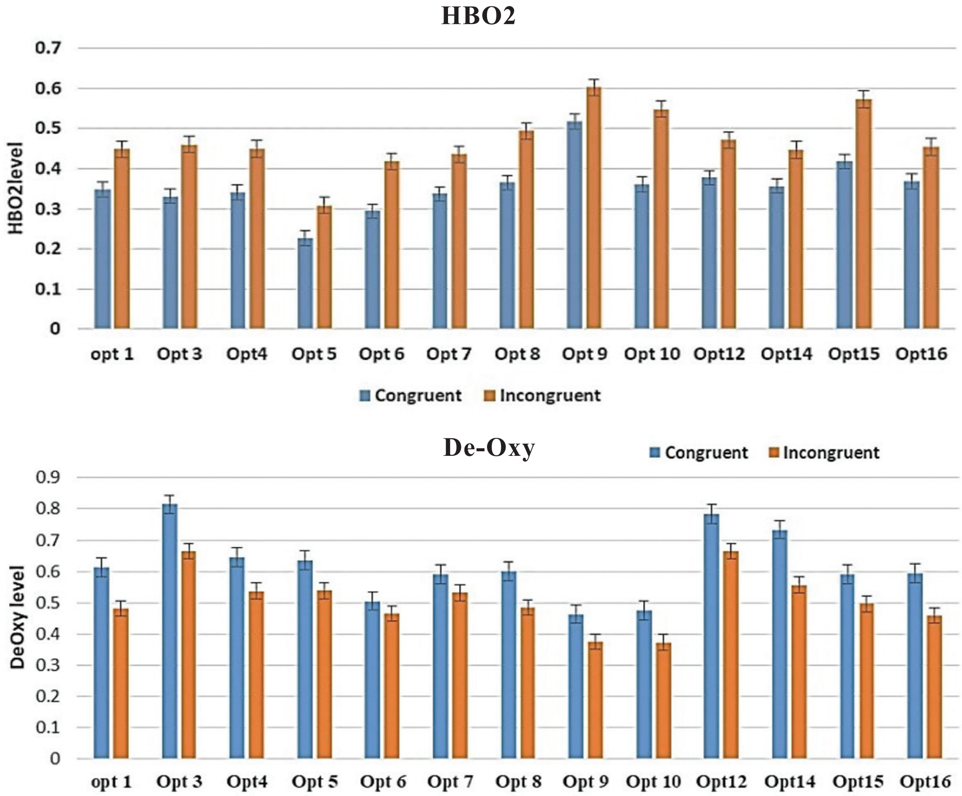

Figure 3. Mean Oxy and De-Oxy level in congruent and incongruent condition.

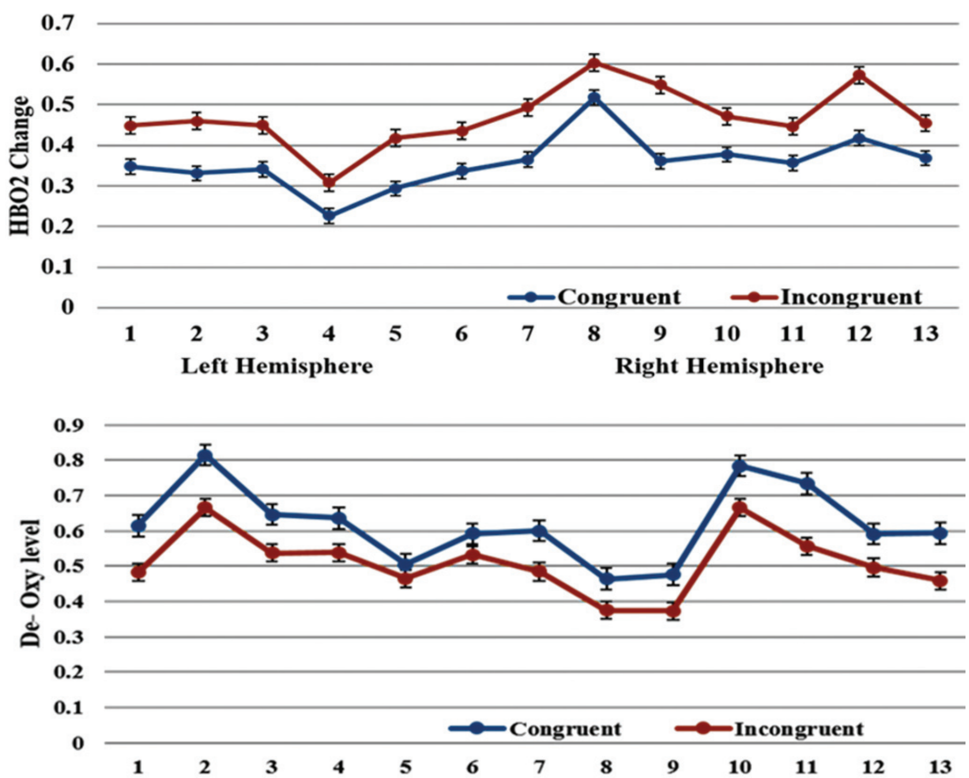

Figure 4. fNIRs Optodes on the prefrontal cortex.

3.3 Workload and Hemodynamic Response

In the data analysis, repeated measure t test shows all the optodes are statistical significant under congruent and incongruent conditions (Table 3 and Table 4). It reveals that under incongruent condition the subject has to name the color of the ink (red, blue, green, or tan) in which the word is printed, it needs lot of cognitive resources (cognitive control, attention and decision-making) to do the task and it takes more blood oxygenation level in the prefrontal cortex. Individual attention demands were higher on Incongruent task due to task-irrelevant information directly conflicted with the task-relevant information. This is in-line with the previous study conducted on undergraduates and found that with increase of working memory load, there is a linear increase in the activation in bilateral prefrontal cortex[17]. Similarly fNIRs brain imaging as a measure of cognitive workload and could find out association between increasing workload and changes in blood oxygenation in relevant areas of the frontal and dorso-lateral prefrontal cortex[12]. Further to examine the frontal asymmetry, respective optodes from each hemispheres oxy and de-oxy changes were compared and found that there is no statistically significant difference in right and left Prefrontal cortex under congruent and incongruent interference condition. To reason that, the task may not have demanded strongly lateralised functions.

For prediction binary logistic regression models applied for that average oxygen and De oxygen level were used as features to classify the congruent and incongruent condition. The results of binary logistic regression analysis of the data showed that the logistic regression model was statistically significant, x^2 = 12.4, DF =1, P<.001 indicating that the independent variables significantly predicted the outcome variable. Data analysis presented in Table 5 show the logistic regression beta coefficients and Wald test, of the predictor variables. Further Cox & Snell, and Nagelkerke R squared estimates indicated that the logistic model explained between 22 per cent and 29 per cent of the variance that can be predicted from the independent variables (Oxy and De-oxy). Results show that both Oxy and De-oxy changes are significantly classifying the workload (congruent/

Table 5. Binary logistic regression for De-Oxy Hemoglobin (Δ[hHb]) under congruent and incongruent condition

	B	S.E.	Wald	df	Sig.	Exp (B)	95% C.I. for EXP(B)	
							LL	UL
De-Oxy	-11.04	3.91	7.94	1	.005	0.00	0.00	0.03
Constant	6.32	2.30	7.54	1	.006	559.50		

Table 6. Classification matrix for binary logistic regression model

Observed		Predicted		
		Category		%
		Congruent	Incongruent	
Category	Congruent Task	20	5	80.0
	Incongruent Task	8	17	68.0
Overall Percentage 74%				

Incongruent conditions). Binary logistic model (Table 6) classified correctly 80 per cent of the congruent task and 68 per cent of incongruent task, for an overall classification success rate 74 per cent (sensitivity 71.4 % and specificity 77.2 %). Result confirmed that the two different engagement levels could be discriminated.

This is in line with previous neuro-ergonomics studies shows brain optical imaging technique is well suited for mental state monitoring in ecological situations[13,5,8,7]. It confirms that fNIRs is a sensitive parameter to estimate the cognitive workload and its applicability in the field related to human cognition. Additionally, this study proves that fNIRs brain imaging technique may be used for Brain Computer Interface (BCI). Apart from that, the accurate estimation of cognitive workload can be used to identify work over and under load so that necessary precautions could be taken in order for safety in transportations and optimal performance on dealing with machines.

4. CONCLUSION

In this study, we obviously reveal that functional near infrared spectroscopy is able to detect the functional hemodynamic changes associated with the changes in cognitive load in frontal lobe. Findings signify an important step forward in the on-going enhancement of the Classification accuracies of fNIRs-based Brain computer Interface (BCI) systems and it can be used for optimizing the human performance.

5. LIMITATIONS

fNIR is not superior in spatial resolution even though it has excellent temporal resolution. Difficulty in precisely localizing the fNIRs signals due to the inability to independently verify fNIRs Optode with respect to corresponding brain regions in frontal lobe.

REFERENCES

1. Hancock, P. A. & Desmond, P. A. (Eds.). Stress, workload, and fatigue., 2001, Mahwah, NJ: Lawrence Erlbaum Associates.
2. Gopher, D. & Donchin, E. (1986). Workload: An examination of the concept, In Boff, K.R., Kaufman, L. & Thomas, J.P. (Eds.), *Handbook of Perception and Human Performance.* Wiley & Sons.
3. Loft, S.; Sanderson, P.; Neal, A. & Mooij, M. Modeling and predicting mental workloadin en route air traffic control: critical review and broader implications. human factors, 2007, **49**(3), 376-399.
4. Wickens, C.D. Multiple resources and mental workload. *Human Factors*, 2008, **50**(3), 449-455.
5. Reason, J. Human error: Models and management. *BMJ (Clinical research ed.)*, 2000, **320**(7237), 768–770.
6. Cain, B.A. Review of the mental workload literature. Defence Research and Development, Toronto, Canada. 2007.
7. Ayaz, H.; Shewokis, P.A.; Bunce, S.; Schultheis, M.; & Onaral, B. Assessment of cognitive neural correlates for a functional near infrared-based brain computer interface system. In Schmorrow, D. D., Estabrooke, I.V., & Grootjen, M. (Eds.), Foundations of augmented cognition: Neuroergonomics and operational neuroscience. Springer, Berlin, Heidelberg. 2009.
8. Izzetoglu, K.; Ayaz, H.; Merzagora, A.; Izzetoglu, M.; Bunce, S.; Shewokis, P. & Onaral, B. fNIR Spectroscopy Studies in Humans. *In* Conference Abstract: 10th International Conference on Cognitive Neuroscience. 2008.
doi: 10.3389/conf.neuro.09.2009.01.356
9. Bunce, S.; Izzetoglu, M.; Izzetoglu, K.; Onaral, B.; & Pourrezaei, K. Functional near-infrared spectroscopy. IEEE engineering in medicine and biology magazine : The quarterly magazine of the engineering in medicine & biology society, 2006, **25**, 54-62.
doi: 10.1109/MEMB.2006.1657788.
10. Izzetoglu, K.; Bunce, S.; Izzetoglu, M.; Onaral, B. & Pourrezaei, K. fNIR spectroscopy as a measure of cognitive task load. Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2003, **4**, 3431–3434.
11. Ayaz, H.; Izzetoglu, M.; Shewokis, P. & Onaral, B. Sliding-window motion artifact rejection for functional near-infrared spectroscopy. *In* Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2010, 6567-70.
doi: 10.1109/IEMBS.2010.5627113.
12. Izzetoglu, K.; Bunce, S.; Onaral, B.; Pourrezaei, K. & Chance, B. Functional optical brain imaging using near-infrared during cognitive tasks. *Int. J. Human–Comput. Interact.*, 2004, **17**(2), 211-227,

doi: 10.1207/s15327590ijhc1702_6

13. Harrison, J.; Izzetoglu, K.; Ayaz, H.; Willems, B.; Hah, S.; Ahlstrom, U.; … Onaral, B. Cognitive workload and learning assessment during the implementation of a next-generation air traffic control technology using functional near-infrared spectroscopy. *Human-machine Syst.*, 2014, **44**, 429-440.
doi: 10.1109/THMS.2014.2319822.
14. Zhang, H.; Hussain, A.; Liu, D. & Wang, Z. Advances in brain inspired cognitive systems. 5th International Conference. Shenyang, Liaoning, China. 2012.
15. Hart, S.G. Nasa-Task Load Index (NASA-TLX); 20 Years Later. Proceedings of the human factors and ergonomics society annual meeting, 2006, **50**(9), 904–908.
doi: 10.1177/154193120605000909.
16. Izzetoglu, M.; Izzetoglu, K.; Bunce, S.; Ayaz, H.; Devaraj, A.; Onaral, B. & Pourrezaei, K. Functional Near-Infrared Neuroimaging. *Neural Syst. Rehabil. Engg.,* 2005, **13**, 153-159.
doi: 10.1109/TNSRE.2005.847377.
17. Fishburn, F.A.; Norr, M.E.; Medvedev, A.V. & Vaidya, C.J. Sensitivity of fNIRs to cognitive state and load. *Front. Human Neurosci.*, 2014, **8**, 76.
doi: 10.3389/fnhum.2014.00076.

CONTRIBUTORS

Dr D. Ravi obtained PhD in Psychometrics from Bharathiar University Coimbatore. He is currently working as Scientist at DRDO-DIPR, Delhi. His areas of research include application of machine learning in Pilot Mental Workload estimation, Development of Cognitive and Psychomotor test for Pilot selection and Assessment of cognitive function in High Altitude.
In the current study he's involved in designing experimental protocol, test administration and Statistical Analysis (fNIRs and NASA TLX).

Dr K. Ramachandran, did his PhD in Psychology from university of Delhi. Currently working as Scientist 'H' & Director DRDO-DIPR, Delhi. He has acquired specialisation in the areas of experimental and human engineering, aviation psychology and environmental psychology.
In the current study, he helped in reviewing experimental protocol, NASA-TLX questionnaire and reviewed inference manuscript.

Mr Pushpendra Kumar Singh obtained his M.Tech in Signal Processing (Electrical Engineering) from IIT Kanpur. He is currently working as Scientist at DRDO-DIPR, Delhi. His areas of research includes system design, machine learning, cognitive science (perception and decision making), cognitive load assessment for air force pilots and BCI.
In the current study, he is involved in conducting experiments and data analysis.

Ms Mistu Mahajabin obtained her B. Tech (Computer Science and Engineering) from West Bengal university of Technology, Kolkata. She is currently working as Scientist at DRDO-DIPR, Delhi. Her areas of research include measuring psychological abilities through computerize test, text analysis using machine learning and big data analysis.
In the current study, she collected data during experiments and its analyses.