



10th International BCI Meeting, Brussel, Belgium



Somatosensory Brain-computer Interface and Sensory Stimulation

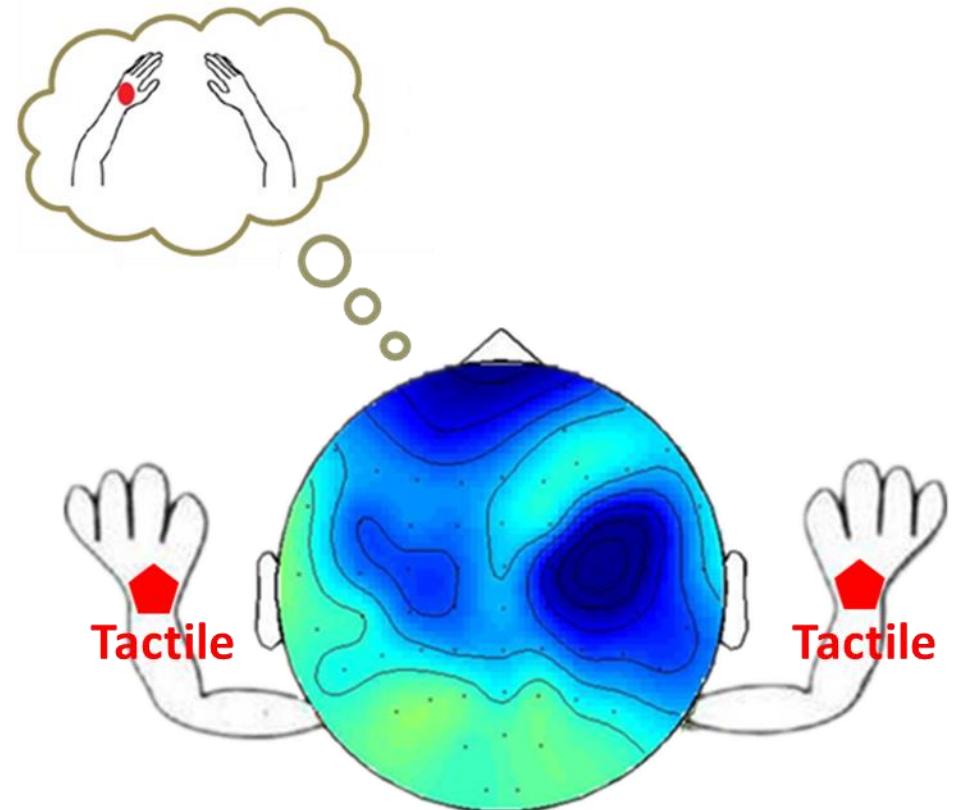
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MOE Frontiers Science Center for Brain and Brain-Machine Integration,
Zhejiang University, Hangzhou, Zhejiang, China
College of Computer Science, Zhejiang University, China
2023.06.08

Outline



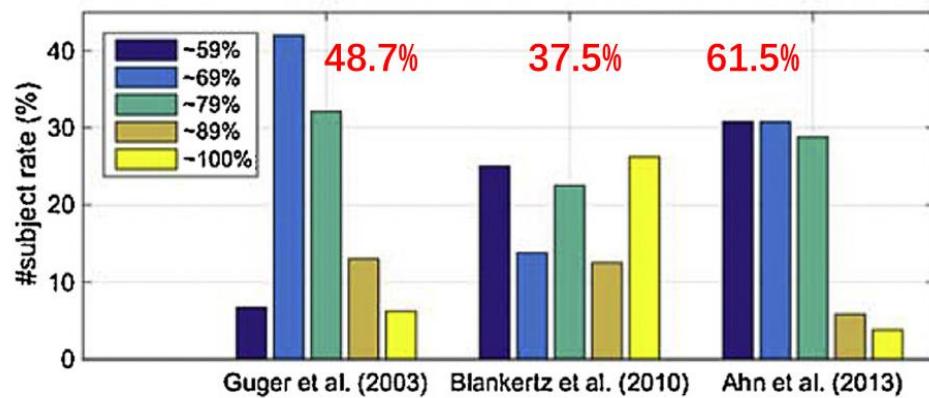
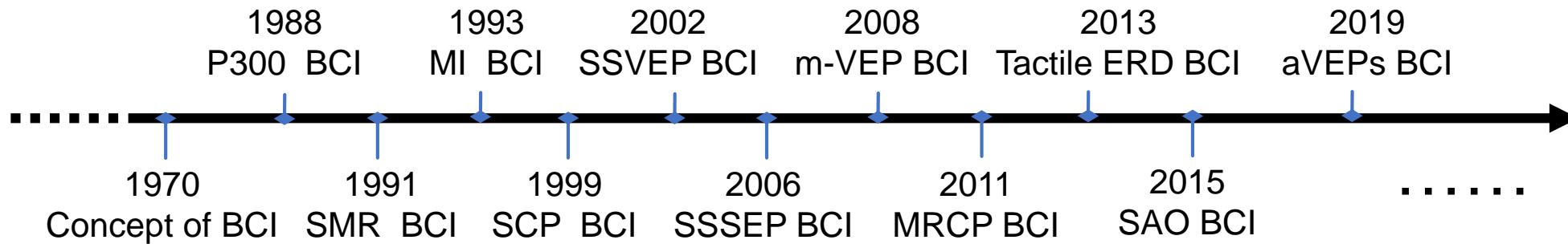
- Background of BCI-deficiency Problem
- Somatosensory BCI (sBCI)
- Sensory Stimulation (SS)
- Future Work



Background: BCI-deficiency Problem

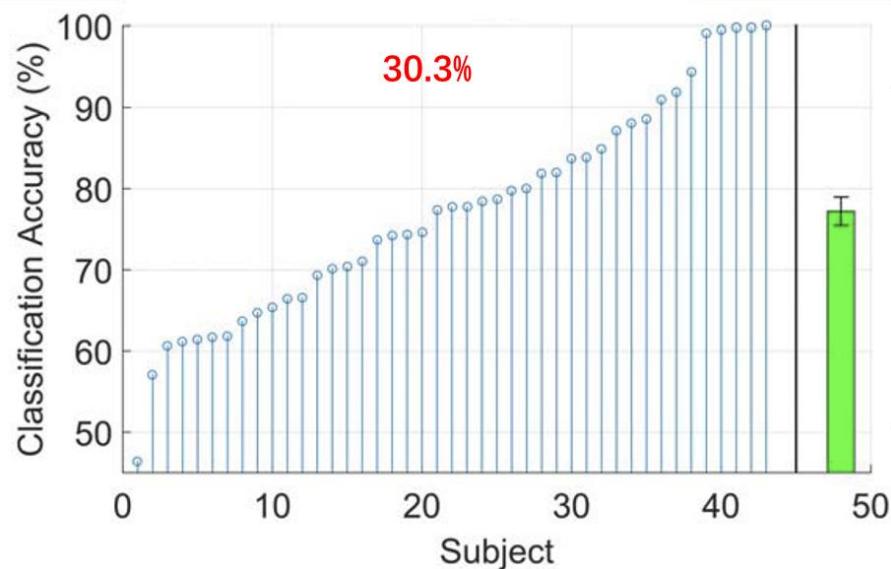


BCI-deficiency Problem: experiment evidence illustrates that there exists
>30% of people, whose BCI performance is <70% accuracy (Vidaurre C., 2010)



#Subjects	193
#Channels	5
Feature	BP + AAR
Classifier	LDA
#trials	40

Guger C., et al, 2003, IEEE TNSRE
Blankertz B., et al, 2010, NeuroImage



Ahn M., et al, 2015, J. Neur. Meth.
Yao L., et al, 2018, IEEE TNSRE

Background: Traditional Decoding Algorithm



- CSP and Regularizing Approach

Subject	BCI competition III									BCI competition IV									Overall		
	data set IVa					data set IIIa				data set IIa											
	A1	A2	A3	A4	A5	B1	B2	B3	C1	C2	C3	C4	C5	C6	C7	C8	C9	Mean	Median	Std	
CSP	66.07	96.43	47.45	71.88	49.6	95.56	61.67	93.33	88.89	51.39	96.53	70.14	54.86	71.53	81.25	93.75	93.75	75.5	71.9	18.2	
GLRCSP	72.32	96.43	66.84	67.86	89.29	95.56	61.67	90	86.11	58.33	93.75	67.36	55.56	65.28	81.25	93.75	88.19	78.2	81.3	14.3	
CCSP1	66.96	96.43	63.27	71.88	84.92	98.89	45	93.33	86.11	60.42	93.75	56.94	49.31	65.28	81.25	93.75	88.19	76.2	81.3	17.5	
CCSP2	65.18	96.43	45.41	71.88	49.6	95.56	61.67	93.33	88.89	53.47	97.22	70.14	54.17	68.06	79.17	95.14	90.28	75	71.9	18.3	
DLCSPauto	66.96	96.43	46.94	71.43	50	94.44	63.33	95	88.89	51.39	96.53	70.14	56.94	71.53	81.94	93.75	93.75	75.9	71.5	18	
DLCSPcv	64.29	96.43	52.04	71.88	82.54	95.56	78.33	93.33	88.89	50.69	96.53	70.14	55.56	62.5	81.25	93.75	86.81	77.7	81.3	16.1	
DLCSPcvdiff	69.64	98.21	55.1	71.88	82.54	95.56	66.67	93.33	88.89	50.69	96.53	70.14	55.56	62.5	81.25	93.75	86.81	77.6	81.3	16	
SSRCSP	70.54	96.43	53.57	71.88	75.39	95.56	61.67	96.67	88.89	53.47	97.22	70.14	56.25	68.75	79.17	97.22	90.28	77.8	75.4	16.2	
TRCSP	71.43	96.43	63.27	71.88	86.9	98.89	56.67	93.33	88.89	54.17	96.53	70.83	62.5	67.36	81.25	95.87	91.67	79.3	81.3	15.3	
WTRCSP	69.64	98.21	54.59	71.88	85.32	98.89	71.67	93.33	88.89	54.86	96.53	70.14	65.97	61.81	81.25	95.83	90.97	79.4	81.3	15.3	
SRCS	72.32	96.43	60.2	77.68	86.51	96.67	53.33	93.33	88.89	63.19	96.53	66.67	63.19	63.89	78.47	95.83	92.36	79.2	78.5	15.2	

- CSP extension based on joint spatial-temporal-spectrum

Left hand vs. Foot

	Mean	S.D.
CSP	80.6	15.3
CSSP	84.3	13.4
SWCSP	83.4	14.5
ISSPL	83.3	14.1
FBCSP	80.4	15.5
MMISS	85.6	11.6

Left hand vs. Tongue

	Mean	S.D.
CSP	84.0	13.7
CSSP	85.2	13.5
SWCSP	84.7	13.6
ISSPL	84.7	13.8
FBCSP	83.5	13.3
MMISS	85.5	13.4

Right hand vs. Foot

	Mean	S.D.
CSP	81.8	14.4
CSSP	84.0	13.3
SWCSP	83.4	14.2
ISSPL	83.5	14.2
FBCSP	82.7	13.8
MMISS	86.6	11.4

Right hand vs. Tongue

	Mean	S.D.
CSP	83.6	13.6
CSSP	84.5	13.0
SWCSP	84.5	11.5
ISSPL	86.2	11.8
FBCSP	84.3	11.8
MMISS	87.2	11.8

Meng, J., et al, 2015, IEEE Trans. Biomedical Engineering

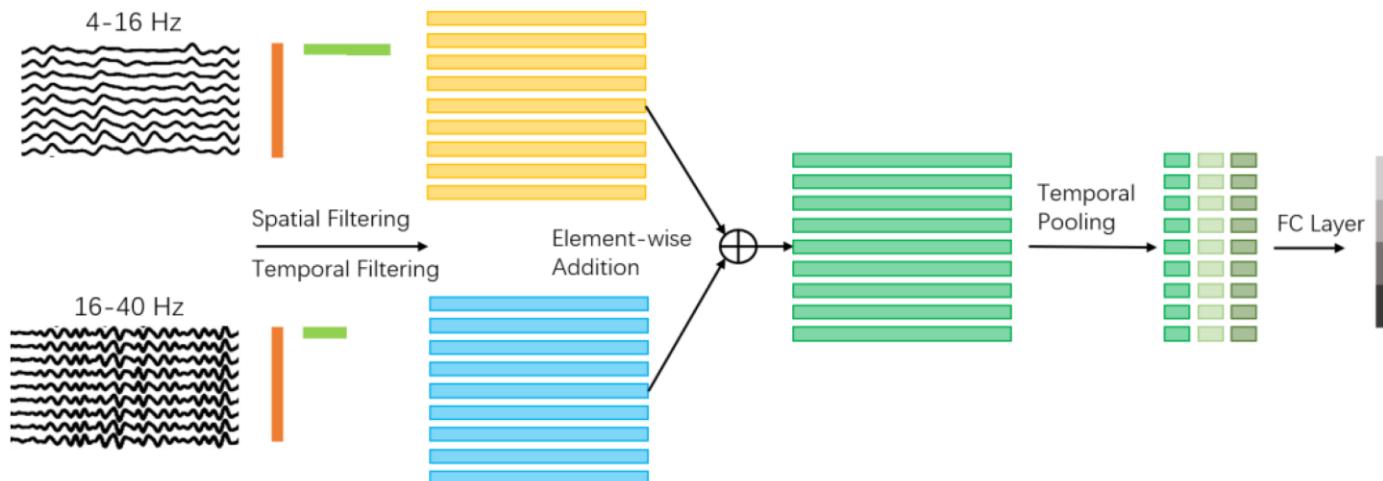
About 5%
Improve above
CSP

Fabien L., et al, 2011,
IEEE Trans. Biomedical
Engineering

Background: Deep Learning Algorithm

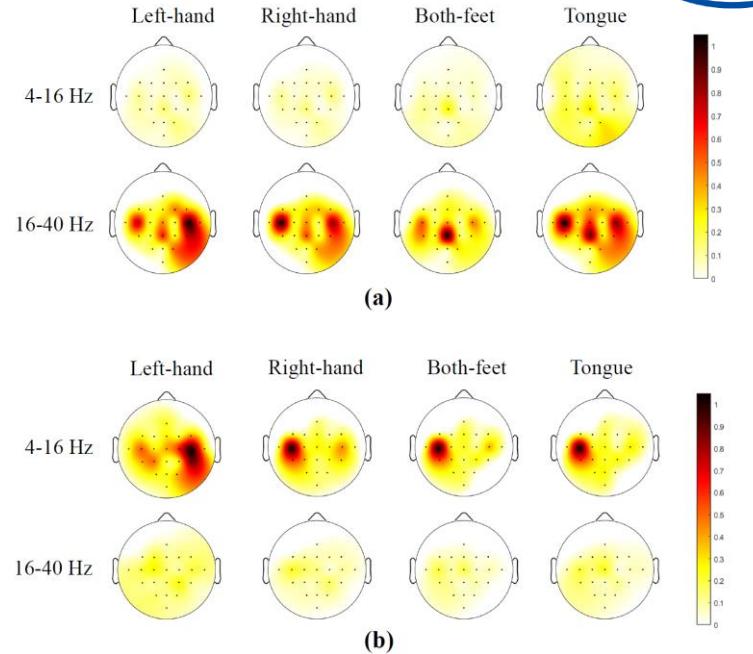


Interactive Frequency Convolutional Neural Network



Subject	FBCSP-SVM	EEGNet	FBCNet	IFNet
1	81.60	85.62	85.80	88.47
2	52.78	49.58	56.01	56.35
3	84.38	90.66	89.67	91.77
4	65.28	67.12	70.87	73.78
5	56.25	62.01	65.70	69.72
6	44.44	53.72	57.17	60.42
7	89.24	82.29	90.70	89.24
8	81.94	81.67	84.48	85.42
9	72.92	84.06	83.06	88.72
Avg	69.87*	72.97**	75.94*	78.21
Std	15.90	15.13	13.73	13.51

BCI-IV-2A Dataset



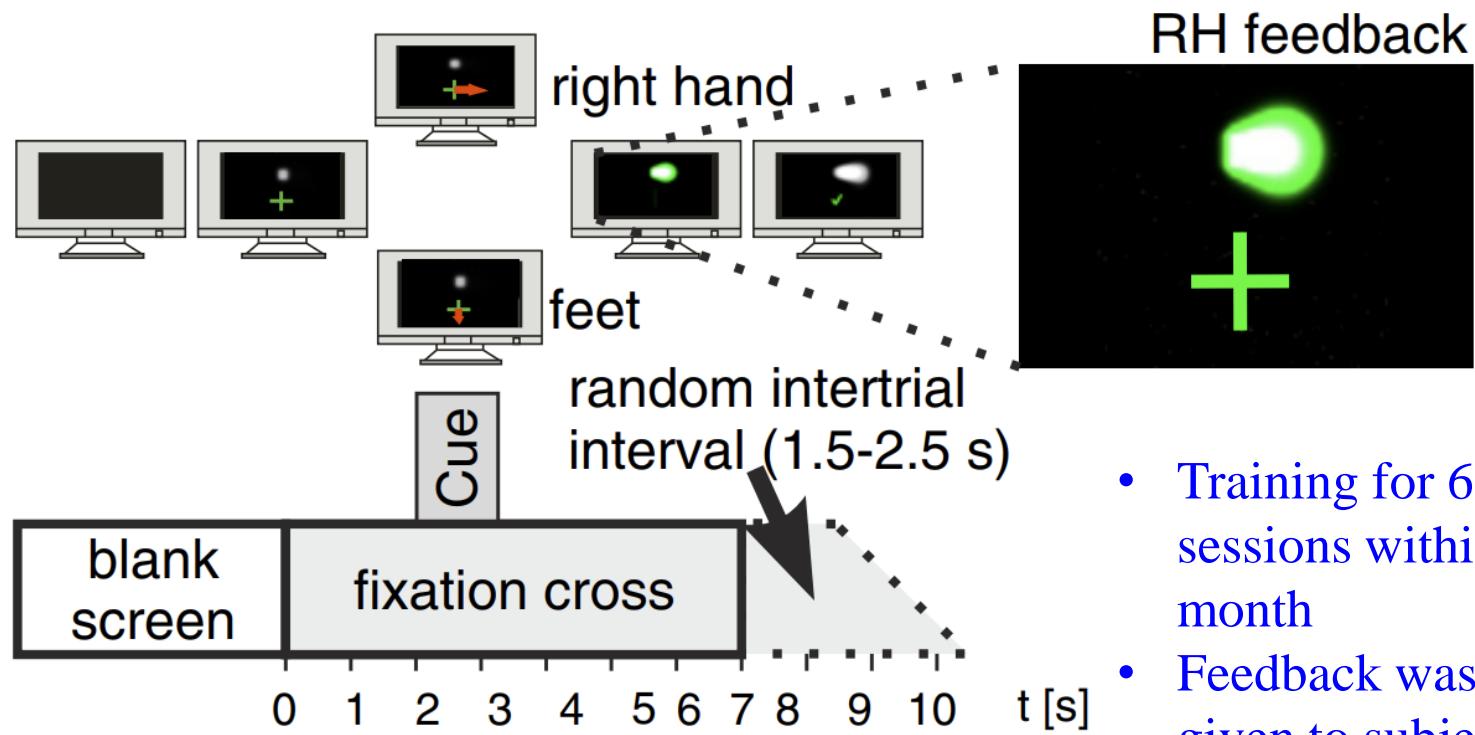
OpenBMI Dataset

Wang, J., Yao, L., Wang Y.,
2023, IEEE Trans. NSRE

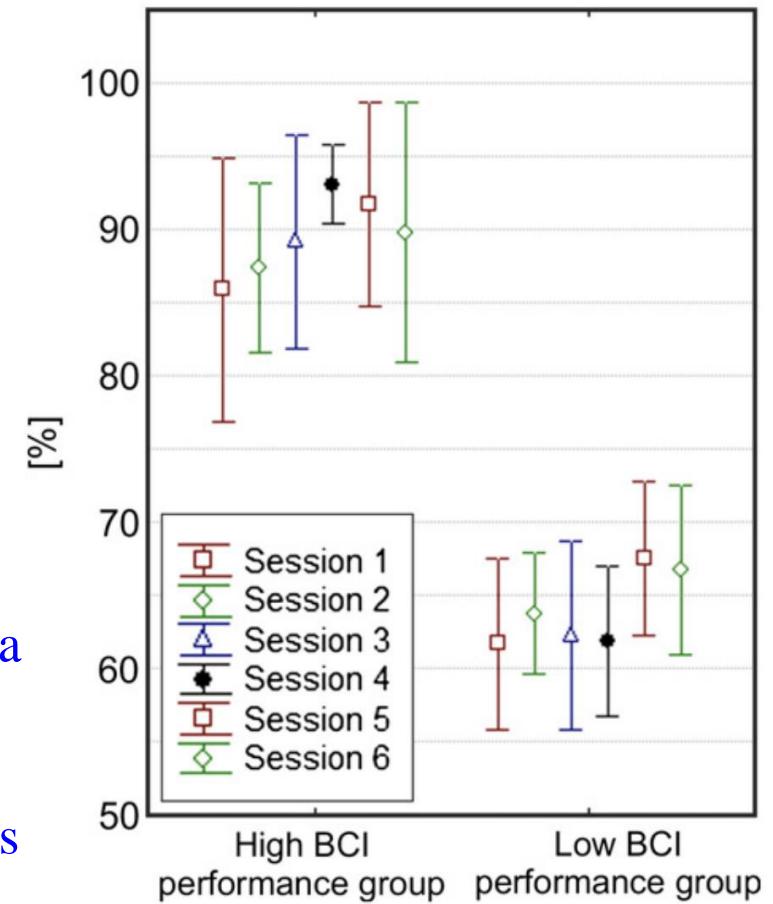
Background: BCI Feedback Training



Neurofeedback-based Training Approach



- Training for 6 sessions within a month
- Feedback was given to subjects for learning

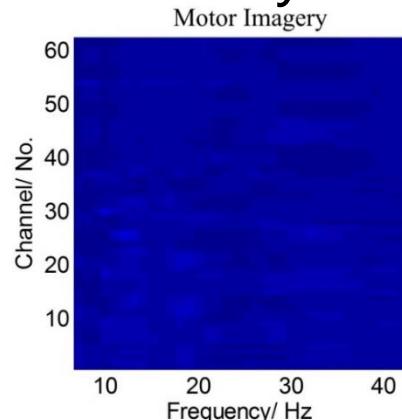


Background: Sensory stimulation Approach

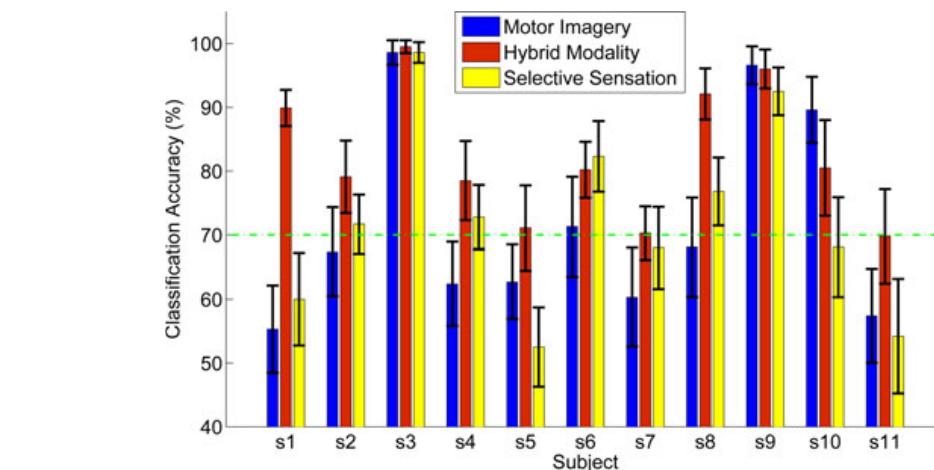
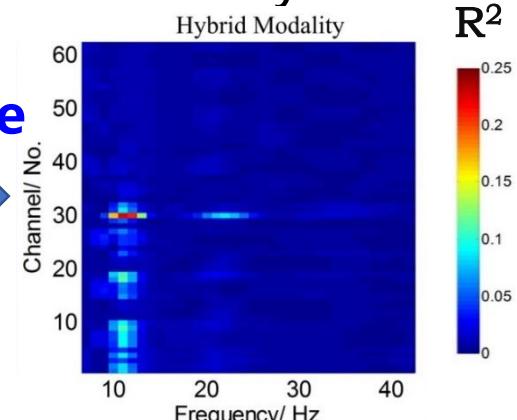


Stimulation → Hybrid BCI

Accuracy 68.0%



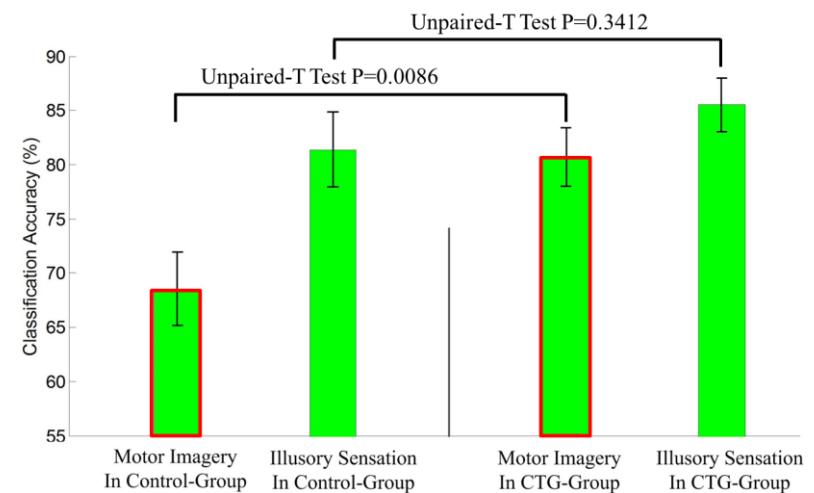
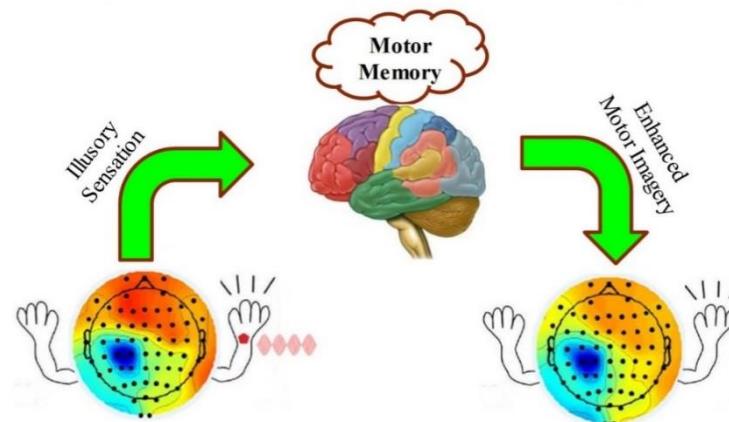
Accuracy 92.7%



- 10% Improvement on average
- Reduce deficiency rate

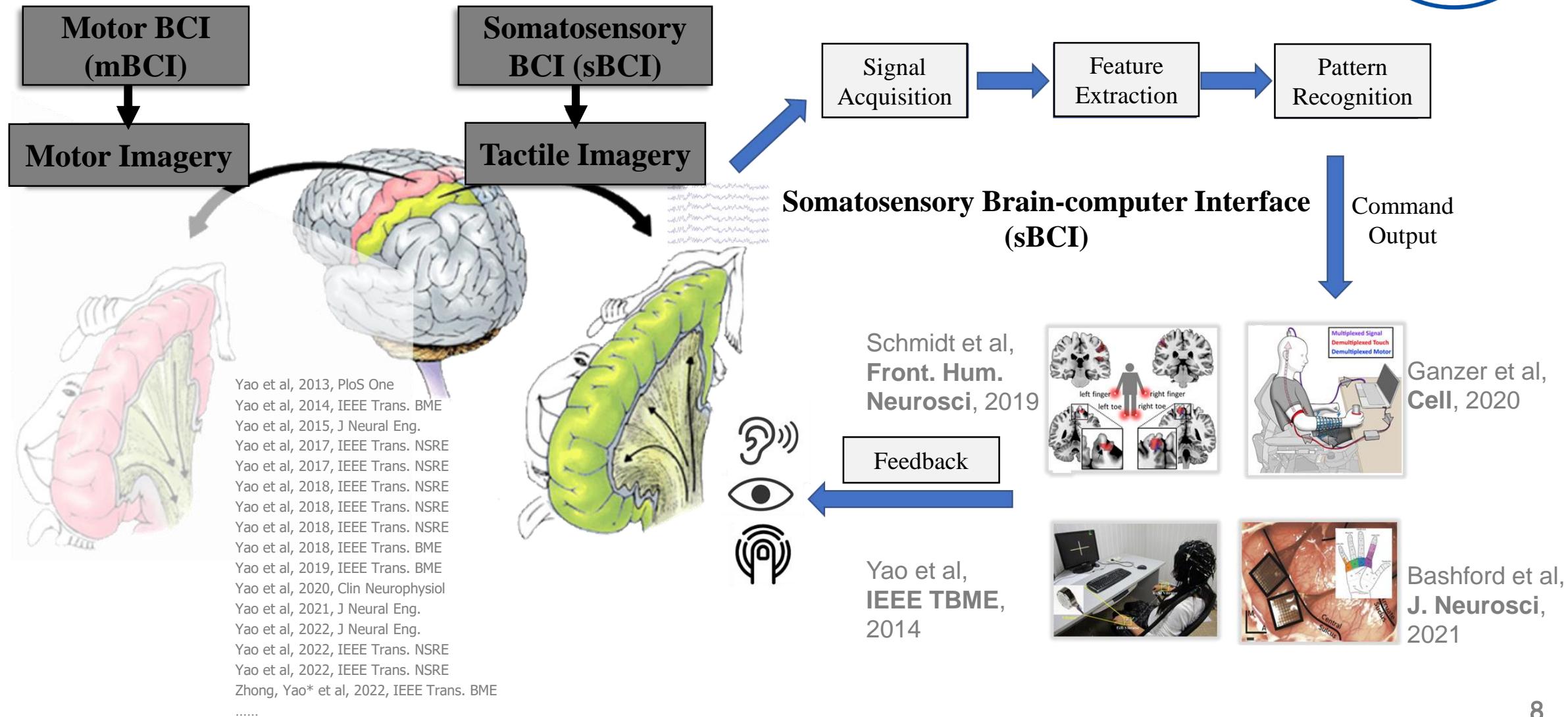
Yao L., et al, 2014, TBME

Stimulation → MI guidance



Yao L., et al, 2015, JNE

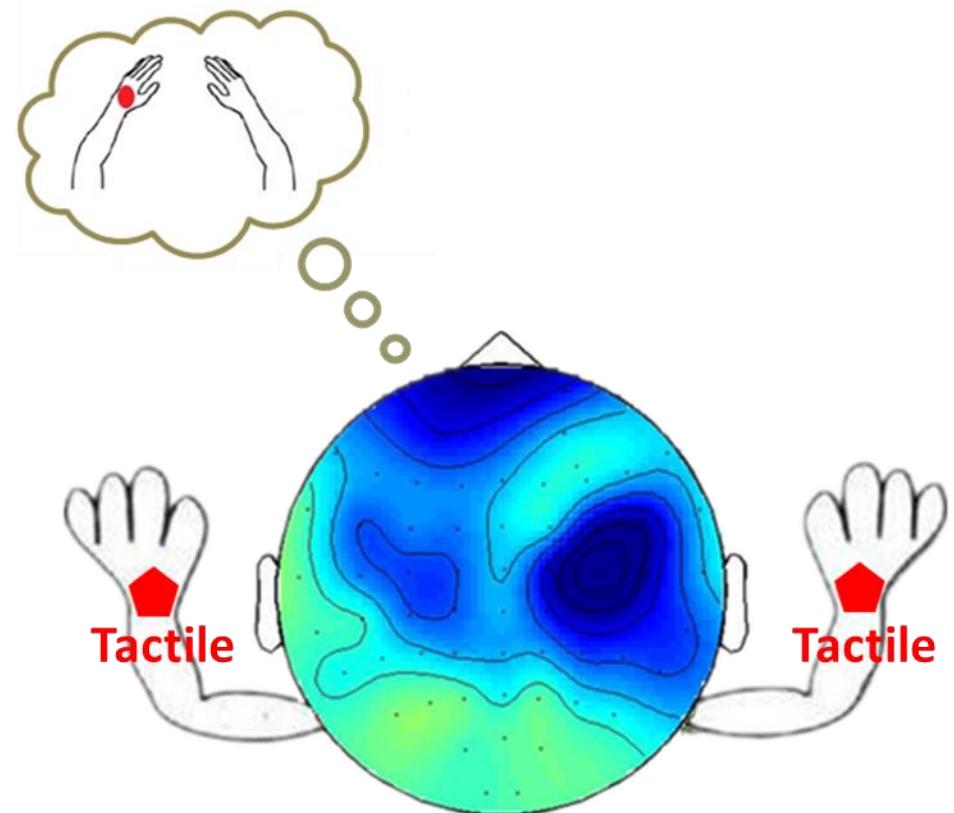
Background: Somatosensory BCI & Stimulation



Outline



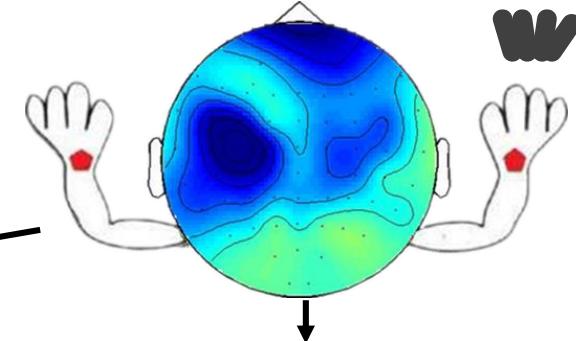
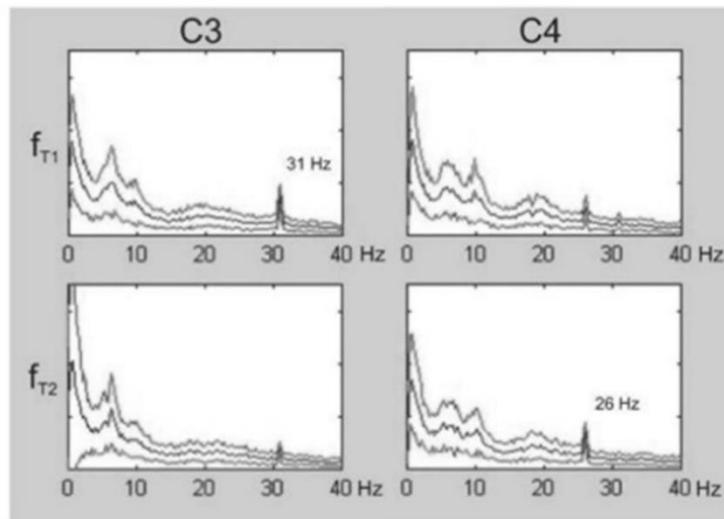
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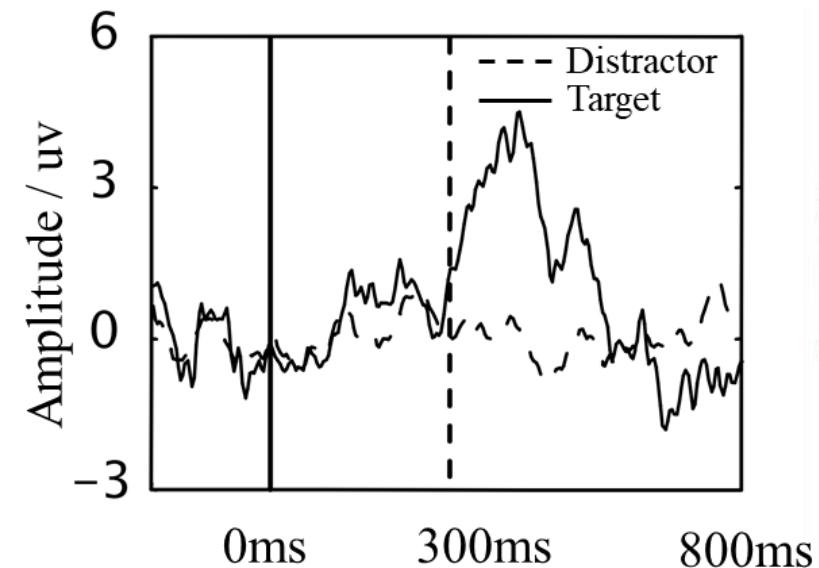
sBCI: Brain Signals for Somatosensory BCI



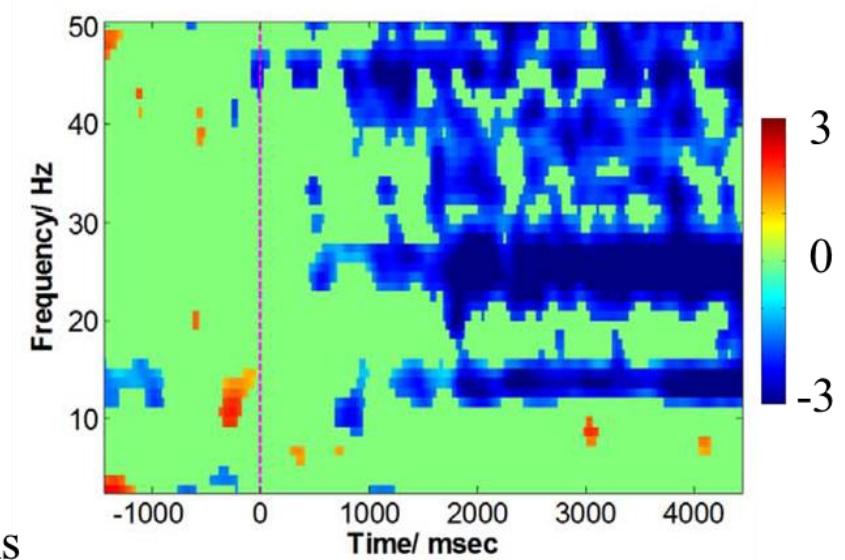
Steady-state somatosensory evoked potential (SSSEP)



Tactile P300



Tactile ERD

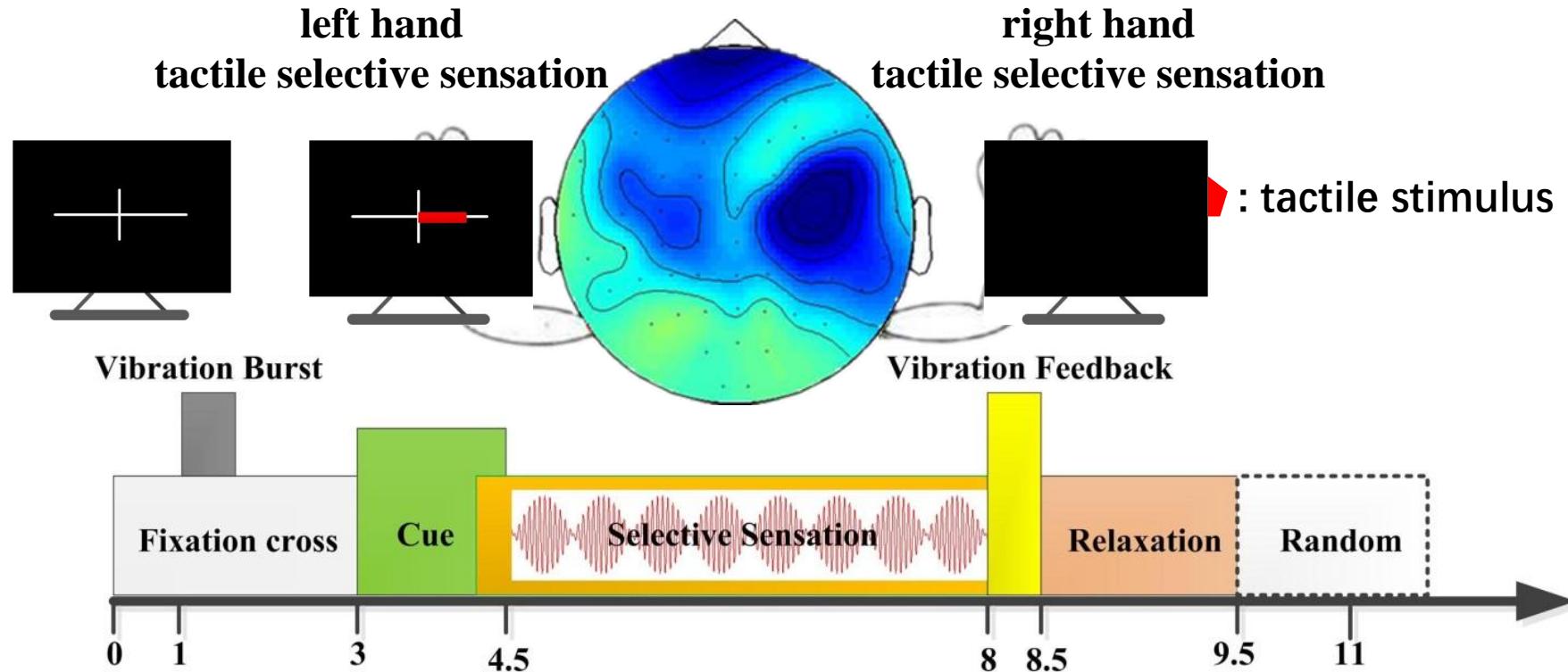


Muller-Putz G R, et al, TNSRE, 2006

Brouwer A, et al, Front. Neurosci, 2010

Yao L, et al, PloS One, 2013

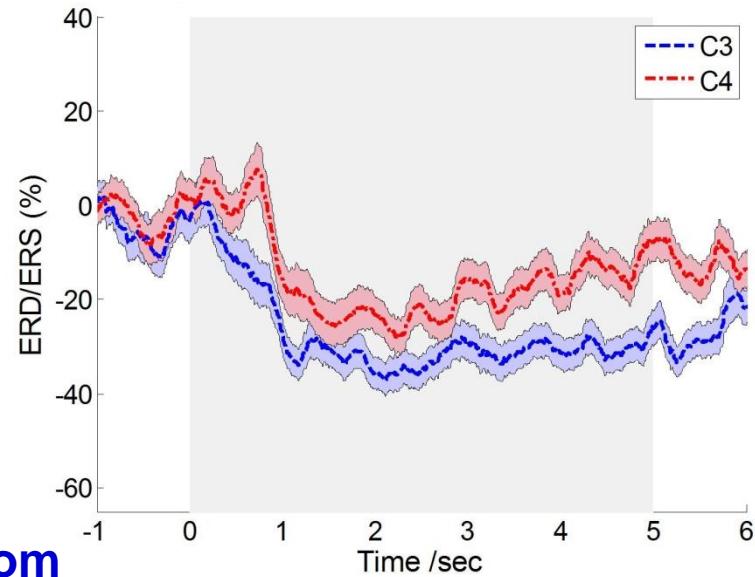
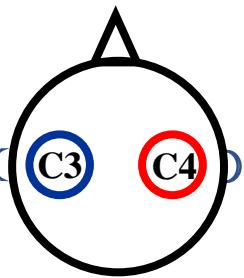
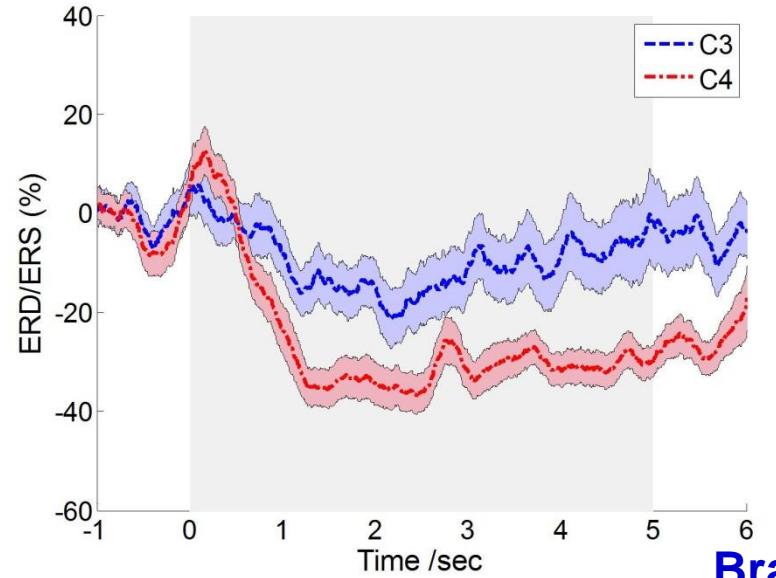
sBCI: Experiment Paradigm



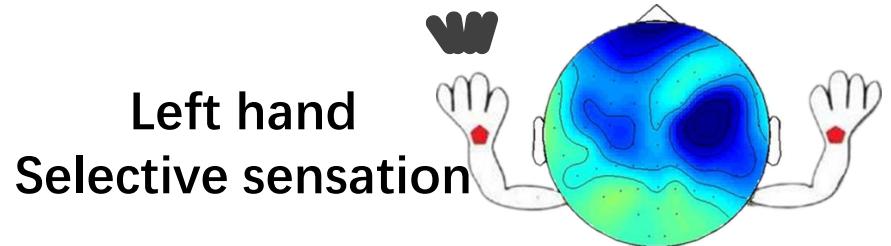
Stimulus: Both hands stimulated simultaneously

Experiment: 120 trials/each / 62-ch EEG / sampled at 250Hz /
2 Tasks (left and right hand tactile selective sensation)

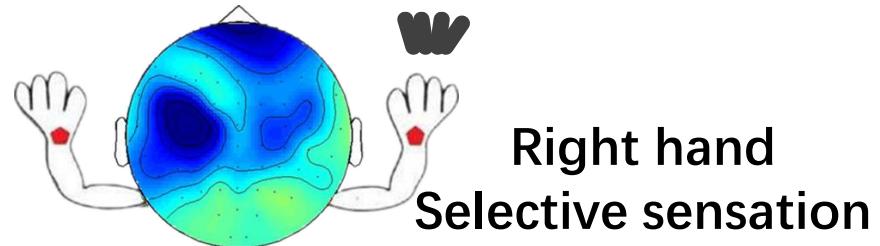
sBCI: Brain Activation Pattern



Brain Signal from
Sensory Cortex



Left hand
Selective sensation



Right hand
Selective sensation

— ERD on contralateral hemisphere



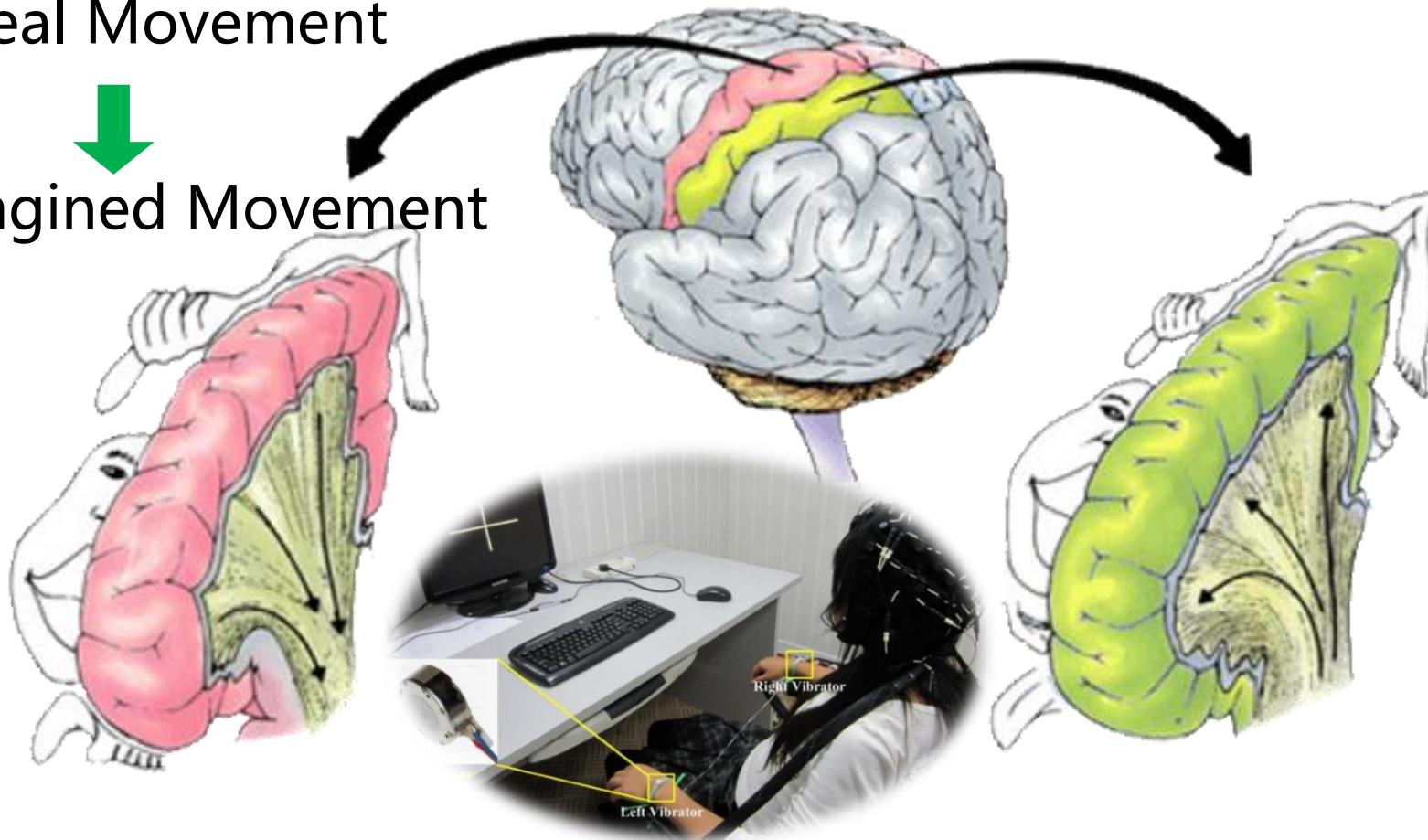
Comparison with state-of-the-art tactile BCI systems

State-of-the-arts works	Yao, 2017, 2018 IEEE Trans. NSRE	Muller-Putz, 2006 IEEE Trans. NSRE	Ahn, 2014, J Neural Eng	Brouwer, 2010, Front. Neurosci.
Averaged Accuracy	80%	70.4%	58%	72%
BCI-deficiency Rate	24.6%	80%	94%	NaN
No. of subjects	57	5	16	12
Mechanism	Tactile ERD	SSSEP	SSSEP	Tactile P300

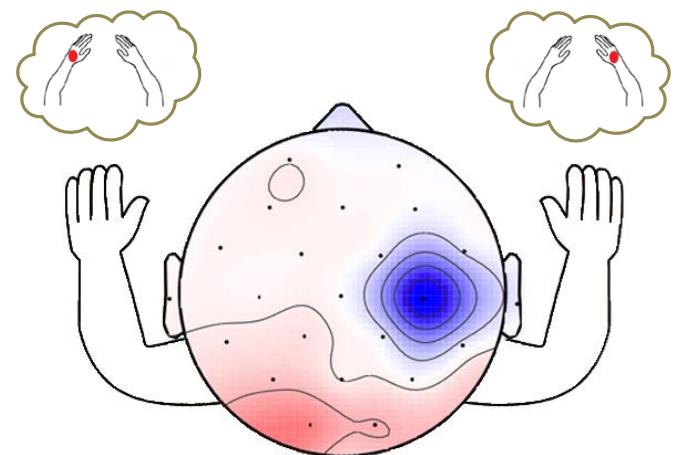
sBCI: tactile sensation → tactile imagery



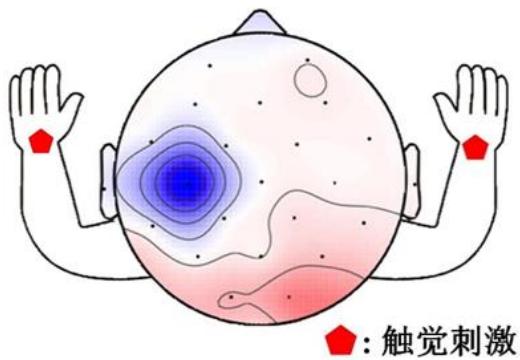
Real Movement
↓
Imagined Movement



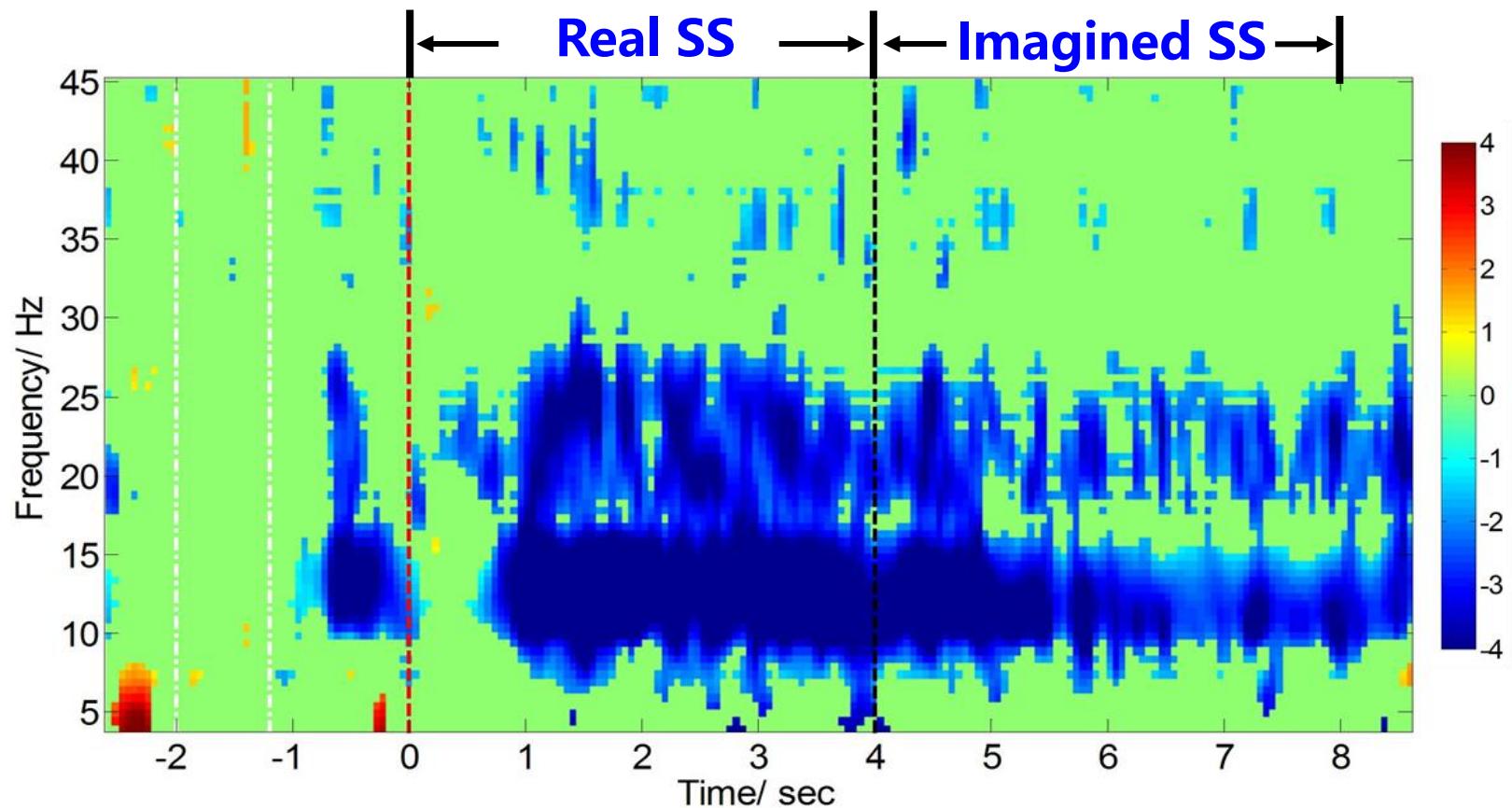
Tactile Sensation
↓
Tactile Imagery



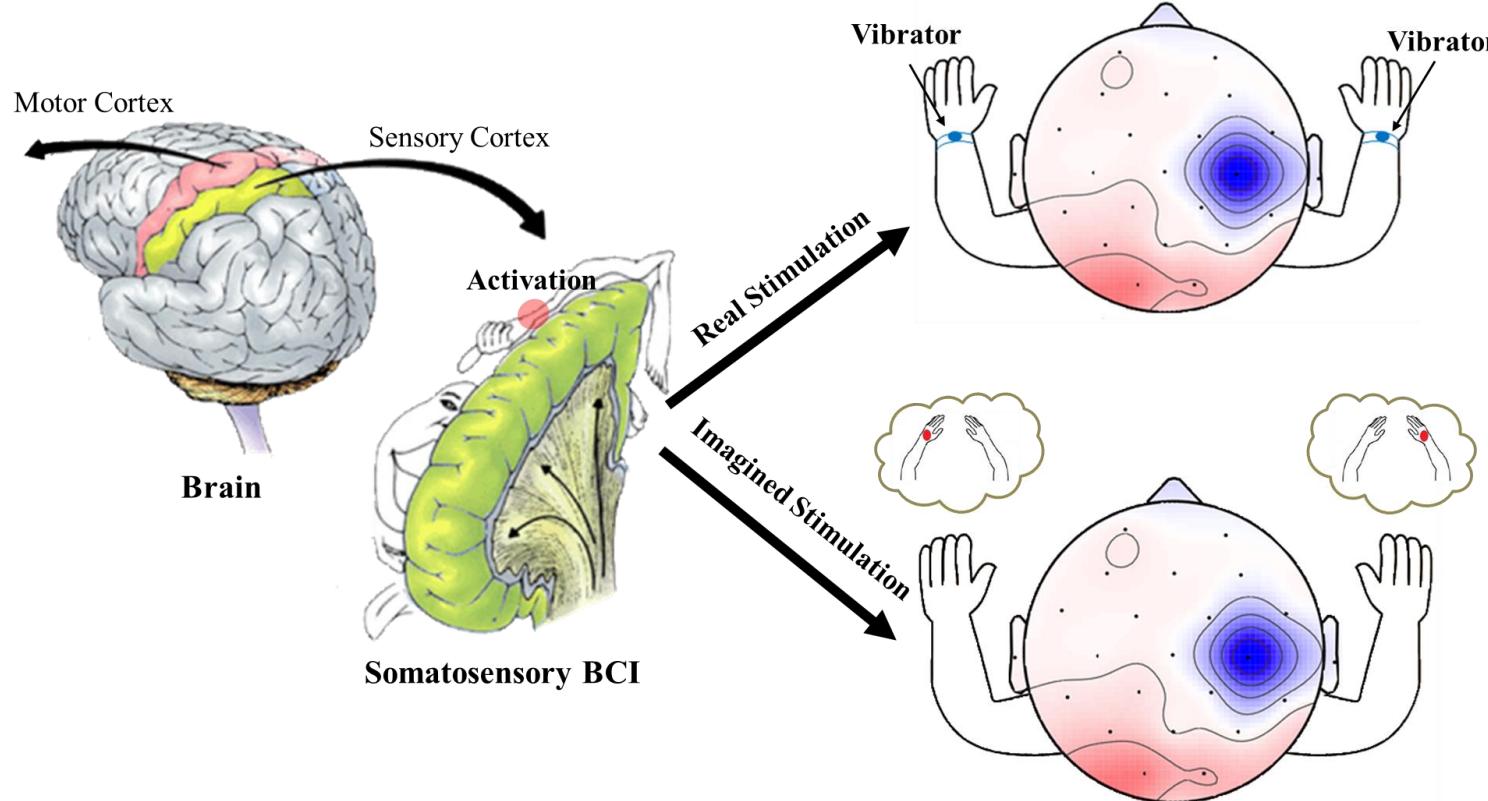
sBCI: ERD for Tactile Imagery



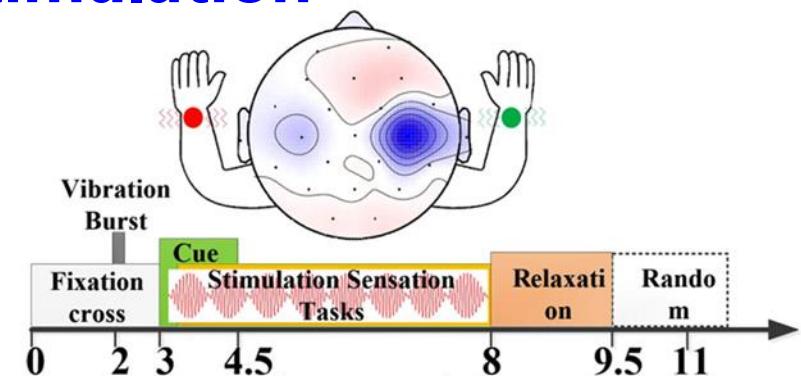
ERD correlates



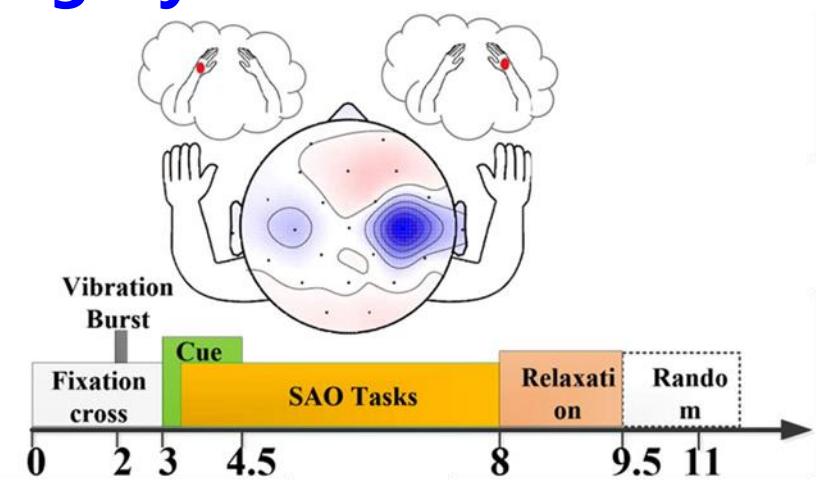
sBCI: Experimental Paradigm



Stimulation



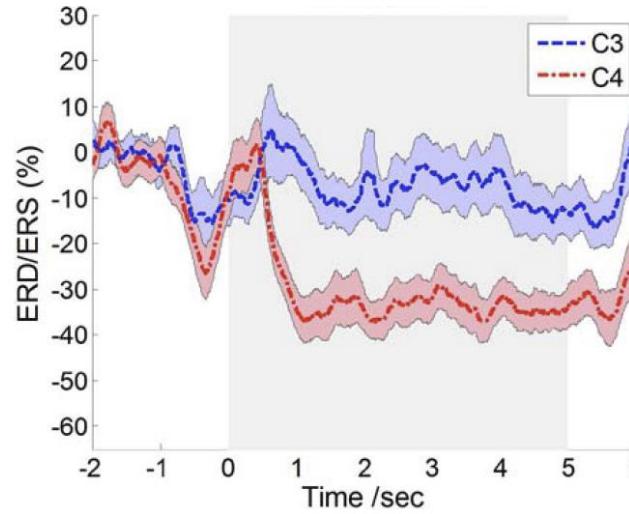
Imagery



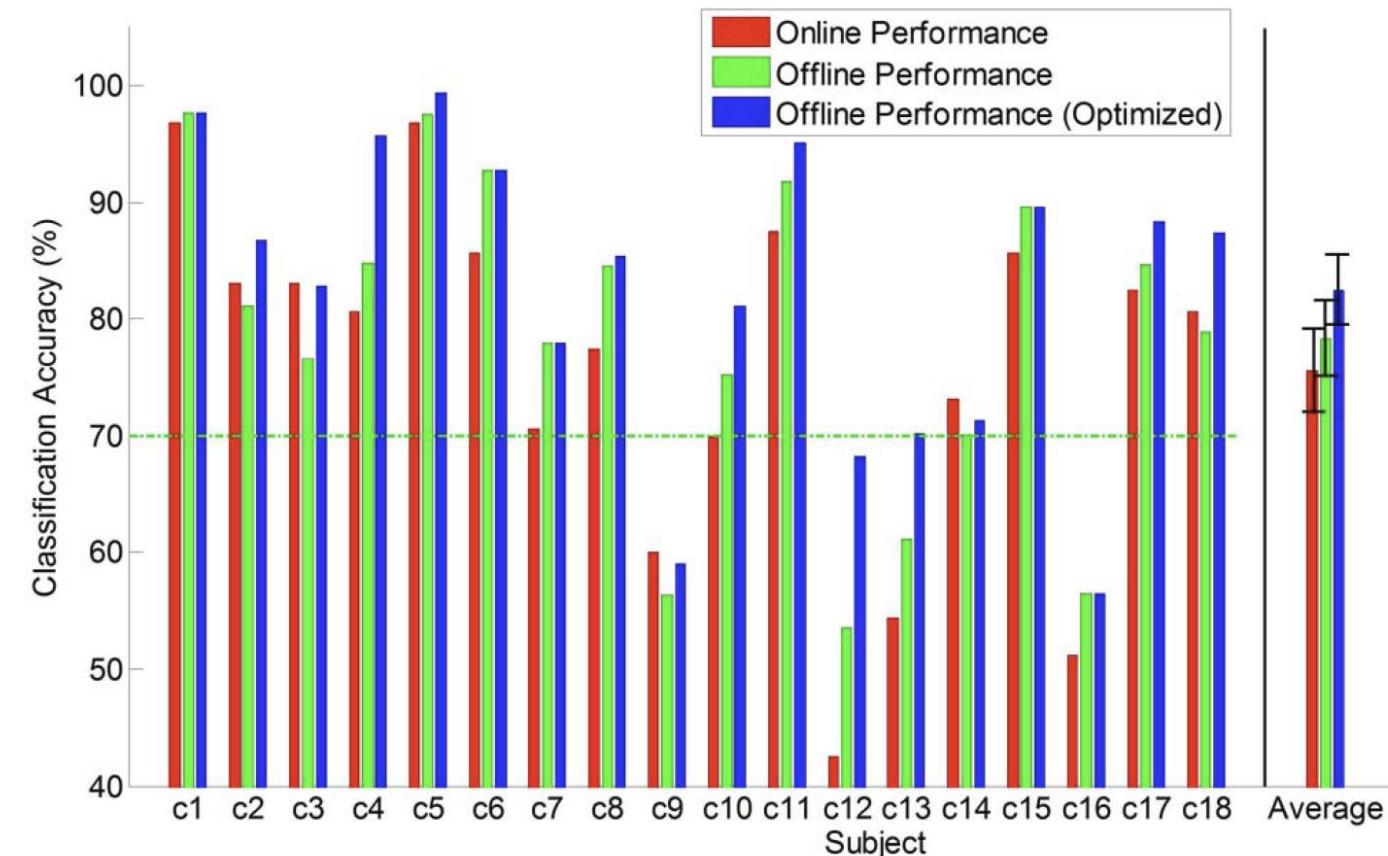
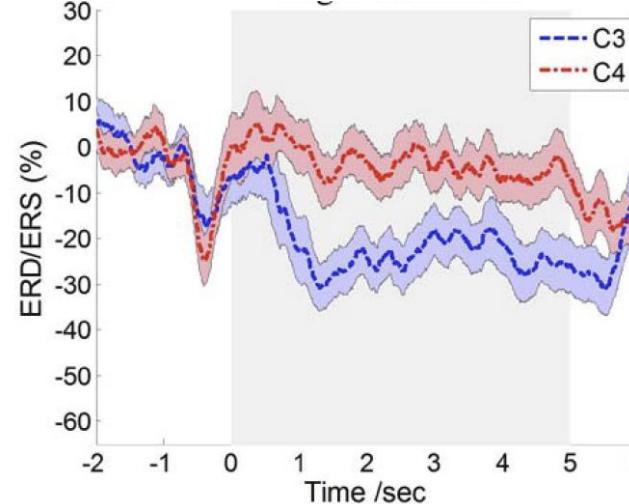
sBCI: Brain Activation Pattern and Performance



Left – Tactile Imagery



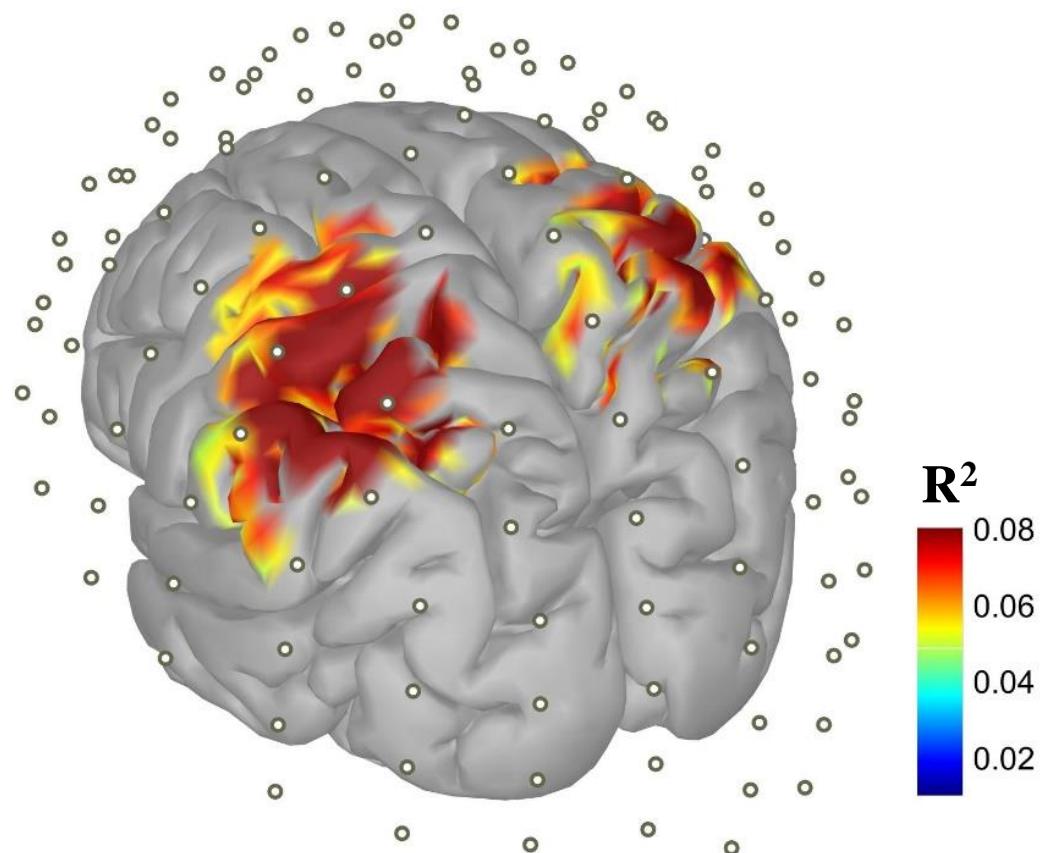
Right – Tactile Imagery



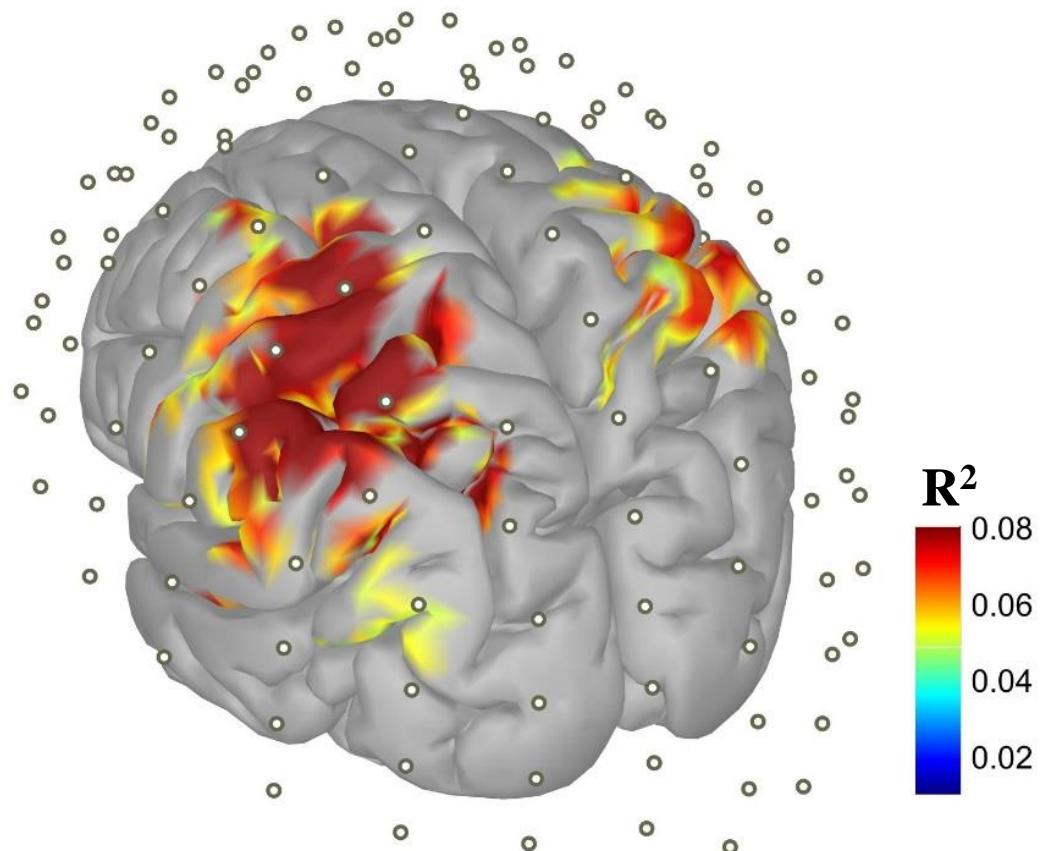
sBCI: Brain Activation Pattern in Source Domain



Tactile Stimulation



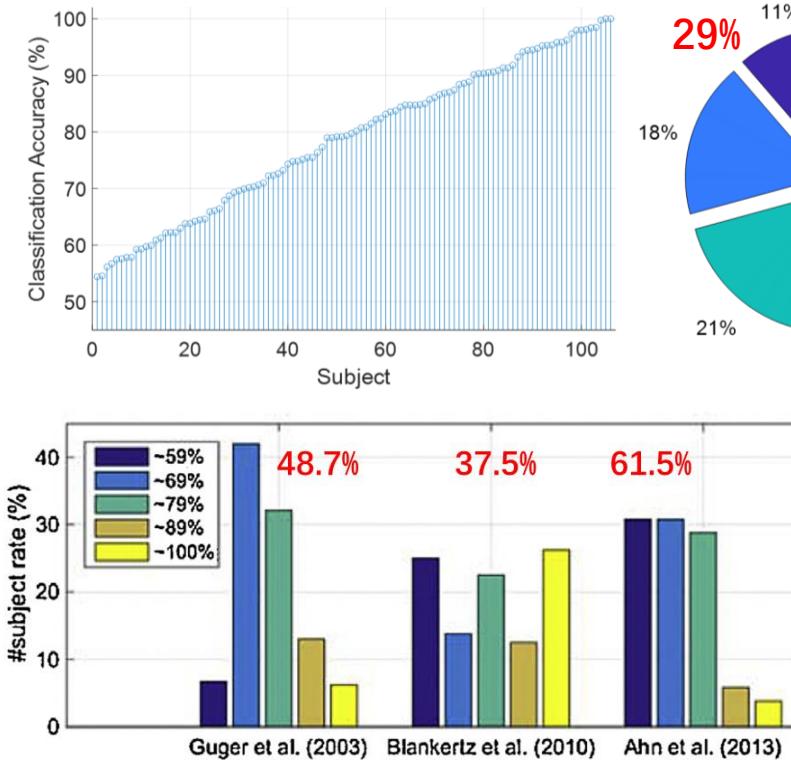
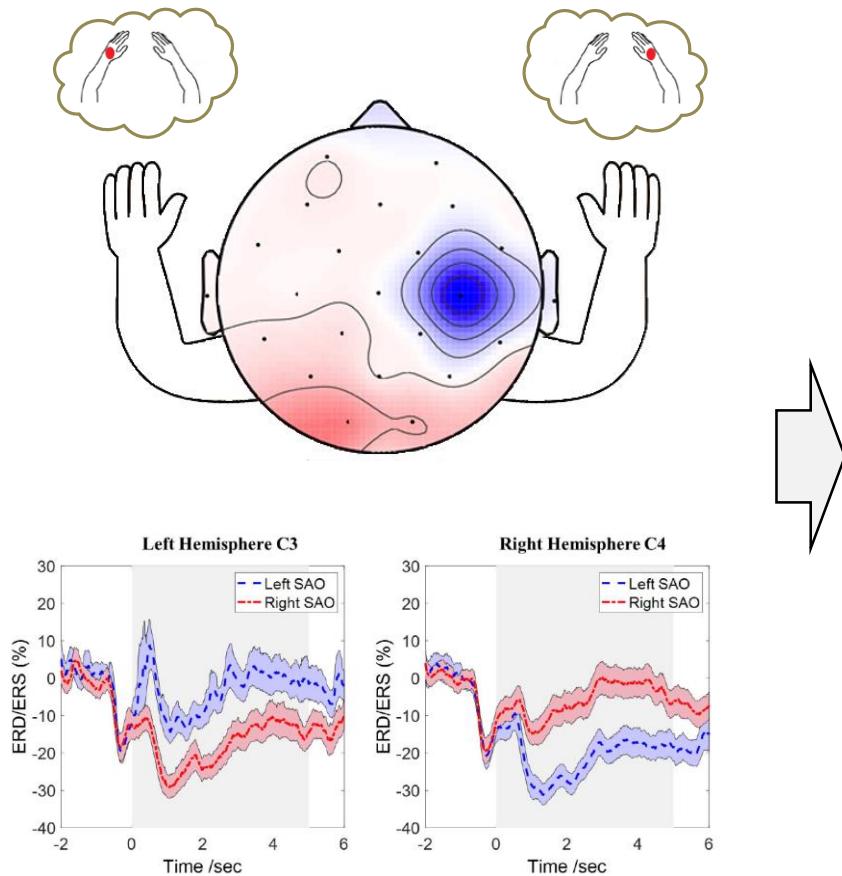
Tactile Imagery



sBCI: BCI-deficiency problem



- Performance variation on a relatively large population

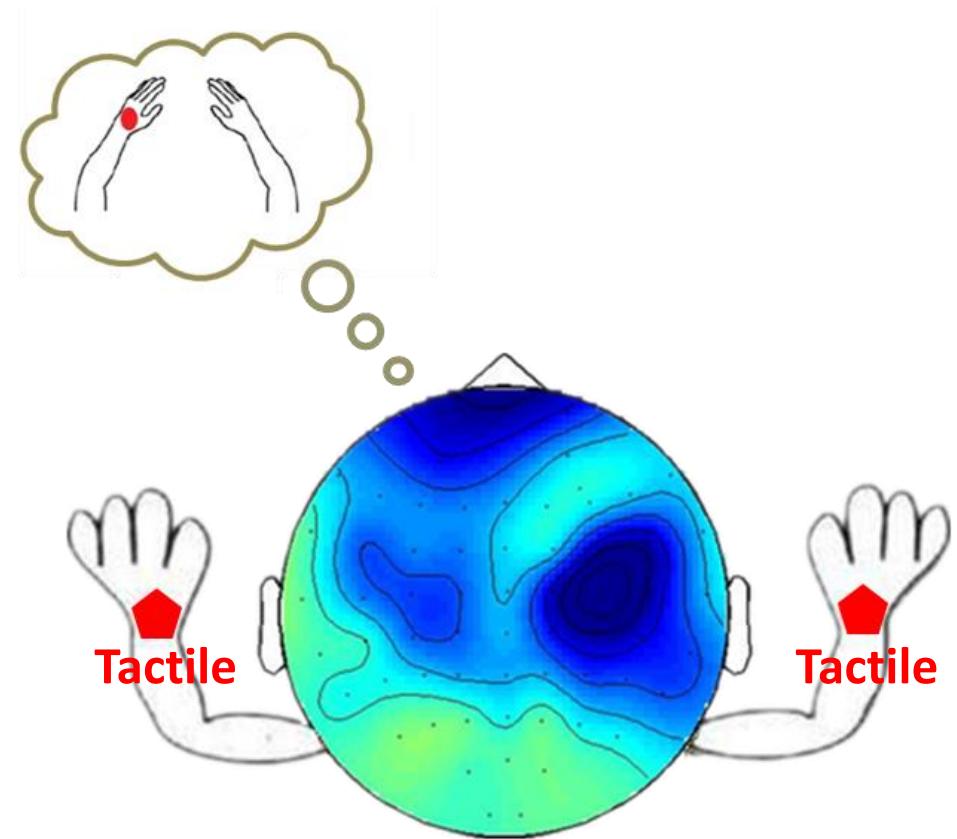


- Lower BCI deficiency rate
- >80% higher portion

Outline



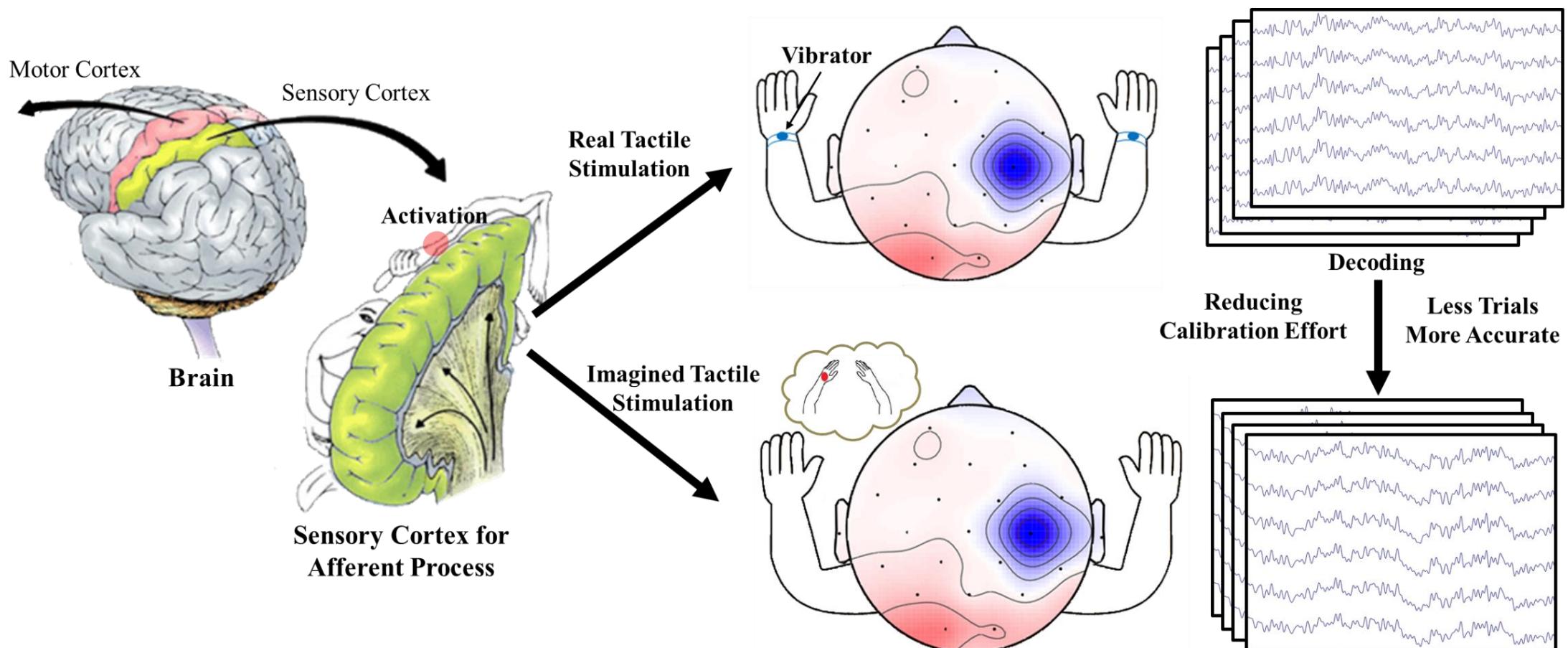
- Background of BCI-deficiency Problem
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- **Sensory Stimulation (SS)**
- Future Work



SS: Sensory Calibration for BCI decoders



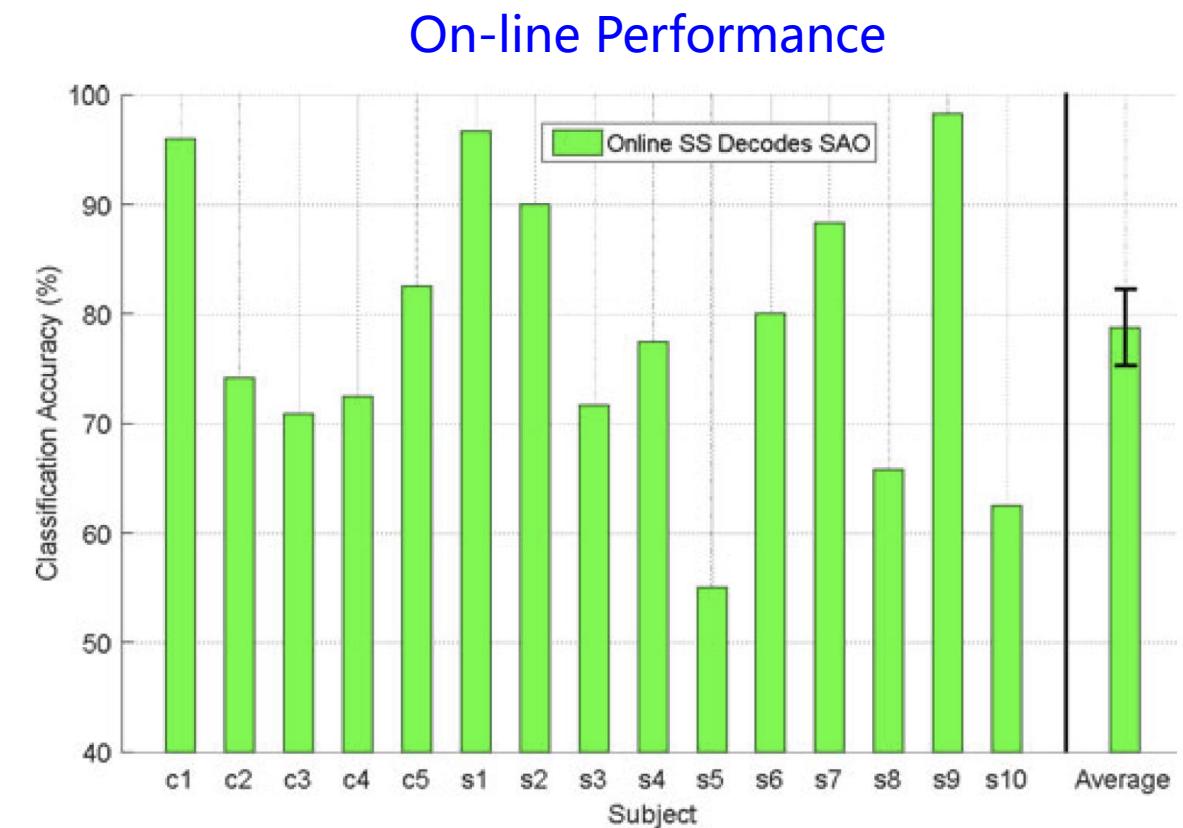
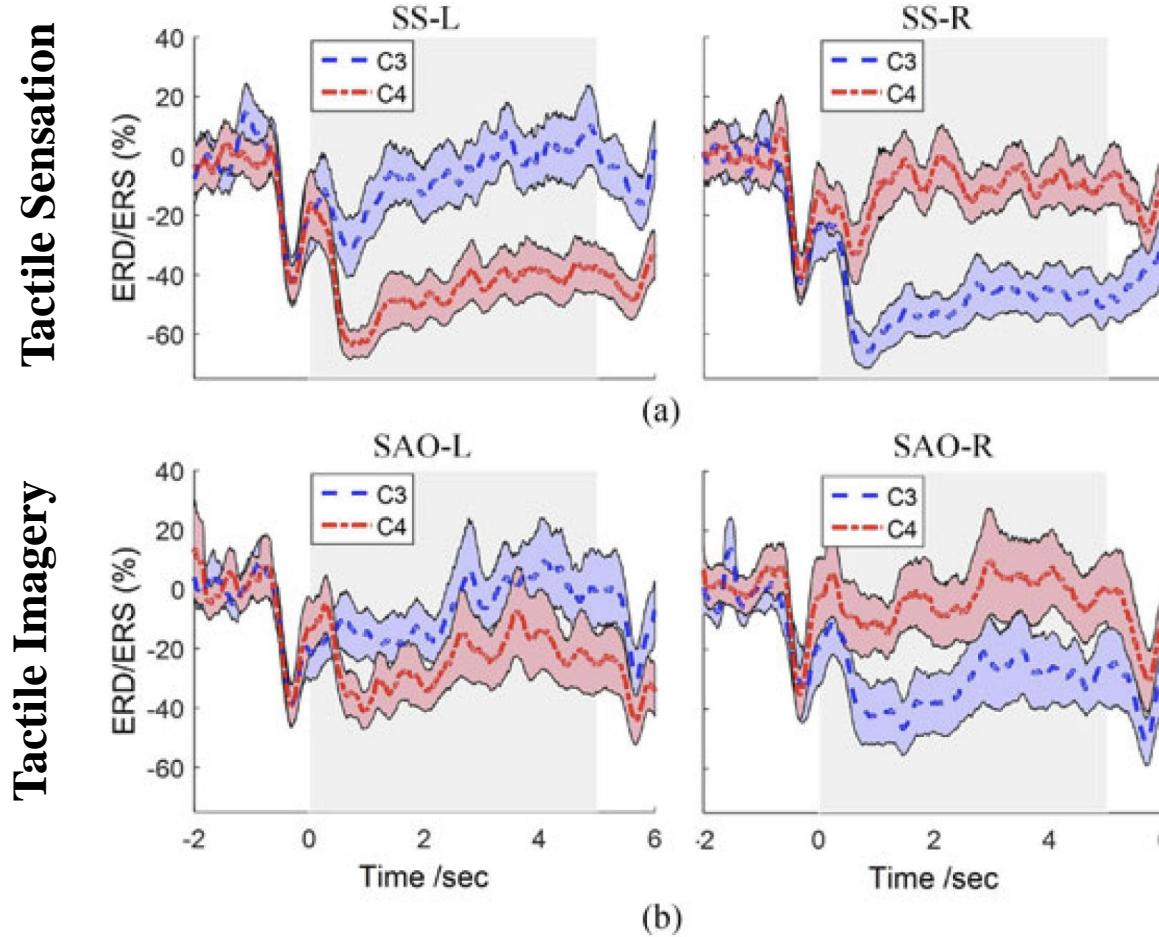
- Calibration training data from sensory stimulation



SS: Sensory Calibration for BCI decoders



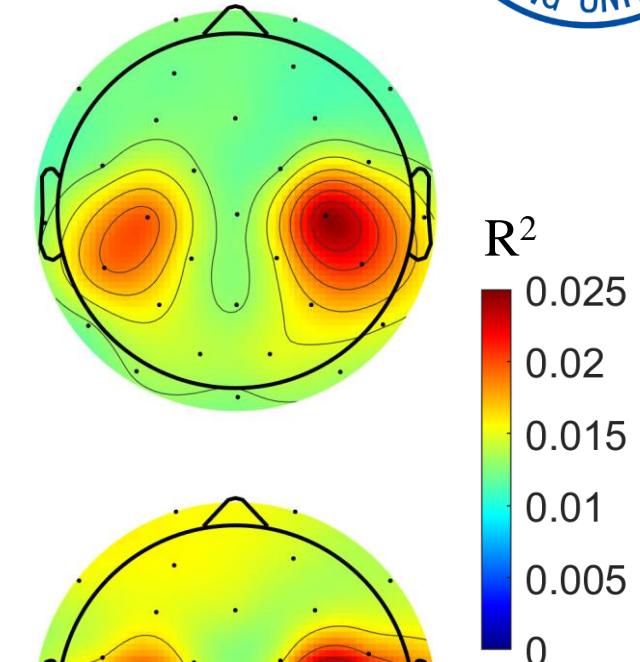
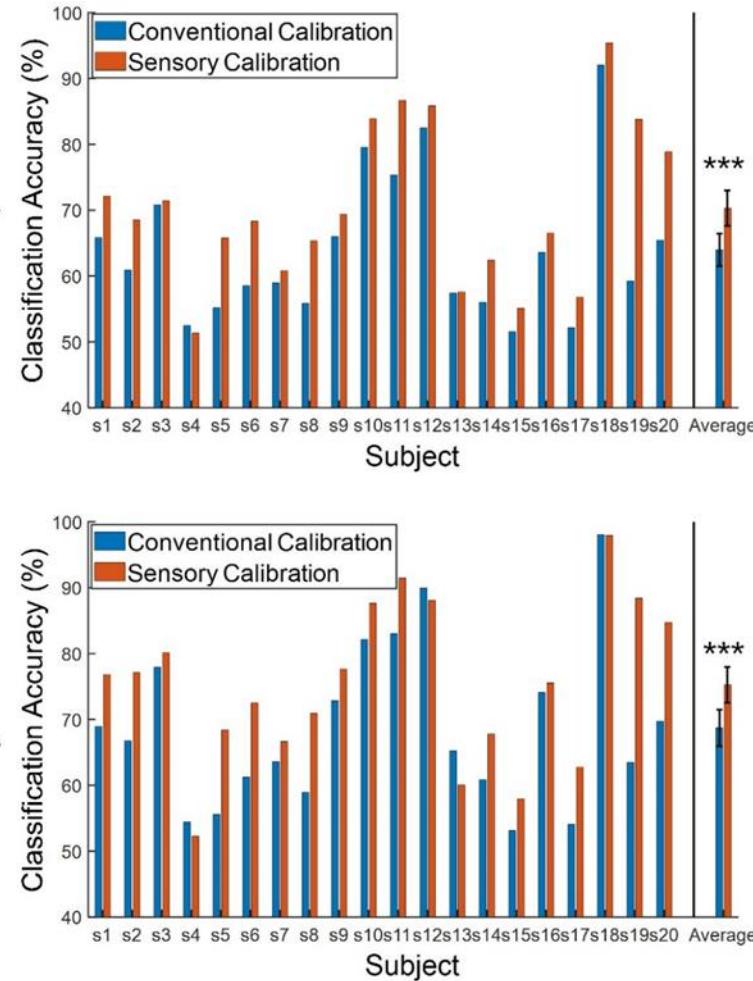
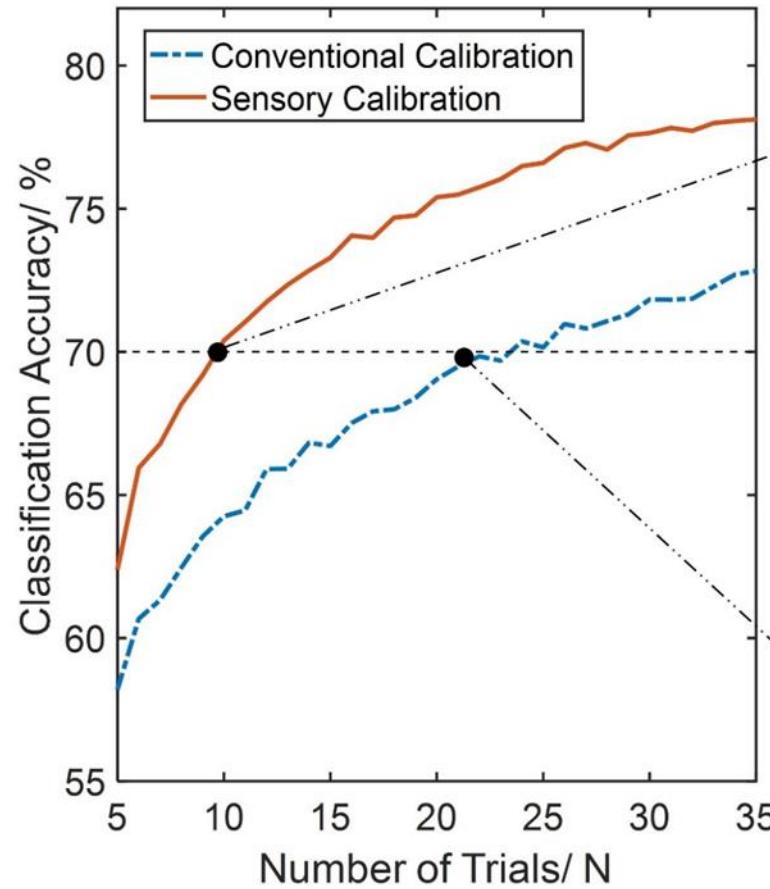
- Calibration training data from sensory stimulation



SS: Sensory Calibration for BCI decoders



- Reducing the Calibration effort and improve BCI performance

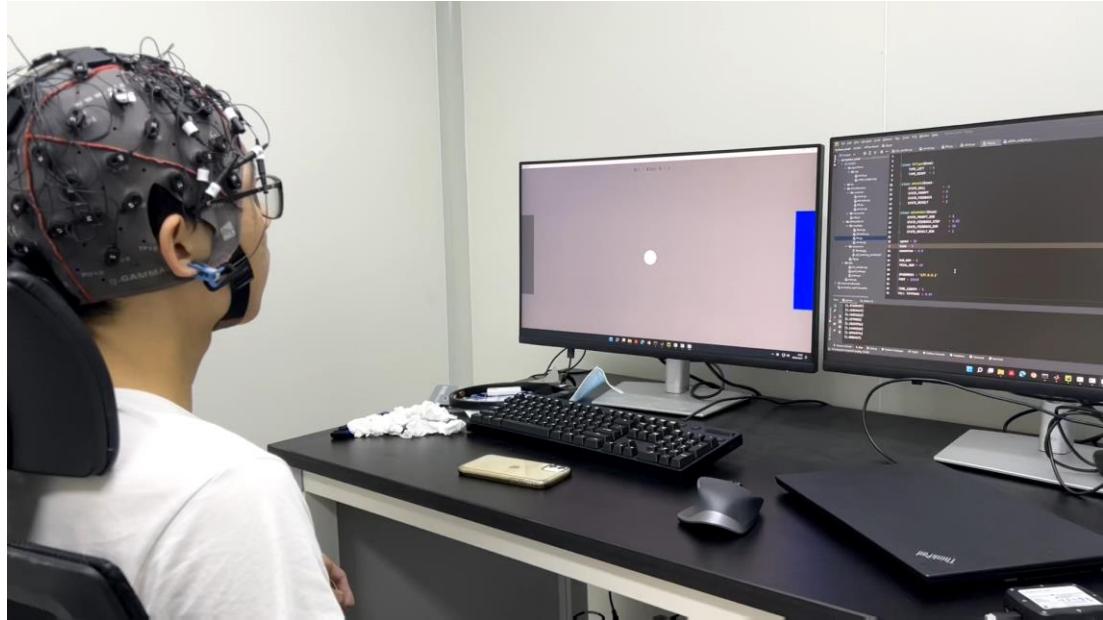


Upper Alpha
[10 13] Hz

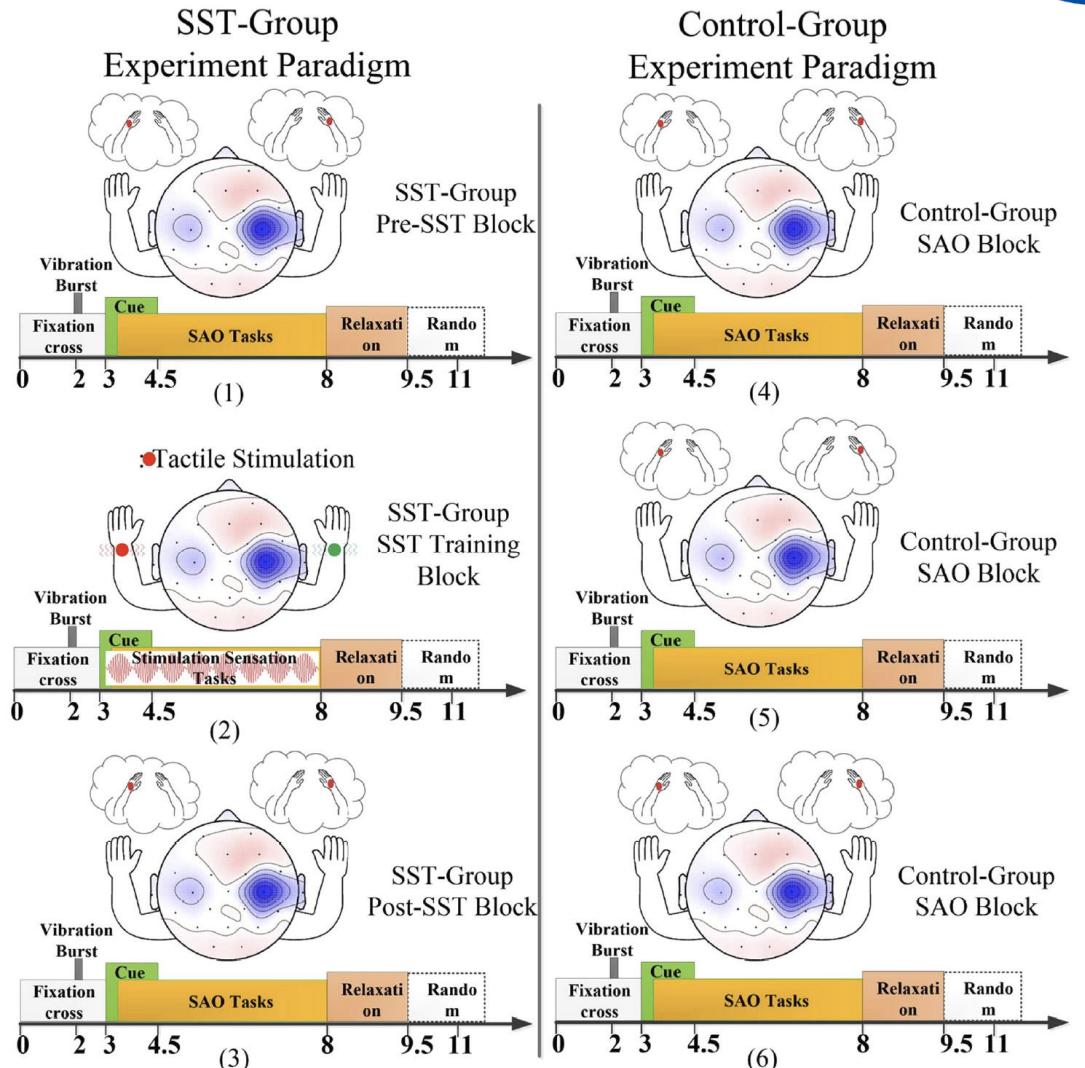
SS: Sensory Training for sBCI



Conventional Neural Feedback Training



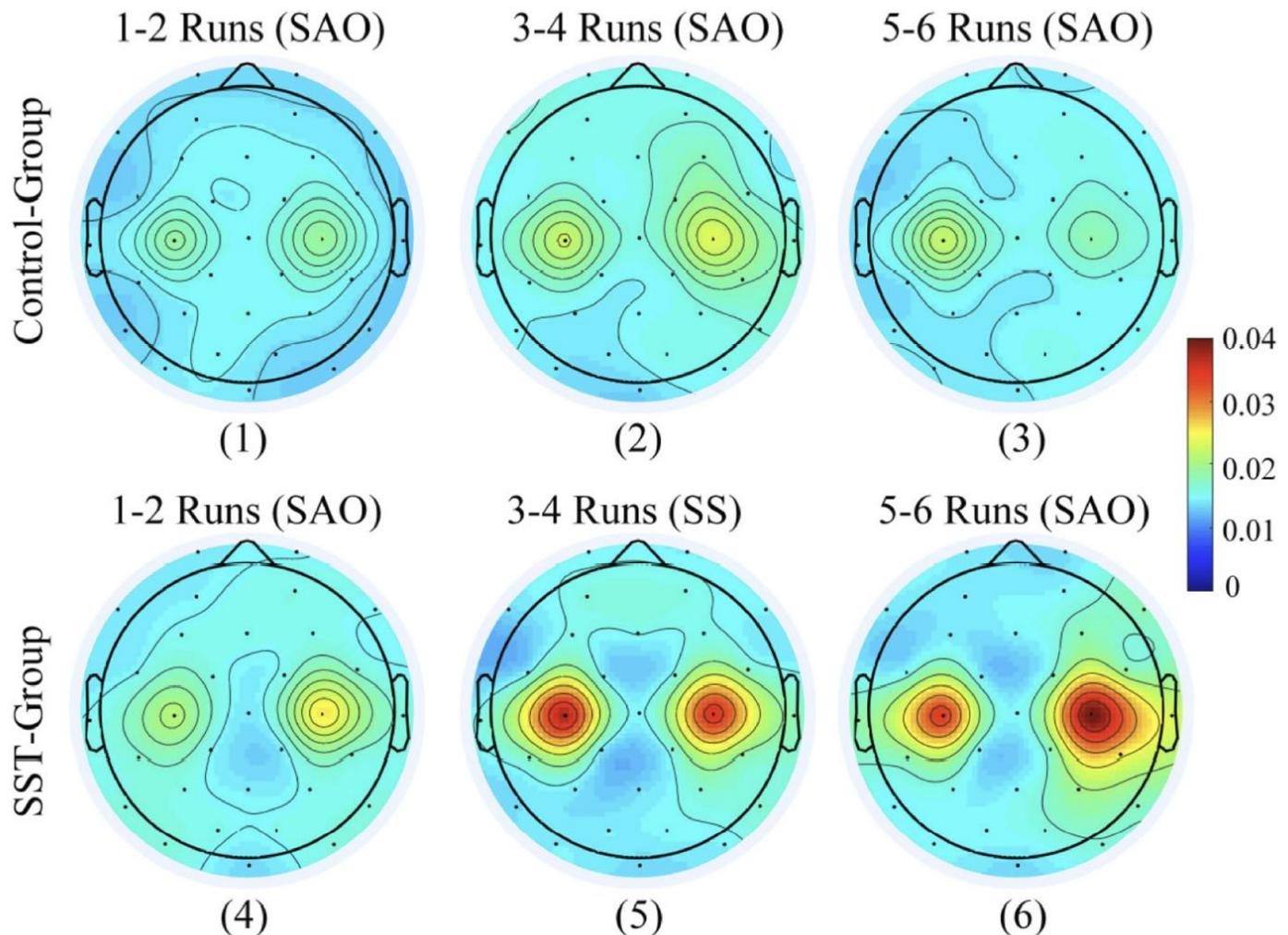
Sensory Stimulation Training (SST)



SS: Sensory Training for sBCI



Without Sensory
Training

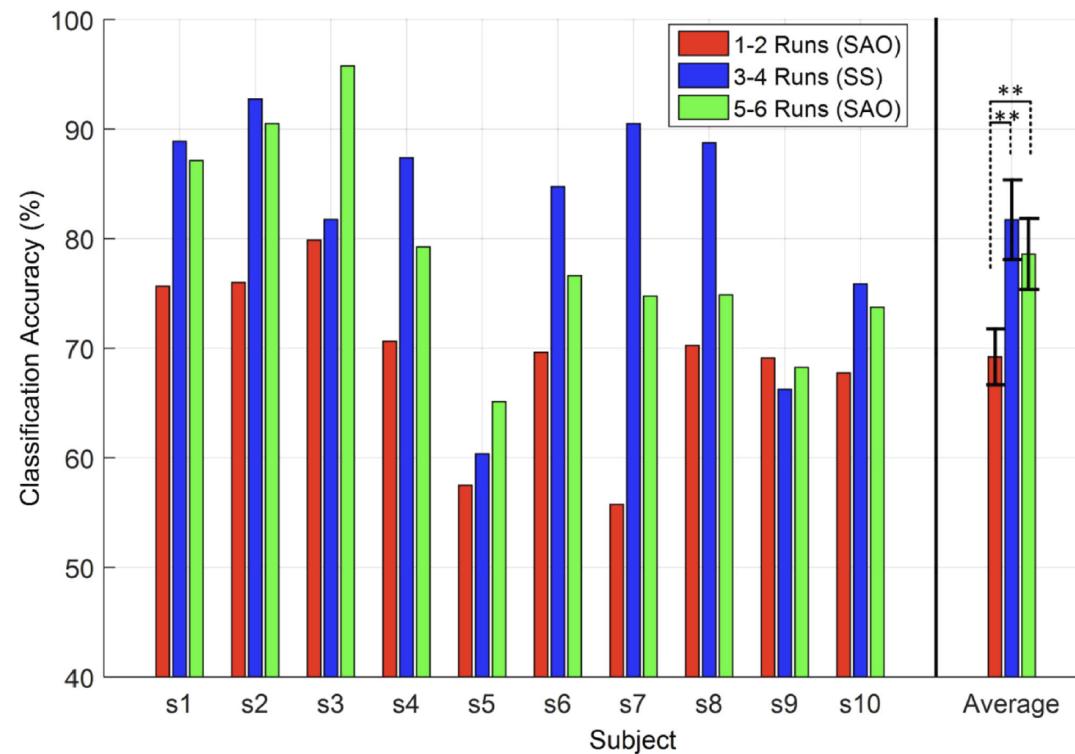


With Sensory
Training

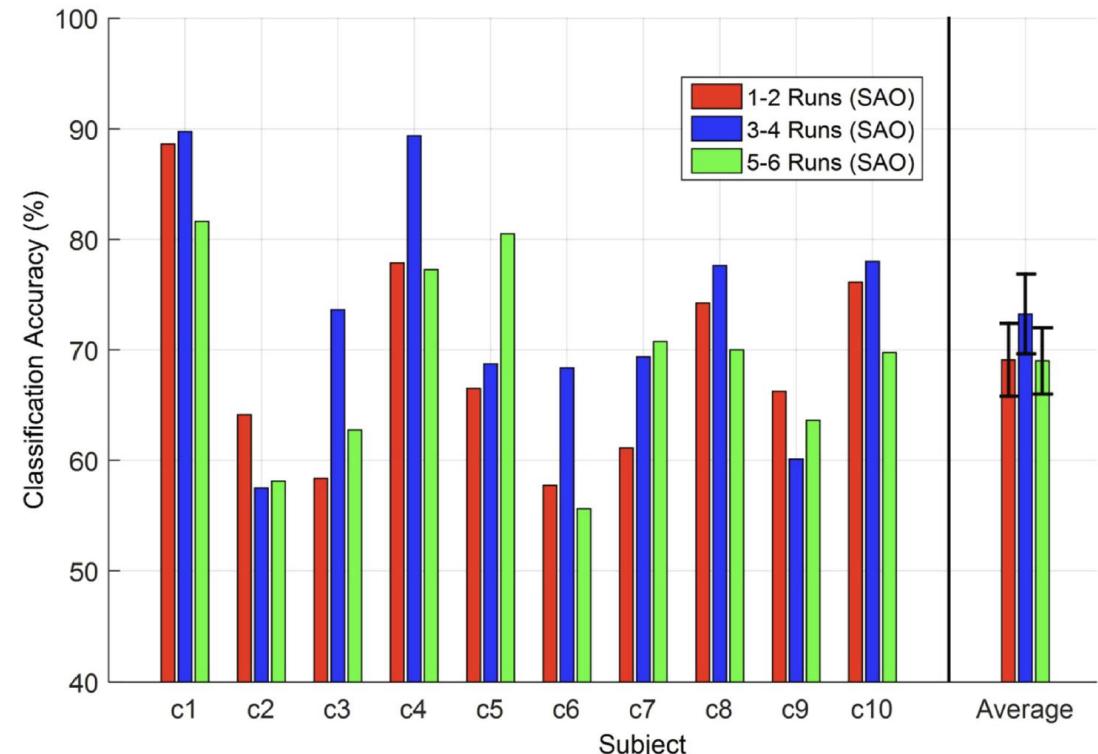
SS: Sensory Training for sBCI



SST-Group



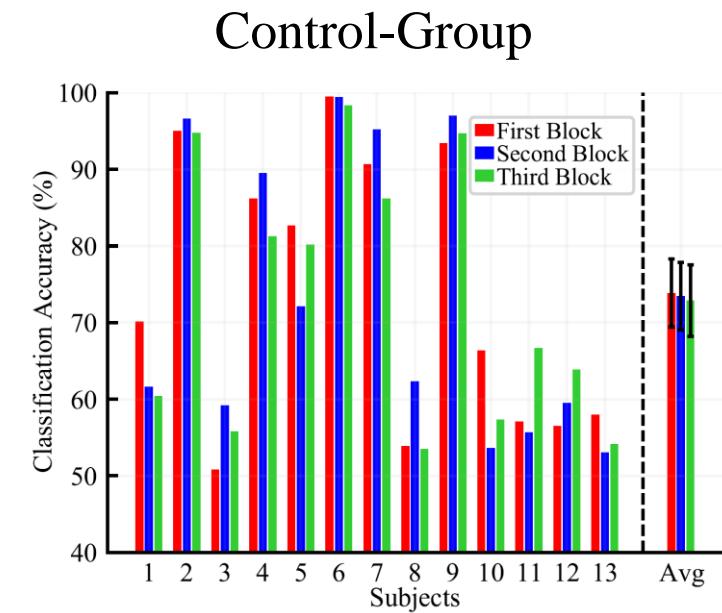
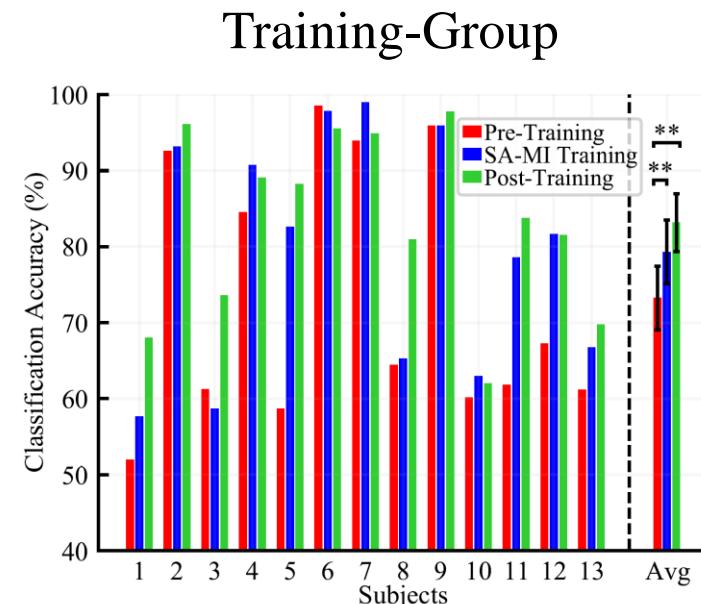
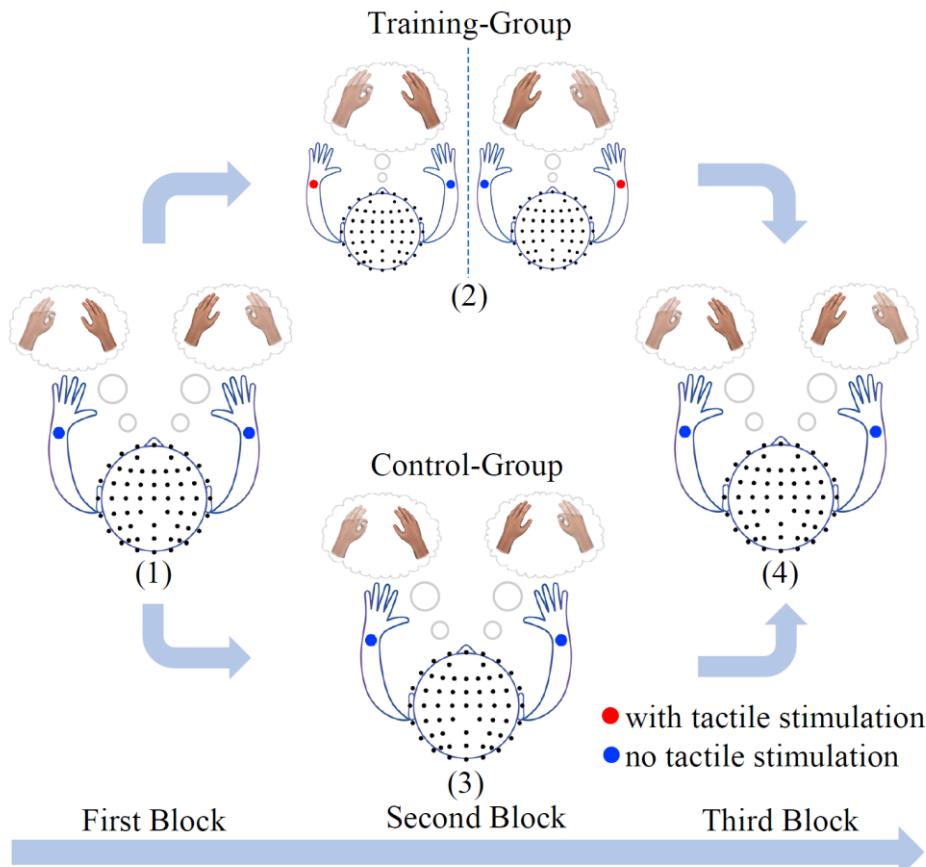
Control-Group



SS: Sensory Training for Motor Imagery



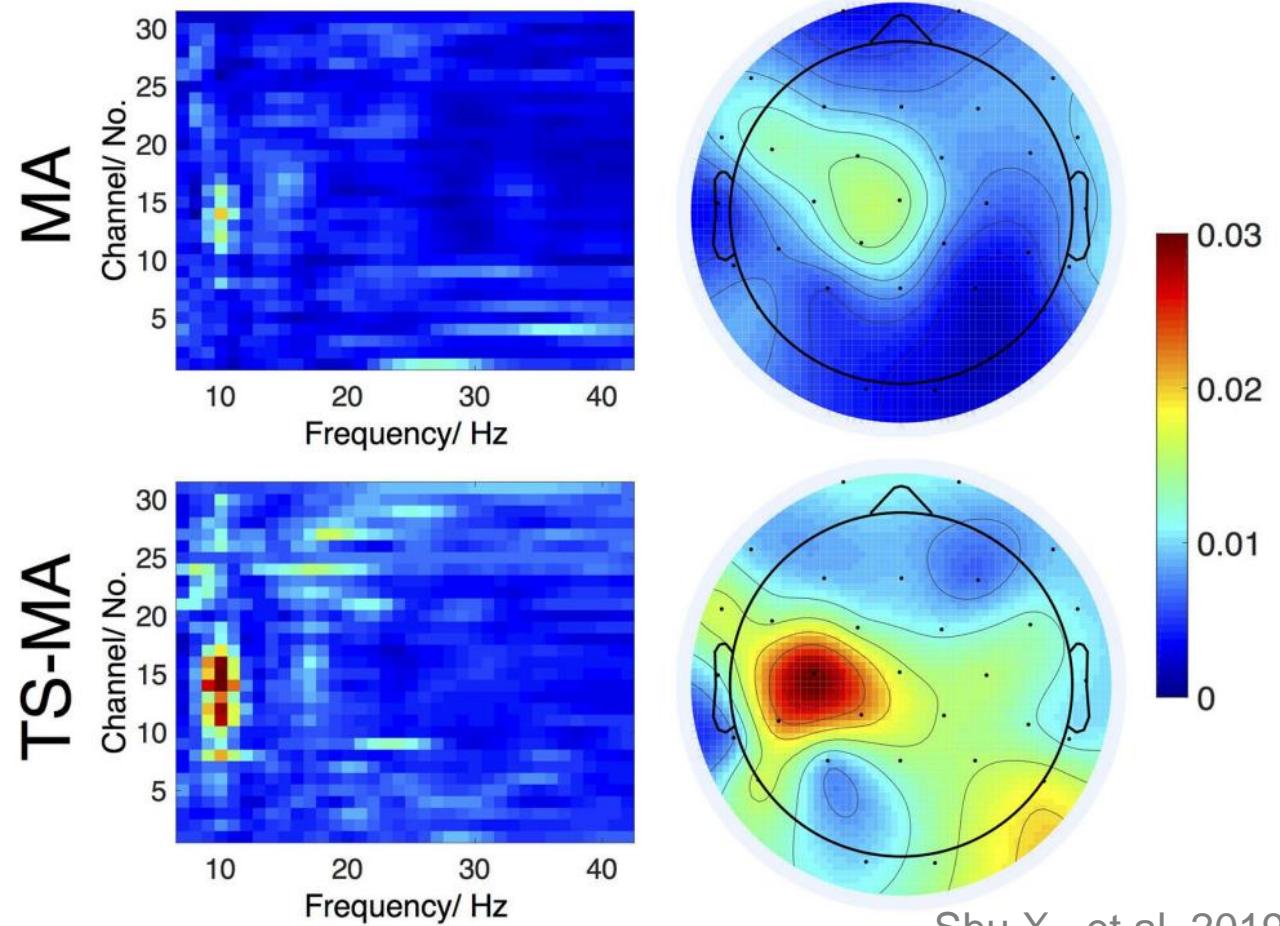
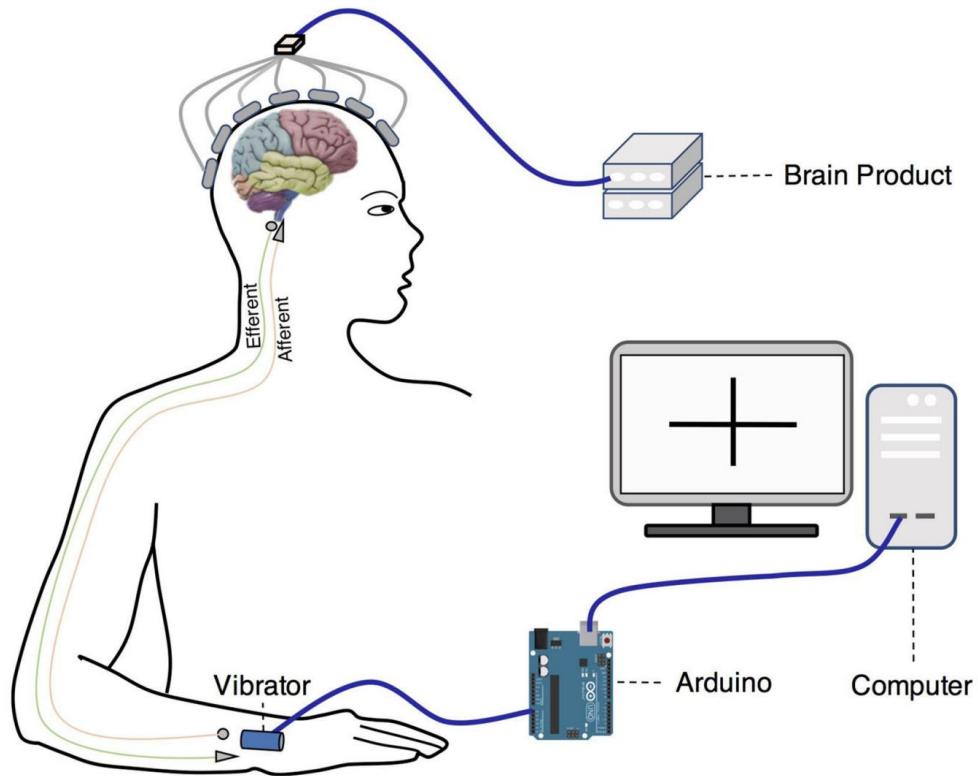
- Tactile-assisted motor imagery training for enhanced performance



SS: Sensory Training for Stroke Patients



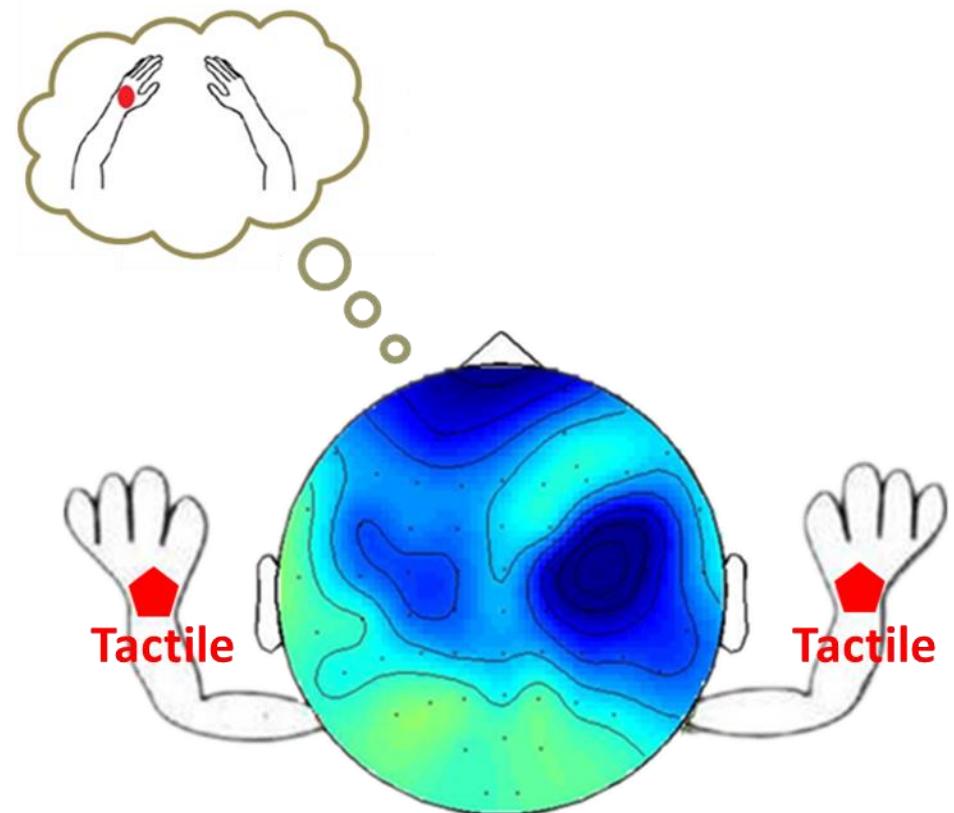
- Tactile-assisted motor decoding in BCI-driven stroke rehabilitation



Outline



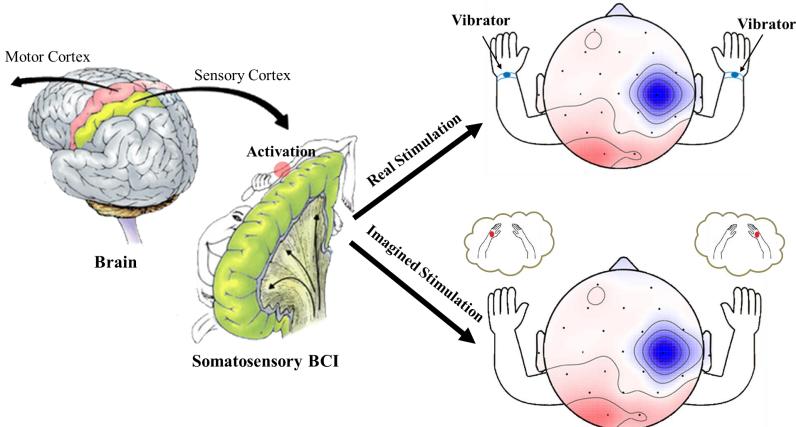
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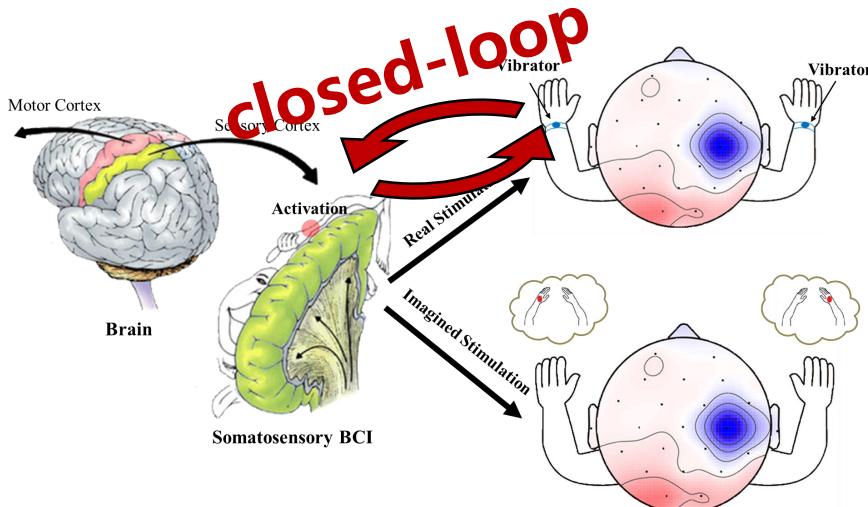
Future Work: sBCI and SS



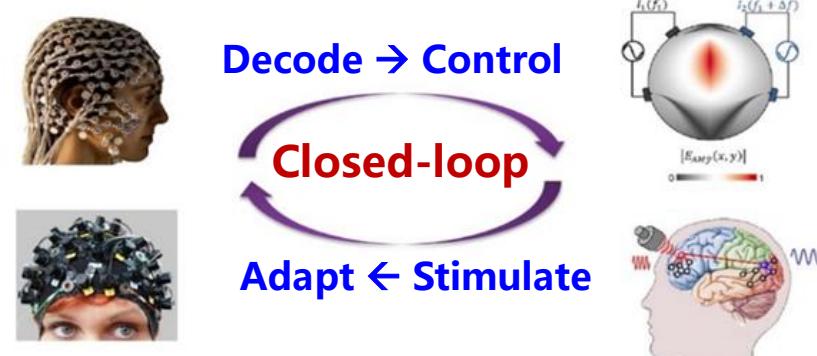
Open-loop peripheral stimulation



Closed-loop peripheral stimulation



Closed-loop adaptive brain stimulation



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