# Brain Computer Interface

# Technology

ARE WE THERE YET?

# My ninja, you can’t dodge *dis*!

Never under-estimate the power of a virtual threat, it will eat away at your nine lives.

# Problem Description

- Certain events which result in the loss of motor control tend to affect the neuromuscular connection
  - Injuries
  - Parkinson’s disease, Huntington’s disease, Amyotrophic Lateral Sclerosis, etc.
- This normally results in the
  - Inability to communicate using digital media
  - Inability to perform certain motor tasks, such as the ability to feed oneself, operating machinery or tools

# Problem Description cont.

- Significance
  - Loss of income
  - Degradation of the quality of life
  - Reduced mobility and independence
  - 2 861 028 people with disabilities above the age of four in South Africa (as measured in 2014)
  - Substantial resources allocated towards disability grants (approx. R17 Billion per annum in SA,  as measured in 2014)
    - Approximately 1 127 285 people with in SA (as measured in 2014)

# Problem Description cont.

This is Hawking, of course with a mind like that, one can only be a ladies’ man.

# State of the Art

Miguel Nicolelis, the man who is leading the BMI chaos.

# State of the Art

- Duke University
  - Nicolelis Lab

# State of the Art

- Some other *cats*
  - John Hopkins APL

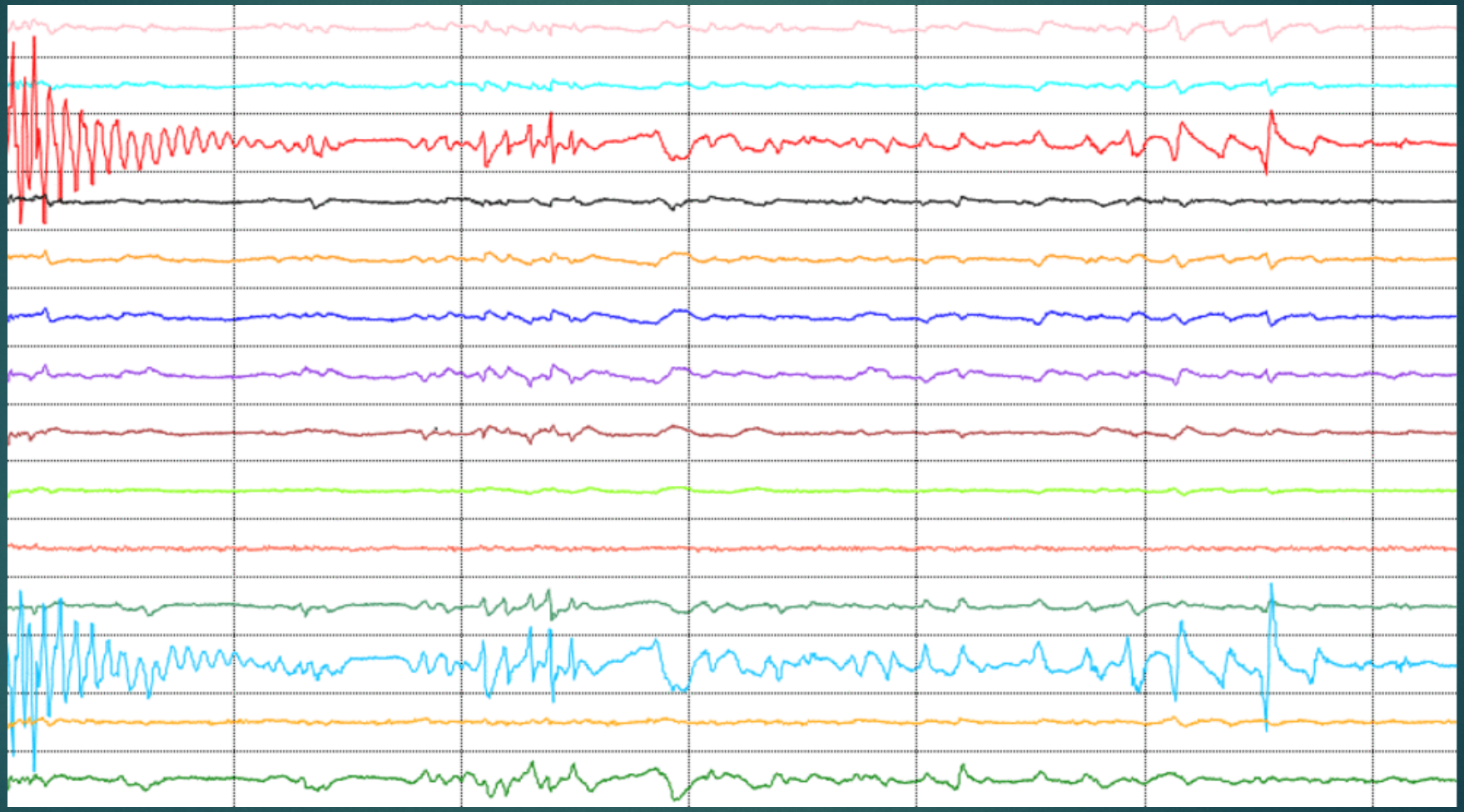
# Proposed solution cont.

- Brain Computer Interface (BCI) for text input that is based on electroencephalography (EEG) data related to motor-imagery task response
  - Perform input to a computer by imagining moving a certain body part
    - Left-hand movement imagination
    - Right-leg movement imagination
  - Different motor-imagery tasks mapped to different computer instructions

# Proposed solution cont.

The stuff it *is not* made of.

# Proposed solution cont.



The stuff it *is* made of.

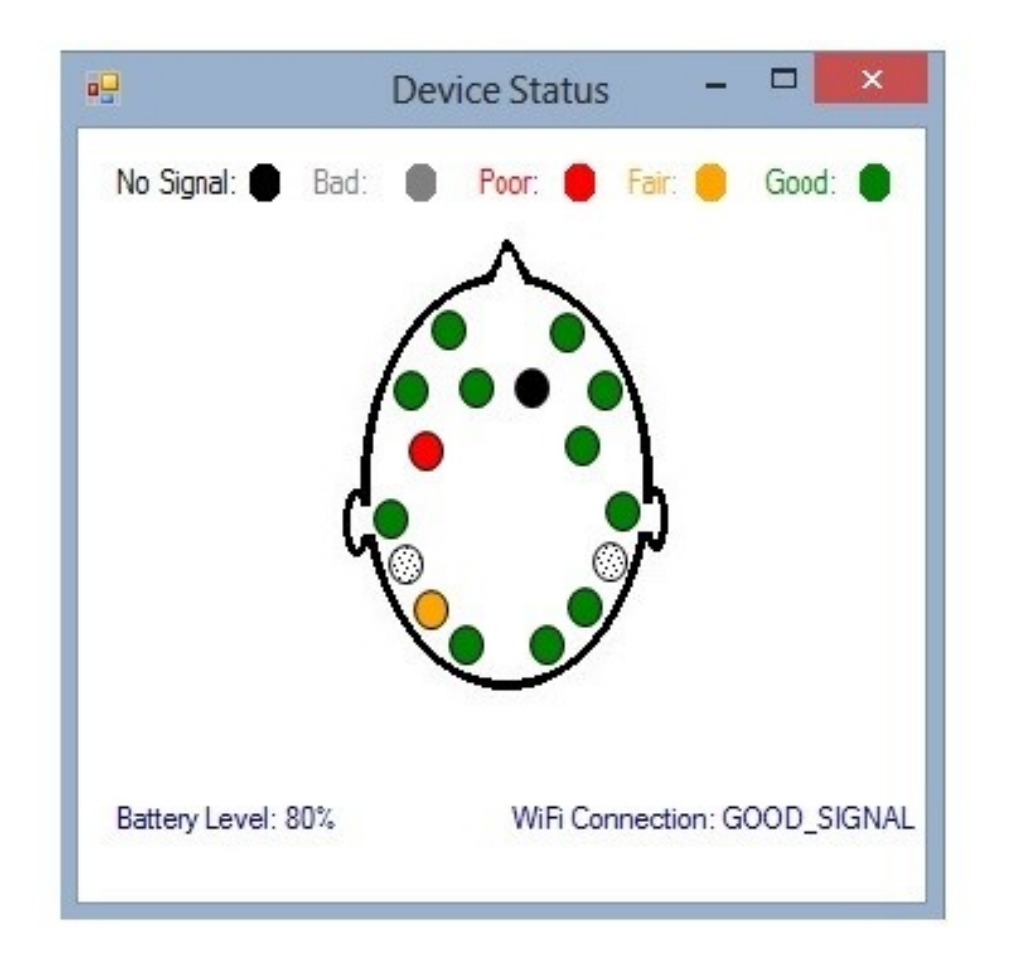
# Proposed solution cont.

- Preliminary findings revealed that we should relax the  constraint of using strictly motor related tasks
  - Investigations into the use of other tasks
    - Arithmetic
    - ..the hunt for more is on
      - Language?

# Experimental Equipment

The Emotiv Epoc is *ouch'ea*, slyza tsotsi.

# The Pre-prototype Concept




If you know what’s good for you, you’ll keep your eyes *only* on me.

# The Pre-prototype Concept


Apple ain’ got nothin’ on us.

# Our Work

- Provide an alternative channel for communication
  - Not dependent on neuro-muscular connections
  - Low-cost solution in order to improve feasibility of everyday use
  - Non-invasive Brain Computer Interface (BCI)

# Our Work cont.

- Advantages
  - Comparatively low latency response
  - Non-invasive technique
  - Proposed sensor is relatively affordable
  - Proposed sensor is portable & easy to use
- Disadvantages
  - Comparatively low spatial resolution
  - High level of noise in the data

# Background Concepts

- Neuroscience
- Signal Processing
- Machine Learning

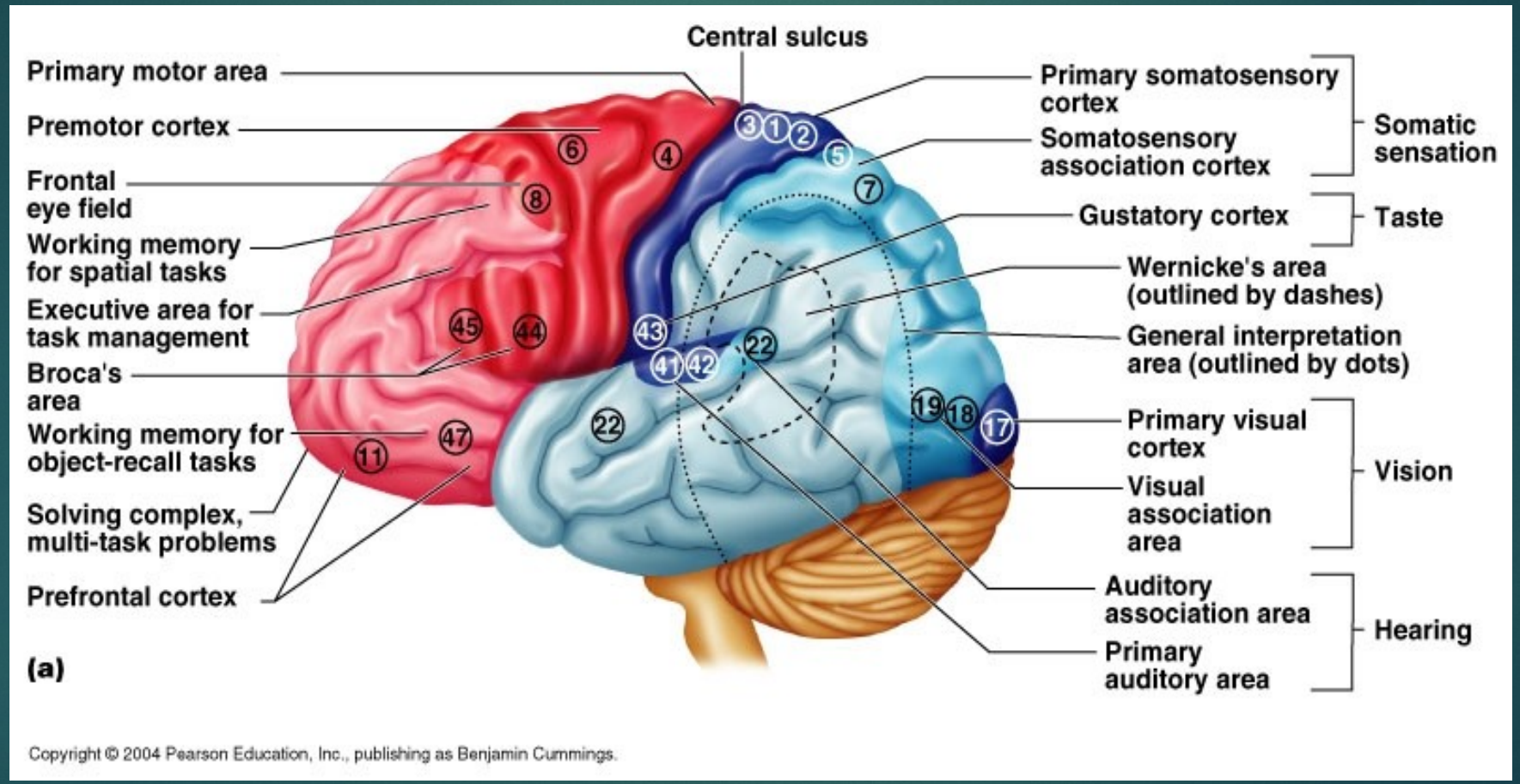
# Neuroscience

This could get very simple, very slowly.

# Neuroscience cont.

- Lesion studies have revealed that brain functions are largely localized
  - Certain regions are associated with sensorimotor functions
- Neuron excitation studies suggested that neural encoding has an anatomical basis
  - There exists a definite encoding mechanism that the brain uses to process and transmit information

# Neuroscience cont.

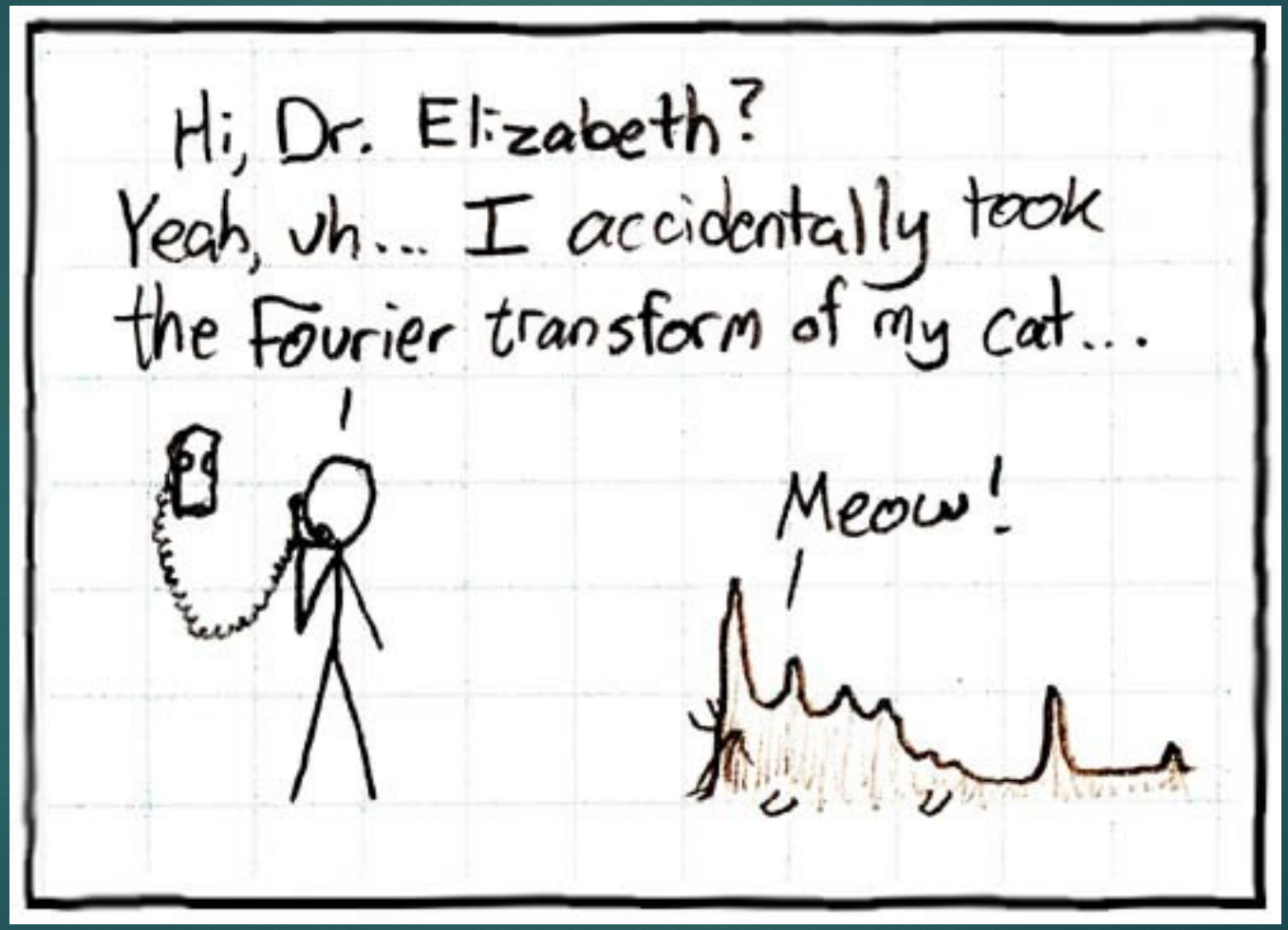



The culmination of decades of cracking open skulls and cutting away on *live* brain tissue.

# Neuroscience cont.

- Motor cortex EEG activity exhibits de-synchronization when a person is either performing a motor-imagery or motor task
- De-synchronization manifests as an attenuation of power over a certain range in the frequency decomposition of the EEG time-series
  - The de-synchronization is the signal we are seeking

# Signal Processing

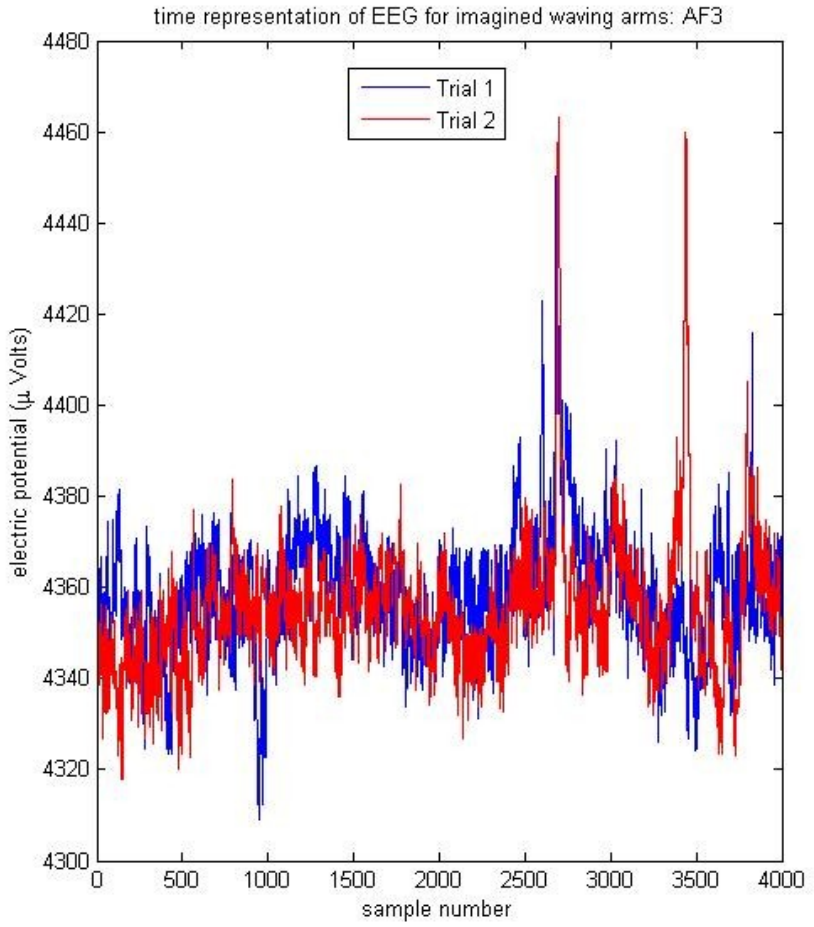


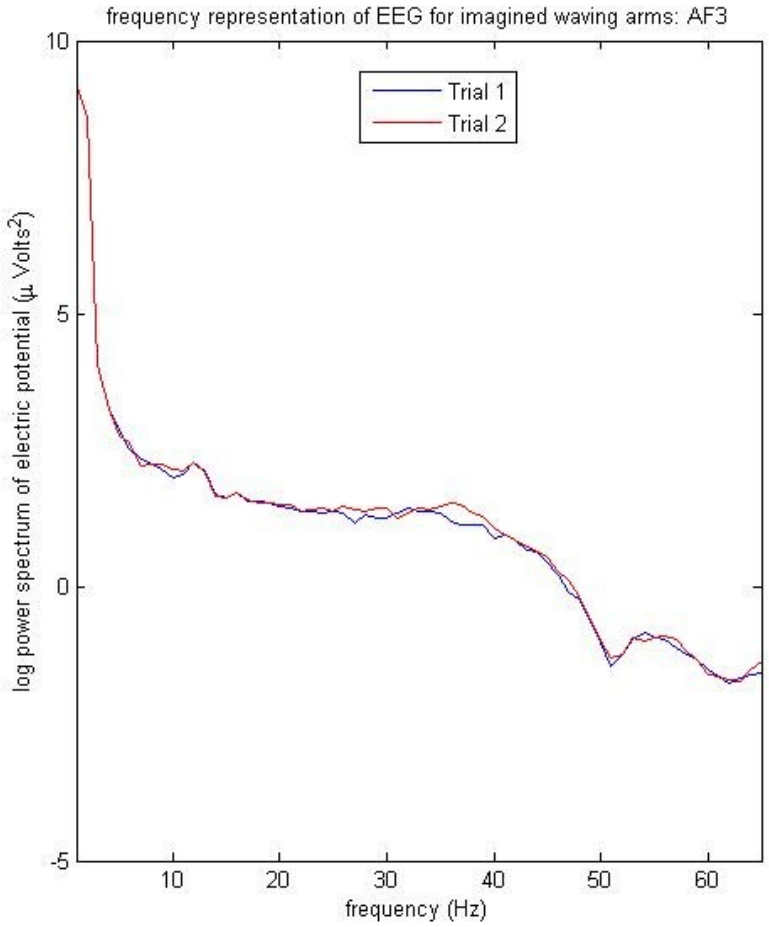

One way of getting rid of something you don’t want expressed in the spatio-temporal domain.

# Signal Processing cont.

- The required information is easily discernable in the frequency domain
  - This necessitates a change in basis
- Fast Fourier Transform to perform the change representation space
  - The state is represented by feature vectors containing frequency related information
  - Feature vectors components contain selected power spectrum measurements over specific frequencies on 8 channels
  - Ultimately we are interested in the temporal evolution of the state vector

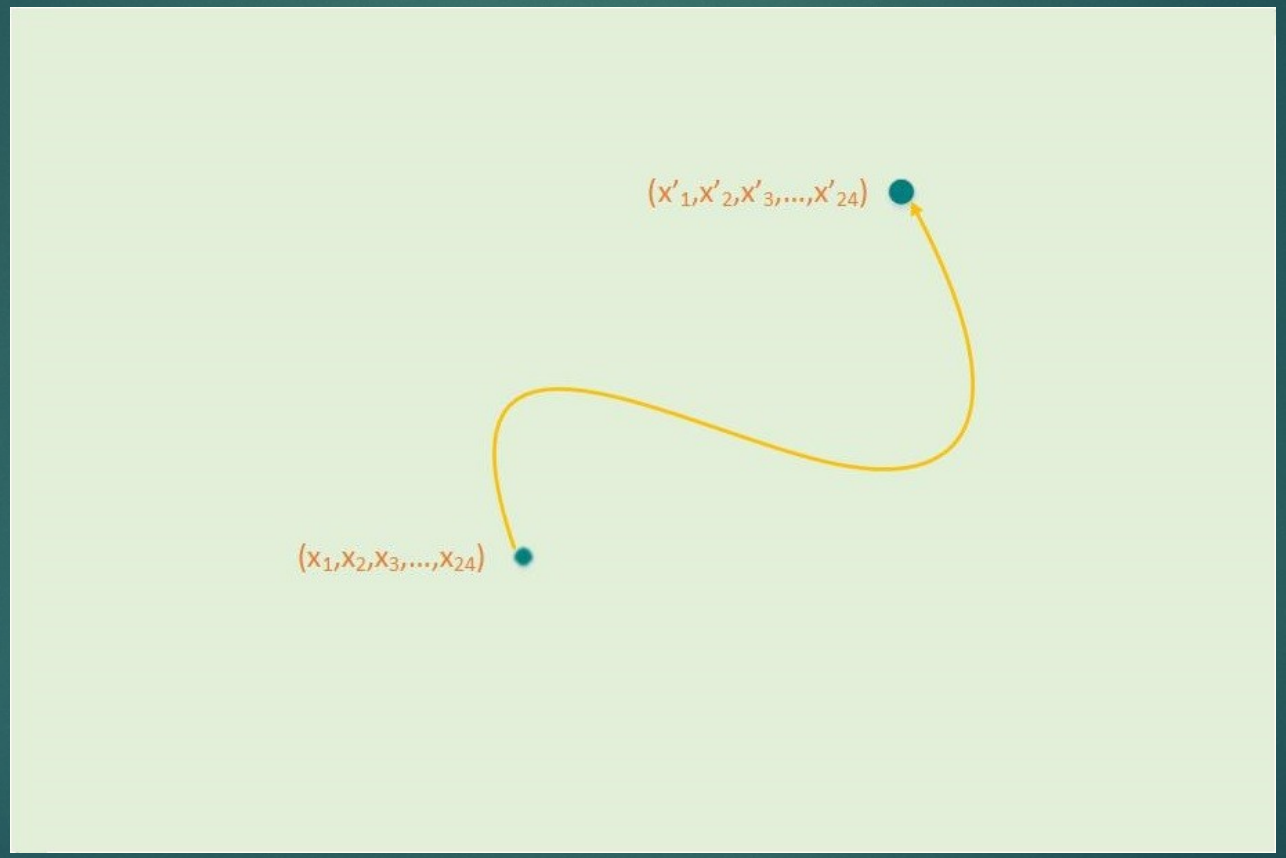
# Signal Processing cont.



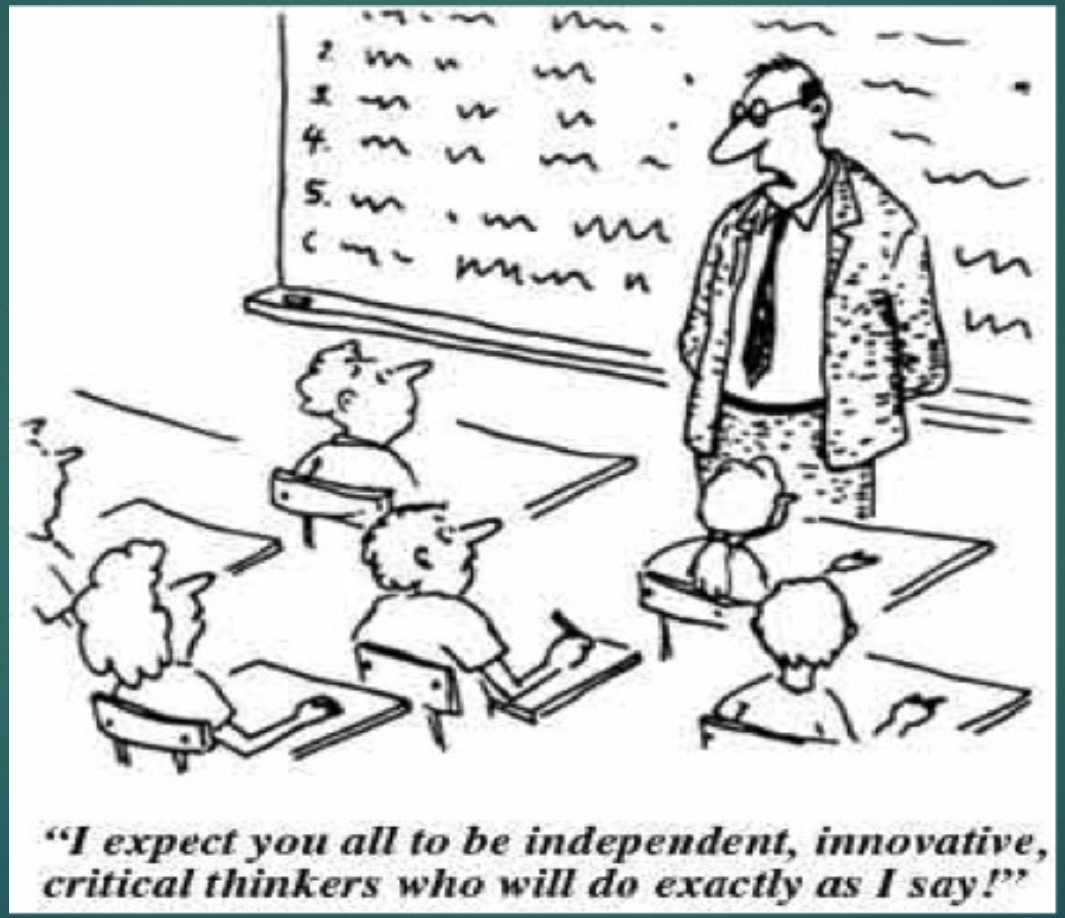

Choose mazikhethela. You decide for yourself.

# Signal Processing cont.




Think of the state vector as a point traversing a 24-D Euclidean space, *no jokes*.

# Machine Learning




You are reading the wrong caption.

# Machine Learning cont.

- Machine learning is required for automatically associating certain inputs to certain outputs
  - Tools that enable a computer program to learn to associate certain input signals to certain output signals
    - Without a programmer having to explicitly write the instructions that have to be followed
  - Learning algorithms modify certain parameters of a mapping function in order to achieve the required association
    - May happen in a supervised or unsupervised manner

# Machine Learning cont.

- Creating the required association is usually reduced to an optimization problem
  - The inputs are the feature vectors that encode frequency information
  - The outputs are abstract classes which represent classification results
  - Automatically identifying (supposedly) classes with similar input structure or *new* classes from continual usage?

# Machine Learning cont.

- A few reasons for applying machine learning techniques to sensor data
  - Sensor data tends to contain noise that a programmer cannot easily remove
    - Noise structure may be complicated by context or temporal sensitivity
  - Mapping input data with output data may be complex in its own right
    - Input data may have high dimensionality making visualization complex
    - Information extraction may require non-trivial transformations of input data

# Machine Learning cont.

- Employ a supervised machine learning technique
- Handle data with temporally encoded structure
  - Hidden Conditional Random Fields
  - Hidden Markov Model

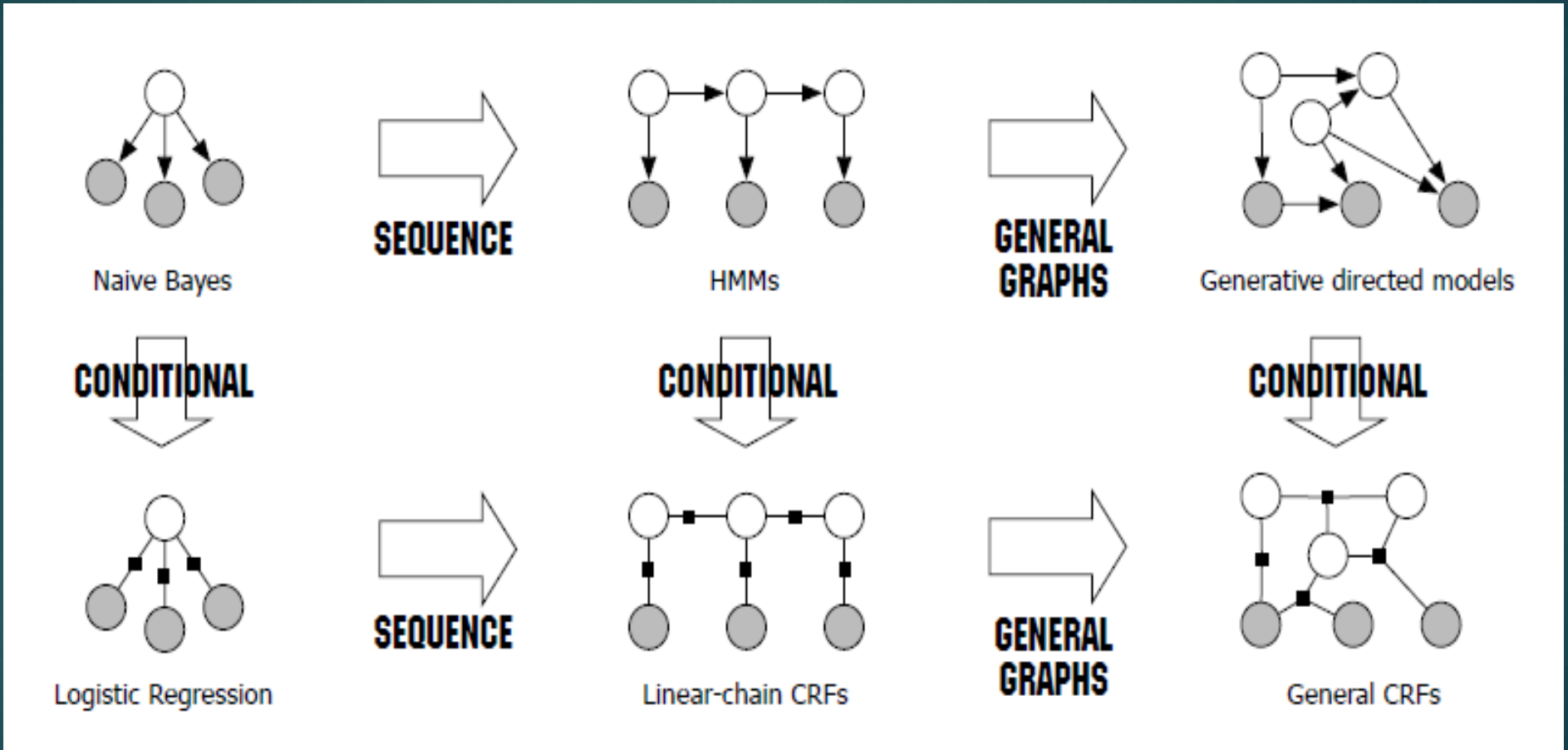
# Machine Learning cont.

- Hidden Conditional Random Fields
  - Undirected probabilistic graphical models
    - The graph expresses the conditional dependence between random variables
  - Augment with hidden variables to find unspecified substructure

# Machine Learning cont.

- Extension of CRF
  - Discriminative approach to classification which depends on modelling the joint pdf between category label & state given observations as opposed to the joint pdf between states & observations
    - Don’t learn *n* parameter vectors which optimize the likelihood function for an observation given a parameter vector in each of the *n* categories independently of other categories given the observation
    - Learn *one* parameter vector to optimize the likelihood function for a category label given the observation
    - Sampling not possible

# Machine Learning cont.

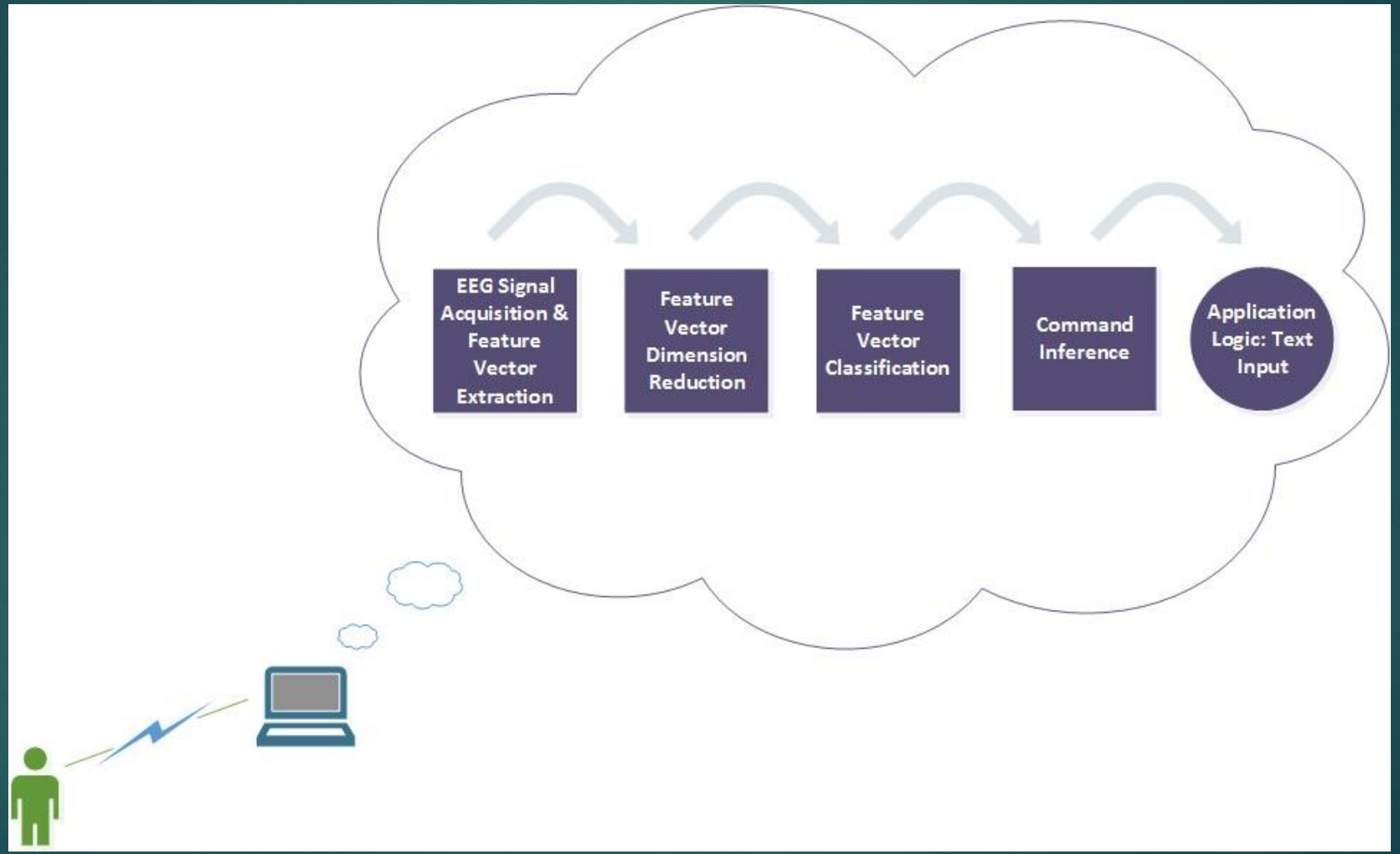



The story in a single image.

# Machine Learning cont.


That’s all folks.

# Basic System Architecture




Modular design to guard against midnight-madness modifications

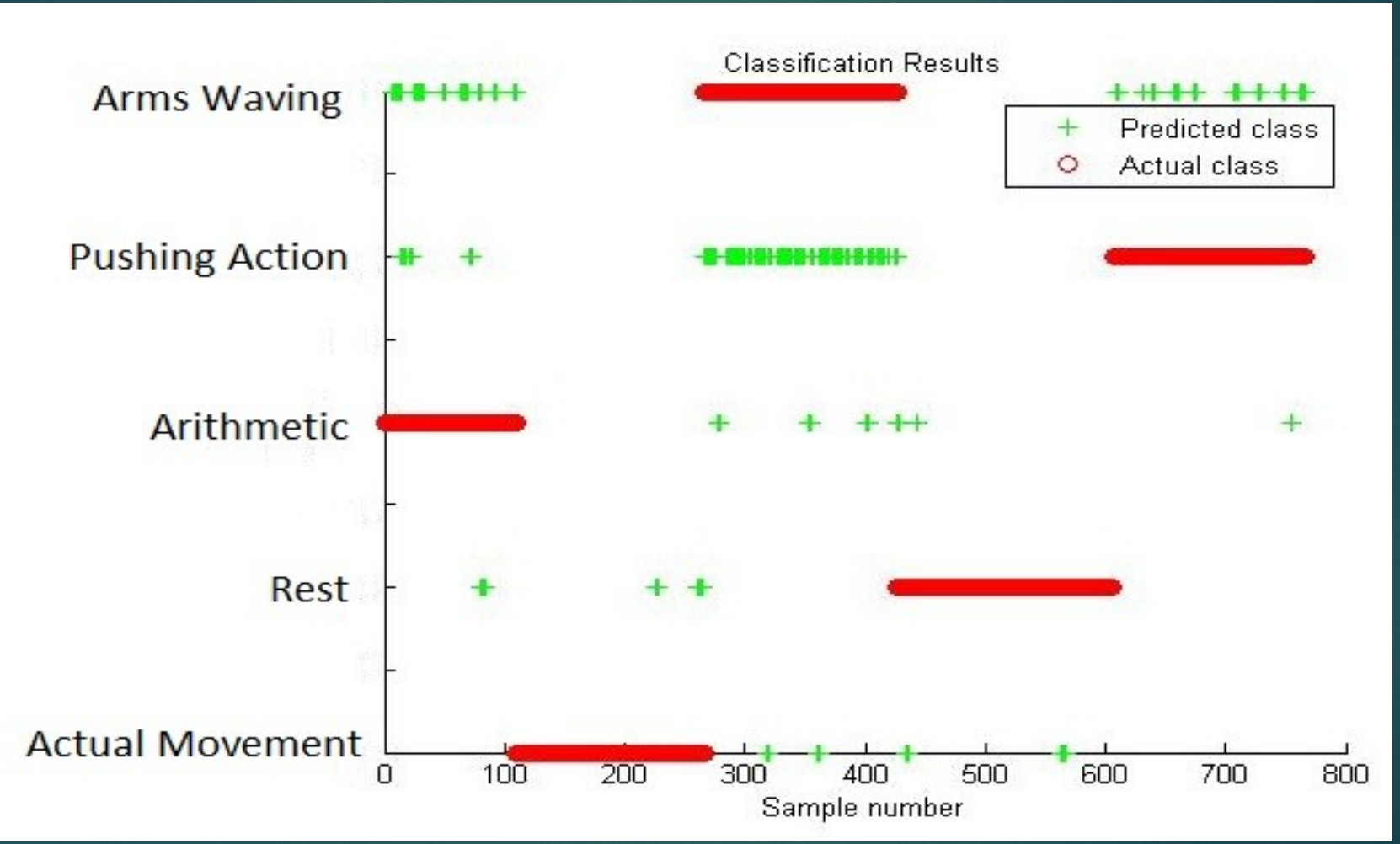
# Research Phases

- System design and development
  - Feature vector extraction
  - Classification
  - Command inference
- Data collection
  - Labeled training data from different individuals
- System performance evaluation
  - Cross-validation in the off-line mode (classification accuracy)
  - On-line assessment for usability of the system in real-time mode

# The Burning Question..

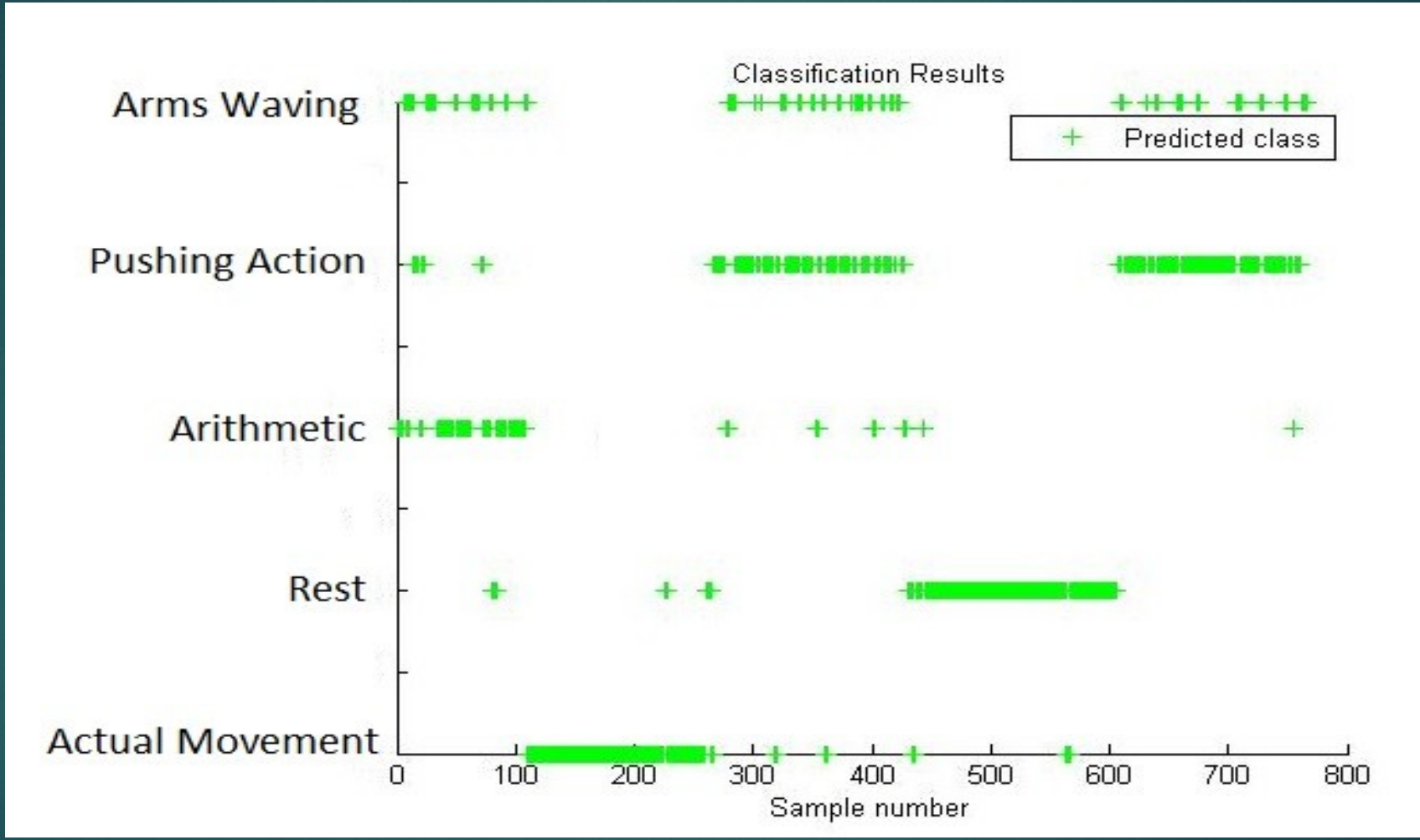
Perhaps, perhaps not. We still have to find out.

# Preliminary Results




More witchcraft, next you will all disappear.

# Preliminary Results




Hmmm, you are still here.

# Preliminary Results

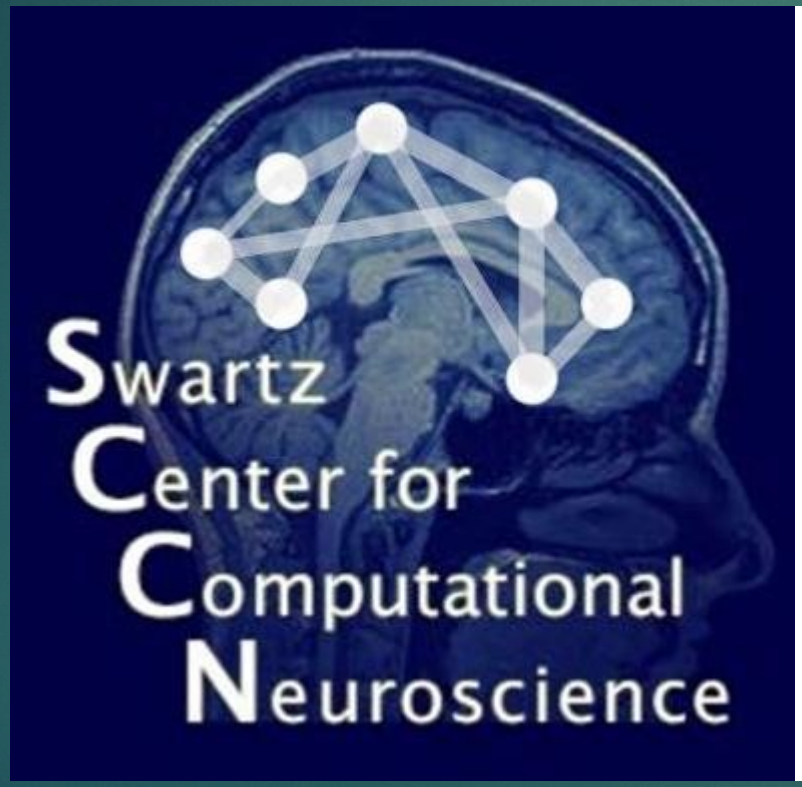
| Number of Hidden States | Classification Accuracy % (Training Data) | Classification Accuracy % (Test Data) |
|---|---|---|
| 1 | 87.3059 | 67.3629 |
| 2 | 87.3059 | 67.4935 |
| 3 | 91.1546 | 72.1932 |
| 4 | 91.4247 | 69.5822 |
| 5 | 90.8845 | 69.7128 |
| 6 | 88.2512 | 66.4491 |
| 7 | 90.1418 | 72.5849 |
| 8 | 90.5469 | 69.3211 |
| 9 | 89.264 | 70.8877 |
| 10 | 93.3153 | 73.1070 |

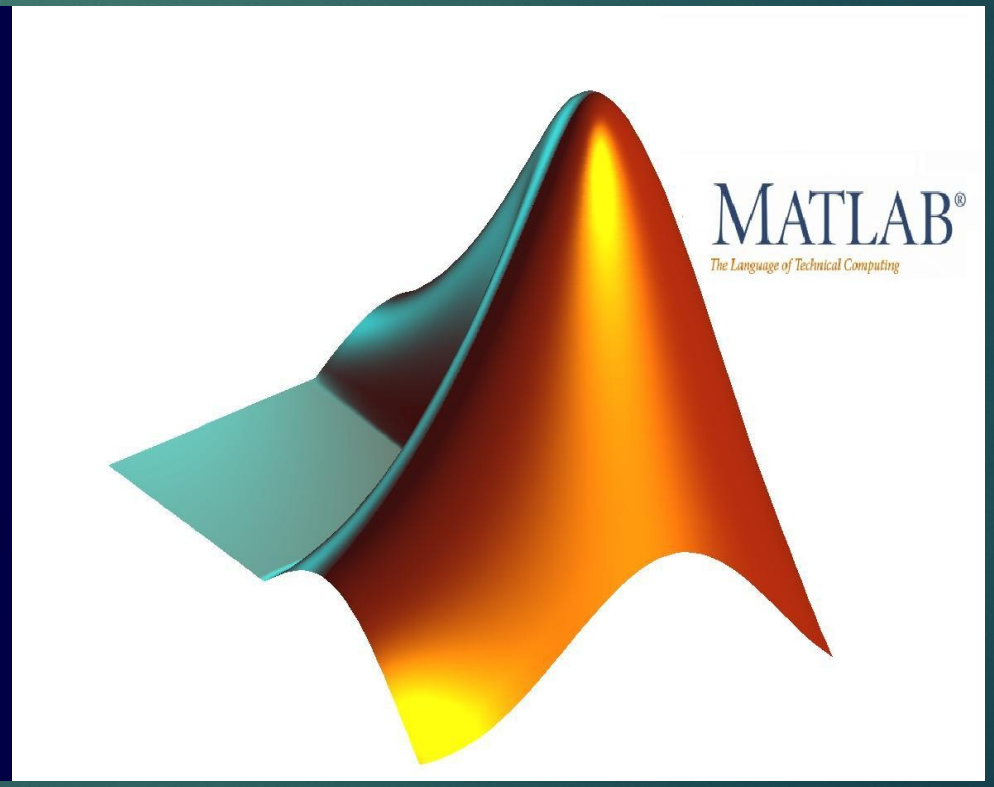
Hidden Conditional Random Fields, it’s all witchcraft to me.

# Current Activities

- Classification accuracy improvement
  - Quite a few things to look at
- Analysis of spatio-spectral topographic maps
  - ‘thought intensity differences’

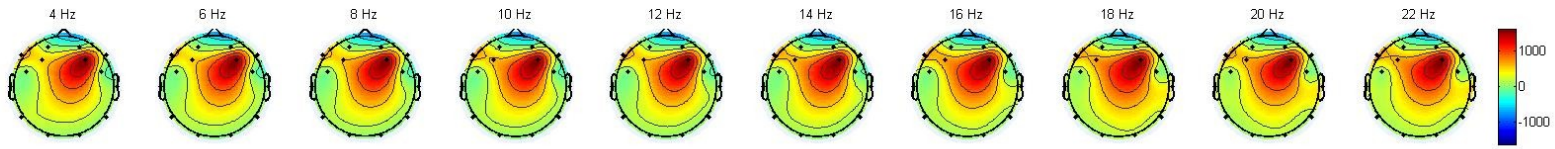
# Current Activities

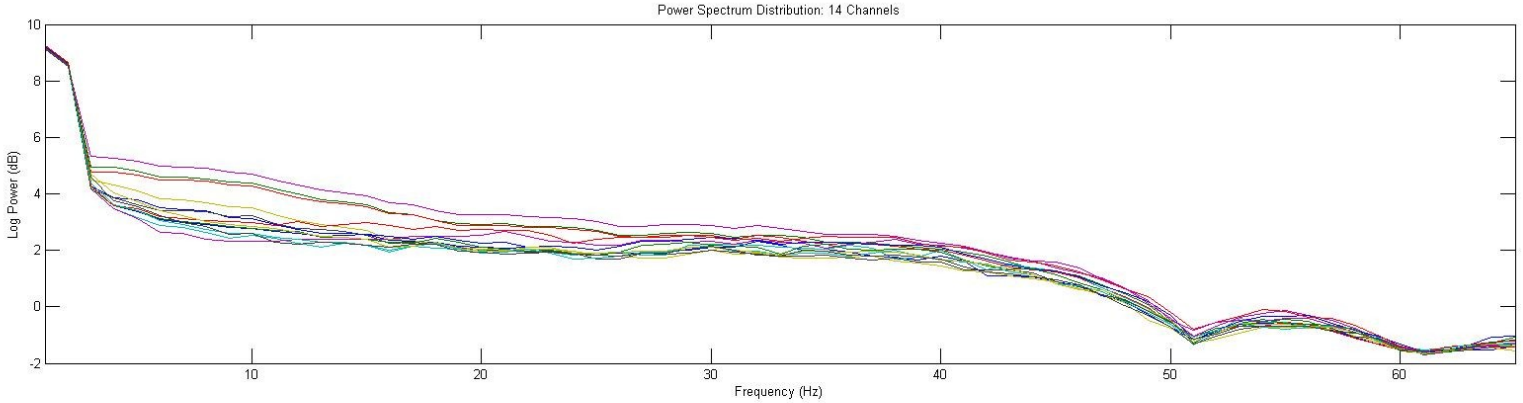



A holy bond. EEGLAB Toolbox has *the answer*, and it's not *42*.

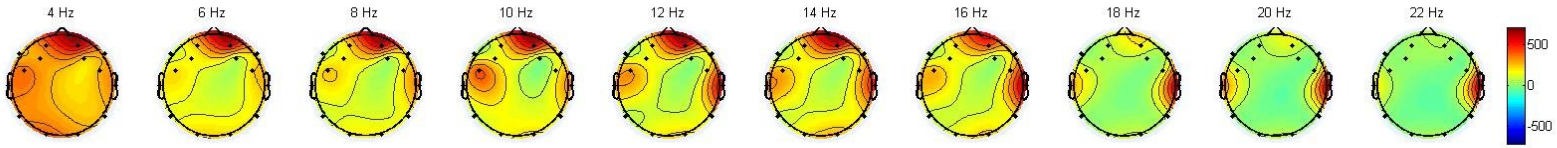
# Preliminary Findings

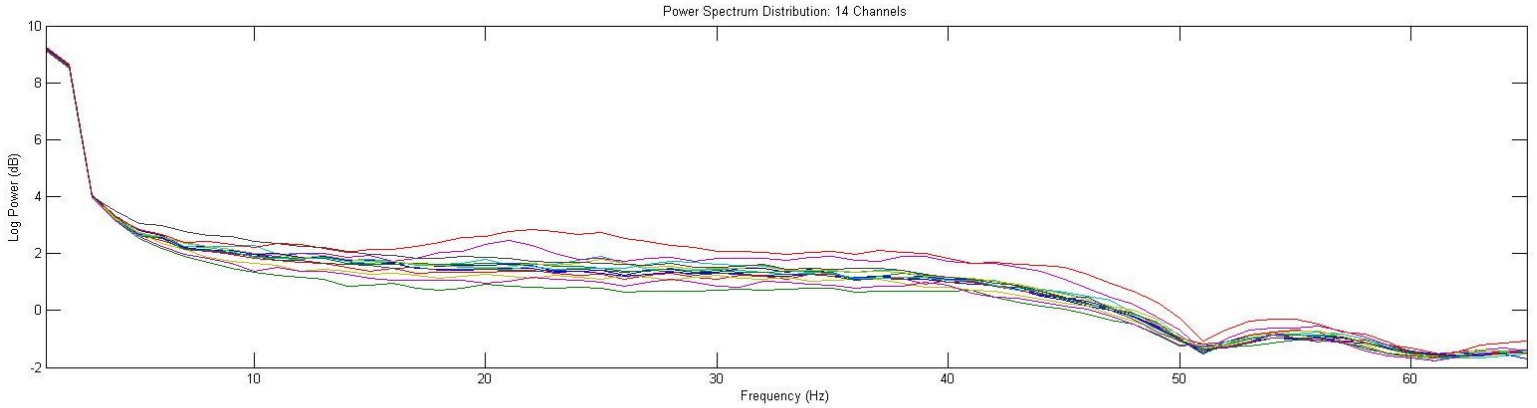



Actual movements task.

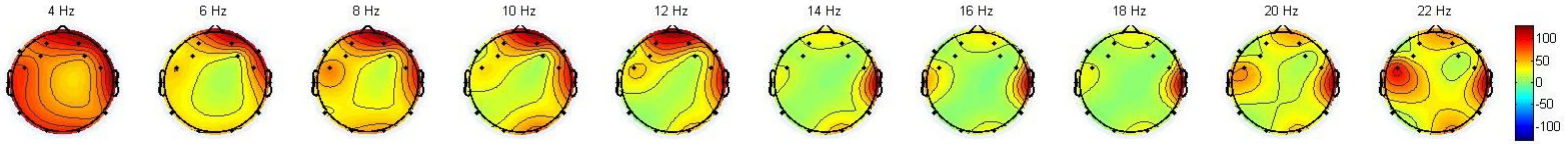
# Preliminary Findings

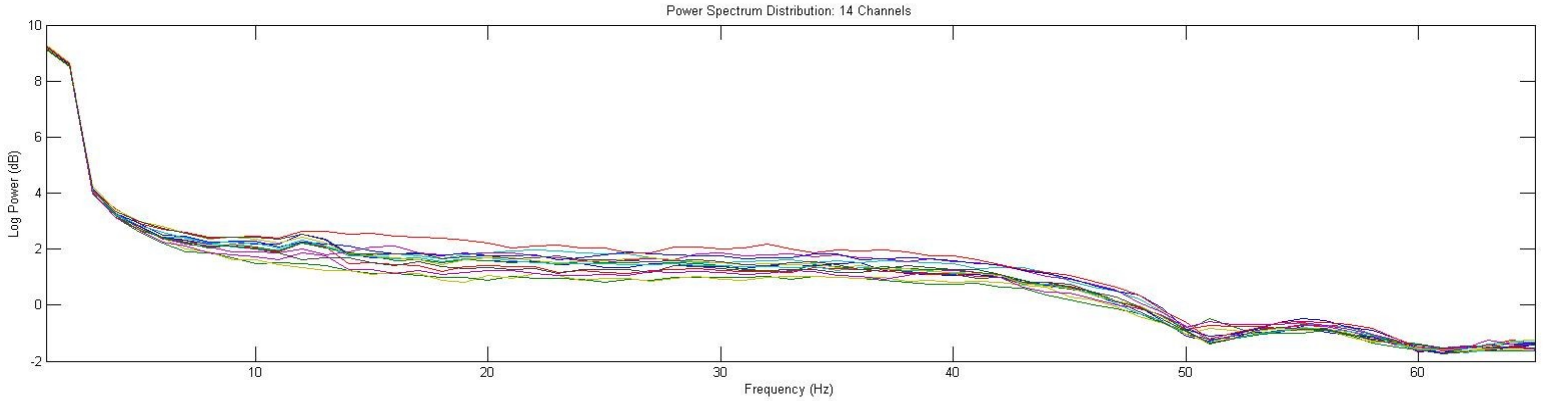



Arithmetic task.

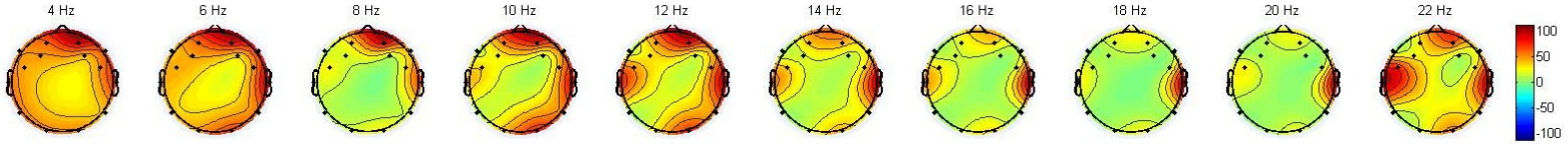
# Preliminary Findings

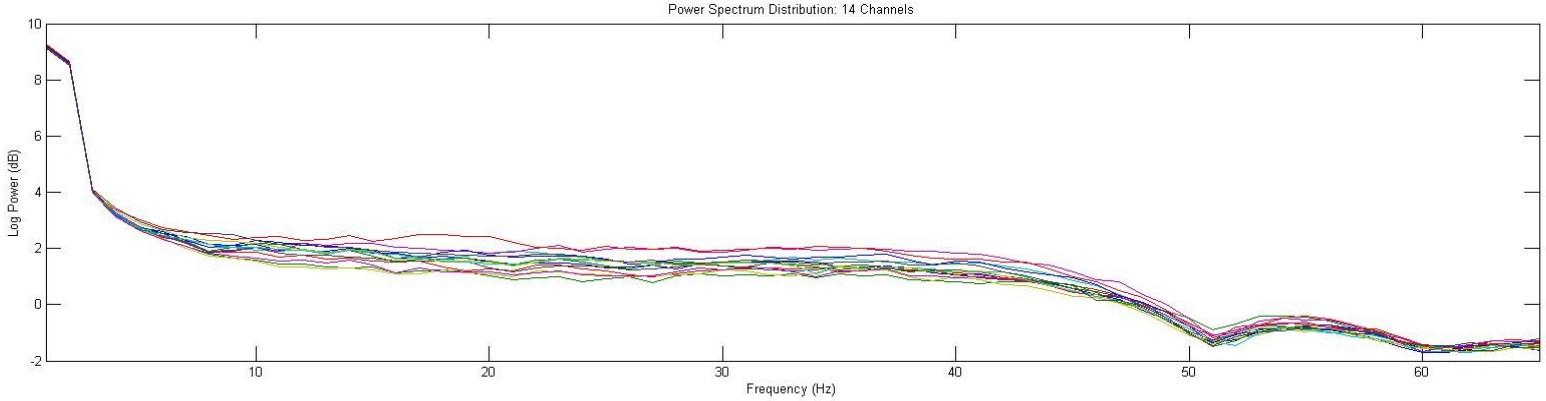



Foot tap task.

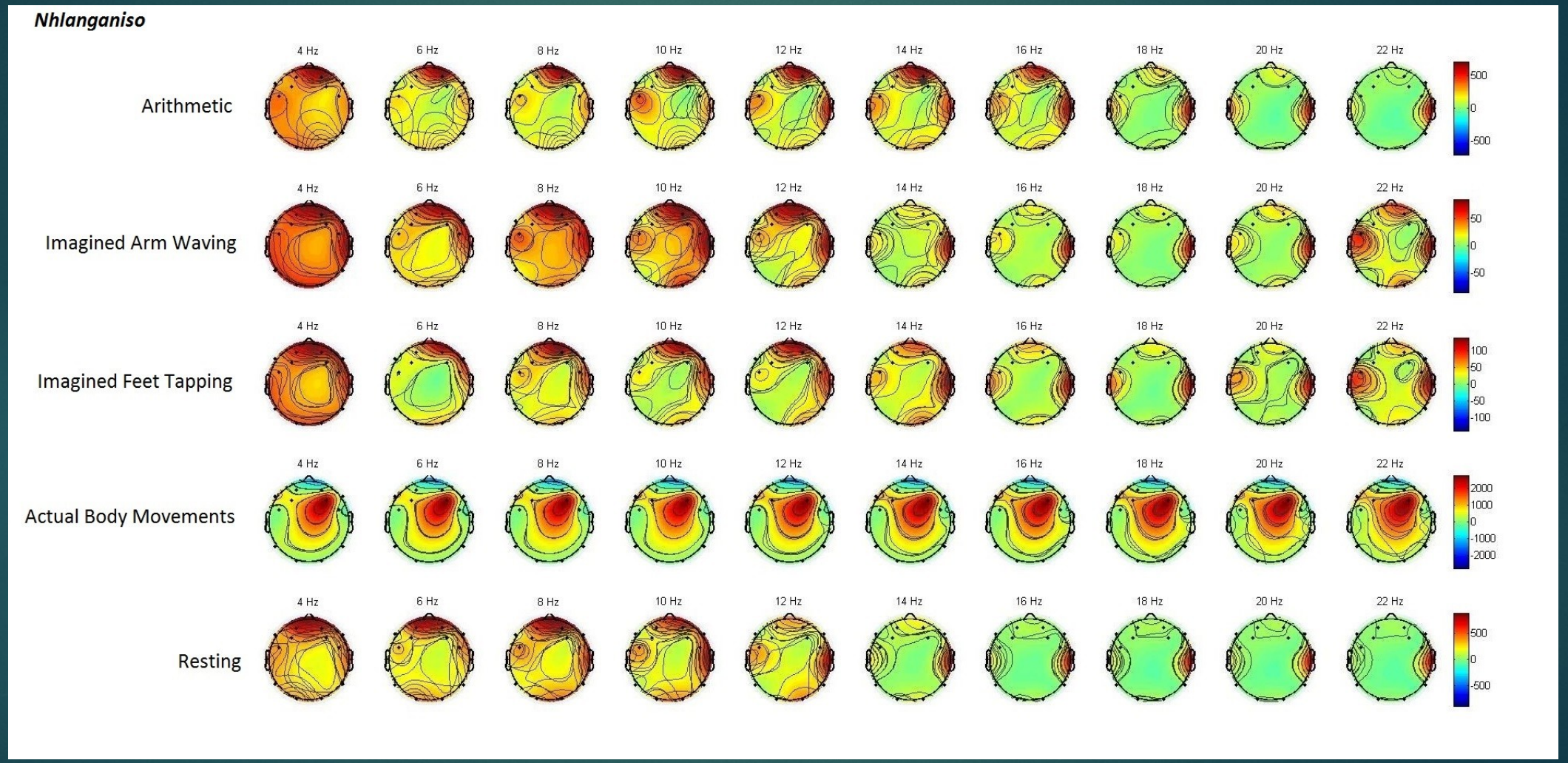
# Preliminary Findings



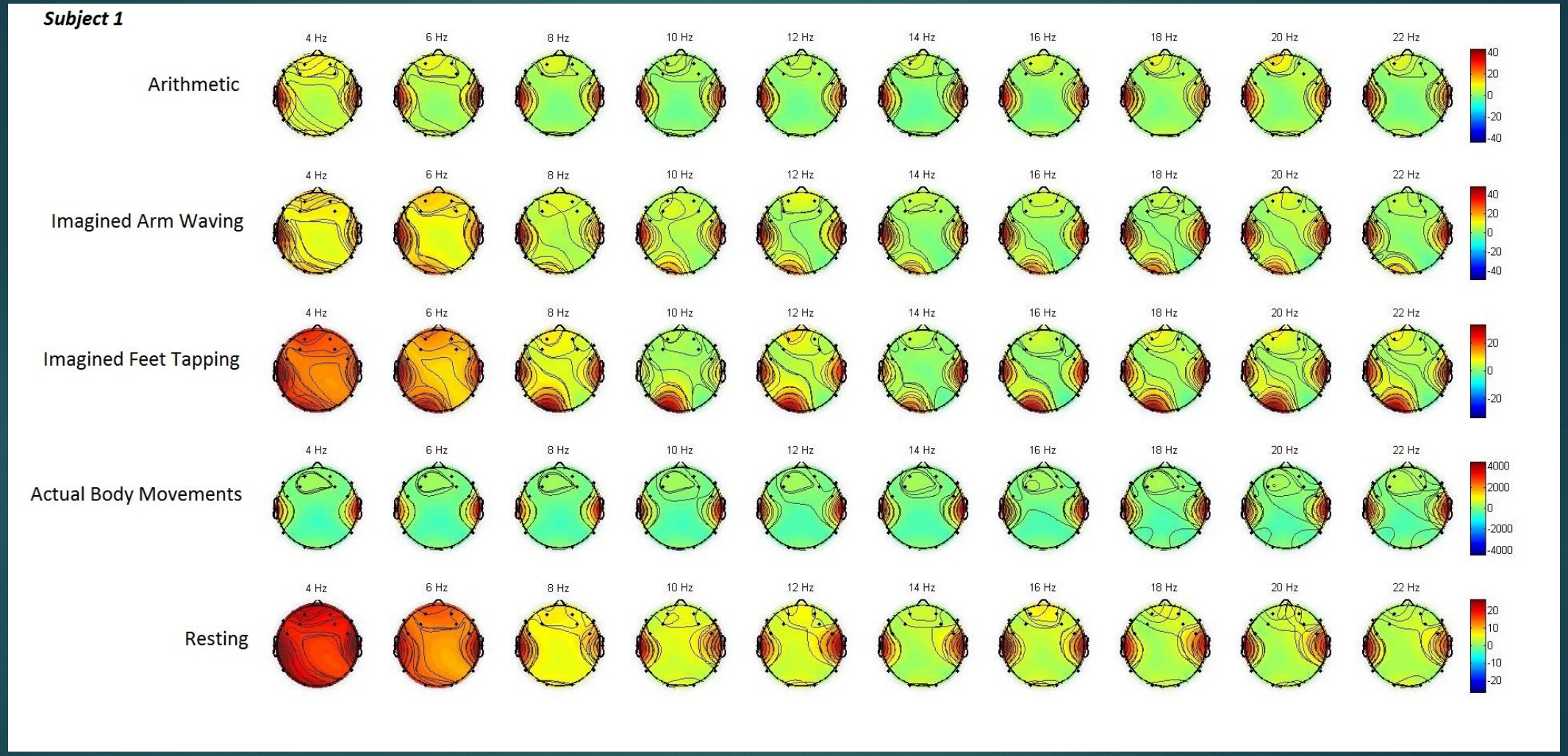

Arms wave task.

# Preliminary Findings



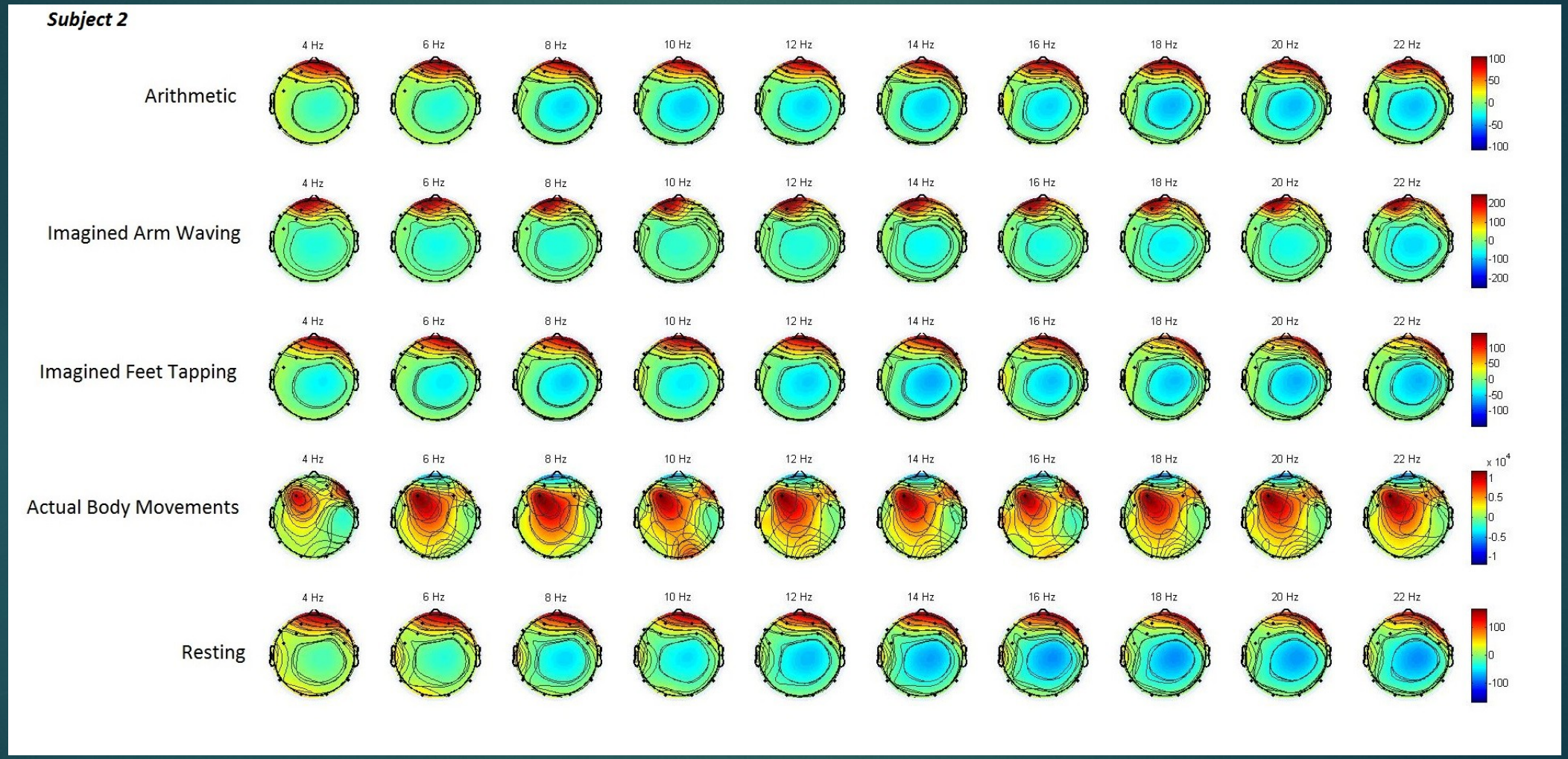

So what's going on here exactly?

# Preliminary Findings




Silly questions should never be asked more than once.

# Preliminary Findings




So what's going on here exactly?

# Upcoming Activities

- Design of experiments
  - Phase 1 data collection
    - Identify easily discriminable maps
    - ‘Priming’ the users

# Upcoming Activities

- Extend feature vector
  - More channels
  - More frequency components
- Finalize remaining modules
  - Command inference
  - Text input
- PhD

# Brain Computer Interface

## Technology

ARE WE THERE YET?

NO!