ISSN 2229-5518

Effect of non-compactible Spatial Referenceframes on Cognitive Workload

Greeshma Sharma, Sushil Chandra, Ronnie V Daniel, Vijander Singh, Alok Prakash Mittal

Abstract—We investigated the cost of information processing incurred by mental workload with non-compactible spatial reference frames, in context of task demands, usig encephalogram (EEG) signals. It is hypothesized that when egocentric people on performing object based transformation strategy (mental rotation) and allocentric people while performing perspective-taking task, their mental workload increases. A total of 28 subjects participated in this study. The participants were classified as egocentric and allocentric based on 'Animal in a row' task. Those participants that were classified as egocentric were made to the task of mental rotation while those that were classified as allocentric were assigned perspective task. The encephalogram signals were taken when the participants performed the tasks. The statistical approach of approximate entropy (ApEn) is used to examine the changes in the workload wherein the median is taken as the threshold value. It is shown in previous works that when mental workload increases the approximate entropy decreases. Results showed a lesser value of approximate entropy for allocentric group during perspective task and similarly a lower value of approximate entropy for egocentric group during mental rotation.

Index Terms—Approximate Entropy, Cognitive workload, EEG, non-compacible spatial reference

1 INTRODUCTION

SPATIALReference Frames (SRF) as described by Klatzky[1] is categorized into two main types namely allocentric and egocentric. Eventhough primary role of egocentric and allocentric reference frames are in perception and action, they can be thought of as specialized cognitive mechanisms essential in performing and guiding spatial motor actions. Egocentric reference frames are involved with controlling movement in surrounding space such as reching objects or surrounding avoiding objects while allocentric representations have special relevance in recognizing objects, scenes and planning future movements. Egocentric frames of reference specify location and orientation with respect to the organism, including eye, head and body coordinates while allocentric frames specify location and orientation with respect to elements and features of environment independently of the observers position. These SRF causes workload when task is not suited by mental transformation strategies. Mental transformation strategies are those strategies, which are required to solve any spatial tasks. These spatial tasks require spatial ability, which is a part of cognitive skill. In this research paper an innovative study was done by expressing mental workload using approximate entropy by providing spatial tasks. Study was conducted using EEG system and spatial task designed in unity. To understand EEG it is necessary to inquire about brain and its signals.

Since the behavior of neurons is governed by threshold and saturation phenomenon of the spikes, non-linearity is present at a cellular level in a neuronal netwok such as the brain [2]. Due to the inability of the brain to perform complex cognitive tasks, the hypothesis that the brain is entirely a stochastic entity is rejected. Causative to the above two reason encephelogram (EEG) signals can be considered as an area of non-linear time analysis approximately [3]. Over the years non-linear techniques have been applied to EEG signals taken from humans, such as healthy participants at rest [4, 6], sleep [7, 8] or from patients suffering from Parkinson's disease [9] or Alzheimer's disease [10] or depression [11] etc.

The non-linear measure of Approximate Entropy (ApEn) reflects the likelihood that similar patterns of samples or data will not be followed by additional similar samples or data. The presence of repetitive patterns of data oin the signal will render it more predictable than a signal with no such patterns. ApEn, generally indicate the complexity of the signal, helps in understanding the non-linearity if the signal and therefore the nonlinear dynamics of the underlying system therby making it a good tool for understanding non physiological signals [12]. ApEn, first proposed by Steve Pincus in 1991 is a statistic measure to quantify the unpredictability of fluctuations in both deterministic and stochastic signals [13]. Low sensitivity to noise, usage with short length data and resistance to short strong fluctuations such as spikes makes ApEn an excellent candidate of nonlinear measure. A lower value of ApEn suggests that the time series is more deterministic in nature and a higher value suggests chaotic behavior. ApEn of given x[n] is calculated by the formulae [14]

$$ApEn(m,r) = \phi^m(r) - \phi^{m+1}(r)$$

$$where, \phi^m(r) = \frac{1}{N-m+1}\sum_{\boldsymbol{i=1}}^{\boldsymbol{N-m+1}} \log\left(\frac{\boldsymbol{C_i^m(r)}}{\boldsymbol{N-m+1}}\right)$$

Greeshma Sharma: PhD student at Institute of Nuclear Medicine and Allied Science (INMAS), email id: greeshmacct@gmail.com
SushilChandra:INMAS, email id: Sushil.inmas@gmail.com
Ronnie V Daniel: M.Tech at Manipal University, email id: ronnievdaniel@live.com
Vijander Singh: Department of Instrumentaion and Control Engineering, NetajiSubhas Institute of Technology (NSIT), Delhi
Alok Prakash Mittal: Department of Instrumentation and Control Engineering, NSIT Delhi

Approximate Entropy have been previously used in the analysis of heart variability [15-17], endocrine release pulsality[18, 19], detection of epilepsy [12] etc. For assessment of mental workload, alpha wave analysis during arithmetic tasks [20], under multitasking conditions [21] have been done, all in which approximate entropy is seen to be increasing with increasing difficulty, but it is reported to be decreasing with increasing task difficulty in [22].

2 Methods

2.1 Paticipants and experimental settings

For this study a total of 28 participants, aged between 12 and 14 (mean age 13), were chosen. All the participants were right handed and had normal or corrected vision. Written consent was taken from their parents for the purpose of this study.

Initially, the participants were classified as allocentric or egocentric based "Animals in a Row" test, proposed byLevinson and Brown[20], in which the participants were asked to observe an arrangement of animals(fish octopus and scorpion) in a row, in front of them on top of a table (Stimulus Table). After a brief interval of time the participants were escorted to another table (Response Table) and were given the same set of animal and was asked to arrange them in the same order as that of the stimulus table. Those participants who have arranged the animalsin accordance with the cardinal direction were classified as allocentric and those participants who have arranged in accordance to the relative direction are classified as egocentric.

The tasks administered on the participants for evaluating the effect of non-preferred frame of reference on mental workload based on object transformation and egocentric perspective transformation. Task was presented in a computer system having RAM 8 GB. Task was done using keyboard and mouse.

Participants were made to do both Mental Rotation test and egocentric perspective test. In object based transformation or Mental Rotation (MR), the participants were asked to compare between two figures taken from the Internet wherein the difficulty is kept to a minimum. If the two figures are matching then the participant was required to press the correct button else the incorrect button. A total of 10 stimuli were presented to the participant with a maximum response time of 15 sec/stimuli including the participant response.

Egocentric perspective test was adapted from that proposed by Kozhevnikov and Heagarty[21]. Here a fixed array of 7 objects was shown to the participant and he/she was asked to point to the third while imaging the position of a particular object facing another object in the array. Output of the test is taken as the angle value in which the participant was making in their imagined perspective. A total of 12 stimuli were given to the participant and a response time of 30 seconds was given to imagine the perspective and make the angle. If the participant responded before the end of 30-second mark, the next stimuli appeared immediately after pressing the button.

The participants were asked to avoid any unnecessary muscle activity inorder to minimize the noise in the signals during the data acquisition. The hands were placed such that the participants could use the mouse and keyboard using minimal muscle movements. Since the temporal regions are susceptible to ocular artifacts, participants were asked to refrain from blinking as much as possible.

2.2 EEG Recording

The encephalogram signals were acquired form one bipolar channel using a NeXus 10 instrument. The channel location was chosen according to the group in which the participant was allocated. In case of allocentric participants, the recording was taken from FT7 and FT8 and for egocentric participants P1 and P2 channel were used[22-25]. The sampling rate was fixed ar 256Hz. The study was conducted under controlled conditions in an electrically isoloated and soundproof room with a minimum distance of five meters from the power supllies and under normal lighting sonditions. The signals were band-pass filtered with cut-off frequencies 0.1 and 100 Hz.

3 Analysis

3.1 Preprocessing

A clean signal is needed to carry out the necessary analysis and to obtain the feature. The raw EEG signal is passed through a band pass filter with cut of frequencies 0.1 and 60Hz so that signals above the gamma range were eliminated. After band pass filtering, a notch filter used so as to remove the 50Hz line interference. Signal artifacts if any were removed by independent component analysis

3.2 Non-Linear Feature Measure

The EEG signal segments denoted as x[n]; n = 1,2,3…N with T = 10 seconds. The non-linear measure of approximate entropy is extracted from them using MATLAB where in the parameters m and r as chosen as 5 and 0.2 times the standard deviation of the signal segment.

4 Results

Out of the 28 participants 13 were grouped into allocentric and the remaining 15 into egocentric groups based in the 'Animals in a row" test. Mental rotation task as well as egocentric perspective task was administered to both the groups. Approximate Entropy (ApEn) was used to classify the workload on two groups of participants. Figure 1 shows the approximate entropy values for both the allocentric and egocentric groups.

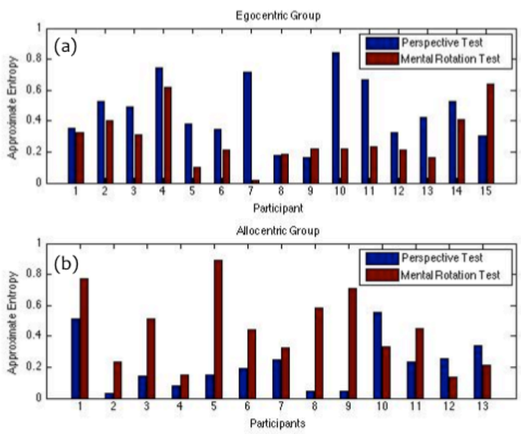

Fig 1: (a) ApEn values for Egocentric Group; (b) ApEn values from Allocentric Group

5 Discussion

To solve any problem requiring spatial ability, mental tranformation strategies are inherently applied, which obviously require cognitive workload. The purpose of this study was to evaluate the effect the same said cognitive workload has when subjected to non-compactible reference frames using the non-linear measure of approximate entropy. Whenever these transformation strategies meet the task at hand, the tasks can be done with lower cognitive workload.

Virtual reality developed using Unity 4.5 is used inorder to create such non-compactible tasks for non-comaptible reference frames. Subjects were grouped into inherent spatial reference frames using the 'Animal in a Row' test, and subsequently the mental rotation and egocentric perspective test were presented to them during which encephalogram signals were collected.

From figure1 (a), it is clear that for most of the participants in egocentric group, the ApEn values for mental rotation is lower that that for perspective test and from figure 1(b) it can be seen that in allocentric group the ApEn values for perspective is lower than that of mental rotation. From these two observations, it is can be concluded that when non-compatible spatial reference frames are presented, the cognitive load has increased due to the decrease in ApEn values.

The limitations while using the measure of ApEn are that it is highly dependent on the sequence length and also its poor inconsistency i.e. the observation that ApEn for one dataset is larger than that of another for a given choice of 'm' and 'r' should, but does not, hold true for other choices of 'm' and 'r'.

References

1. Klatzky, R.L., *Allocentric and Egocentric Spatial Representations: Definitions, Distinctions and Interconnections*. Spatial Cognition - An interdisciplinary Approach to Representation and Processing of Spatial Knowledge (Lecture Notes in Artificial Intelligence 1404), 1998: p. 1 - 17.
2. Ralph G. Andrzejak, K.L., Florian Mormann, Christoph Rieke, Peter David, Christian E. Elgar, *Indiacations of nonlinear deterministic and finite-dimentional structures in time series of brain electrical activity: Dependence on recording region and brian state.* Physical Review E, 2001. **64**.
3. T.Schreiber, H.K.a., *Nonlinear Time Series Analysis*. 1997, Cambridge University Press.
4. S.A.R.B. Rombouts, R.W.M.K.a.C.J.S., *Investigation of Nonlinear structure in multichannel EEG.* Physical Letters A, 1995. **202**(352).
5. F.H Lopes da Silva, J.P.P., D. Velis and P.C.G Nijssen, *Nonlinear Analysis of intracranial human EEG in temporal lobe epilepsy.* International Clinical Neurophysiology, 1999. **110**(1801).
6. W.S. Pritchard, K.K.K., D.W Duke, *Dimentional Analysis of resting Human EEG II: Surrogate-data testing indicates nonlinearity but not low dimentional chaos.* Psychophysiology, 1995. **32**: p. 486-491.
7. Peter Acherman, R.H., Anton Gunzinger, Walter Guggenbuhl, Alexander A. Borbely, *All-Night Sleep EEG and Artificial Stochastic Control Signals have Similar Correlation Dimentions.* Clinical Neurophysiology, 1994. **90**(5): p. 384-387.
8. A. Babloyantz, J.M.S.a.G.N., *Evidence of Chaotic Dynamics of Brain Activity During Sleep Cycle.* Physical Letters A, 1985. **111**: p. 152-156.
9. V. Muller, W.L., F. Pulvermuller, B. Mohr, N. Birbaumer, *Investigation of Brain Dynamics in Parkinson's Diseas by methods derieved from Nonlinear Dynamics.* Exp. Brain Res., 2001. **137**(1): p. 103-110.
10. Jeong J, C.J., Kim SY, Han SH, *Nonlinear Dynamic Analysis of the EEG in Patients with Azheimer's Diseas and Vascular Dementia.* Journal of Clinical Neurophysiology, 2001. **18**(1): p. 58-67.
11. J-L. Nandrino, L.P., J. Martinerie, F. el Massioui, B. Renault, R. Jouvent, JF. Allilaire, D. Wildlocher, *Decrease of Complexity in EEG as a Symptom of Depression.* Neuroreport, 2001. **5**(4): p. 528-530.
12. G.R Kiranmayi, V.U., *EEG Subband Analysis Using Approximate Entropy for the Detection of Epilepsy*. IOSR Journal of Computer Engineering, 2014. **16**(5): p. 21-27.
13. Pincus, S.M. *Approximate Entropy as a Measure of System Complexity*. in *Proceedings of the National Academy of Science*. 1991. USA.
14. D. Abasolo, R.H., P. Espino and et al., *Analysis of Regularity in the EEG Background activity of Alzheimer's Disease patients with Approximate Entropy.* Clinical Neurophysiology, 2005. **116**: p. 1826-1834.
15. Steven M. Pincus, A.L.G., *Physiological time-series analysis: what does regularity quantify.* Amercian Journal of Physiology, 1994. **266**: p. H1643-H1656.
16. D. Sapoznikov, e.a., *Detection of regularities in heart rate variations by linear and non-linear analysis: Power spectrum versus approximate entropy.* Computer Methods and Programs in Biomedicine, 1995. **48**: p. 201-209.
17. Pincus, S.M., *Heart rate control in normal and aborted-SIDS infants.* Amercian Journal of Physiology 1991. **33**: p. R638-R646.
18. Pincus, S.M., *Older males secrete luteinizing hormone and testosterone more irregularly and joint more asynchronously than younger males.* Proceedings of the National Academy of Sciences of the United States of America, 1996. **93**: p. 14100-14105.
19. J.D. Veldhuis, e.a., *Differential impact of age, sex steroid- hormones, and obesity on basal versus pulsatile growth- hormone secretion in men as assessed in an ultrasensitive chemi-luminesceneassay.* Journal of Clinical Endocrinology and Metabolism, 1995. **80**: p. 3209-3222.
20. Zheng Wei, C.Z., Huo Li. *Approximate Entropy Analysis of Alpha Wave Evoked by Mental Arithmetic Tasks*. in *International Conference on Electronics and Optoelectronics*. 2011.

ISSN 2229-5518

21. Lei Yao, X.L., Wei Wang, Yuanzhe Dong, Ying Jiang, *Approximate Entropy: a New Evaluation Approach of Mental Workload under Multitask Conditions*, in *International Conference on Digital Image Processing*, C.-C.C. Charles M. Falco, Xudong Jiang, Editor. 2014.
22. Pega Zarjam, J.E., Nigel H.Lovell, Fang Chen, *Characterization of Memory Load in an Arithmetic Task using Non-Linear Analysis of EEG Signals*, in *34th Annual International conference of the IEEE EMBS*. 2012: San Diego, California, USA.
23. Brown P, L.S.C., *Linguistic and Non-Linguistic Coding of Spatial Arrays: Explorations in Mayan Cognition*. Working Paper, 1993. **24**.
24. Kozhevnikov, M. and M. Hegarty, *A dissociation between object manipulation spatial ability and spatial orientation ability*. Memory and Cognition, 2001. **29**(5): p. 745-756.
25. Galati, G., Pelle, G, Berthoz, A, Committeri, G. , *Multiple reference frames used by the human brain for spatial perception and memory*. Experimental Brain Research, 2010: p. 140-155.
26. Feigenbaum, J.D., Morris, R.G., *Allocentric versus egocentric spatial memory after unilateral temporal lubectomy in humans*. Neuropsycology, 2004. **18**(3): p. 462-472.
27. Kesner, R.P., *Behavioral analysis of the contribution of the hippocampus and parietal cortex to the precessing of information: interactions and dissociations*. Hippocampus, 2000. **10**(4): p. 483-490.
28. Save, E., Poucet, B.,, *Hippocampal-parietal cortical interactions in spatial cognition*. Hippocampus, 2000. **10**(4): p. 491-499.