



COMMONWEALTH OF AUSTRALIA

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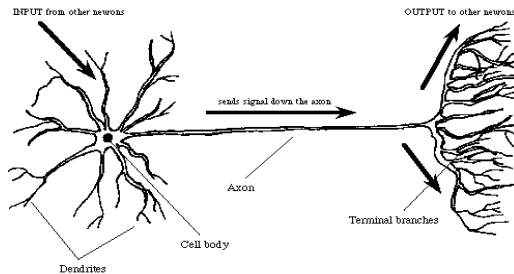
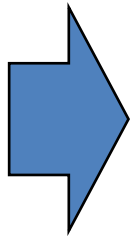
Cognitive Neuro-Engineering Research @ UniSA

Prof D (Nanda) Nandagopal
Chair Defence Systems &
Dean: International

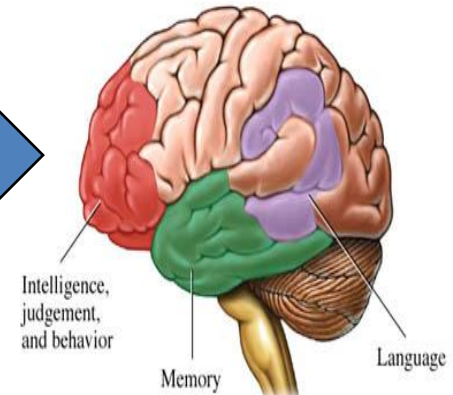
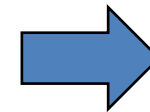
Emergence

Human Brain → ~ 100 B Neurons

part



SYSTEM



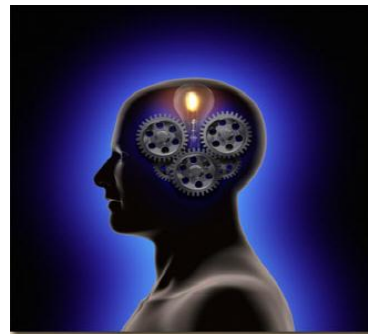
**Combined effect – self awareness – puzzling
Scientists today**

Cognition

- Cognition results from coordinated brain activity
 - Interaction & integration of “building blocks” like perception, attention & memory

Cognition is how Brain transforms sensed information into Action

Sense



ACT

Cognition

- Cognition is normally developed through
 - **Education** and **training** which develops specific skills and knowledge
 - Paying attention, memory and thinking

Functional blocks: Attention

(Intrinsic limitations) Learning

Memory

Comprehension

Visualization

Decision Making

Cognitive Capabilities

- Depend on expertise, training, aptitude etc
- Impaired by
 - Information overload
 - Stress
 - Fatigue
 - Injuries (physical & psychological)
 - Attention/memory lapses etc

What is Cognitive Augmentation?

Cognitive Augmentation is an emerging interdisciplinary bio-technology research area of growing importance to Defence

- Cognitive Augmentation is the enhancement of core capabilities of the mind through improvement of internal or external neural information processing systems

Why is Cognitive Augmentation important to Defence?

- Deployed Defence Force personnel experience very high levels of both physical and mental stress during operations.
- Combat personnel are exposed to more stressful environments such as roadside bombs, IEDs, suicide bombers, seeing women, children and mates being blown away and handling of exploded body parts.

Why is Cognitive Augmentation important to Defence?

- Exposure to such events profoundly perturbs the cognitive ability of Defence Force Personnel causing serious changes to decision making ability, mood, thoughts and behaviour.
- The cognitive ability of combat personnel vary greatly due to injuries, battle stress, fatigue, attention lapses and other distractions.

Why is Cognitive Augmentation important to Defence?

- As a result, combat personnel returning home from deployment experience a number of mental health conditions such as Post Traumatic Stress Disorder (PTSD) and cognitive impairments.
- Mental and emotional issues associated with combat are well known and well documented in a recent RAND report - Invisible wounds of war : psychological and cognitive injuries, their consequences, and services to assist recovery - **Terri Tanielian and Lisa H. Jaycox, editors, 2008**

Cognitive Augmentation Research Benefits to Defence

Research results may lead to following Benefits:

- Better representation of cognition
- Better quantification of cognitive abilities and mental functions
- New approaches to improving cognitive function & hence better decision making under stress
- May assist Human Performance Modification

Cognitive Augmentation Research

Key Issues need addressing:

- Metrics to assess relative cognitive capabilities
 - Non invasive and cost effective
- Cognition Improvement techniques
 - Simple
 - Instrument/ computer assisted
 - Self generative
 - Cost effective

Cognitive Augmentation

There have been a number of studies relating to cognitive enhancement using techniques such as mental training & visualisation, bio-feedback, yoga and meditation.

Pharmacological and herbal infusions have also been found to improve alertness levels.

**Cognitive Enhancement
Augmented cognition
Intelligence Amplification
Intelligence Augmentation**



**Cognitive
Augmentation**

Cognitive Augmentation Techniques

- Bio/Neuro-Feedback
- Meditation
- Pharmacological
- Psychological

What is Biofeedback ?

Biofeedback is providing a person with information about their own on-going physiological processes, through parameters such as EEG, Electro-myogram (EMG), temperature, Galvanic Skin response(GSR) etc.

Since a person is made aware of one's own physiological variables, the person can then learn to control them by consciously influencing the specific parameters.

This mode of feedback is known as information feedback or volitional feedback.

Studies on Neuro-feedback

Neuro-feedback Applications

<u>Academic Cognitive Enhancement</u>	<u>AD/HD and Learning Disabilities</u>	<u>Addiction</u>	<u>Adverse Reactions and Side Effects</u>	<u>Anger</u>
<u>Anxiety</u>	<u>Asthma</u>	<u>Autism and Asperger's</u>	<u>Autoimmune Disorders</u>	<u>Brain Injury</u>
<u>Cerebral Palsy</u>	<u>Creatvity</u>	<u>Chronic Fatigue Syndrome</u>	<u>Cognitive Decline</u>	<u>Coma</u>
<u>Criminals & Juvenile Offenders</u>	<u>Depression</u>	<u>Developmental Disorders</u>	<u>Dissociative Disorders</u>	<u>Epilepsy</u>
<u>Fibromyalgia</u>	<u>Headache</u>	<u>Hemoencephalography</u>	<u>Hemispheric Asymmetry</u>	<u>Hypertension</u>
<u>LENS Neurofeedback</u>	<u>LORETA Neurofeedback</u>	<u>Medical Conditions</u>	<u>Obsessive Compulsive Disorder</u>	<u>Optimal Functioning</u>
<u>Post Traumatic Stress Disorder</u>	<u>Pain</u>	<u>Parkinson's Syndrome</u>	<u>Premenstrual Syndrome</u>	<u>rTMS</u>
<u>Review Articles</u>	<u>Schizophrenia</u>	<u>Sleep</u>	<u>Slow Cortical Potentials</u>	<u>Spasticity</u>
<u>Standards</u>	<u>Stroke</u>	<u>Theoretical Treatices</u>	<u>Tinnitus</u>	<u>Tourette's Syndrome</u>
<u>Withdrawal</u>	<u>Z-Score Neurofeedback Training</u>	<u>Functional MRI (fMRI) Neurofeedback</u>		

Neuro-feedback

By monitoring brain activity, it's possible to train our brains to produce specific cognitive patterns which can aid relaxation, help us be more efficient in our daily tasks, or provide non-pharmaceutical therapy for many conditions and disorders.

Electrophysiological Studies on Meditation

No of studies done: ~ 1600

No of articles written on Meditation: ~20,000

Meditation and Cognition

- **Brief Meditative Exercise Helps Cognition,** ScienceDaily (Apr. 19, 2010)
- **Study: Meditation Improves Cognitive Skills in Four Days,** Author: Wee Peng Ho , Published: May 09, 2010
- **Mindfulness Meditation Can Improve Deep Cognitive Processing**

In a study it has been shown that meditation improves not only mood and stress levels but also improves deep cognitive processing efficiency – core aspects of fluid intelligence such as working memory and sustained attention, as well as long term memory efficiency.

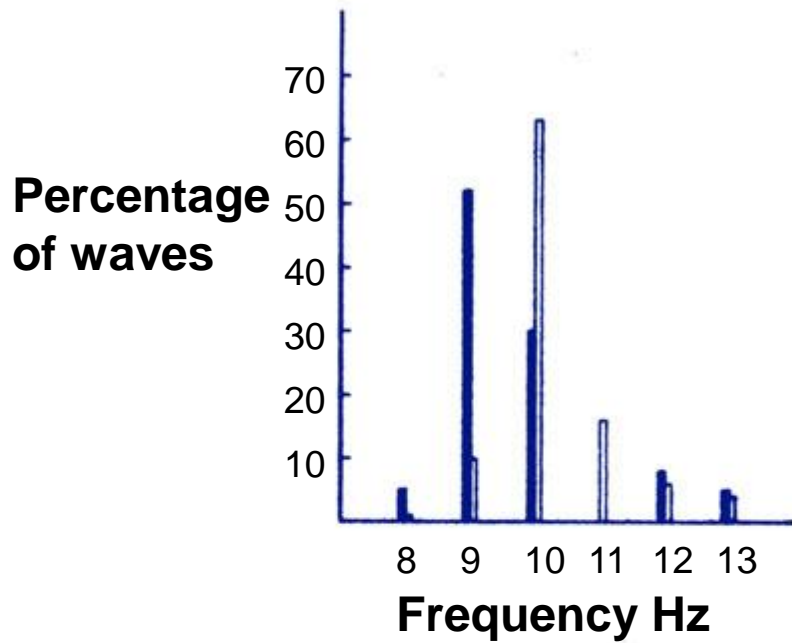
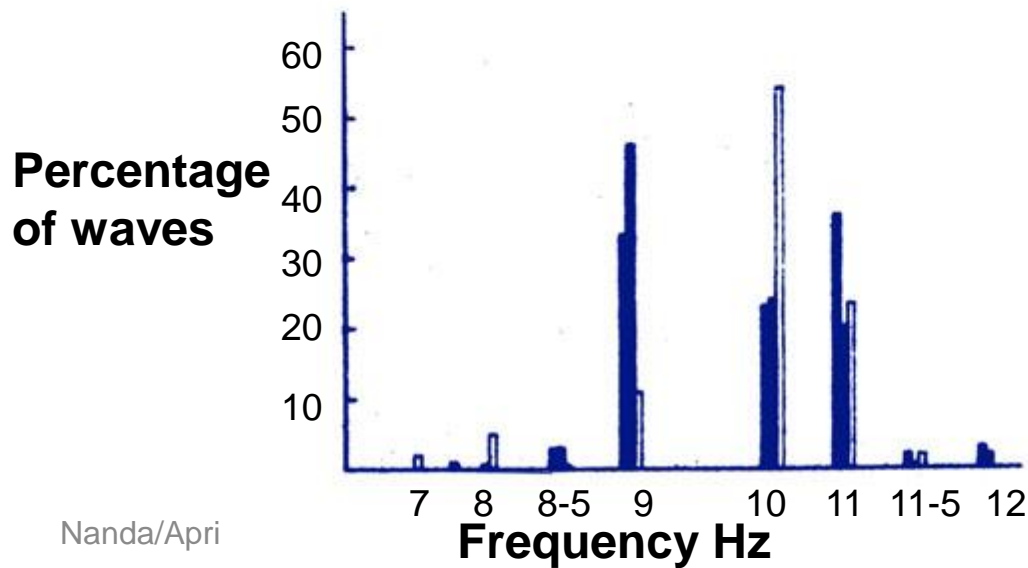


Figure 1a. Subject D. (expt. 1)



b. Subject D. (expt. 2)

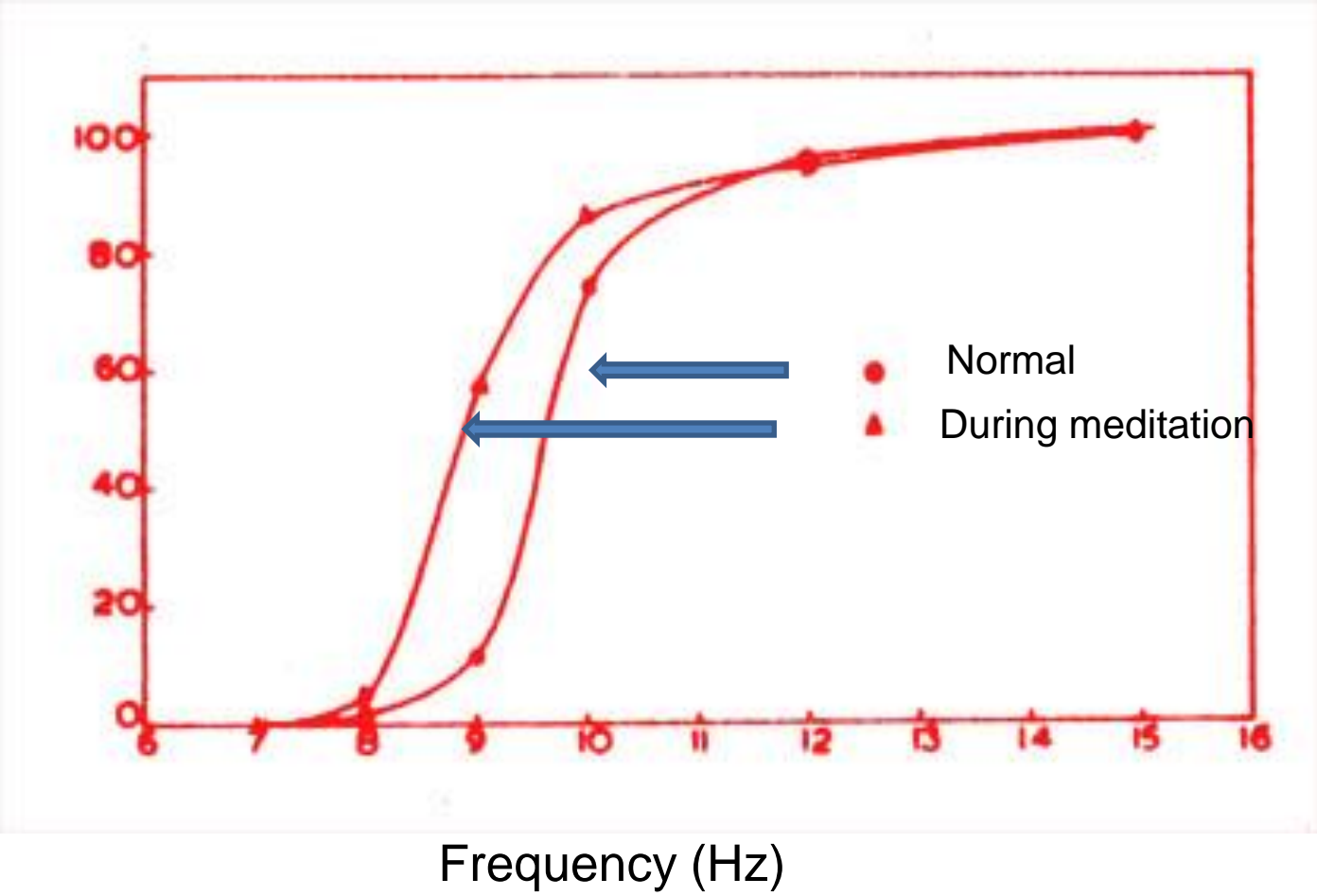


Figure 2. Cumulative frequency plot for subject A (expt.1)



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MODELLING OF HEART RATE VARIABILITY UNDER NEUROPSYCHIC LOAD

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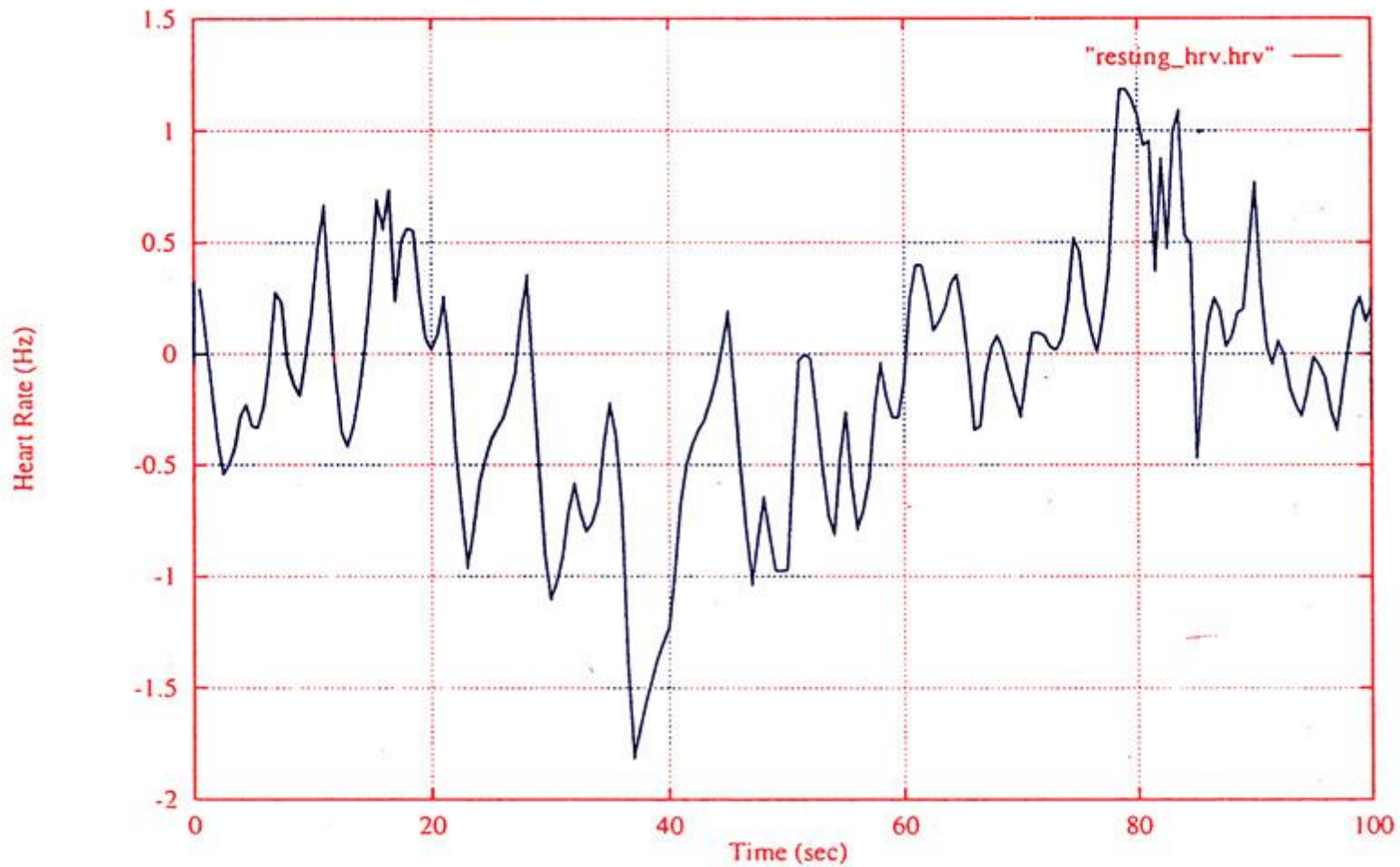
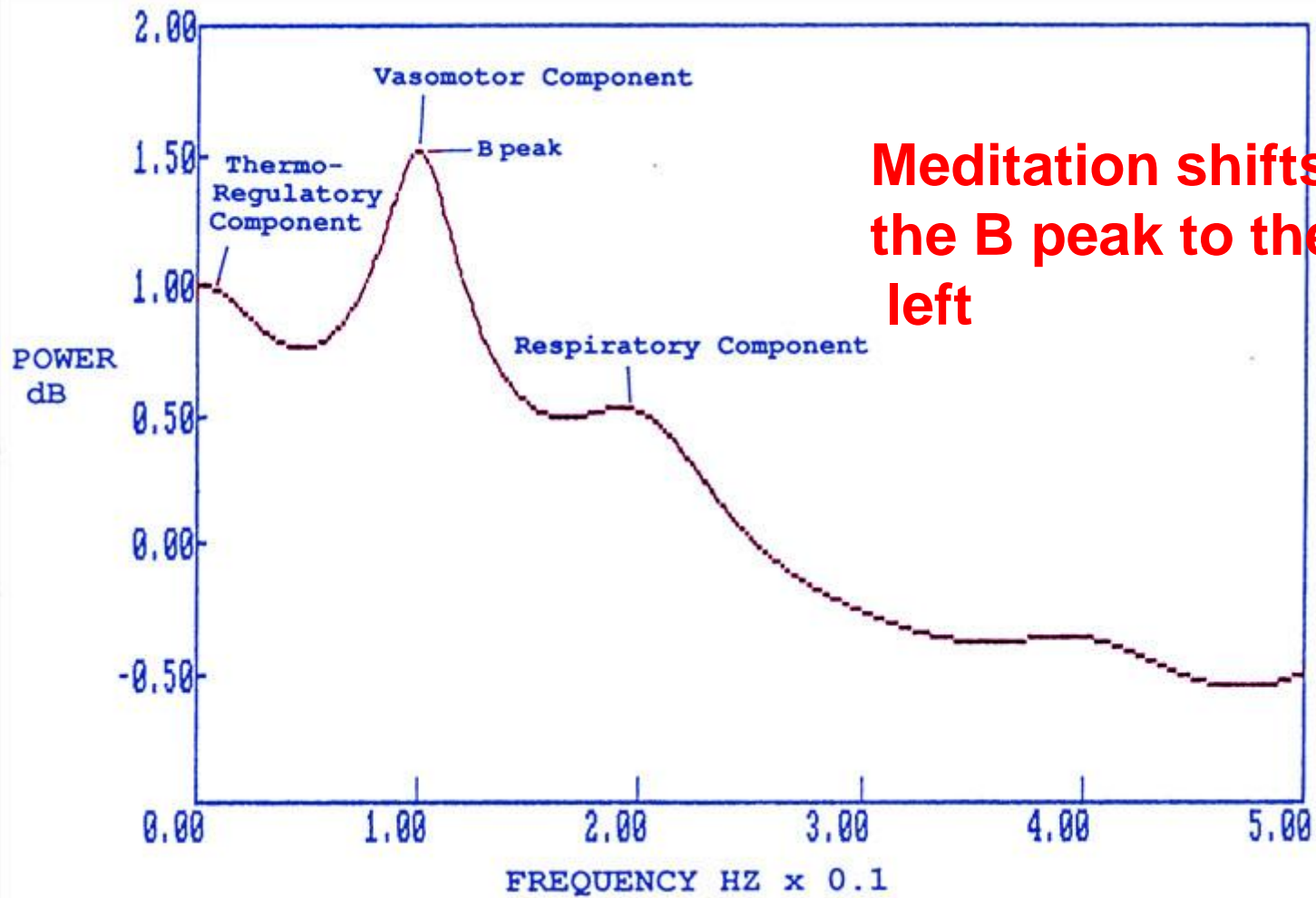


Figure 3 Resting Heart Rate Variability Signal.



Meditation shifts the B peak to the left

Scientific evidence suggests :

- meditation is a self generative process of developing calmer mental states**
- meditation produces decreased neuro-muscular activity**
- autonomous nervous system of meditators exhibit low sympathetic & high vagal tone during mental load in contrast to non meditators who exhibited high sympathetic and low vagal tones**

Cognitive Neuroengineering Research @ UniSA

- Cognitive Neuroengineering is about understanding the human cognitive function through the application of Signal Processing, Computational Techniques, Complex data modelling and analysis of the electrical activity of the brain (EEG).
- It is a System Identification Problem (reverse engineering process).
- It also involves exploration of techniques and methodologies to enhance cognitive ability of individuals through cognitive augmentation – **Human Performance Modification**

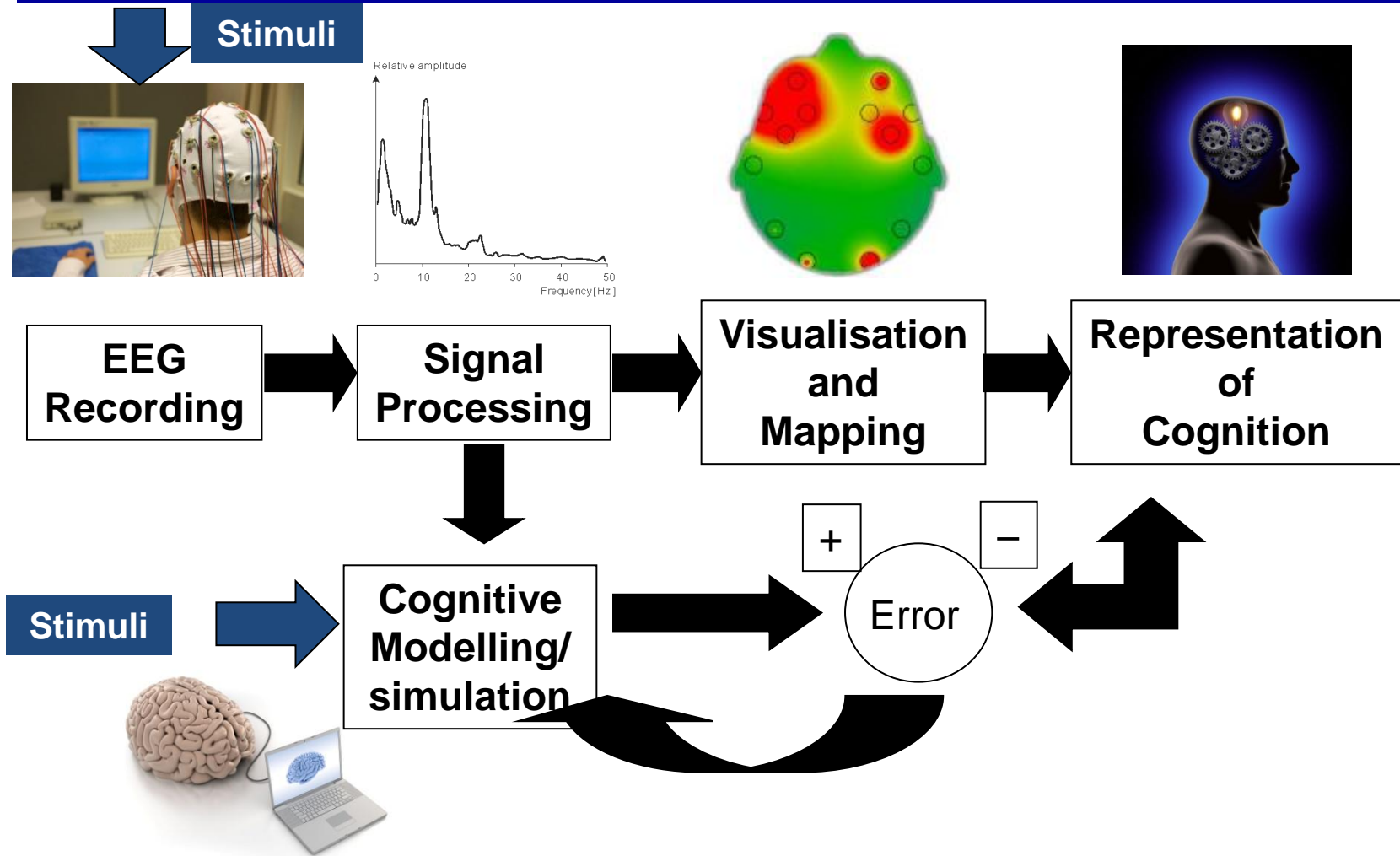
Cognitive Neuroengineering Research @ UniSA

Characterization of Cognition, Cognitive modeling and methodologies for Cognitive Augmentation – A new approach

Aim

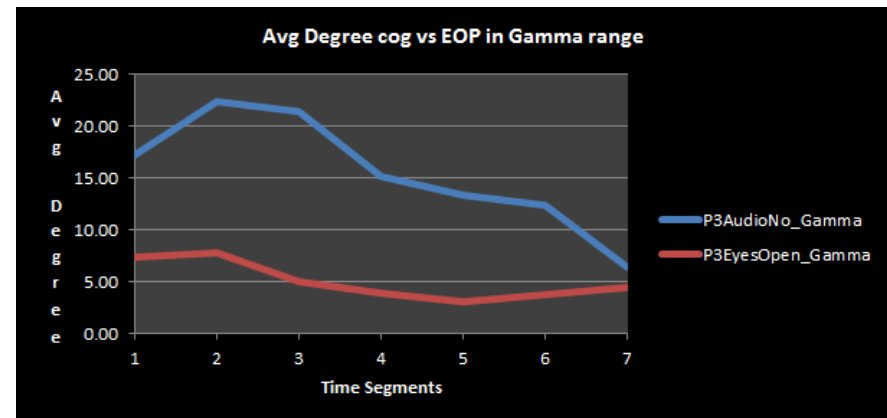
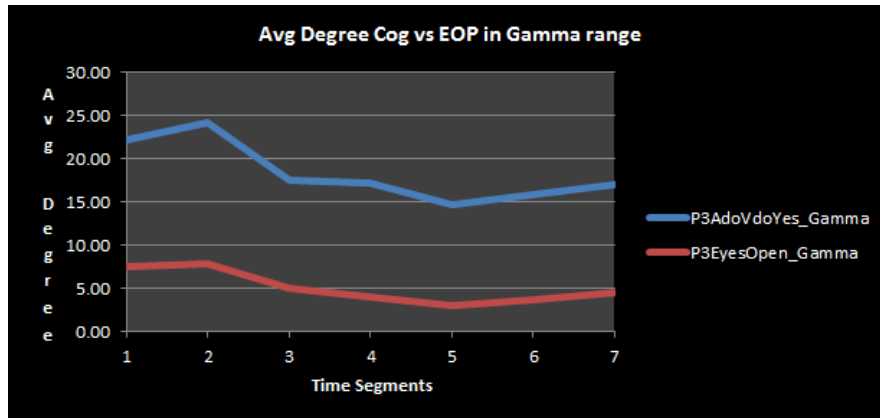
To develop advanced signal processing techniques, mathematical modelling, complex network/graph mining techniques and visualization, computational techniques and information retrieval techniques to characterize cognition using EEG data and explore methodologies such as Bio feedback, Meditation etc to improve cognitive abilities

Cognitive Neuro-Engineering Research @ UniSA – Phase 1- Characterization of Cognition

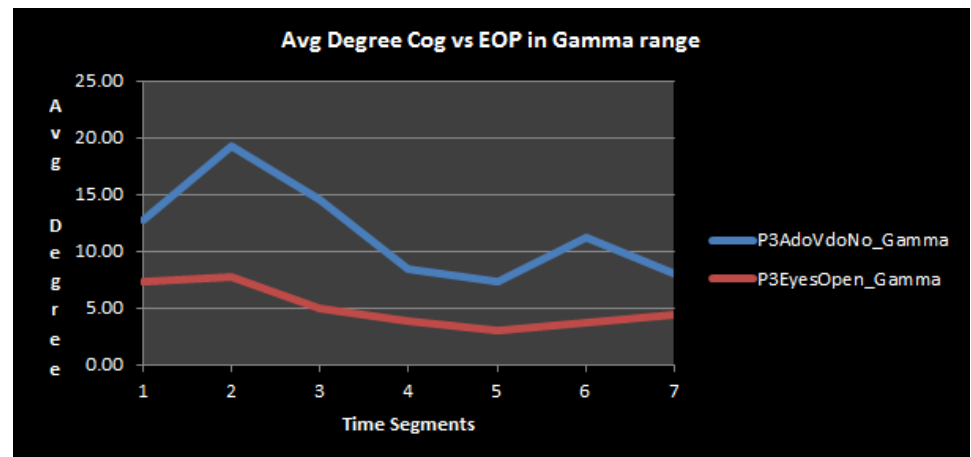


Recent Results on Gamma Activity in EEG

Average degree of functional brain network at Gamma Frequency during cognitive load and eyes open states using r



Degree centrality (DC) measure reflects the influence of an electrode site over its neighbours. Average Degree reflects the overall performance of the functional network during a short duration – 500 ms- the plot gives the dynamics of the network over a period of time from DC point of view





Cognitive Neuro Engineering Team @ UniSA

- Prof. Nanda Nandagopal, Chief Investigator - UniSA
- Bernie Cocks, Cognitive Psychologist - Research Assistant, UniSA
- Prof. Paul Gaertner - Defence Scientist, DSTO
- Prof. Bruce Thomas, Computer Science - Visualisation, UniSA
- Prof. Javaan Chahl, School of Engineering - UniSA
- Dr. Tina Du, IT and Mathematical Sciences - IR Techniques, UniSA
- Lynne Kruger - Project Officer, UniSA

PhD Students

- Nabaraj Dahal - Cognitive modelling techniques, UniSA
- Naga Dasari - Computer visualisation techniques, UniSA
- Md Hedayetul Islam Shovon – Information Retrieval from EEG, UniSA

International Team:

- Prof. Mika Sato-Ilic – Data Clustering Techniques - Tsukuba University, Japan
- PSG Tech/Anna University, India
- A/Prof. Vijayalakshmi R
- A/Prof. Thilaga M
- C. Archana, MSc Software Engineering, 7th Semester - Student Intern
- R. Subhiksha, MSc Software Engineering, 7th Semester - Student Intern

Recent Publications

- Nanda(D) Nandagopal, Vijayalakshmi R, Bernie Cocks, Nabaraj Dahal, Naga Dasari, Thilaga M, Shamsu Dharwez S, "Computational Techniques for Characterizing Cognition using EEG - New Approaches", Invited paper in the proceedings of the 17th International Conference in Knowledge Based and Intelligent Information and Engineering Systems - KES2013, Japan, October 2013
- Cocks B, Nandagopal D, Vijayalakshmi R, Dasari, N, and Dahal N, "Breaking the Camel's Back: Can Cognitive Overload be Quantified in the Human Brain?", At the 9th International Conference on Cognitive Science, Kuching, Sarawak, Malaysia, 27 - 30 August 2013.
- Nabaraj Dahal, Nanda (D) Nandagopal, Bernadine Cocks, Naga Dasari, Vijayalakshmi R, "Event Related Synchronization and Desynchronisation of EEG Data during Distracted Virtual Driving", Seventh Asia International Conference on Mathematical Modelling and Computer Simulation, Kuala Lumpur, 25 July 2013
- Naga M. Dasari, Nanda (D) Nandagopal, Bruce Thomas, Bernie Cocks, and Nabaraj Dahal, Vijayalakshmi R. and Paul Gaertner, "A Signal Processing System for Visualizing Complex Functional Brain Networks during Cognitive Load", In the Proceedings of IEEE ICCSII 2013 conference, Bandung, Indonesia June 2013
- R Vijayalakshmi, N Dahal, N Dasari, B Cocks, D Nandagopal, "Identification and Analysis of Functional Brain Networks", International Conference on Pattern Recognition (ICPR) 2012, Tsukuba, Japan
- B Cocks and D Nandagopal, "Systems and Technology Drivers, requirements and Challenges that Characterise Cognition", a commercial in confidence report submitted to the Defence Science and Technology Organisation, Department of Defence, November 2012
- N Dahal, D Nandagopal, B Cocks, R Vijayalakshmi, N Dasari, " Modeling of Cognitive Functions In Driving Environments Using EEG", The 3rd Australasian Cognitive Neuroscience Conference (ACNS 2012), University of Queensland, Brisbane, Australia
- N Dasari, D Nandagopal, R Vijayalakshmi, B Thomas, N Dahal, B Cocks, "Visualization of Complex Neural connections during Cognitive load using EEG data", The 3rd Australasian Cognitive Neuroscience Conference (ACNS 2012), University of Queensland, Brisbane, Australia
- B Cocks and D Nandagopal, "Cognitive Structures, Processing, Modelling, Experimentation and measurement with recent developments on Cognitive Augmentation and their impact on Defence Force capabilities" a commercial in confidence report submitted to the Defence Science and Technology Organisation, Department of Defence, August 2012
- N Dahal, D Nandagopal, A Nafalski, Z Nedic, "Modeling of Cognition using EEG: A Review and a New Approach." TENCON 2011 - 2011 IEEE Region 10 Conference Digital Object Identifier: 10.1109/TENCON.2011.6129270 Publication Year: 2011 , Page(s): 1045 – 1049

Symposium Wrap up

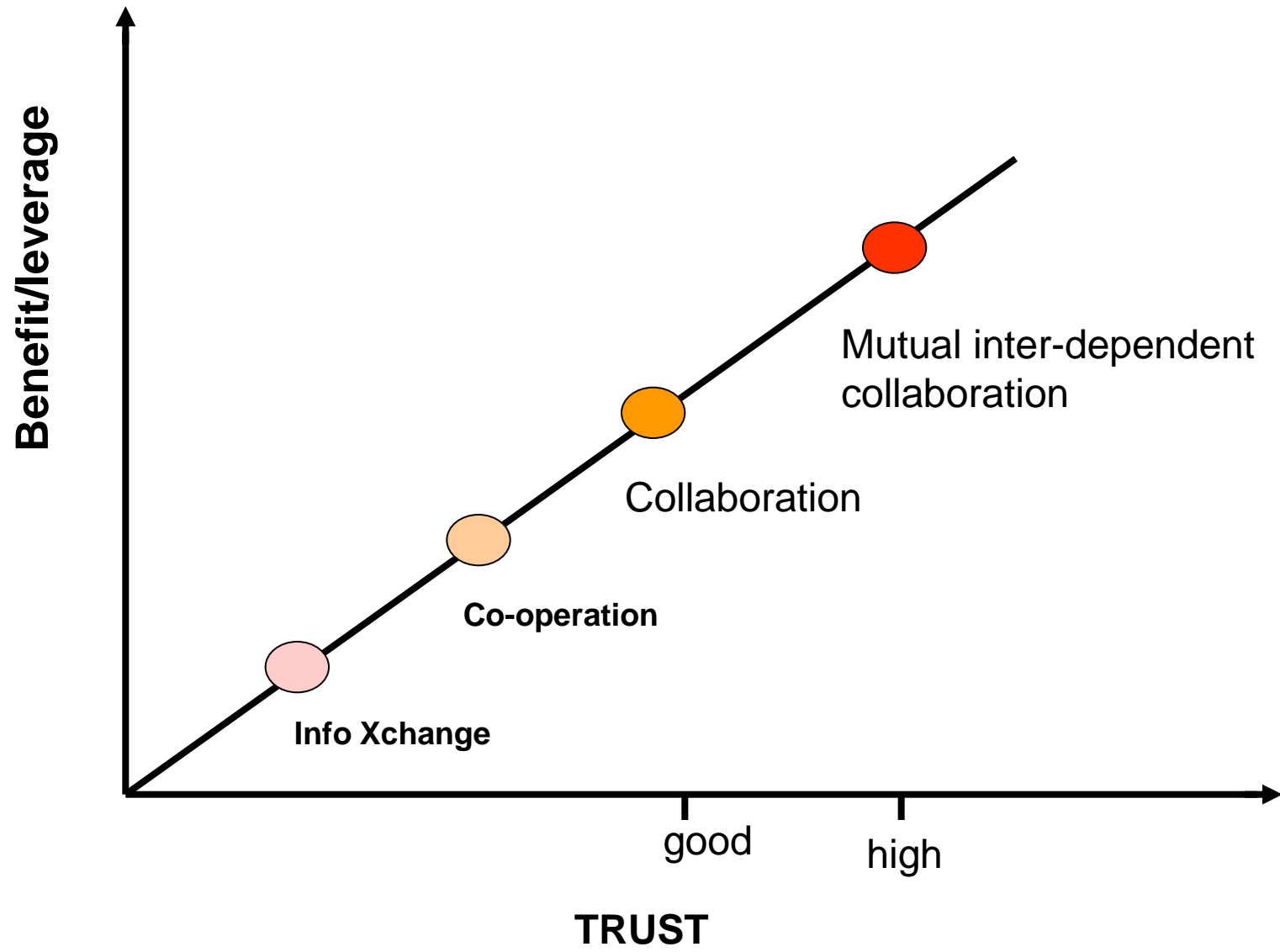
Cognitive Neuroengineering & Computational Neuroscience Symposium

Outcomes

- A broad spectrum of interesting issues and findings presented. - from iRats, Dragon flies to highly mathematical Graph data mining approaches
- Learned about opportunities and challenges in this complex field of Neuroengineering & computational Neuroscience - Jonathan challenging some of our basic beliefs and shed some light on new way of looking at old issues
- A shared understanding of each other's Research strengths, approaches, methodologies, tool and techniques.
- Meta cognitive realisation of the value of possible collaboration particularly in a funding constrained environment
- Good networking
- Forged new relationships

Where do we go from here ?

When do relationships turn strategic & deliver real value ?



Cognitive Neuroengineering Research

interdependent collaboration

Some questions to ponder over

- Do we have any synergy between the programs ? Level ?
- Do the two programs/skill sets/tools/techniques compliment or compete?
- Does the combined program expand the problem space?
- Does the combined skill sets increase solution space?
- Does the combined program offer a strategic advantage in the market place? to both parties
- Will the return on investment be likely more than the sum of individual returns?

Thank YOU

DSTO

Joanne, David

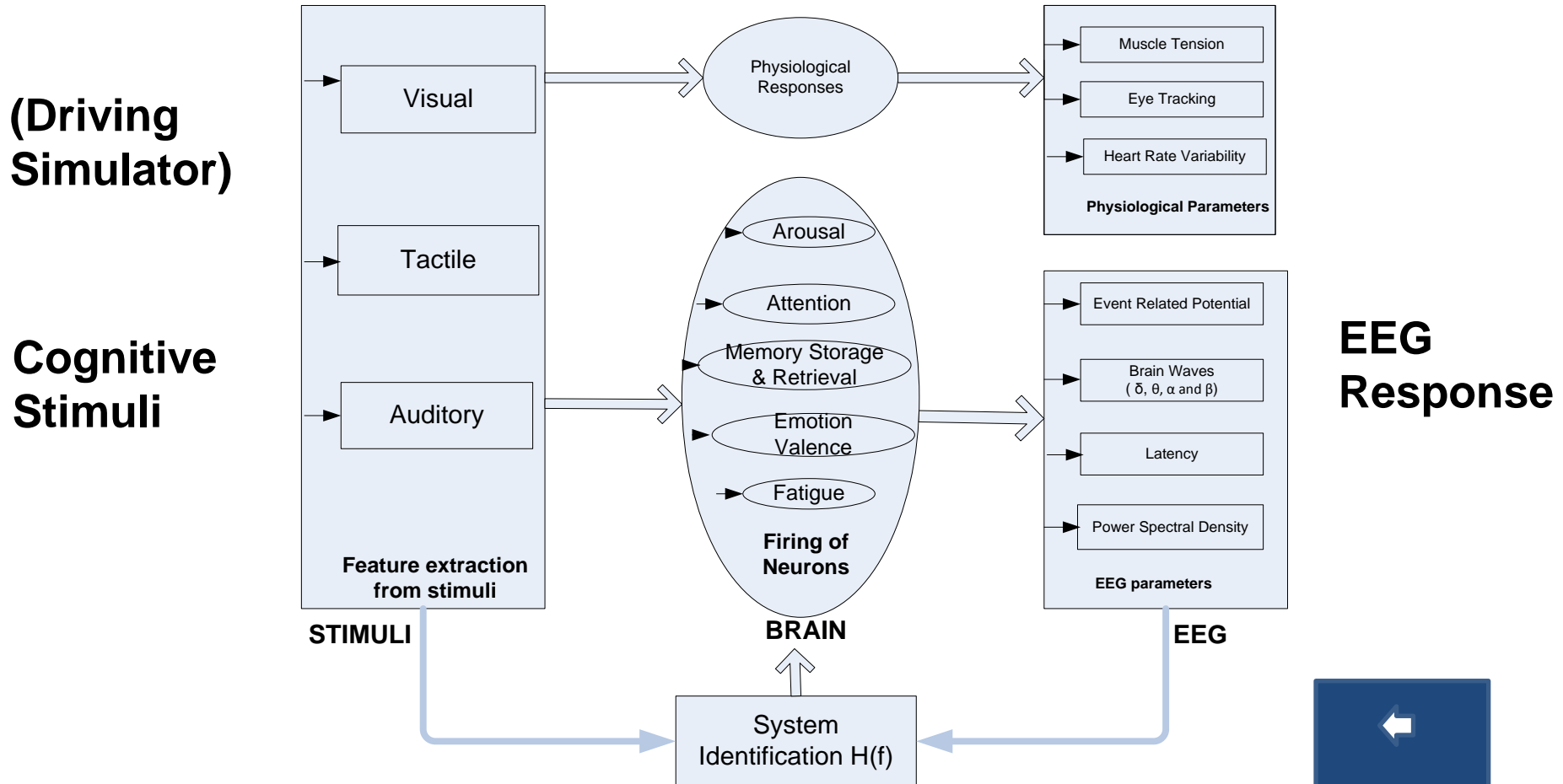
Bernie & Lynne

All Speakers & Participants

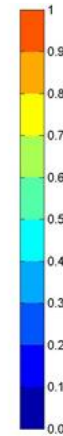
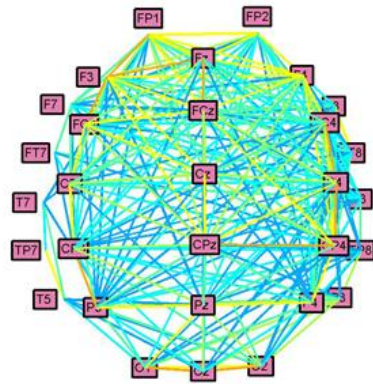
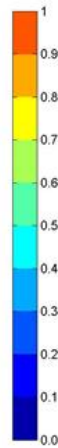
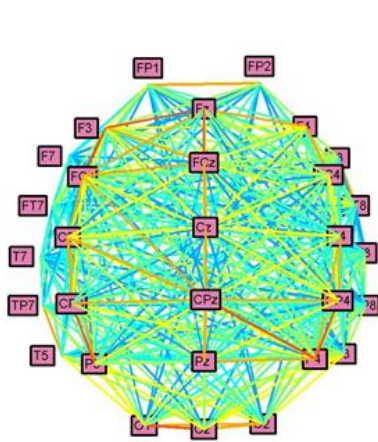
Wish you all a safe journey back
home

Modelling of Cognitive Function

A Methodology



Visualization of Functional Brain Network



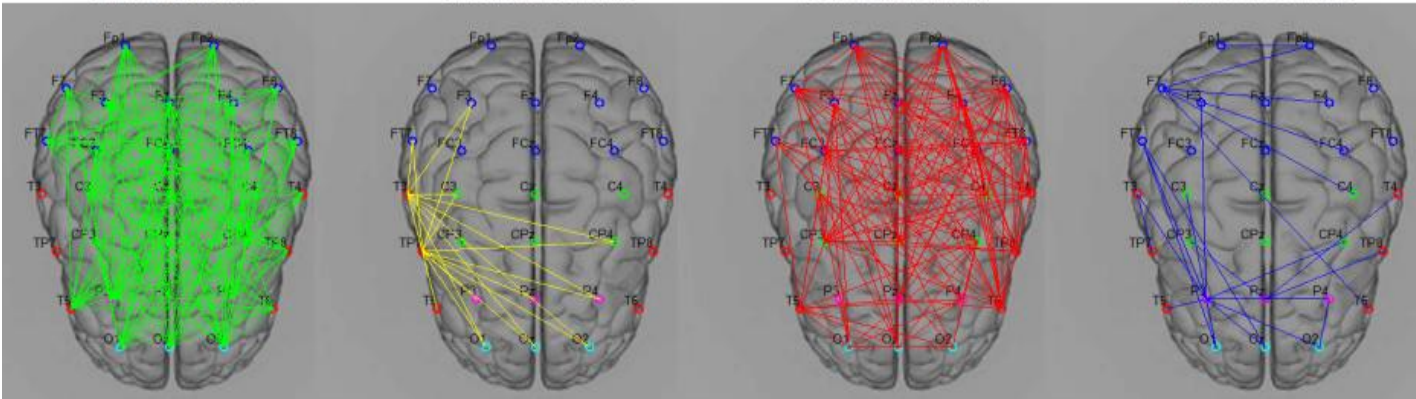
Functional brain network during cognitive load and Eyes Open using **Magnitude Squared Coherence (MSC)** for a Subject - Threshold: 0.3

P3-NEW Neural Connections

P3-MISSING Neural Connections

P3-STRONG Neural Connections

P3-WEAK Neural Connections



Positive Phase correlations using **Pearson Correlation Coefficient (r)** demonstrating neuronal clusters formed during cognition for a subject

