Nervous System Augmentation

Hasan Al-Nashash
Biomedical Engineering Graduate Program
American University of Sharjah, UAE

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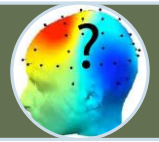
DR. HASAN AL-NASHASH

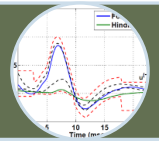
NEUROENGINEERING RESEARCH GROUP

The Neuroengineering Research Group is part of the College of Engineering and the Biosciences and Bioengineering Research Institute. Our highly qualified and experienced faculty members and students are conducting theoretical, computational and experimental research work in a wide variety of topics aimed at advancing our understanding of the human brain and helping to treat nervous system diseases. There are a number of active and exciting research projects covering both healthy subjects and patients with focus on cognitive vigilance assessment and enhancement, emotions monitoring, flexible implantable electrodes in peripheral nerve injury, cortical source imaging in epilepsy and severity assessment of spinal cord injury. These projects are conducted in collaboration with the Dubai Police and Rashid Hospital, and are funded internally by AUS and externally by the Aljalilah Research Foundation.

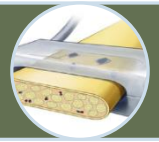
Neuroengineering Research Group



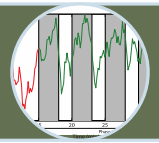
Cortical Source Imaging Using EEG



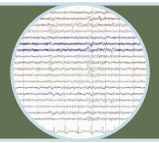
Severity Assessment of Spinal Cord Injury



Flexible Implantable Electrodes



Cognitive Vigilance Assessment and Enhancement



Quantitative Assessment of Brain Injury

Nerve Injury

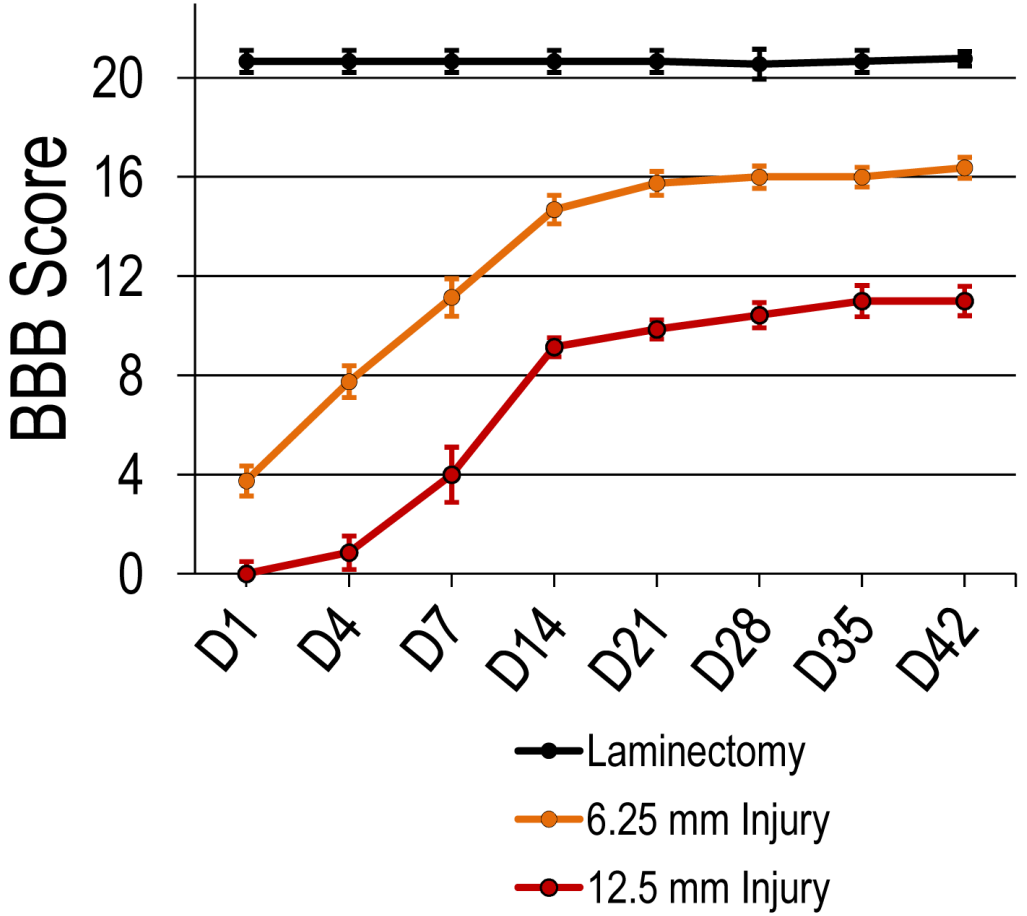
- Traumatic injury
  - Spinal cord injury
  - Peripheral nerve injury which results in nerve-muscle and related limb functions
- Other forms of neuromuscular function loss which may result from disorders such as multiple sclerosis or neuropathy, or injury to nerves affecting the bladder or prostate and related sexual dysfunctions

Research Challenges in Nerve Injury

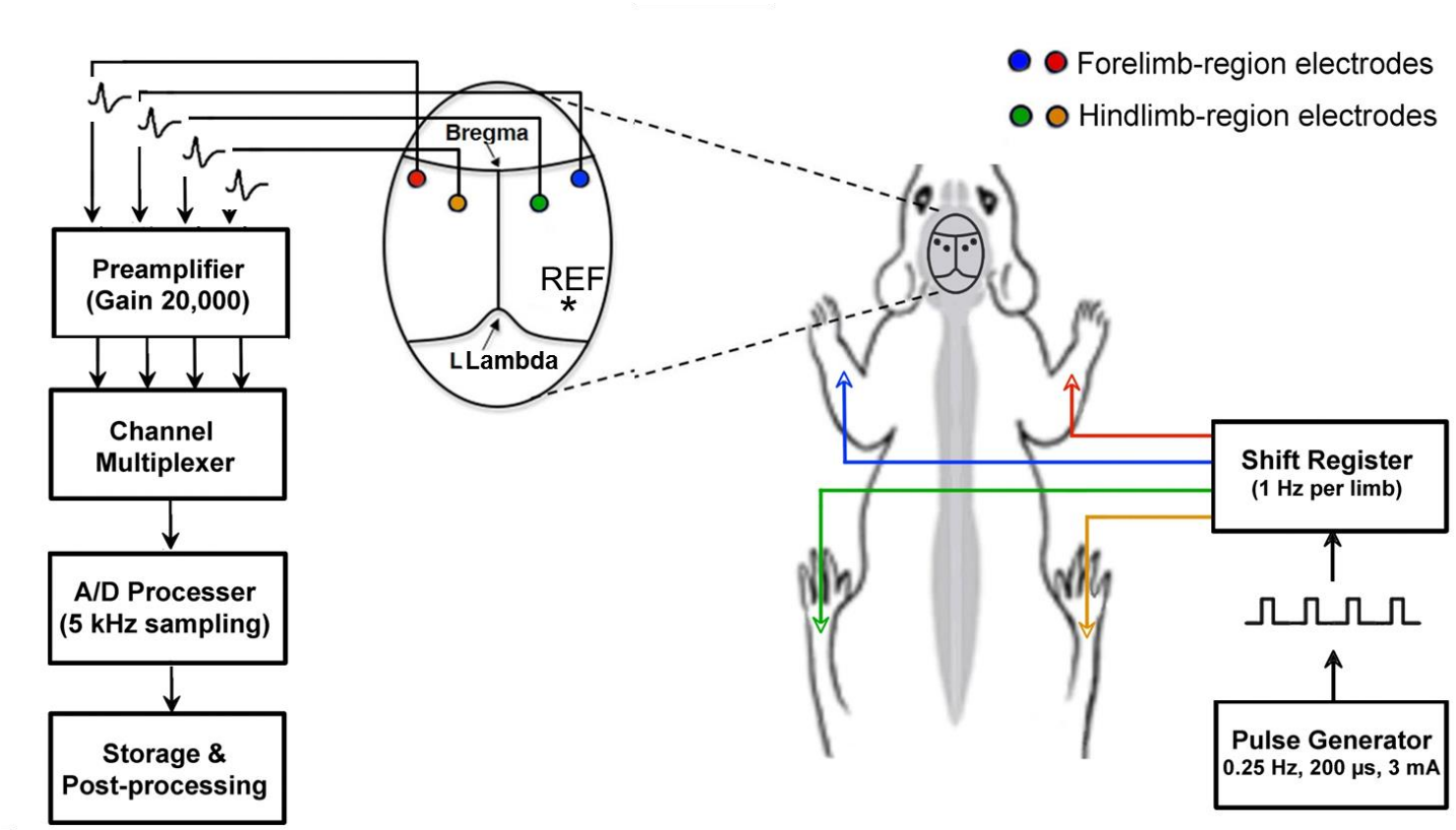
- Assessment of injury level
  - Subjective tests
  - Objective tests
- Therapy/Augmentation
  - Functional electrical stimulation
  - Brain computer interface for artificial prostheses control

Basso, Beattie and Bresnahan (BBB) score

- **Open-field test**
- **(Score ranges from 0-21)**
- It consists of assessments of:
  - Hindlimb joint movements
  - Trunk positions
  - Paw placement
  - Stepping
  - Coordination
  - Toe clearance
  - Paw & tail positioning



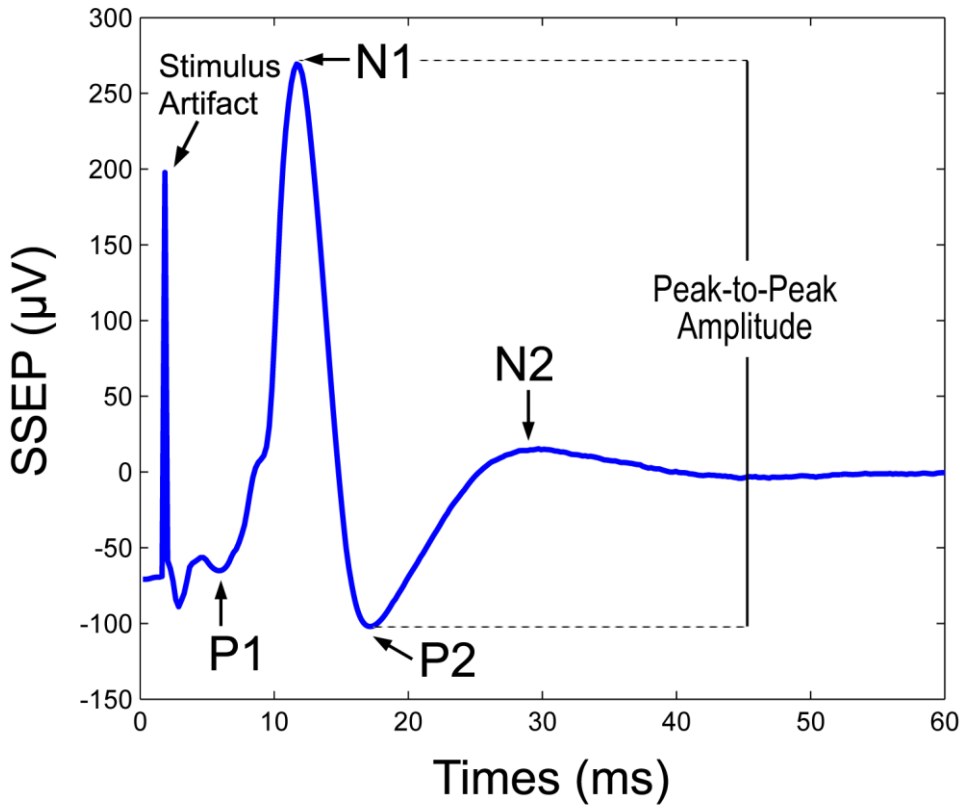
Spinal Cord Injury



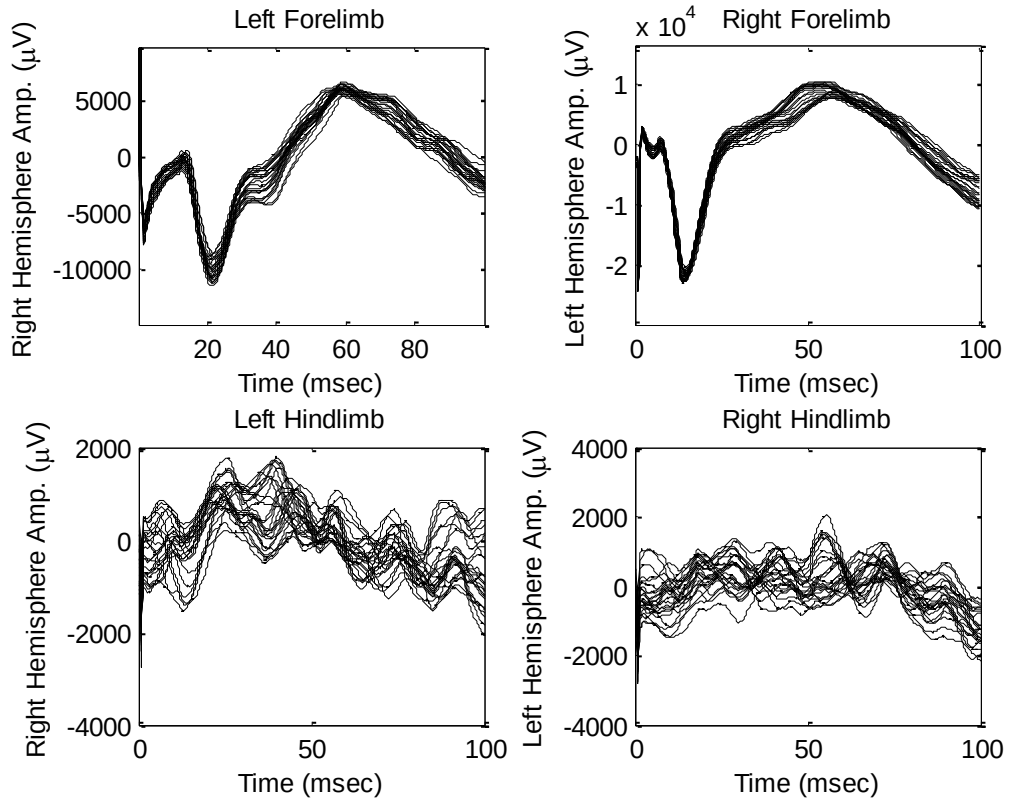
SSEP

Electrical response of the nervous system to a sensory stimulus, recorded from the somatosensory cortex

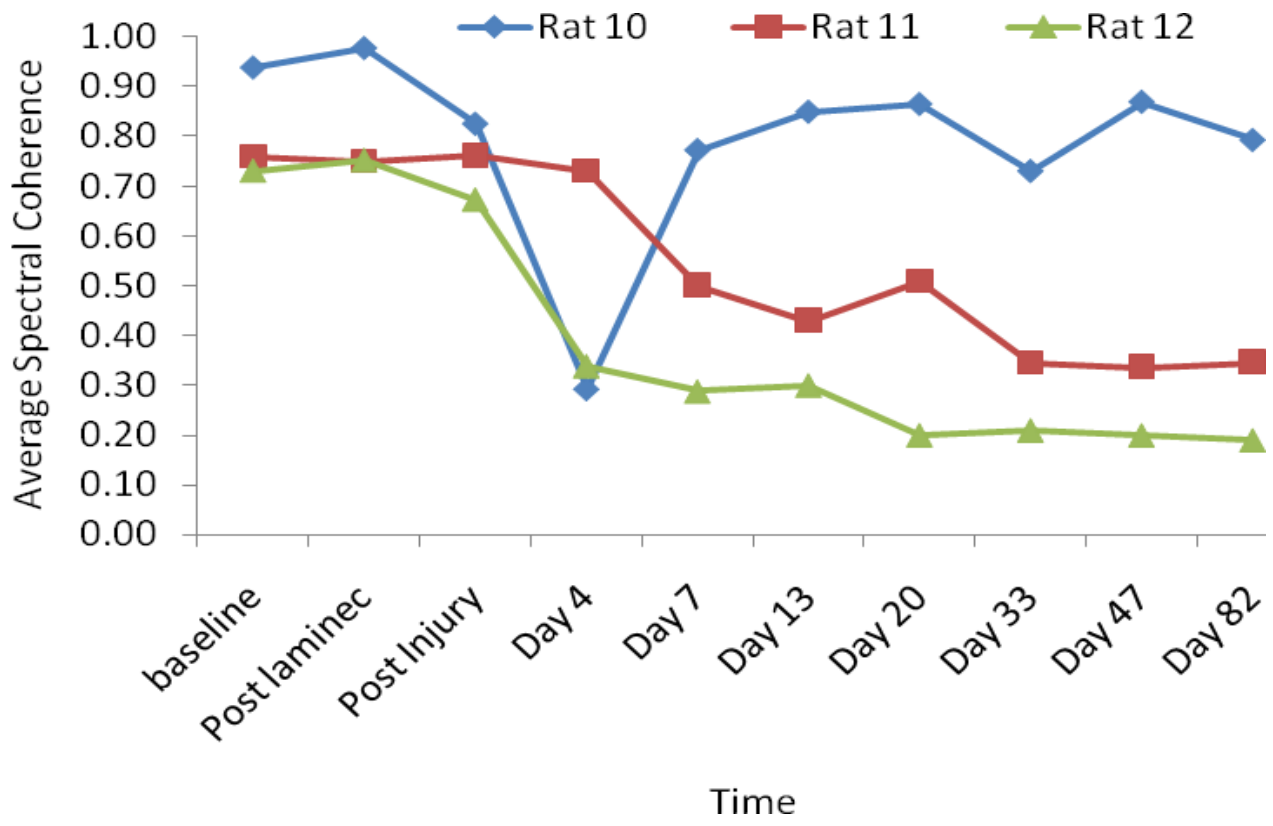
Measures the integrity and conductivity of the sensory pathways through spinal cord



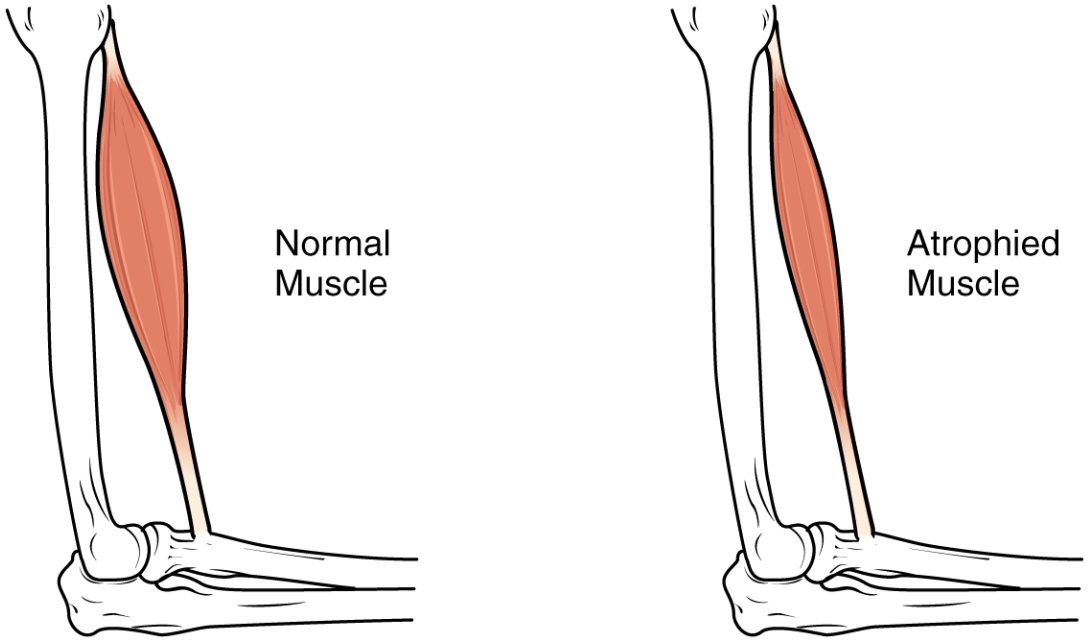
Week 7 Postinjury SEP signals obtained from a rat in the 25 mm injury group



Spectral Coherence Measure



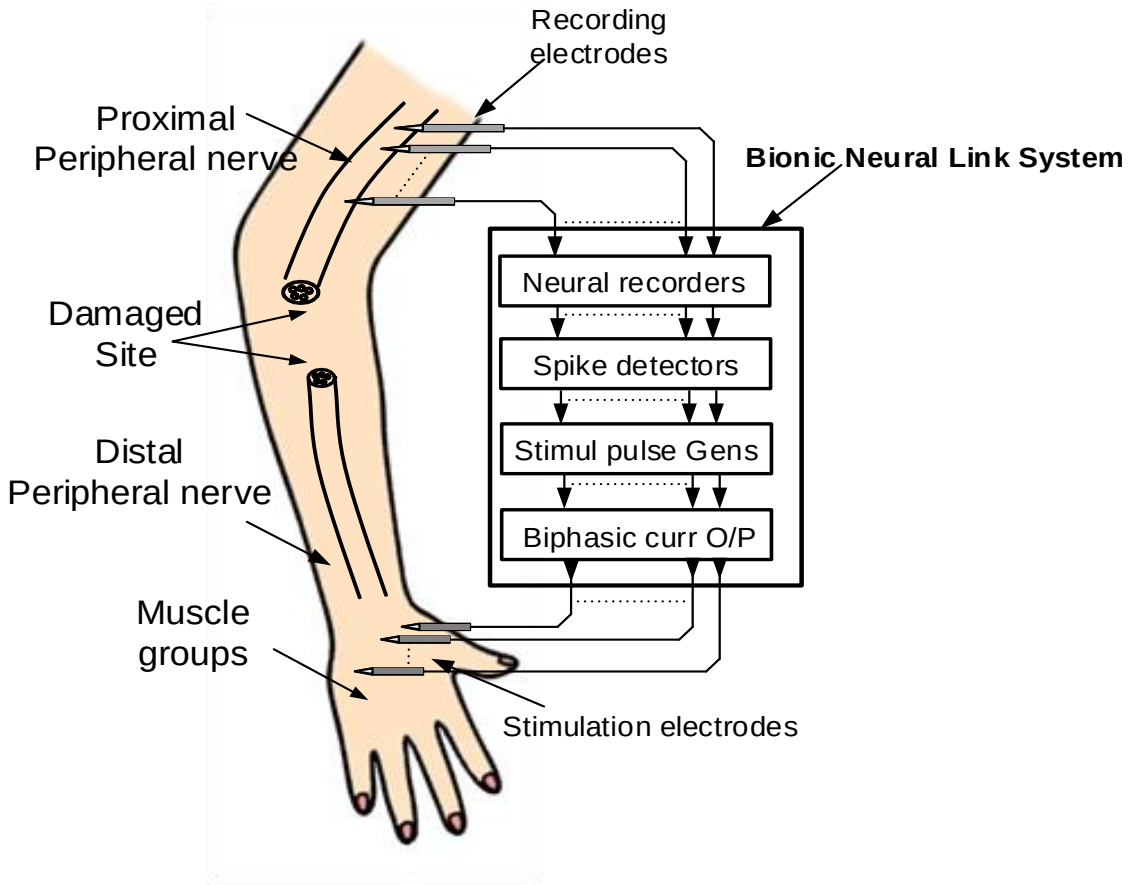
Peripheral Nerve Injuries-Muscle Atrophy



Muscle atrophy due to damage of PNS connection to muscles

Peripheral Nerve Injury

- Implantable electrodes for restoring motor function after peripheral nerve injuries
- Market demands integrated designs for restoring sensory and motor function after nerve injuries
- Electrical stimulation therapy helps to restore limb muscle function, sensory feedback and reduce the risk of muscle hypotrophy.
- Simultaneous recording of the desired nerve Electroneurograph (ENG)



Bioelectrodes

Interface between the biological tissue and the electronic system:

- Sense/measure the bioelectrical signals within the body
- Deliver stimulation signal from the instrumentation system to the target tissue (nerve/muscle)

Bioelectrodes Materials

Inert metal electrodes:

- Platinum
- Gold Iridium
- Silver
- Platinum-iridium

Bioelectrodes Materials

Polymer-based electrodes with modification:

- PEDOT
- Polyimide (PI)
- Polyaniline (PANi)
- Polythiophene (PTh)
- Polypyrrole (PPy)

Grand Challenge

- Current implantable electrodes are metal-based
- Limitations:
  - Mechanical Mismatch
  - Foreign Body Response
  - High Cost

Proposed Novel Solution

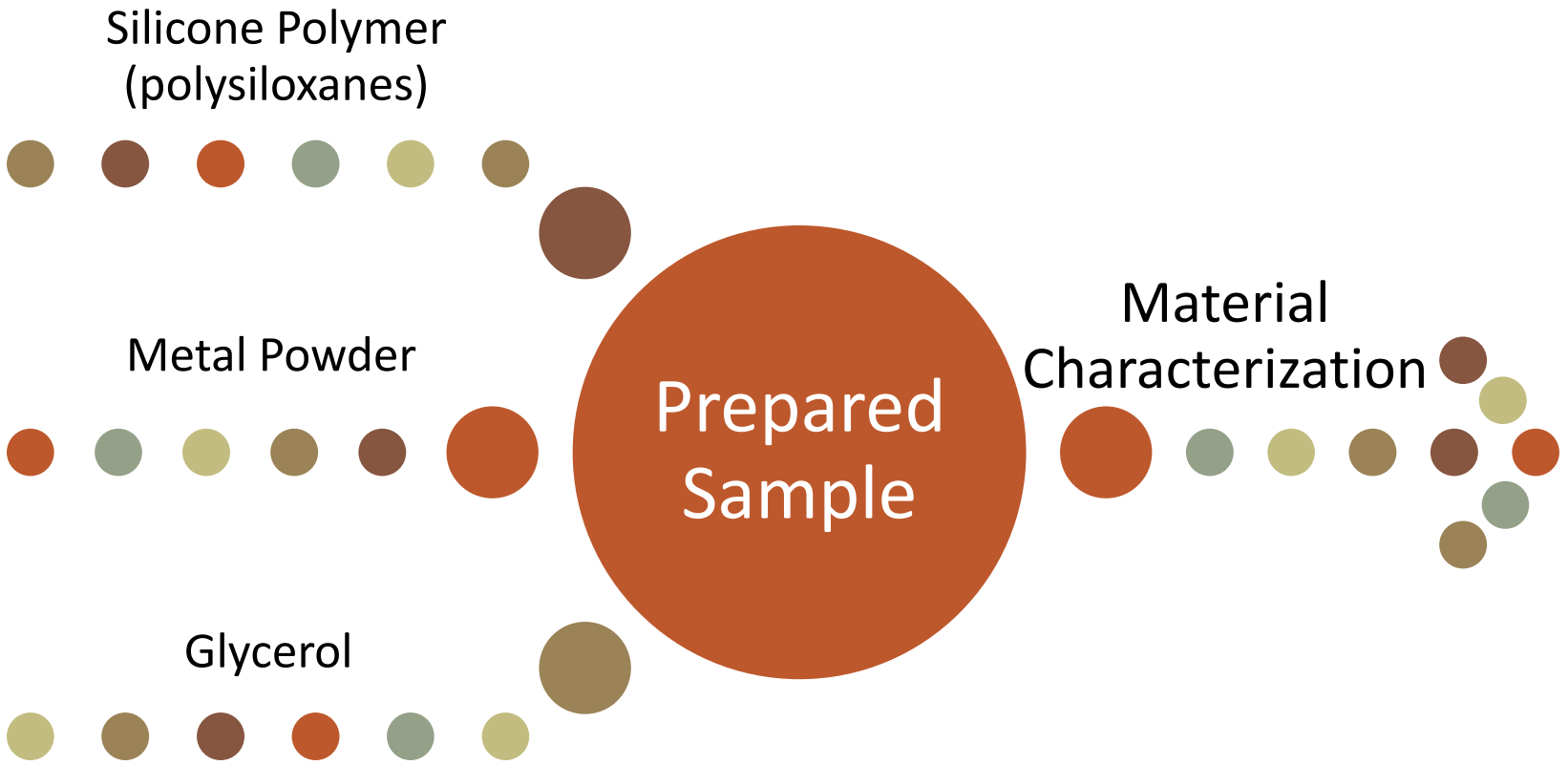
DESIGN REQUIREMENTS

- Low Cost
- Flexible
- Conductive
- Biocompatible

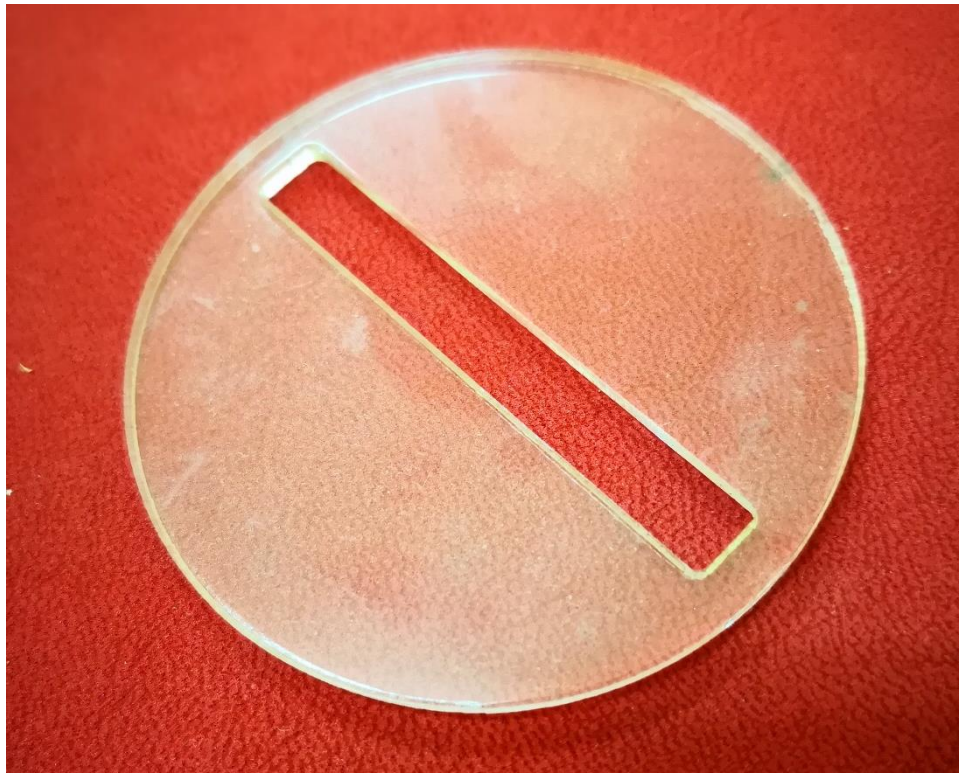
MATERIALS

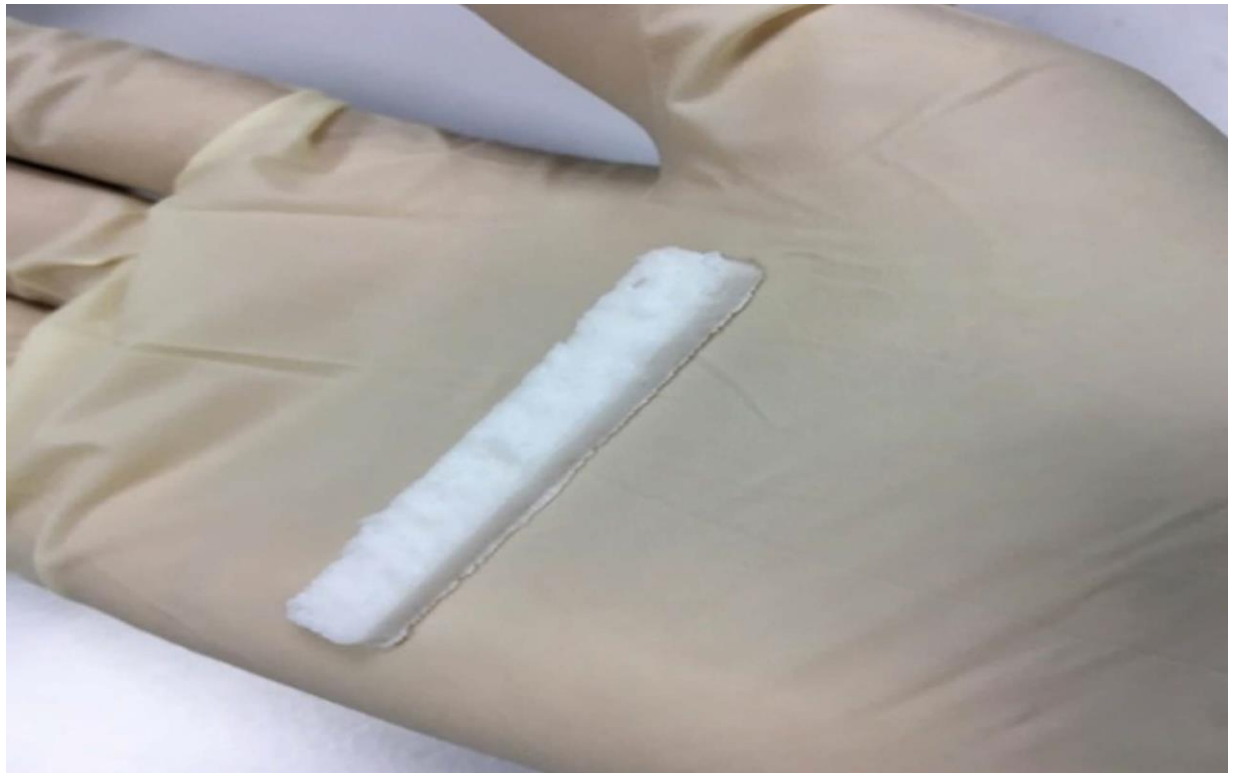
- Polymer + Metal + Mixing Assistant
- Materials:
  - Silicone Polymer
  - Titanium (IV) Oxide
  - Glycerol

Methodology: Material



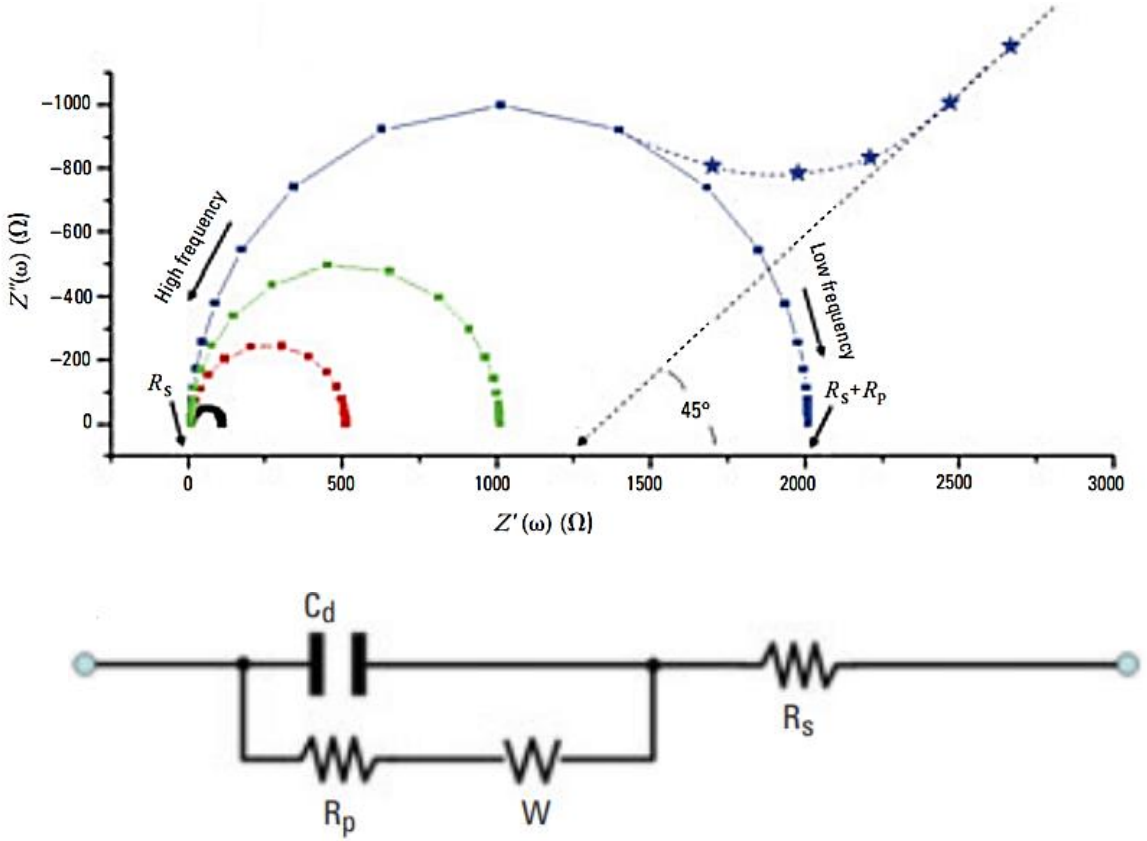
Methodology: Sample Preparation





Teflon mold (left) electrode sample prepared (right)

Electrochemical Properties



Equivalent Randle's Circuit

Potentiostat Setup

Electrochemical Properties

Material	Specimen	R_s (KΩ)	Z at 1KHz
PEDOT:PSS	Thin film	2.23 [7]	2.54 [7]
Ultrathin parylene C coated platinum	Needle-shaped	359 [8]	21,000 [8]
Platinum	Thin film	2.96 [7]	-
Gold	Thin film	10 [9]	17.2 [9]

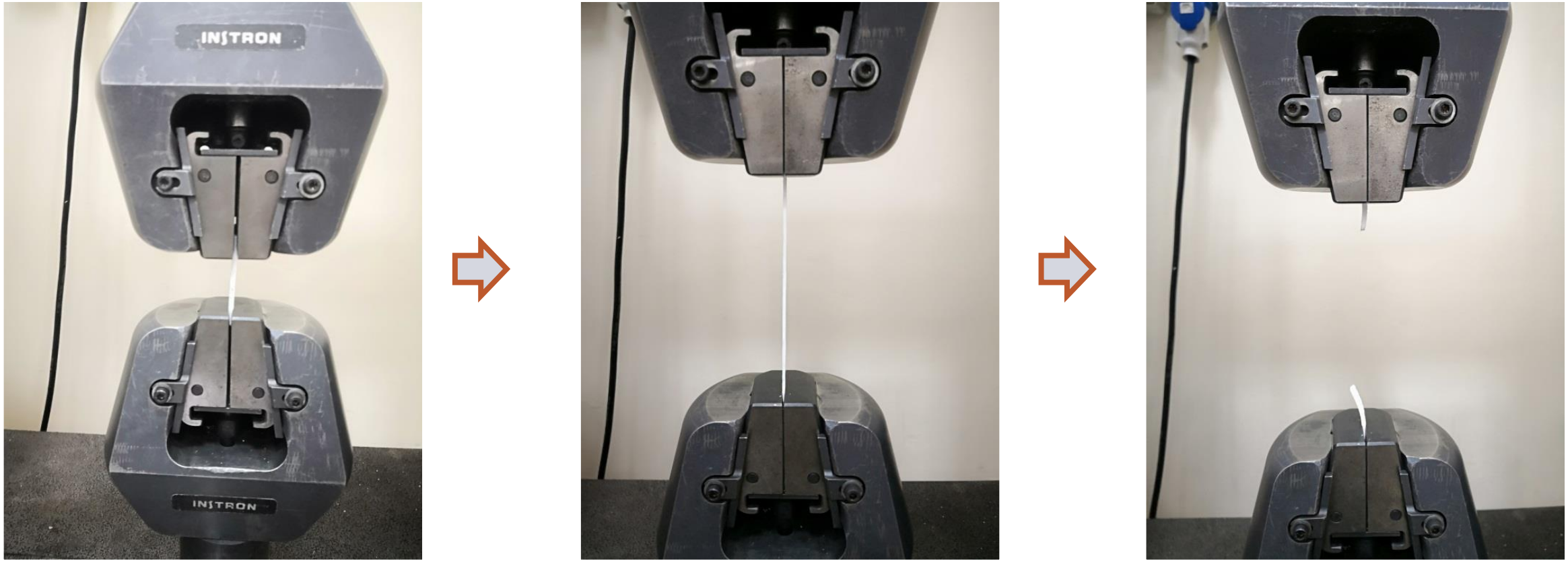
Literature values for electrochemical properties of conductive polymers and metal electrodes

Ratio Testing with TiO_2

Sample \ Si:TiO_2:Gl	70:15:15		50:30:20	
	Bulk Impedance (kΩ)	Impedance at 1 kHz (MΩ)	Bulk Impedance (kΩ)	Impedance at 1 kHz (kΩ)
Sample 1	17.2	1.48	4.25	78.2
Sample 2	7.62	1.14	3.55	24.2
Sample 3	17.5	1.51	4.38	105
Average	**8.96 ± 0.799**	**1.37 ± 0.206**	**4.06 ± 0.448**	**69.0 ± 41.0**

EIS testing results for 3 samples of 15% TiO_2 and 3 samples of 30% TiO_2

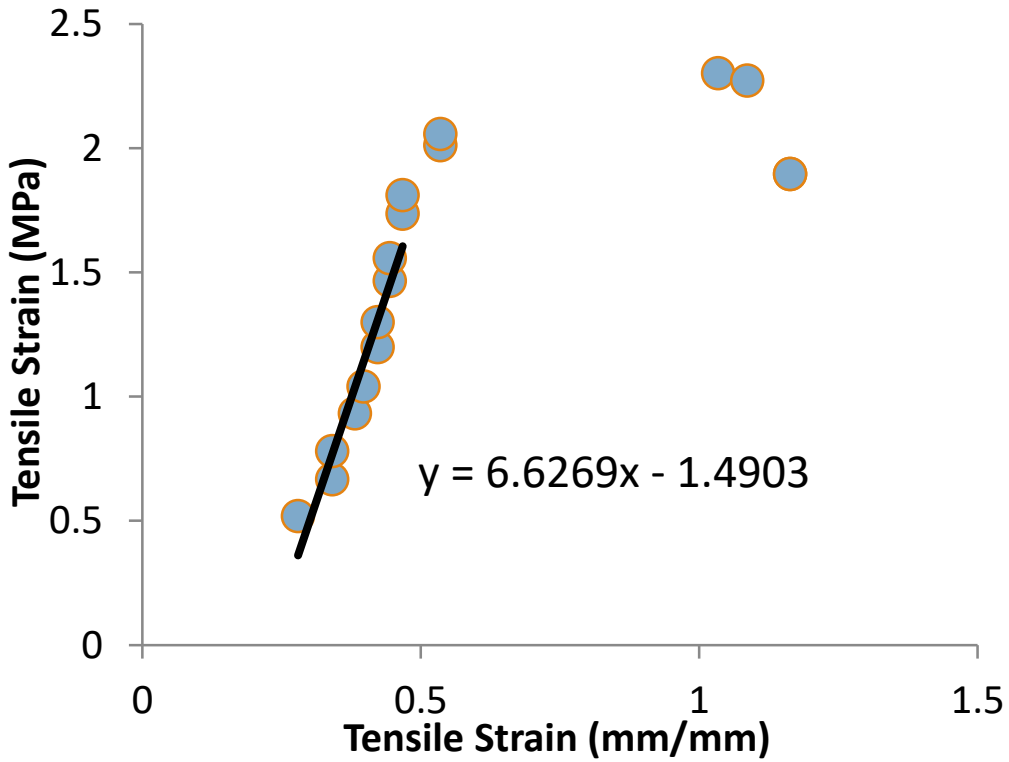
Methodology: Mechanical Characterization



Mechanical Testing Results

Modulus of Elasticity = 6.63 MPa

Elongation = 266%



Stress-strain curve for a sample of 30% TiO_2, 50% silicone and 20% glycerol

Mechanical Testing Results

Material	Specimen	Modulus of Elasticity (MPa)	Elongation%
PEDOT:PSS	Cast film	1.8×10^3 [57]	4.3 [58]
PI	Thin film	6×10^3 [59]	<10% [59]
Platinum	Thin film	140×10^3 [60]	35 [60]
Gold	Thin film	69.1×10^3 [60]	-
This Work	Rectangular shape	4.519 ± 1.154	266 ± 27.1

Comparison of mechanical testing results for 30% TiO_2 samples with conventional materials

Vigilance Decrement and Enhancement

Vigilance could be define as the sustained attention to a particular stimulus over a prolonged period of time.

GRAND CHALLENGE

Extreme *high* or *low* cognitive workload in active applications which require **vigilance** can lead to reduction in **cognitive efficiency**.

Methods for Cognitive Enhancement

TRADITIONAL

Education and learning

Mental training and encoding strategies

Meditation and yoga

Martial arts, sports and exercise

Caffeine and nicotine

Diet and herbal extracts

CONTEMPORARY

Pharmaceuticals

Psychological interventions

Molecular and gene therapy

Transcranial magnetic stimulation

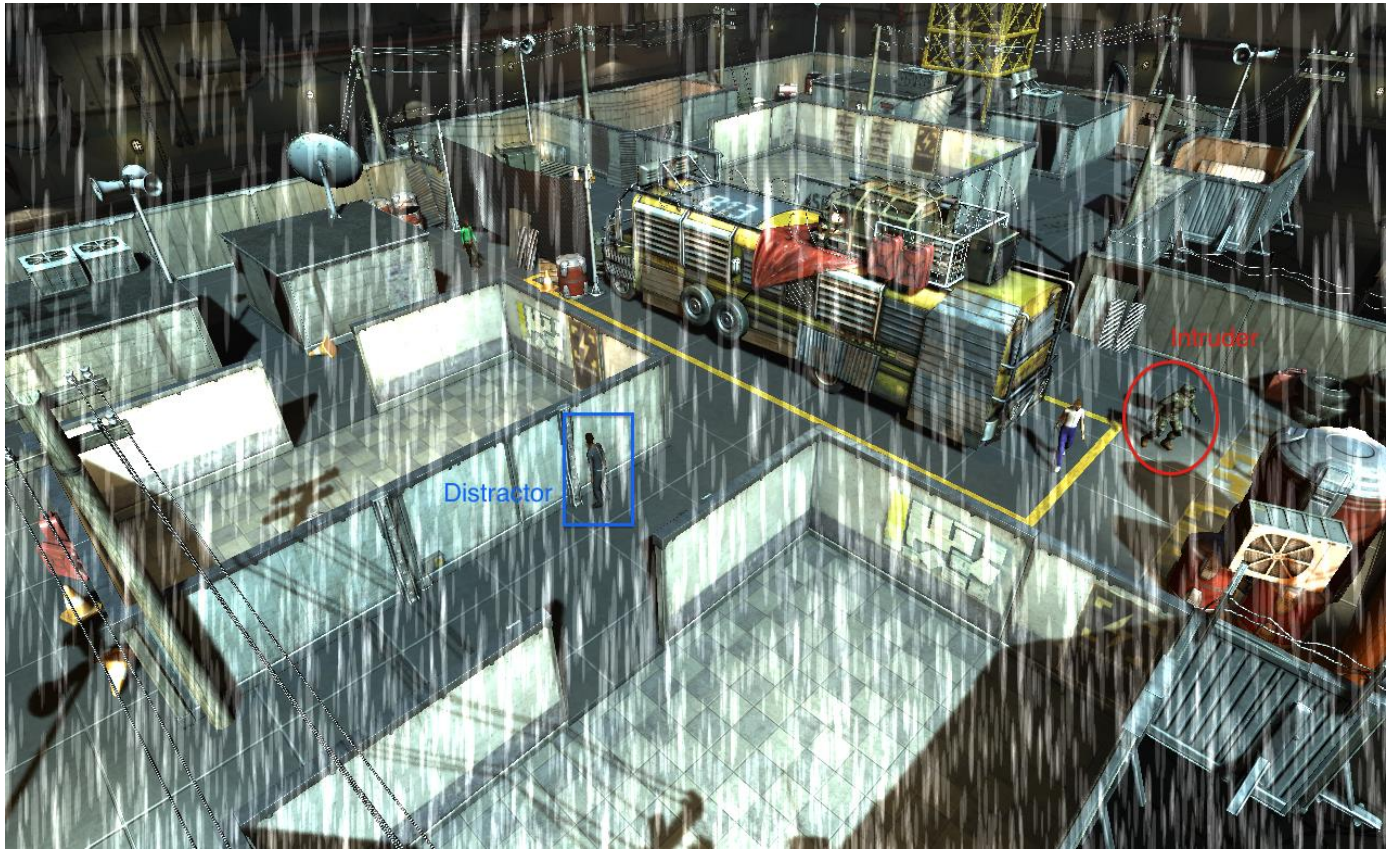
Electrical stimulation

Gaming/Challenge integration

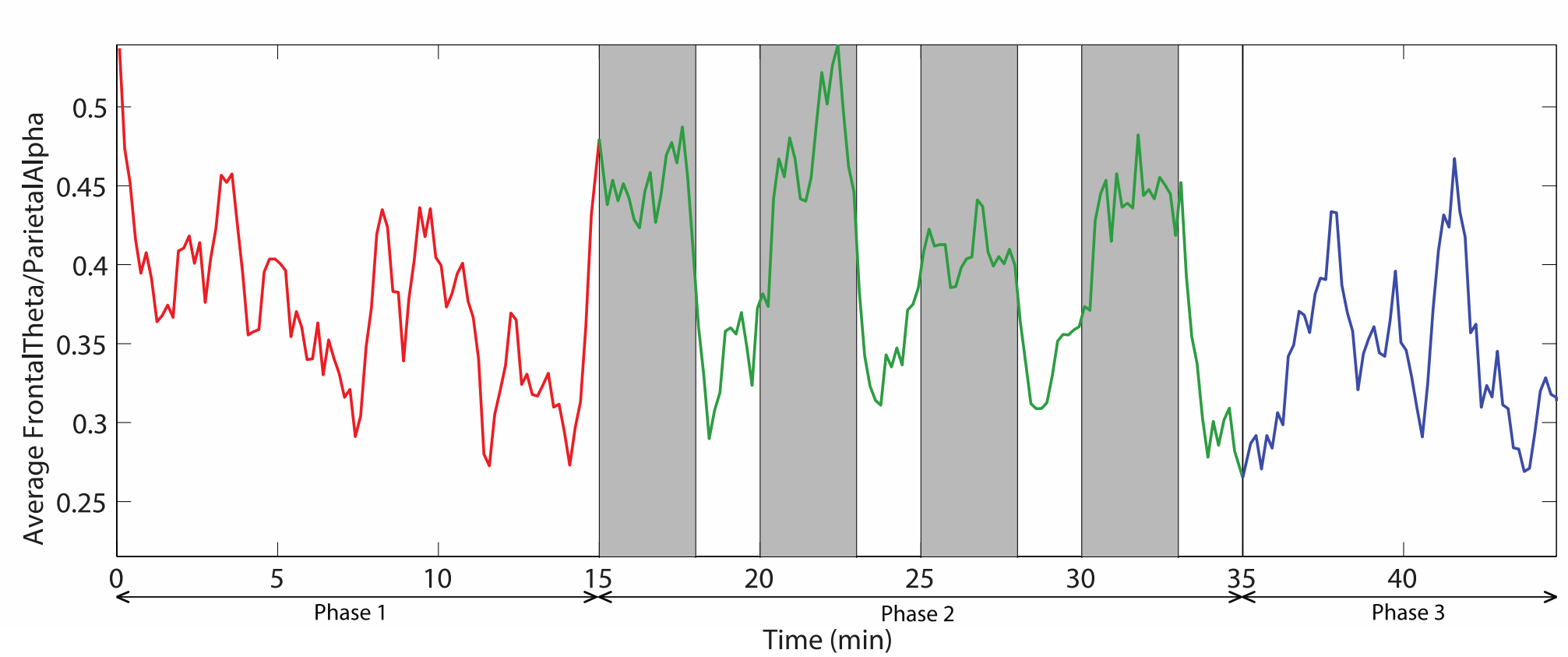
Tactile and rhythmic haptic

Audio (Music, Binaural Beats)

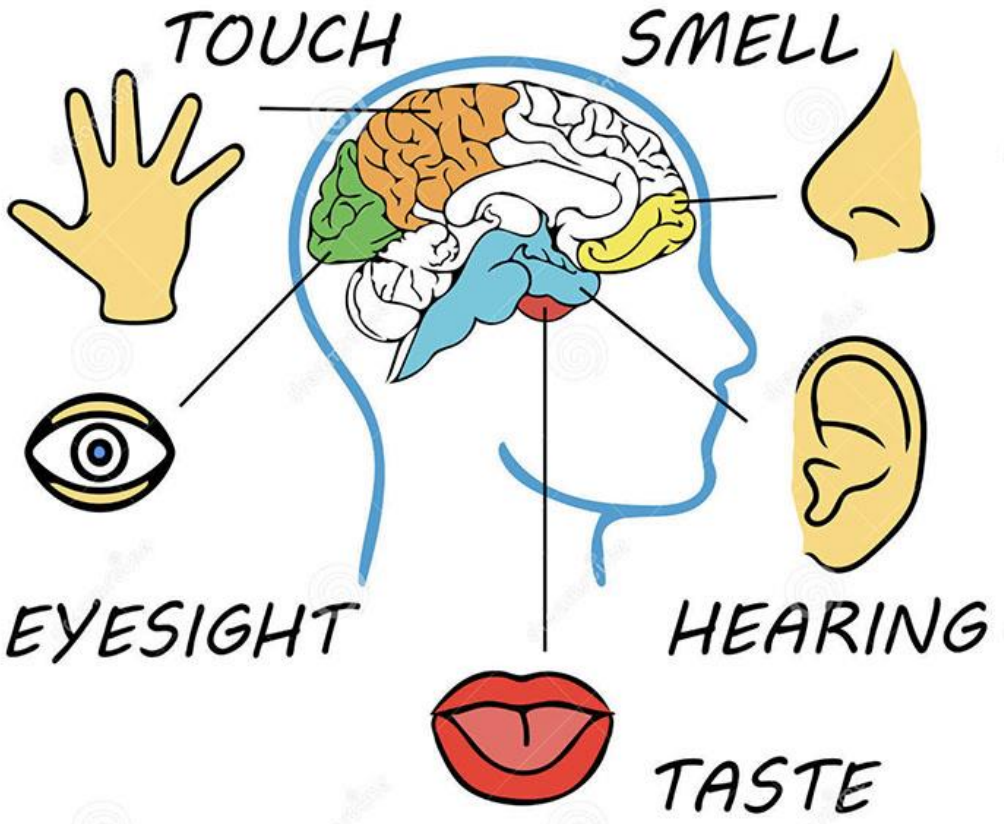
Challenging Noise – 20 Minutes



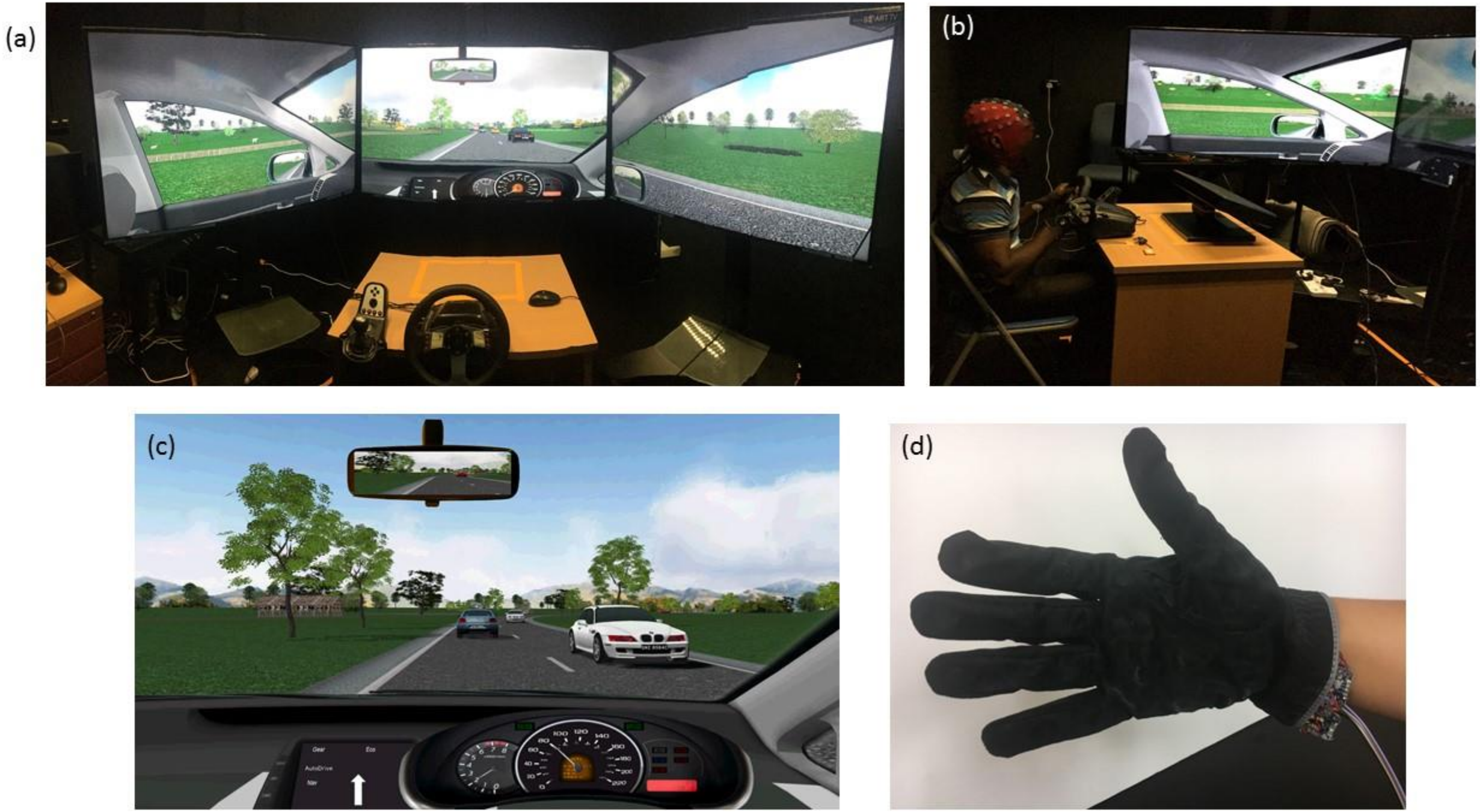
Results – EEG PSD, n=12

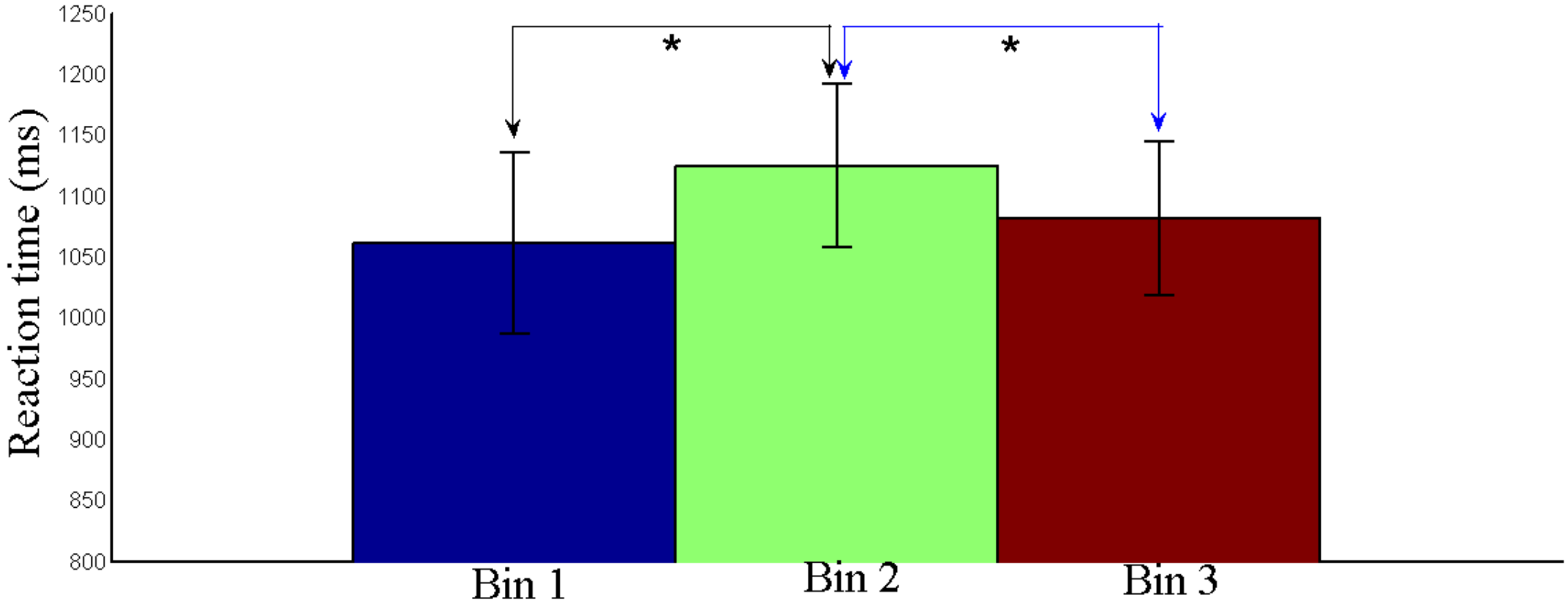


Human Brain Senses and Waves




Gear
Eco
N
Nav
GTI

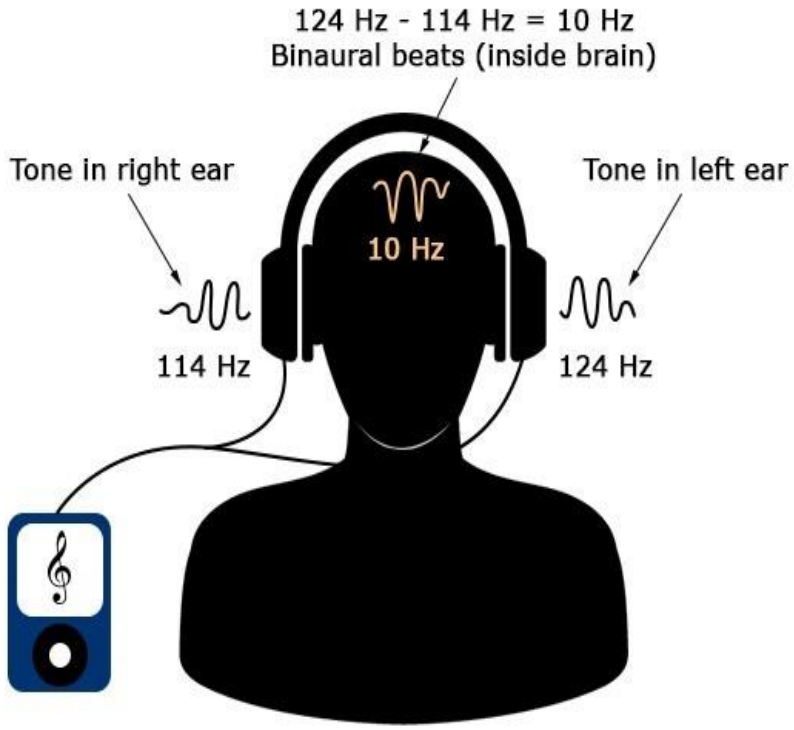

(a)
(b)
(c)
(d)


Reaction time (ms)
1250
1200
1150
1100
1050
1000
950
900
850
800
*
*
Bin 1
Bin 2
Bin 3

p<0.05

Binaural Auditory Beats (BBs)

- When two auditory stimuli of different frequencies are presented to each ear, binaural beats are perceived by the listener.
- The binaural beat frequency is equal to the difference between the frequencies applied to each ear.



Objective

- Develop a novel computerized vigilance test
- Explore the effectiveness of BBs in vigilance enhancement
- Identify useful frequencies
- Investigate the vigilance permanence with time

Proposed Binaural beats (BBs)

The Carrier frequency is set to: [250 Hz]

BBs are presented at:

[**4** Hz, correspond to EEG Theta rhythm]

[**10** Hz, correspond to EEG Alpha rhythm]

[**16** Hz correspond to EEG Beta rhythm]

Data Collection

Sign the informed consent form approved by the AUS IRB

Subject data: survey, data sheet

Epworth sleepiness scale test (ESS)

Short Stress State Questionnaire (SSSQ)

NASA TLX questionnaire

Reaction time

Response accuracy

Eye tracking variables

EEG

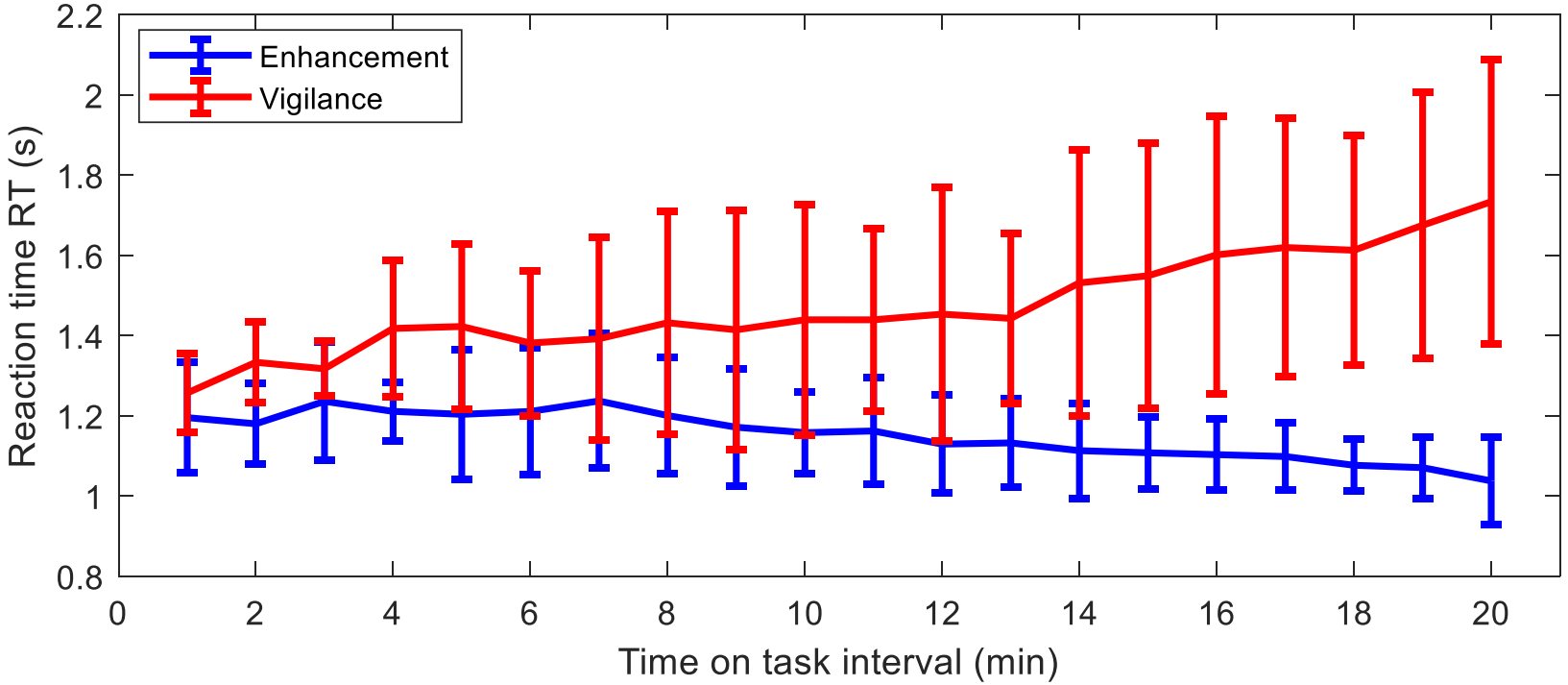
ECG

EOG

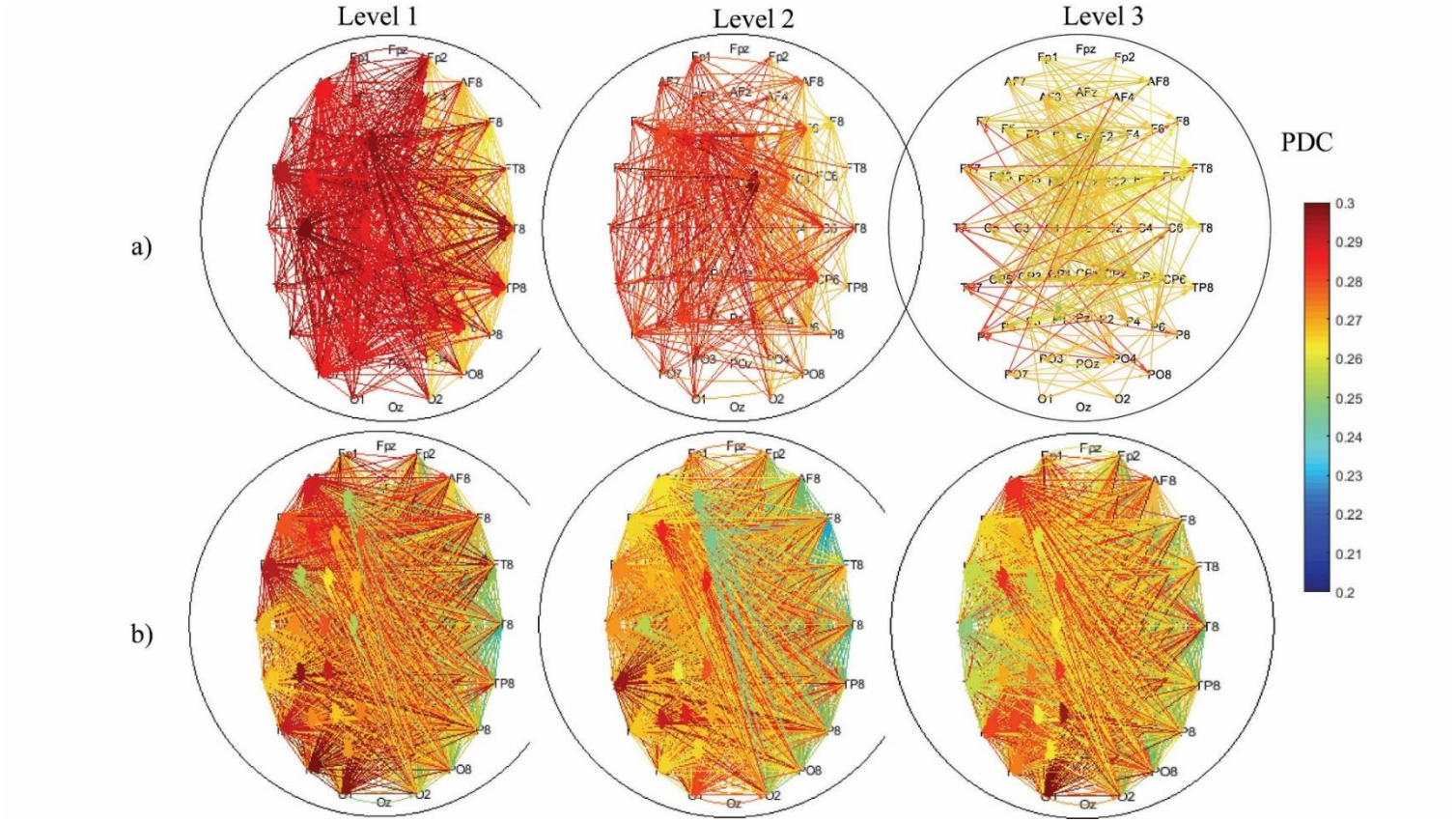
Assessment Methods

- Power spectrum analysis
- Functional connectivity
- Brain Source localization
- Data fusion
- Machine learning

Results


Enhancement
Vigilance
Reaction time RT (s)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0
2
4
6
8
10
12
14
16
18
20
Time on task interval (min)

EEG connectivity network



Average weighted directed connectivity network for (a) Vigilance, (b) Enhancement. Red indicates high connectivity strength

Thank You