



Discrimination by Deep Learning of 1Hz Difference in Auditory Cortex Using fMRI Activation Patterns

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Presenter

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Belong to

Graduate school of
Kochi University of Technology,
Masters Program,
Intelligent Mechanical Engineering Course

Research Focus

AI-based auditory decoding using
fMRI activation patterns

Member of the Japan Society of Mechanical Engineers

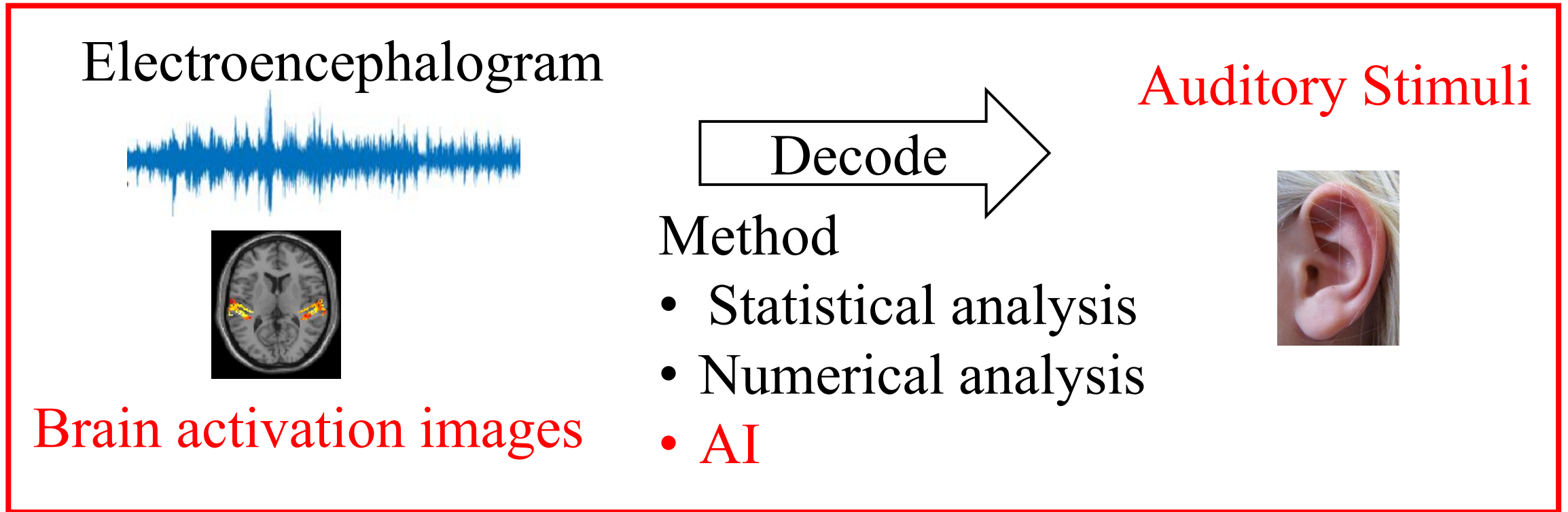
The topic of research interest

Image analysis

Auditory decoding

Frequency estimation based on tonotopy

Introduction (Auditory decoding)



Auditory decoding is a technology that decodes auditory stimuli from brain activity.

Methods is statistical analysis, numerical analysis, and AI.

This technology is expected to serve as a means of medical support and communication for people with disabilities.

I am focusing on using AI to decode Auditory Stimuli from Brain activation images.

Introduction (Auditory decoding in music)

Qualitative musical characteristics[5][6]

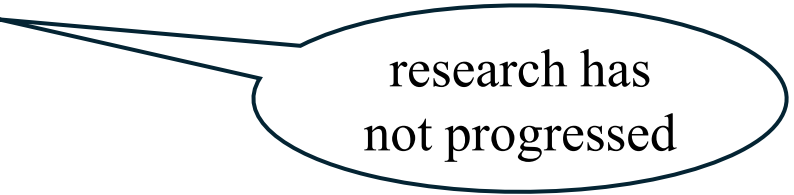
- Music genre
- Mood(cheerful, somber, uplifting)



research is progressing

Quantitative musical characteristics

- Frequency
- Sound pressure



research has not progressed

[5] M. Guilhem, “The Music of Silence: Part I: Responses to Musical Imagery Encode Melodic Expectations and Acoustics”, 2021

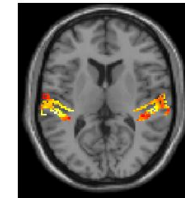
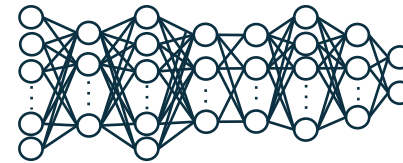
[6] I. Daly, “Neural decoding of music from the EEG”, 2023

Introduction (Our research group)

Aim

The decoding of quantitative musical characteristics

Previous worked on frequency discrimination[7]



①Brain activation image

②Annotation

③Deep Learning

④Discriminate

Auditory stimuli
2093 Hz and 2217 Hz

Data correction
ROI setting

Model
CNN

Labeling test data
2093 Hz or 2217 Hz

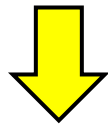
Imaging devices
fMRI

Introduction (Discrimination accuracy in the previous work [7])

The discrimination accuracy for each of the three subjects
Results of the research using the method described on the previous page

Subject ID	Discrimination accuracy
Subject A	75.0%
Subject B	62.5%
Subject C	70.8%

High accuracy



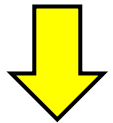
Challenge : discrimination an even smaller frequency difference

Introduction (My research)

Tonotopy : spatial organization of frequency specific responses in auditory cortex



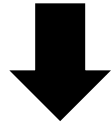
Hypothesis : even frequency differences that cannot be perceived by humans could still lead to distinct patterns of activation in auditory cortex



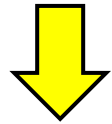
Aim : develop a method capable of discriminating 1 Hz difference between two sounds using fMRI data

Introduction (Research challenges)

Selection of deep learning model

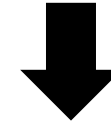


Brain has an inherently **3D structure**



**3D Convolutional Neural Network
(3DCNN)**

**The method of acquiring
brain activation images**



There are primary two designs for fMRI experiments

- Event-related design
- Block design

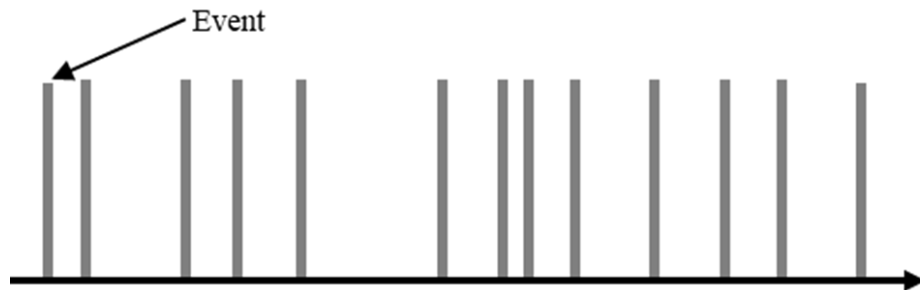


Focuses on two designs

Introduction (Event-related design Block design)

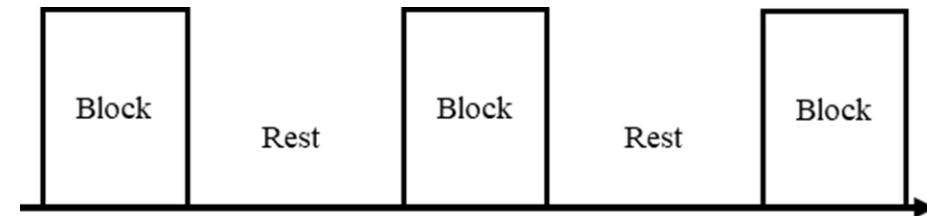
Focus on two designs in fMRI experiments

Event-related design



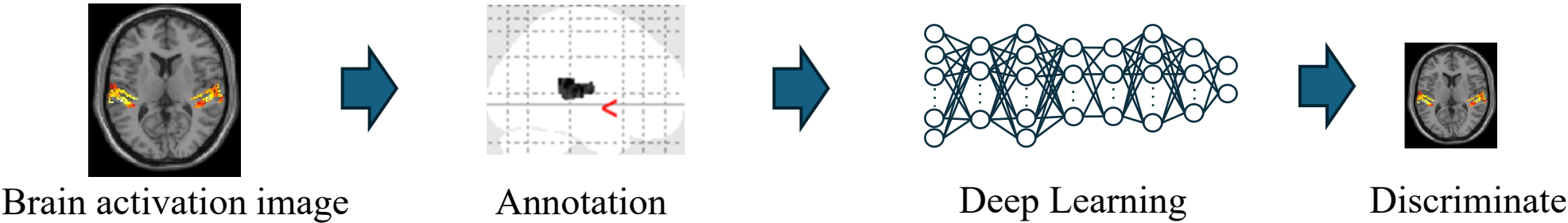
- Limited image clarity
(the constrained temporal parameters allocated for imaging procedures)
- Acquire a substantial volume of data

Block design



- Acquire superior image clarity
(the consequence of its prolonged imaging duration)
- Limited acquisition of data.

Introduction (Previous work of my research [13])



Auditory stimuli
523 Hz and 524 Hz

The method is the same as [7]

TABLE IV HYPERPARAMETERS AND DISCRIMINATION ACCURACY IN TWO DESIGNS. (ROIS: BA41, 42) [13]

Designs	Discrimination accuracy	Hyper parameter
Event-related	55.90%	Ks:6, F:6, Bs:16
Block	63.41%	Ks:3, F:14, Bs:16

Low accuracy

Aim : further improve accuracy compared to previous works [13]

[7] N. Shigemoto, “Study of Deep Learning for Sound Scale Decoding Technology from Human Brain Auditory Cortex”, 2019
[13] Y. Ooyashiki, “Discrimination fMRI Learning of 1Hz Difference in Primary Auditory Cortex of Human Brain using fMRI”, 2024

Methods (fMRI Experiments)

Auditory stimuli

Frequency : 523 Hz and 524Hz

Sound pressure : 78 to 83 dB

Subject

one 20-years-old healthy male

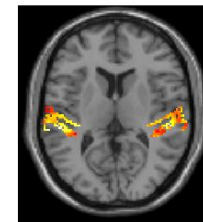
Imaging designs

Event-related : Task 3 s, Rest 3 to 21 s in multiples of 3

Block : Task 9 s, Rest 15 s



The MAGNETOM Prisma 3T,
manufactured by SIEMENS



Brain activation image

Methods (Annotation)



Preprocessing included several steps

Realignment, Slice Timing, Coregistration, Normalization, Smoothing

Statistical image

Extract brain activation characteristics, Data augmentation

Analysis software

SPM12 in MATLAB

TABLE I NUMBER OF TRAINING DATA AND TEST DATA. LINE 1 IS EVENT-RELATED DESIGN.
LINE 2 IS BLOCK DESIGN.

Designs	Train data	Test data
Event-related	192	24
Block	80	24

Methods (Annotation)

Region of Interest (ROI) setting

Tonotopy has been primarily confirmed in Brodmann Areas (BA) 41 and 42 [8][9][10][11].

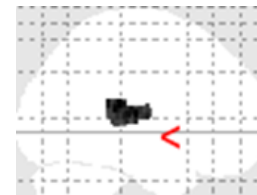
Previous works [12][13] also set BA 41 and 42 as ROI

However, since tonotopy was also suggested in BA 22 [14]



Focus : ROI augmentation (adding BA22) This report details the results of this investigation

Reason : the increased activation information obtained through ROI augmentation may enhance the performance of deep learning models



[8] D. R. M. Langer, "Representation of lateralization and tonotopy in primary versus secondary human auditory cortex", 2007

[9] W. Guo, et al., "Robustness of Cortical Topography across Fields, Laminae, Anesthetic States, and Neurophysiological Signal Types", 2012

[10] V. A. Kalatsky, "Fine functional organization of auditory cortex revealed by Fourier optical imaging", 2005

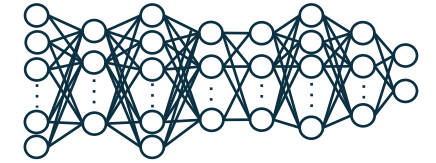
[11] S. Romero, et al., "Cellular and Widefield Imaging of Sound Frequency Organization in Primary and Higher Order Fields of the Mouse Auditory Cortex", 2020.

[12] Y. Ooyashiki, "Identification of Small Frequency Differences in Primary Auditory Cortex of Human Brain by Deep Learning Using fMRI", 2023

[13] Y. Ooyashiki, "Discrimination fMRI Learning of 1Hz Difference in Primary Auditory Cortex of Human Brain using fMRI", 2024

[14] J. B. Issa, et al., "Multiscale optical Ca²⁺ imaging of tonal organization in mouse auditory cortex", 2014

Methods (Deep Learning)

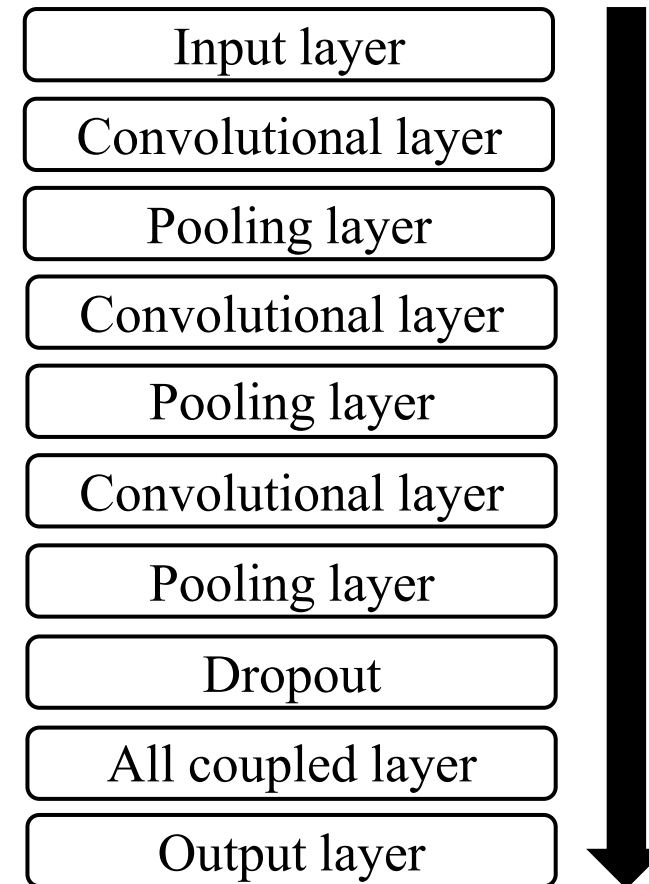


Discrimination uses 3D convolutional neural network, which is the same model as in the previous work [13]

All models have been successfully trained

Learning Condition

Layer			Set value
Input Layer			$41 \times 50 \times 15 \times 1$
Condition	Convolution	Stride	1
	Pooling	Filter size	$2 \times 2 \times 2$
		Stride	2
	Output	Class	2
	Learning rate		0.01
	Error rate		0.1
	Termination condition		Error rate
Hyper parameter	Convolution	Kernel size	3,4,5,6,7
		Filters	16,32
	Drop out		0.2
	Batch size		8,16,32



Results

Event-related design

ROIs : BA41 & 42 [13]

Discrimination accuracy	Hyper parameter
55.9%	Ks:6, F:6, Bs:16

ROIs : BA41 & 42 & 22 (this report)

Discrimination accuracy	Hyper parameter
60.4%	Ks:6, F:16, Bs:16

5% improvement

Block design

ROIs : BA41 & 42 [13]

Discrimination accuracy	Hyper parameter
63.4%	Ks:3, F:14, Bs:16

ROIs : BA41 & 42 & 22 (this report)

Discrimination accuracy	Hyper parameter
100%	Ks:4,7, F:32, Bs:8

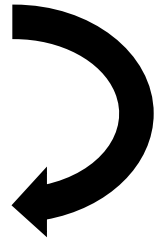
40% improvement

Confirmed accuracy improvement by expanding the ROI in both designs

[13] Y. Ooyashiki, “Discrimination fMRI Learning of 1Hz Difference in Primary Auditory Cortex of Human Brain using fMRI”, 2024

Discussion

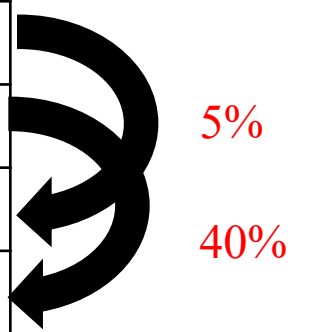
ROIs : BA41 & 42	Event-related	55.9%
	Block	63.4%
ROIs : BA41 & 42 & 22	Event-related	60.4%
	Block	100%



Confirmed accuracy improvement by expanding the ROI in both designs

⇒ Adding BA22 to the ROI provided additional activation information, leading to improved accuracy

Discussion

ROIs : BA41 & 42	Event-related	55.9%	
	Block	63.4%	
ROIs : BA41 & 42 & 22	Event-related	60.4%	
	Block	100%	

- 5% improvement in event-related design
⇒ Adding activation information to less clear images had no effect
- 40% improvement in block design
⇒ Adding activation information to clear images had effect

Event-related design

- Limited image clarity
- Acquire a substantial volume of data

Block design

- Acquire superior image clarity
- Limited acquisition of data

Discussion

Effective method for discriminating 1 Hz difference between two sounds

- Block design (fMRI experiment)
- Statistical images from 2 scans [12]
- BA41, 42, 22 (ROIs setting)

Result

- High discrimination accuracy

Limitations

- Only 1 subject
- Small test dataset (24 samples)

Conclusion

- In this report, we attempted to improve accuracy compared to previous works [13]
- We proposed ROI expansion as a method
- The results showed an accuracy improvement of 5% with the event-related design and 40% with the block design
- My interpretation is that the accuracy improvement was due to ROI expansion, which added activation information
- From the results of this research, it was found that for discriminating 1 Hz difference between two sounds in brain activation images using deep learning, it is effective to employ a block design for imaging and select ROIs BA41, 42, and 22
- This research also presents a novel finding: even when the difference cannot be consciously perceived, the brain still responds.

Future Work

- This research is fundamental. To connect it to applied research, we aim to develop a model capable of achieving high accuracy even for untrained individuals.
- With further progress, this line of this study is expected to contribute to the early detection of disease and to improvements in hearing aid performance.

- THANK YOU -



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