On the Reliability of Frequency-Domain Features for fNIRS BCIs in the Presence of Pain

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Outline

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- **Introduction**
  - Background
  - Motivation
- **Methods**
  - Experimental Design
  - Analysis
- **Results**
- **Conclusions**

Background

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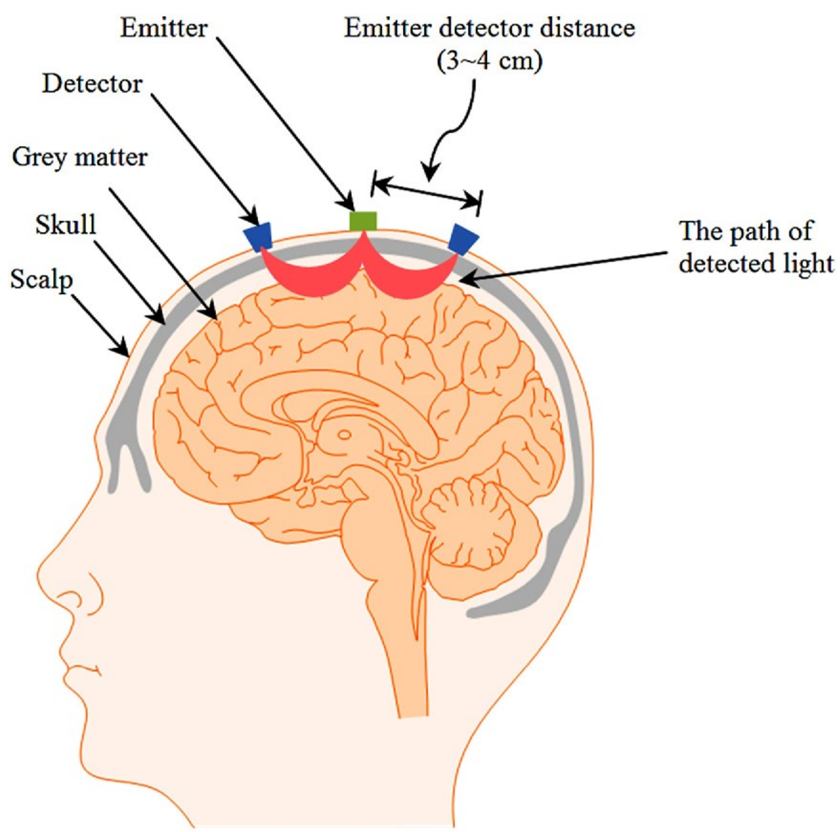
- **functional Near Infrared Spectroscopy (fNIRS)**
  - Brain activation causes changes in the concentration of
    - Oxy hemoglobin **[HbO]**
    - Deoxy hemoglobin **[HbR]**

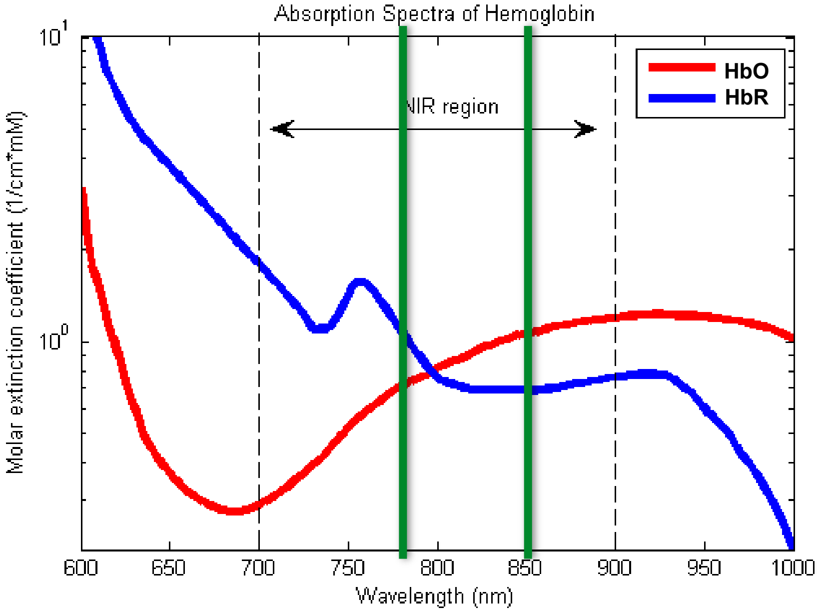
modified Beer Lambert Law

$$\Delta c_{HbO} = \frac{\alpha_{HbR}^{\lambda_1}\frac{\Delta A^{\lambda_2}}{L^{\lambda_2}} - \alpha_{HbR}^{\lambda_2}\frac{\Delta A^{\lambda_1}}{L^{\lambda_1}}}{\alpha_{HbR}^{\lambda_1}\alpha_{HbO}^{\lambda_2} - \alpha_{HbR}^{\lambda_2}\alpha_{HbO}^{\lambda_1}}$$

$$\Delta c_{HbR} = \frac{\alpha_{HbO}^{\lambda_1}\frac{\Delta A^{\lambda_2}}{L^{\lambda_2}} - \alpha_{HbO}^{\lambda_2}\frac{\Delta A^{\lambda_1}}{L^{\lambda_1}}}{\alpha_{HbO}^{\lambda_1}\alpha_{HbR}^{\lambda_2} - \alpha_{HbO}^{\lambda_2}\alpha_{HbR}^{\lambda_1}}$$



[1]

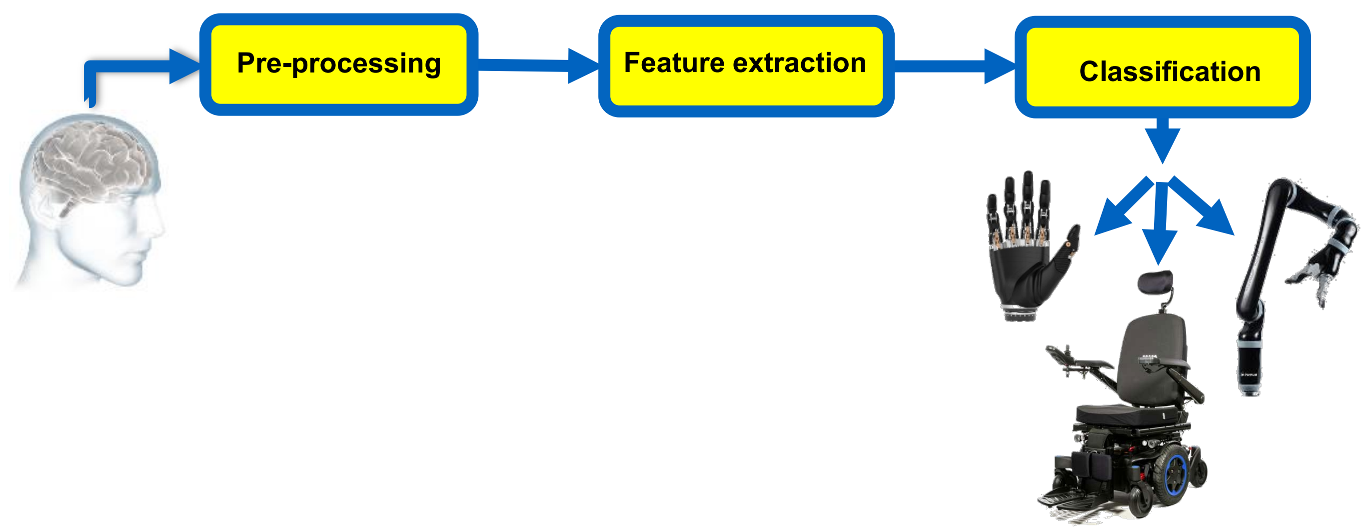


[2]

1. N. Naseer, et al. "fNIRS-based brain-computer interfaces: a review“, *Frontiers in human* neuroscience, vol. 9, pp. 3, 2015.
2. M. Abtahi, et al. "Hand Motion Detection in fNIRS Neuroimaging Data." *Healthcare*. vol. 5, no. 2, 2017.

Background

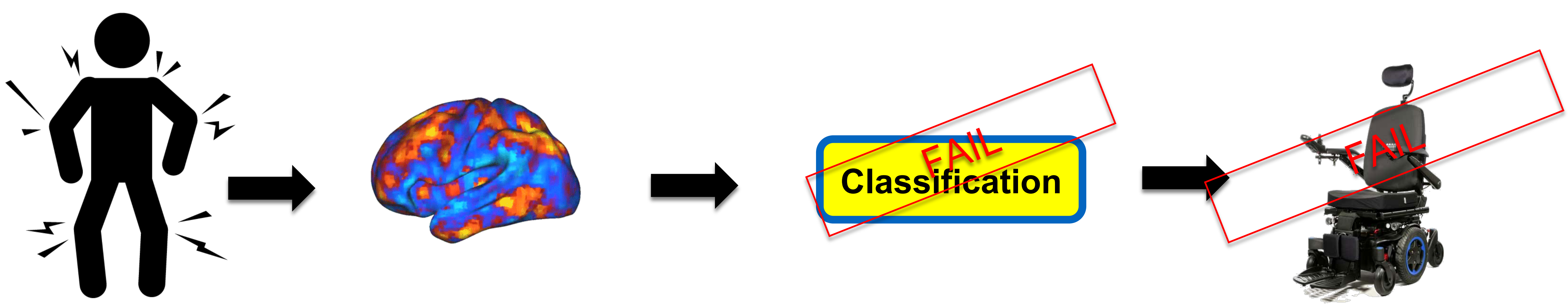
- **Brain Computer Interfaces (BCIs):**
  - An interface between brain and an external device to control the device using the brain
  - Key applications : Assistive interfaces for disabled patients



- **fNIRS-Based BCIs:**
  - Use fNIRS for brain signal acquisition
  - Advantages :
    - Non-invasive, low cost, easy to use, portable
    - No vulnerability to electromagnetic environment
    - Relatively low sensitivity to head motion artifacts as compared to EEG and fMRI

Motivation

- **Most BCI Users Are Patients Who Experience Pain**
  - Often, pain is prevalent in patients with motor disabilities – could be chronic or acute in nature
  - Pain is expected to impact cortical activity related to the task at hand [3]
  - This in turn would impact the BCI performance potentially resulting in failure of assistive devices



3. D. A. Seminowicz and M. Moayedi, “The dorsolateral prefrontal cortex in acute and chronic pain,” The Journal of Pain, vol. 18, no. 9, pp. 1027–1035, 2017.

Motivation

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- **Goals of This Study**
  - Study the impact of the presence of pain on the classification accuracy of fNIRS-based BCIs
  - Explore the impact of cortical region-based channel selection on the classification accuracy of BCIs

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Experimental Design

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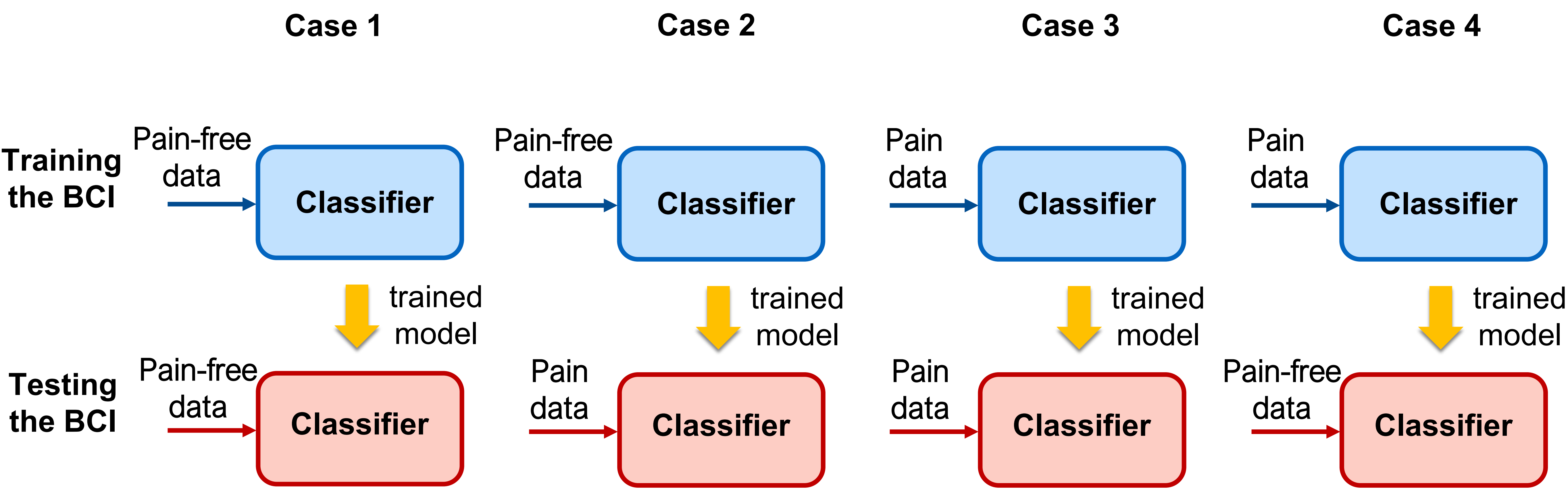
- **Four Cases Are Considered To Study The Impact of Pain**



Experimental Design

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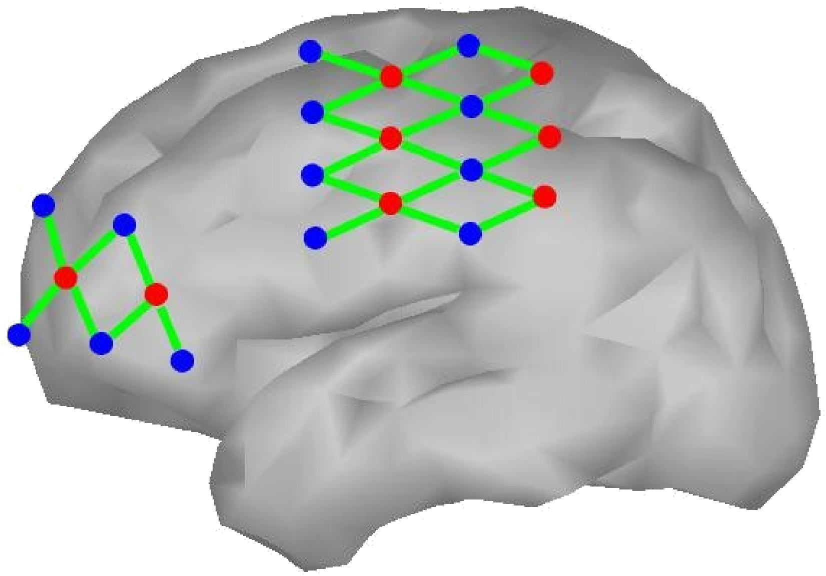
- **fNIRS Recordings**
  - Experimental setup for data collection : NIRx system (sampling rate: 10.41 Hz)
  - Channels:
    - number: 50 (16 sources and 24 detectors)
    - location: prefrontal and motor cortices
    - source-detector separation: 3 cm

NIRx system

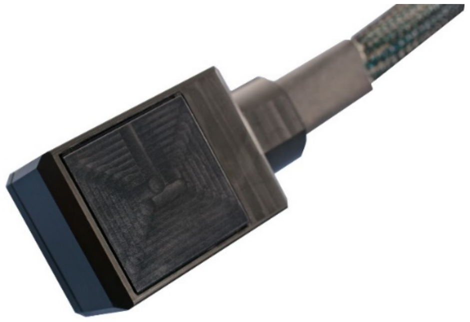


Channel configuration

Experimental Design

- **Pain Stimulation**
  - TSA-II Medoc System
  - 30 × 30 mm standard thermode
  - Painful stimuli on dorsum of left hand

TSA-II system.

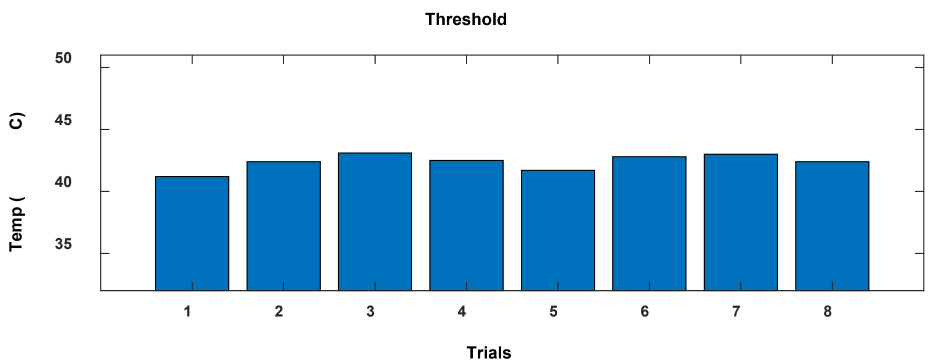


Standard thermode

The thermode attached to the subject's dorsum of the left hand

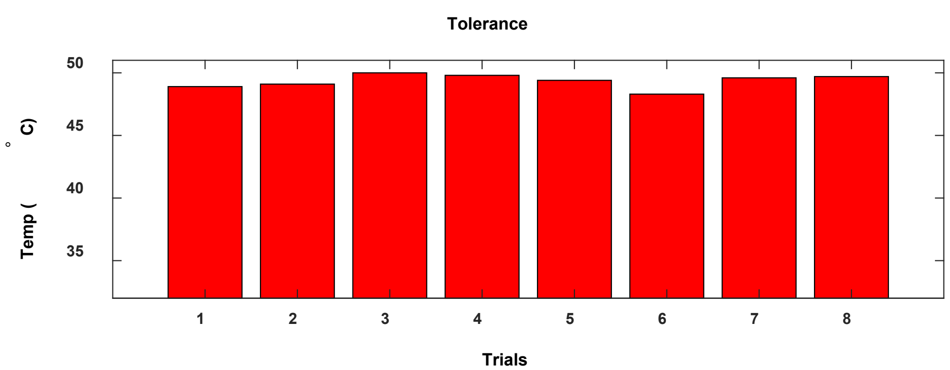
Experimental Design

- **Pain Threshold And Tolerance Measurement**



$T_{threshold}$

$$T_p = \frac{T_{threshold} + T_{tolerance}}{2}$$



$T_{tolerance}$

$$T_{\mathrm{stim}} \in [T_p - 1 \quad T_p + 1]$$

Experimental Design

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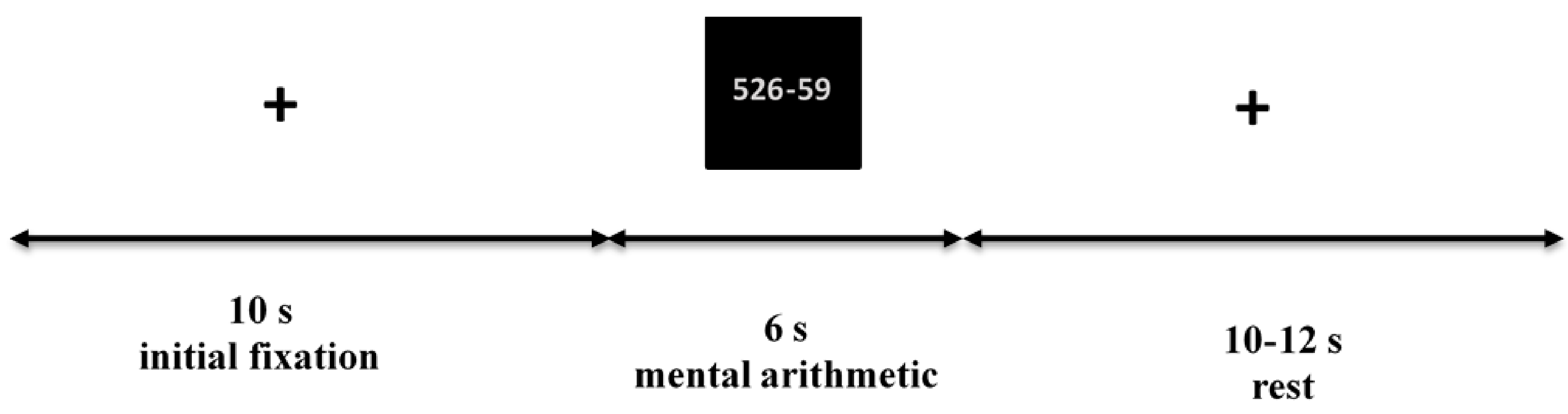
- **Experimental Paradigm**
  - 3 healthy right-handed subjects
  - 5 no-pain and 5 pain blocks in random order
  - 2 classes of mental arithmetic tasks
    - mental subtraction
    - mental back counting
  - T_{stim} (stimulus temperature) for pain blocks and baseline temperature (32℃) for no-pain blocks
  - 65 trials of each task were recorded under pain and no-pain conditions



Visual illustration of a single trial.

Analysis

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- **Preprocessing**
  - [ΔHbO] signal from [0-6] sec window
  - Drifts and artifact removal using nirsLAB [1]
  - Bandpass filtering [0.01-0.2] Hz
  - Baseline correction (baseline: [−1~0])

- **Feature Extraction**
  - Features from frequency domain representation of [ΔHbO] signal from all channels using discrete Fourier transform (DFT) and power spectral density
    - maximum value of power spectral density
    - median value of power spectral density
    - variance of power spectral density
    - maximum value of real part of DFT
    - frequency corresponding to maximum value of real part of DFT
    - frequency corresponding to maximum value of power

Analysis

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- **Classification**
  - Support vector machine with quadratic kernel (QSVM)
  - Training and validation: 75% , testing : 25%
  - 10-fold cross-validation to avoid overfitting

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Results

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- **Classification Results For 4 Cases Of Training And Testing, Using Data From All 50 Channels Covering PF And Motor Cortices**
  - Presence of pain impacts classification accuracy and lowers the accuracy to the chance levels
  - It is essential to consider the presence of pain in developing BCI algorithms for patients

	Case 1 Train (no-pain) Test (no-pain)	Case 2 Train (no-pain) Test (pain)	Case 3 Train (pain) Test (pain)	Case 4 Train (pain) Test (no-pain)
Maximum of PSD	84.87± 2.2	50.72± 2.5	85.09± 2.3	50.63± 2.6
Median of PSD	85.09± 2	51.09± 2.3	85.02± 2.2	50.54± 2.5
Variance of PSD	76.60± 2.6	50.46± 2.4	76.02± 2.3	50.72± 2.7
Maximum value of real part of DFT	88.65± 1.9	52.68± 2.6	89.91±1.7	53±2.3
Frequency of Maximum value of real part of DFT	81.47± 1.9	50.51± 2.7	83.14± 2.7	50.52± 2.3
Frequency of maximum power	50.43± 2.4	50.71± 2.2	49.96± 2.1	50.85± 2.4

Results

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- **Classification Results For The 4 Cases, Using PF Cortex Channels Only**
  - For case 1 and case 3, use of only the PF channels lowers the classification accuracy
  - For case 2 and case 4, results still remain at chance level

	Case 1 Train (no-pain) Test (no-pain)	Case 2 Train (no-pain) Test (pain)	Case 3 Train (pain) Test (pain)	Case 4 Train (pain) Test (no-pain)
Maximum of PSD	71.08± 2.2	54.13± 2.4	72.49±2.2	53.75±2.2
Median of PSD	71.56± 1.9	54.72± 2.3	72.68±2.4	54.05±2.4
Variance of PSD	56.81± 4.8	51.63± 2.7	60.29±3.2	50.78±2.6
Maximum value of real part of DFT	72.24± 2.2	52.4± 2.6	73.65±2	53.52±2.5
Frequency of Maximum value of real part of DFT	63.01± 2.3	51.83± 3	65.54±2.3	50.69±2.2
Frequency of maximum power	49.36± 2.1	49.67± 2.1	48.80±2	49.22±2.4

Results

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- **Classification Results For The 4 Cases, Using Motor Cortex Channels Only**
  - For case 1 and case 3, use of only the motor channels again lowers the classification accuracy
  - For case 2 and case 4, results still remain at chance level

	Case 1 Train (no-pain) Test (no-pain)	Case 2 Train (no-pain) Test (pain)	Case 3 Train (pain) Test (pain)	Case 4 Train (pain) Test (no-pain)
Maximum of PSD	83.26±2.1	50.36±2.3	82.75±2.3	50.92±2.4
Median of PSD	83.91±2.1	50.22±2.3	83.07±2.3	50.57±2.3
Variance of PSD	75.60±2.3	50.27±2.6	73.69±2.6	50.95±2.6
Maximum value of real part of DFT	86.60±2	52.32±2.6	87.09±1.9	51.60±2.7
Frequency of Maximum value of real part of DFT	77.41±1.9	50.63±2.4	80.13±1.9	50.13±2.5
Frequency of maximum power	49.74±2.2	51±2.1	50.82±2.4	50.47±2.4

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Conclusions

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- The presence of pain significantly impacts the cortical activity. Thus, a model trained on pain-free data but used in the presence of pain or vice-versa will fail resulting in the failure of the assistive device for the user

- Frequency-domain features of fNIRS provide high accuracy results for classification of mental arithmetic tasks, but are not immune to the presence of pain

- Additionally, our results indicated that features extracted from both the PF and motor cortices collectively yield better accuracy results as opposed to using features extracted from these areas individually

- The results of this study emphasize the significance of considering pain conditions in the development of BCI algorithms for assistive devices

- Future work will involve identifying features that are immune to the presence of pain, so that the BCI can perform as intended irrespective of the presence of pain

Thank You!