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ADAPTIVE CSP FOR USER INDEPENDENCE IN MI-BCI PARADIGM FOR UPPER LIMB STROKE REHABILITATION

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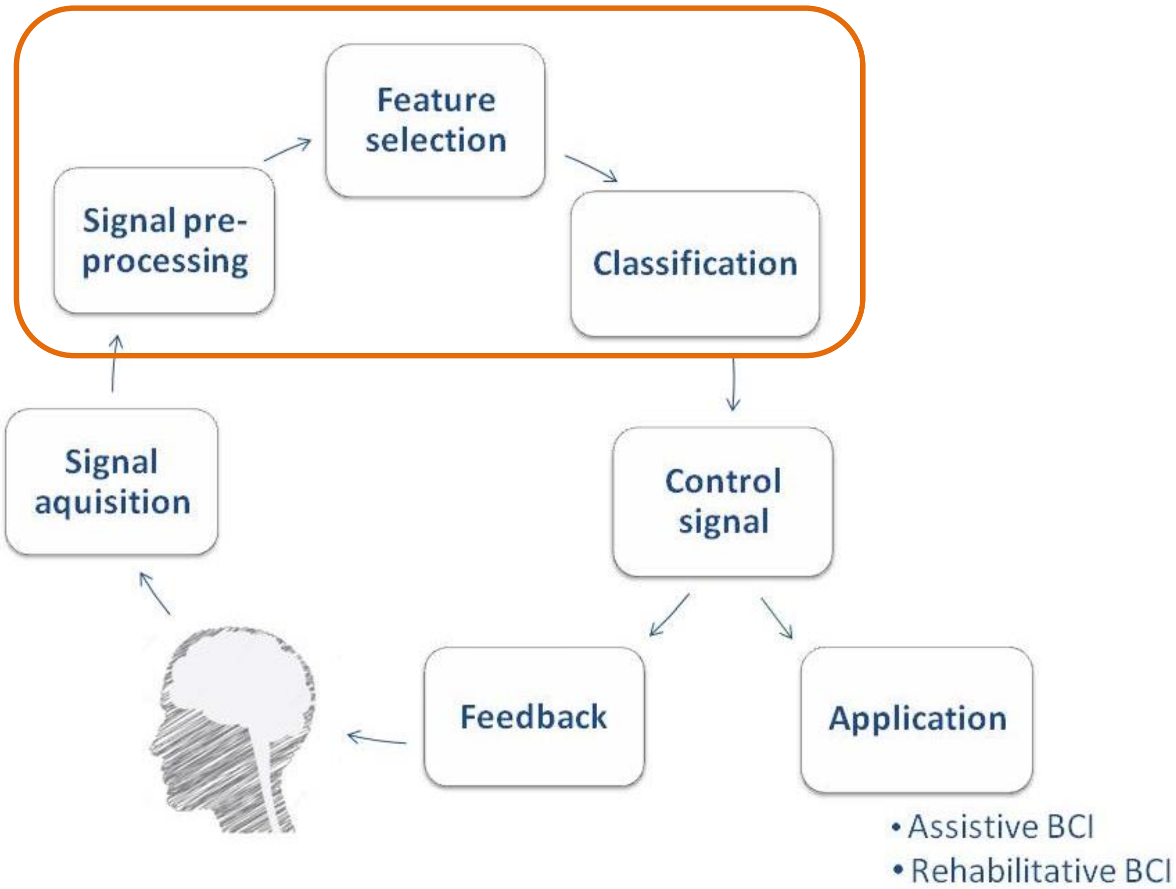
Outline

- Introduction: Motivation & BCI systems
- Materials and Methods – Signal Processing
- Dataset Description & Experimental Design
- Results and Discussion
- Conclusion

Motivation

- Stroke as one of the **global leading causes of disability**
  - One third of survivors with chronic impairments
  - High personal and social cost
- **Motor-Imagery BCI** as an emergent therapy method
  - Increased neuroplasticity
  - Limitations?

BCI system


Feature selection
Signal pre-processing
Classification
Signal aquisition
Control signal
Feedback
Application
• Assistive BCI
• Rehabilitative BCI

Materials and Methods: Signal Processing

1. Pre-processing

Band-pass filtering 7 – 30 Hz

4th order Butterworth zero-phase distortion filter

Materials and Methods: Signal Processing

2. Feature extraction

Spatial filter: Common Spatial Patterns (CSP)

- Source localization
- Parametrizing matrix: $\mathbf{Z}_{CSP} = \mathbf{W}\ \mathbf{X}$

$\mathbf{X}$: 1 EEG trial *[no. channels x no. samples]*

$\mathbf{W}$: Projection matrix *[no. channels x no. channels]*

- Increase variance of one condition while decreasing it for the other

Materials and Methods: Signal Processing

2. Feature extraction

Spatial filter: Common Spatial Patterns (CSP)

- Parametrizing matrix: $\mathbf{Z}_{CSP} = \mathbf{W}\ \mathbf{X}$

- Solution: solve GED problem $\mathbf{C}_1\mathbf{w}_i = \lambda_i \mathbf{C}_2\mathbf{w}_i$

$\mathbf{C}_1$, $\mathbf{C}_2$: Covariance matrix of classes 1 & 2

$\mathbf{w}_i$, λ_i : Generalized eigenvector & eigenvalue *i*

Materials and Methods: Signal Processing

2. Feature extraction

Adaptive filter: ACSP

- Rayleigh quotient:

$$\underset{\mathbf{W}}{\operatorname{argmax}} \frac{\mathbf{W}^T(\mathbf{C}_1 - \mathbf{C}_2)\mathbf{W}}{\mathbf{W}^T(\mathbf{C}_1 + \mathbf{C}_2)\mathbf{W}}$$

$$= \underset{\mathbf{W}}{\operatorname{argmax}} \frac{\mathbf{W}^T\mathbf{C}_1\mathbf{W}}{\mathbf{W}^T(\mathbf{C}_1 + \mathbf{C}_2)\mathbf{W}}$$

- **RLS** algorithm for incremental updates of filter coefficients

- Solution:

$$\hat{\mathbf{w}}_{\mathbf{1}}(n) = \frac{\mathbf{w}_{\mathbf{1}}(n-1)^T \mathbf{C}_{\mathbf{c}}^{\mathbf{1}}(n)\mathbf{w}_{\mathbf{1}}(n-1)}{\mathbf{w}_{\mathbf{1}}(n-1)^T \mathbf{C}_{\mathbf{1}}^{\mathbf{1}}(n)\mathbf{w}_{\mathbf{1}}(n-1)} \mathbf{C}_{\mathbf{c}}^{\mathbf{1}}(n)^{-1}\mathbf{C}_{\mathbf{1}}^{\mathbf{1}}(n)\mathbf{w}_{\mathbf{1}}(n-1)$$

Materials and Methods: Signal Processing

2. Feature extraction

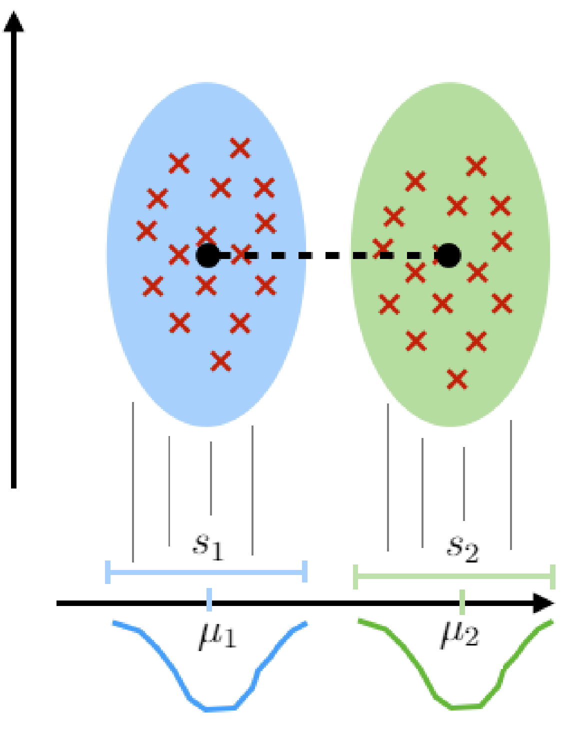
Features:

- Number filter pairs (m) = 2
- Log [variance of filtered signals]
- OVR strategy: Total number of features = no. classes x 2 x m

Materials and Methods: Signal Processing

3. Classification

Regularized Discriminant Analysis



- Control over border geometry

- Regularized covariance matrix estimation

Dataset description

2 datasets

- **4-class**: BCI competition IV dataset 2a

- **3-class**: in-house dataset

Dataset description

4-class: BCI competition IV

- 2 sessions (training [long] & evaluation)
- Evaluation: trial-wise maximum average **kappa value**

$$k = \frac{p_o - p_e}{1 - p_e},$$

p_o - Accuracy
p_e - Chance level

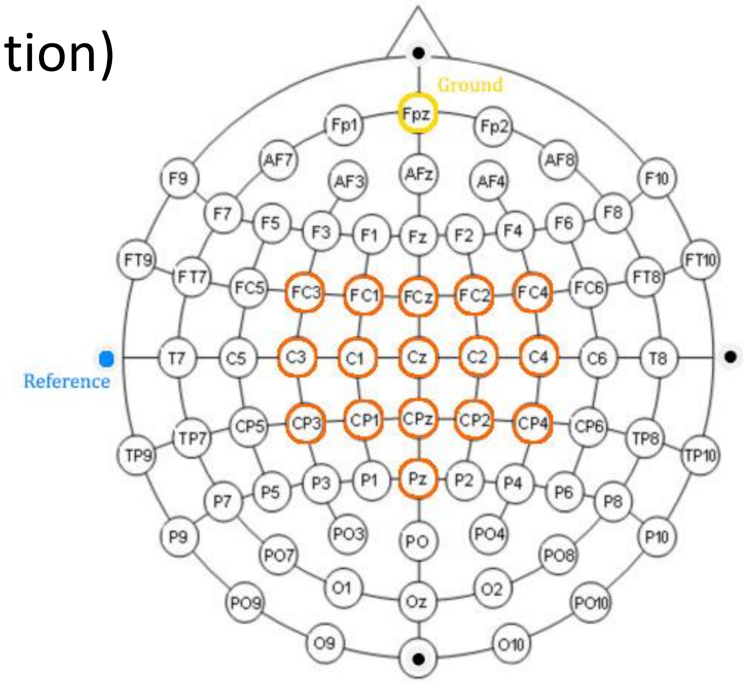
- Competition winner: Filter-Bank CSP (**FBCSP**)
- 9 subjects

Dataset description

3-class: Stroke rehabilitation setting

Settings:

- 2 sessions (training [short] & evaluation)
- 16 electrodes
- 14 subjects



Experimental design

3-class: Stroke rehabilitation setting

- Interface:

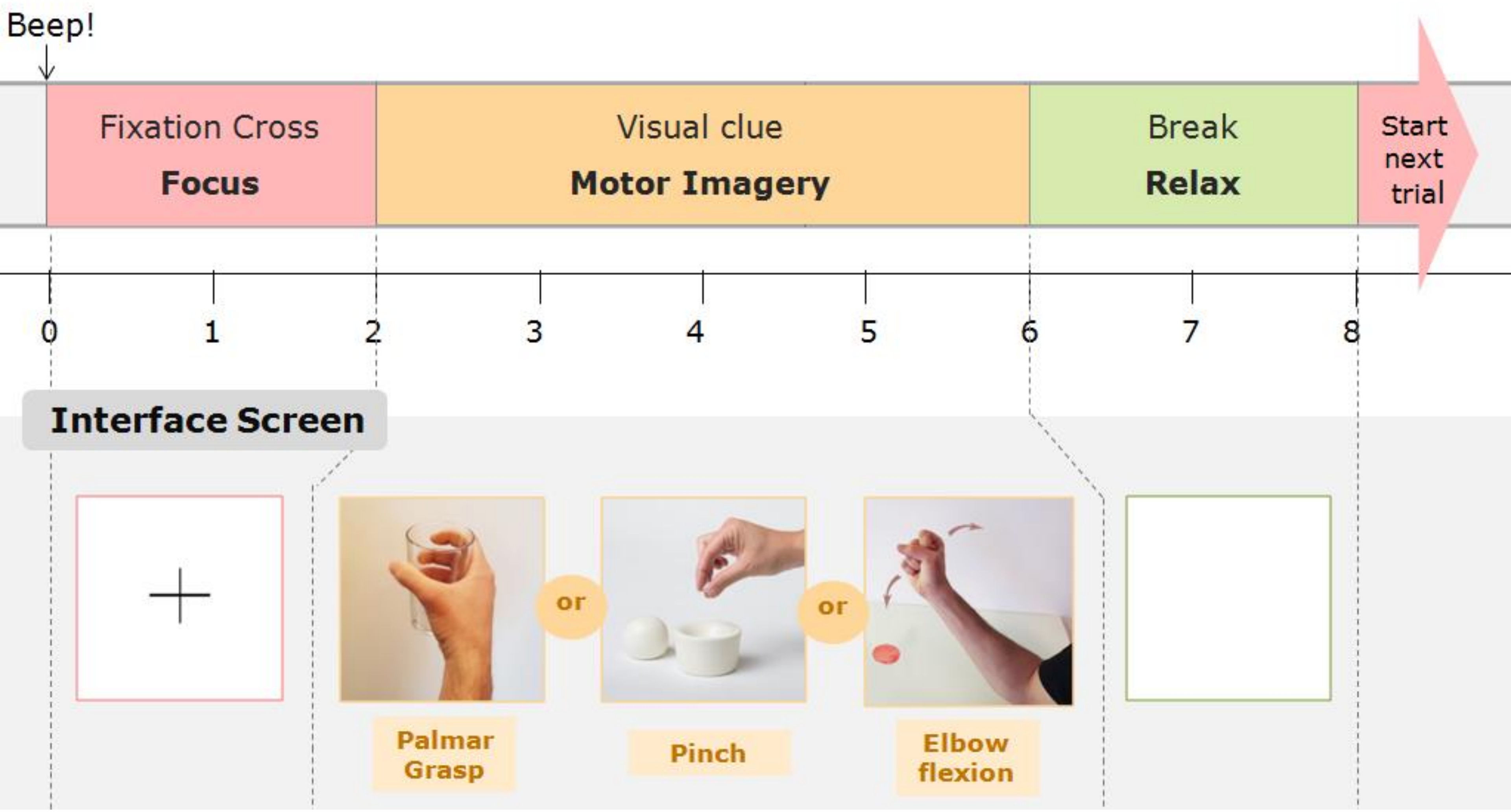
Palmar grasp (class 1)

Pinch (class 2)

Elbow flexion (class 3)

Experimental design

Trial scheme:



Results and Discussion

4-class MI of different limbs: BCI competition data

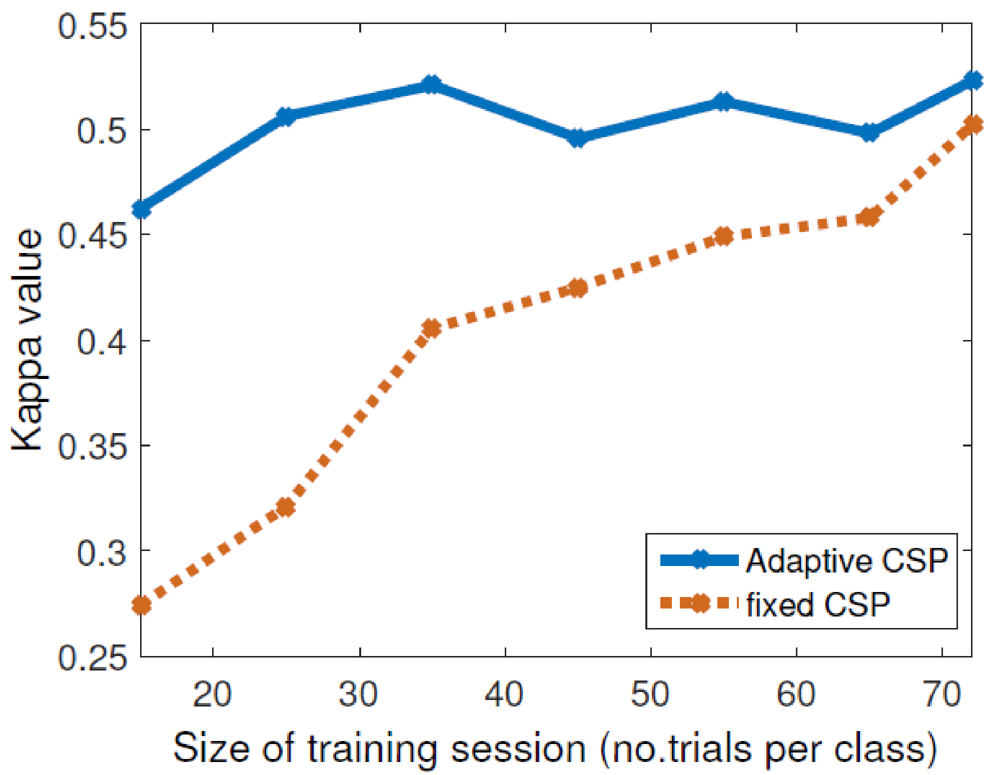
Classification performance

Subjects	CSP	ACSP	FBCSP
1	0.677	**0.683**	0.676
2	0.363	0.231	**0.417**
3	0.602	0.677	**0.745**
4	0.465	0.377	**0.481**
5	0.246	0.330	**0.398**
6	0.243	**0.366**	0.273
7	0.612	0.568	**0.773**
8	0.749	0.704	**0.755**
9	0.565	**0.771**	0.606
Mean	0.502	0.523	**0.569**
Median	0.565	0.568	**0.606**

Results and Discussion

4-class MI of different limbs: BCI competition data

Semi-user independent strategy



Results and Discussion

3-class MI of same limb: in-house dataset

Subjects	**DLCSP**	
	Fixed	Adaptive
1	0.10	**0.36**
2	0.08	**0.49**
4	0.05	**0.52**
5	0.19	**0.46**
6	0.05	**0.49**
7	0.10	**0.65**
8	0.08	**0.50**
9	0.05	**0.71**
10	0.21	**0.65**
11	0.05	**0.48**
12	0.30	**0.33**
13	0.13	**0.33**
14	0.08	**0.22**
Mean	0.11	**0.47**
Median	0.08	**0.49**

Results and Discussion

3-class MI of same limb: in-house dataset

Confusion matrix

Predicted labels

True labels

	Grasp	Pinch	Elbow flex	
Grasp	16 %	6.2 %	11 %	48.2 %
Pinch	2.4 %	22.2 %	9.6 %	64.9 %
Elbow flex.	2.6 %	3.4 %	26.6 %	81.6 %
	76.2 %	69.8 %	56.3 %	64.8 %

K-value for binary classification

C1 vs C2
0.632

C1 vs C3
0.516

C2 vs C3
0.579

Conclusion

- **Feasible** BCI system for stroke rehabilitation
- ACSP outperforms CSP ⟵ Short training session
  - Personalized BCI system
- **Future work**:
  - Practical system: channel reduction/wireless solution
  - Unsupervised method

Questions?