NEURAL INFORMATION PROCESSING SYSTEMS

NeuroBOLT: Resting-state EEG-to-fMRI Synthesis with Multi-dimensional Feature Mapping

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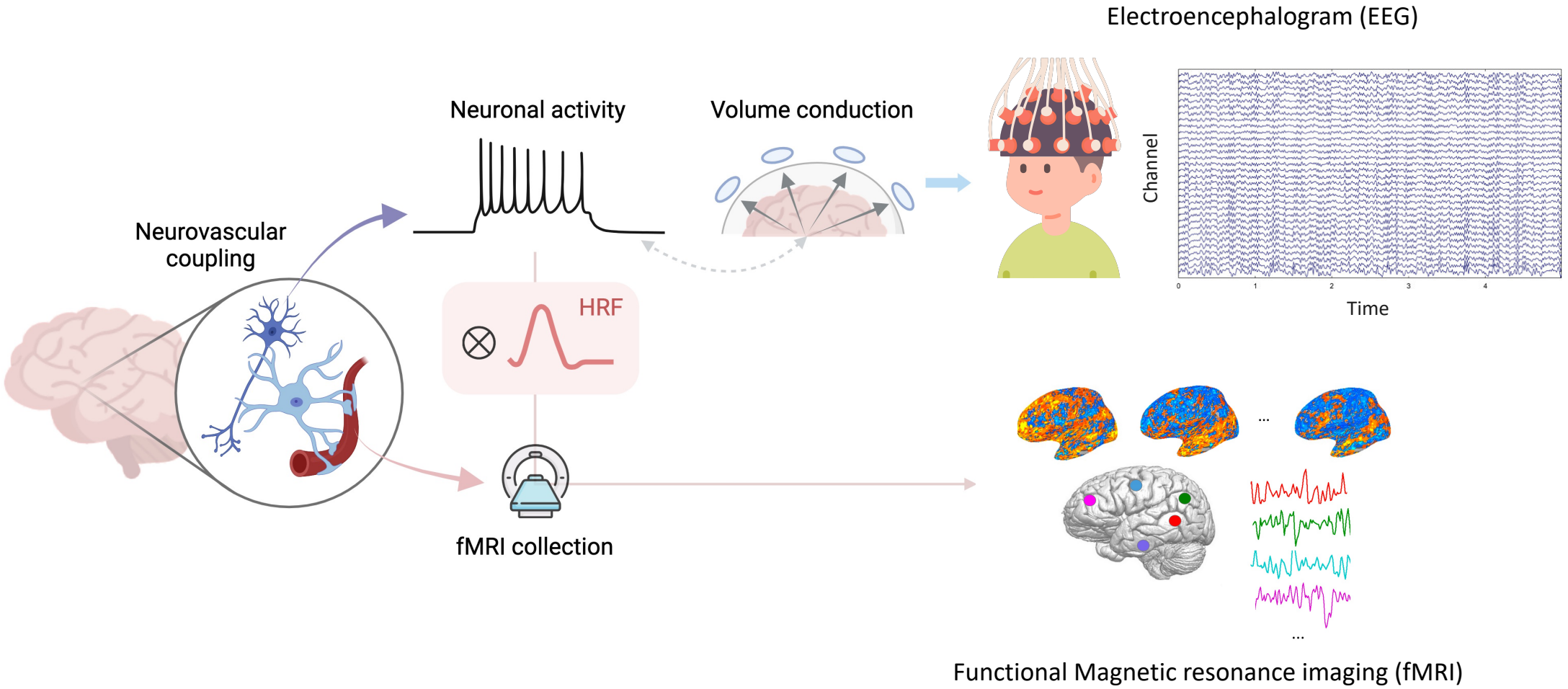
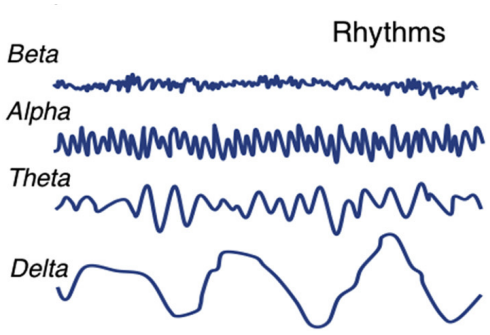
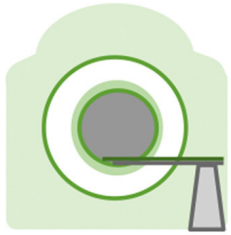
Background - EEG-fMRI

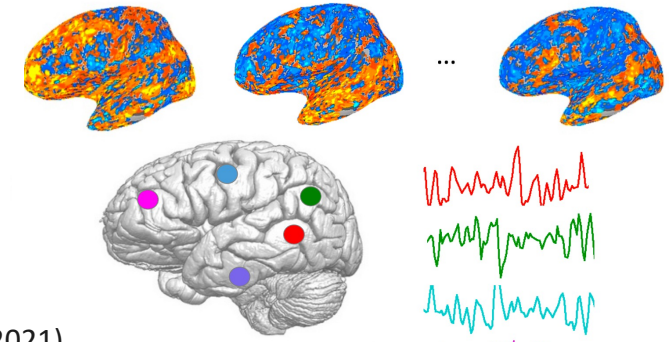


Background EEG-fMRI

EEG







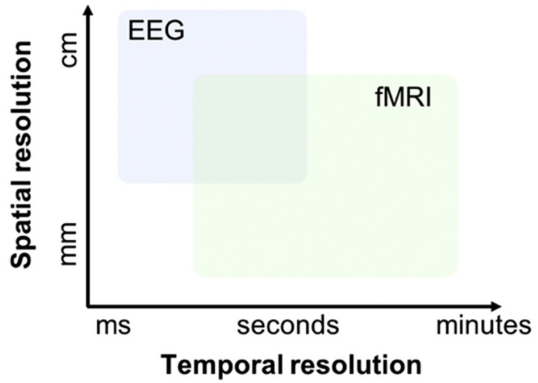
fMRI

(Chang and Chen, 2021)

Pros:
- Direct measure of brain electrical activity
- High temporal resolution
- Cheap, easy to collect
- Can be portable (Mobile EEG cap)

Cons:
- Low spatial resolution
- Low SNR
- Limited depth

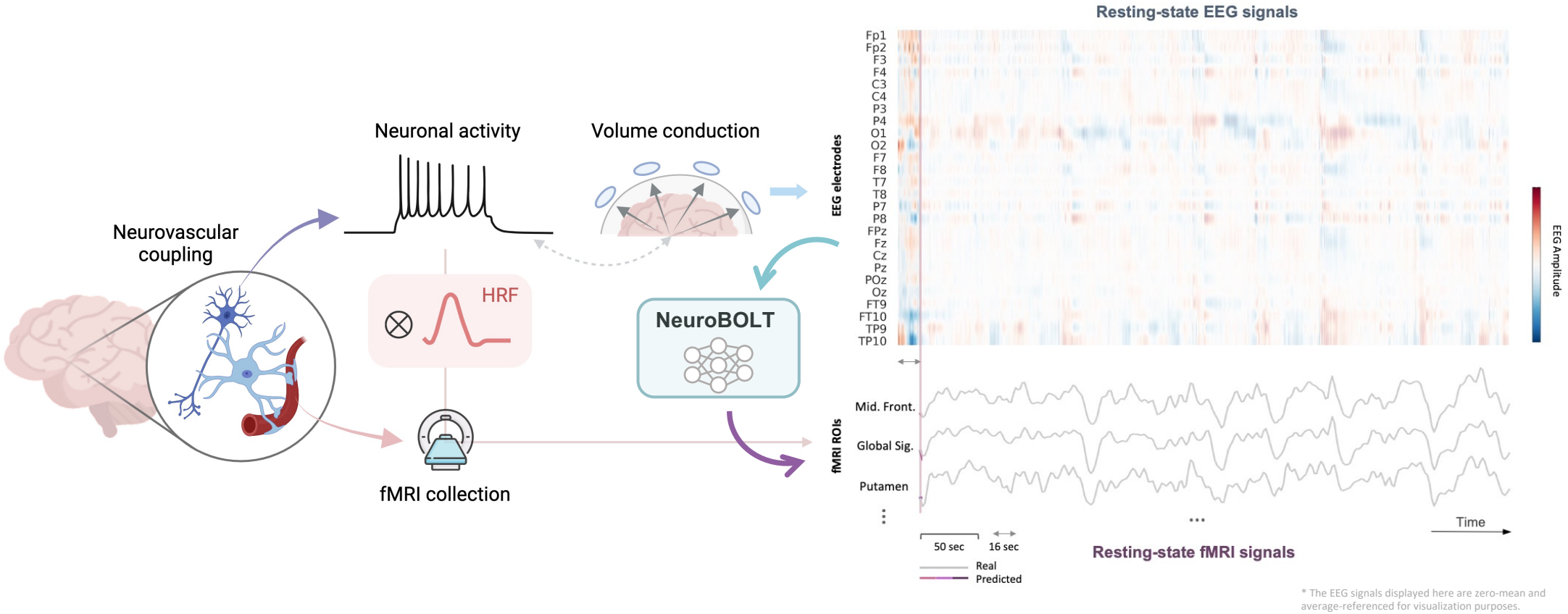
Other challenges:
- The projection from neural activity to fMRI hemodynamic responses is only partially understood.
- HRF varies significantly across different brain regions and between individuals.



Pros:
- High spatial resolution
- 4D brain mapping
- Precise localization of brain activity, including in deep brain regions

Cons:
- Very expensive to purchase and operate
- Hemodynamic blurring
- Low temporal resolution
- Incompatibility with metal implants
- Loud sound

NeuroBOLT - Overview



- A sequence-to-one model without relying on predefined assumptions about hemodynamic delay between fMRI and EEG.
- Taking EEG window as input and learn its projection to the corresponding fMRI value in a defined ROI.

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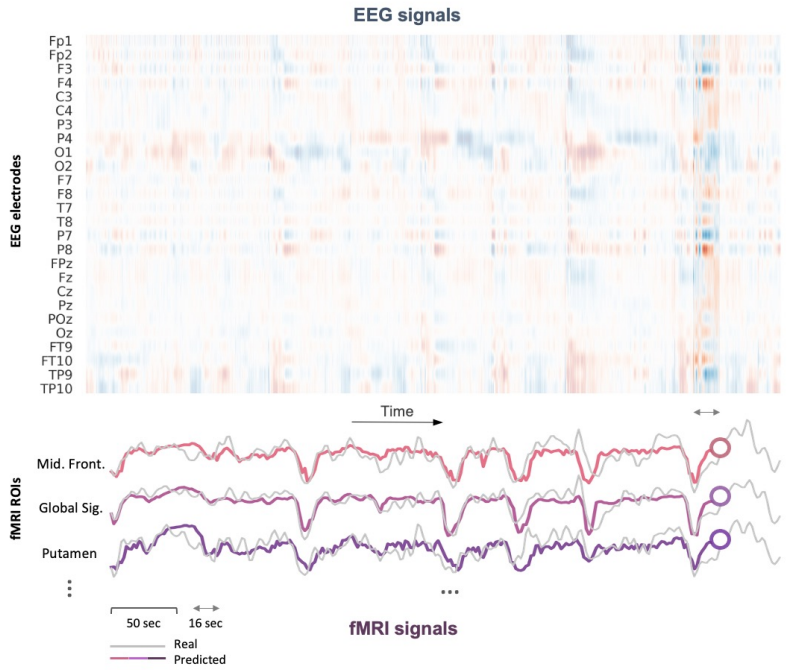

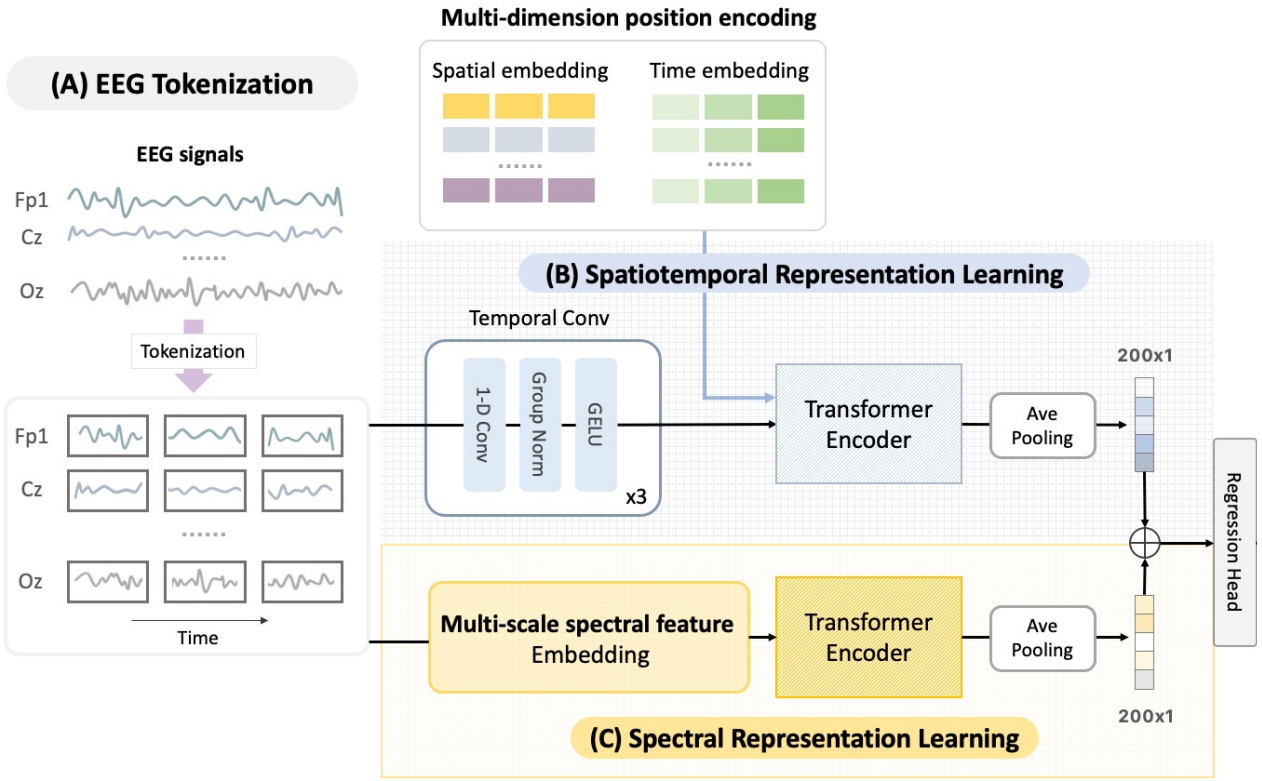

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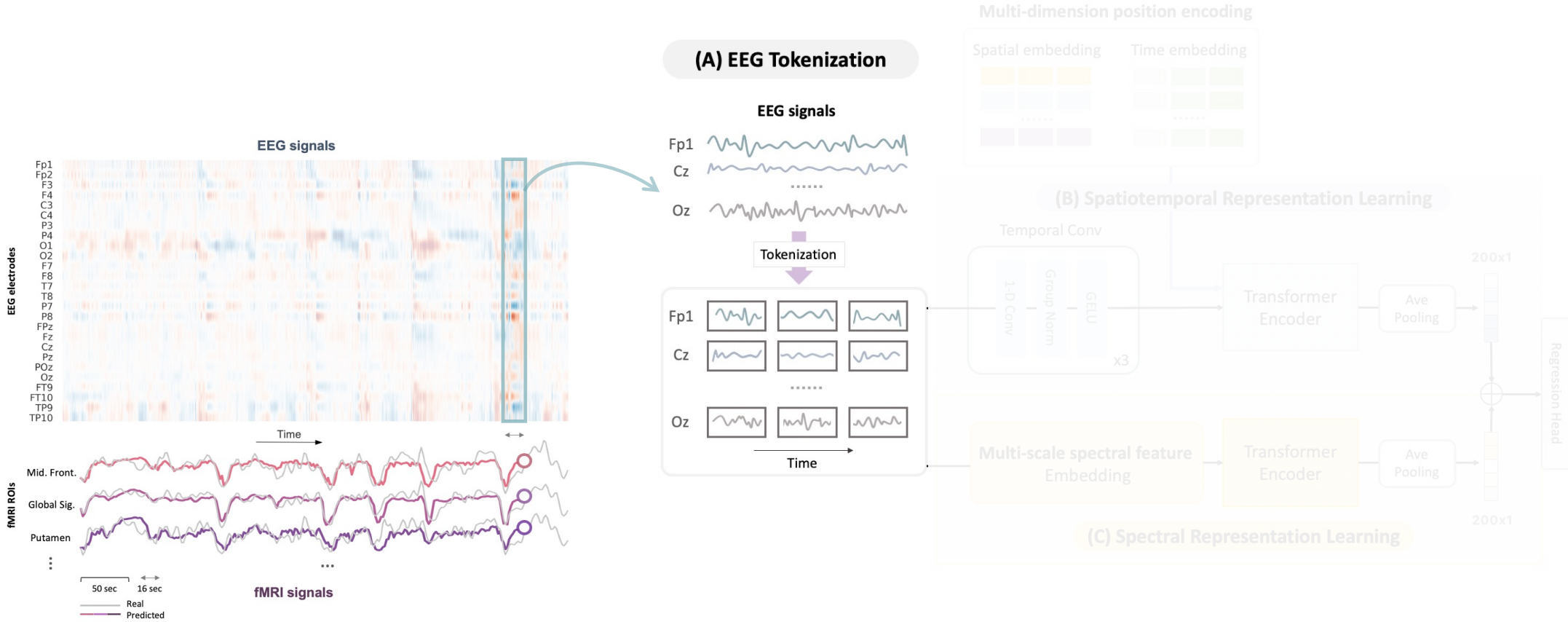

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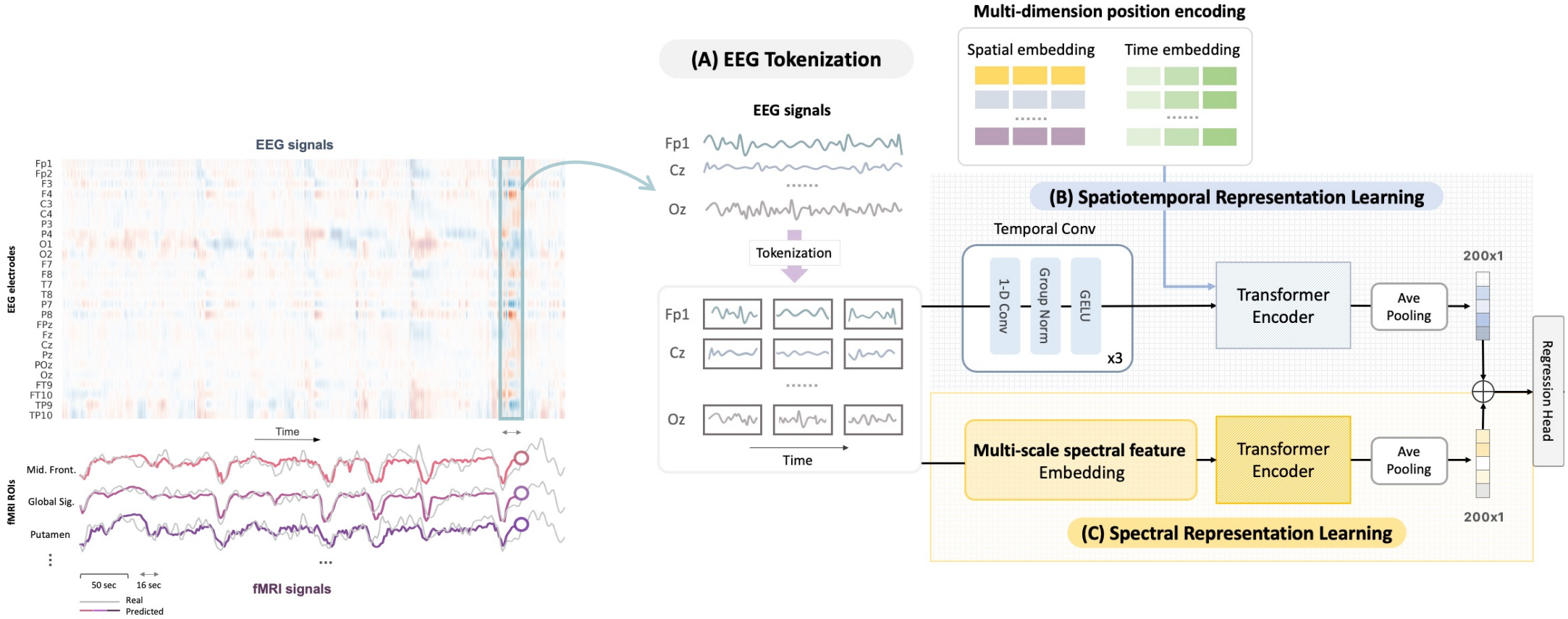
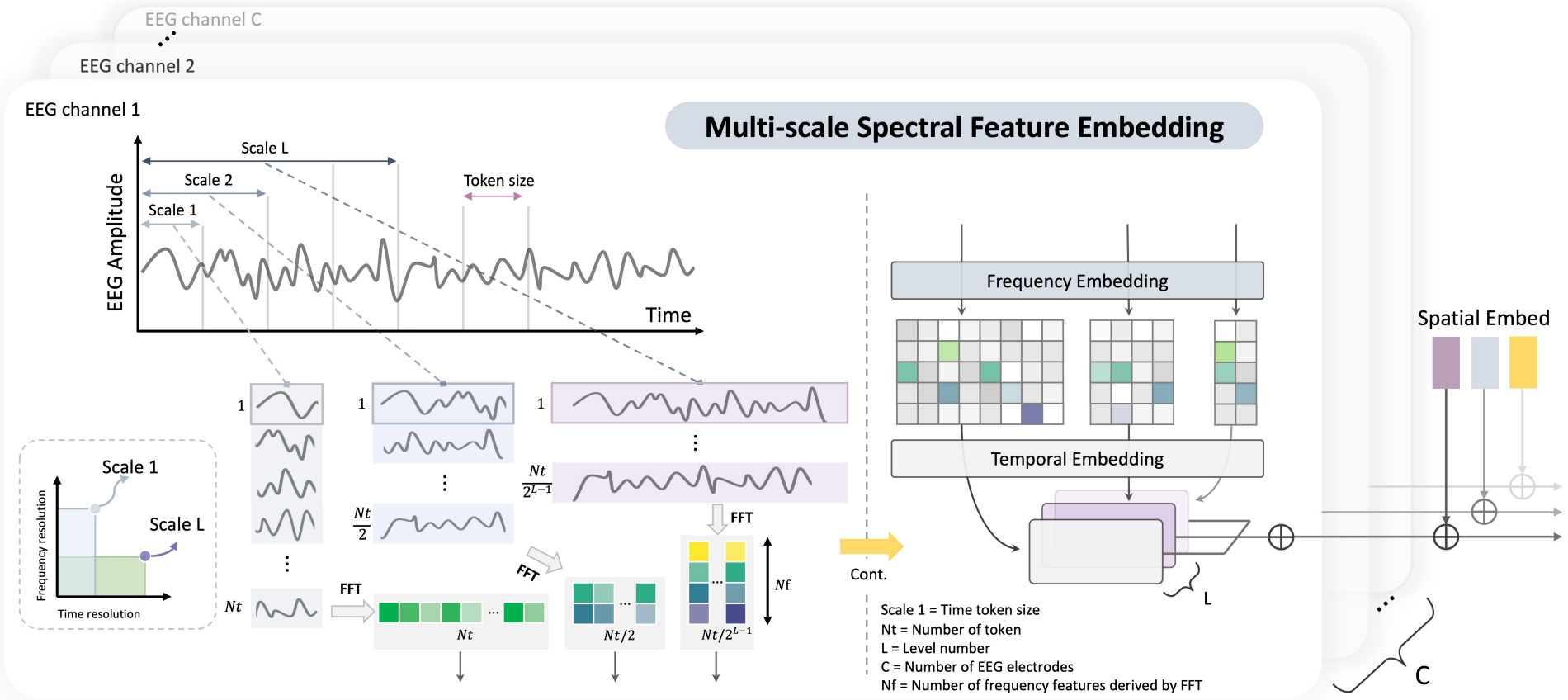


Multi-scale Spectral Feature Embedding



* Please see the ablation study in our paper.

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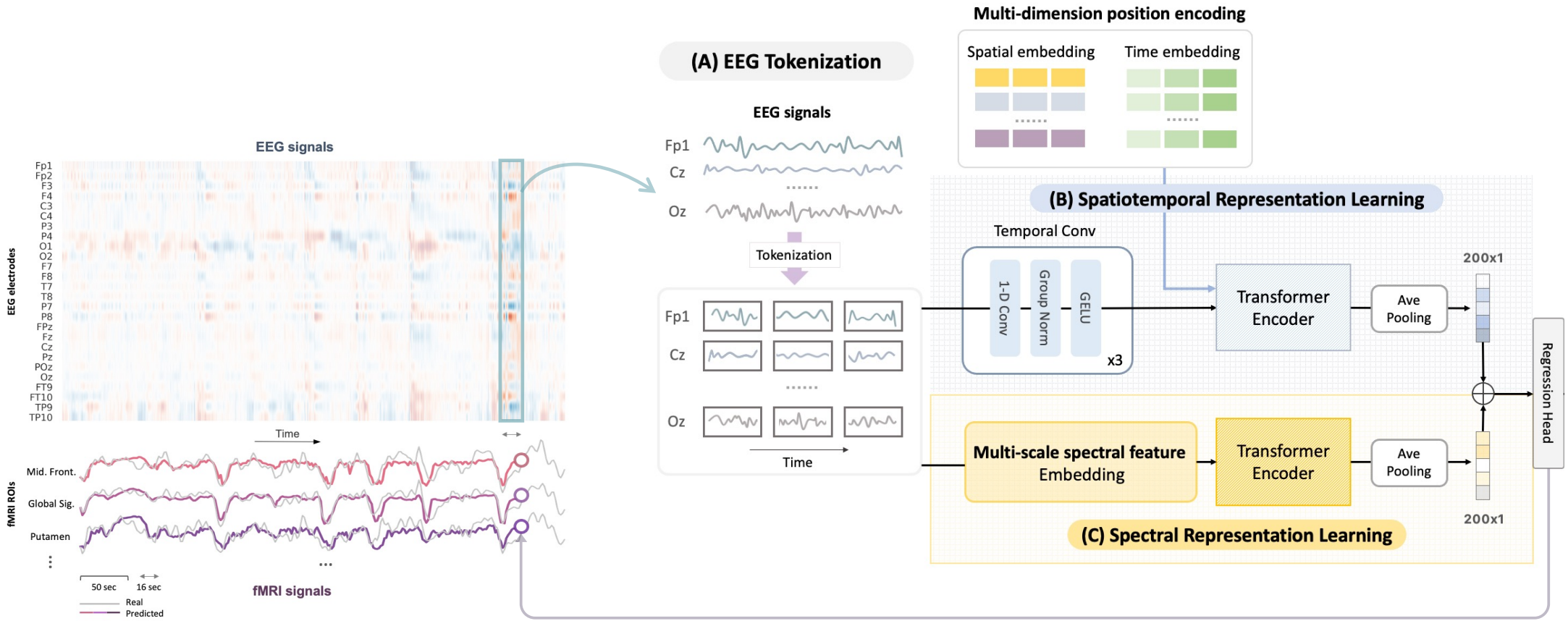
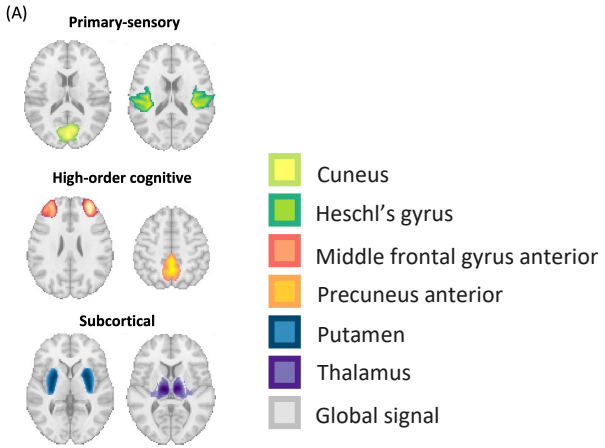


Results – Resting-state fMRI prediction

Resting-state Dataset

- **Simultaneous EEG-fMRI data:** 29 scans from 22 healthy volunteers
- **Scan duration:** 20 minutes
- During these scans, subjects rested passively with eyes closed.

fMRI ROIs:



Experiments:

- **Intra-subject prediction:** Train and test on data from the same scan.
- **Inter-subject prediction:** Train on a set of scans from multiple subjects and test on completely unseen scans from different subjects.

Table 1: Model performance (R) in intra- and inter-subject experiments. **Bold**: the best performance; the underlined: the second-best performance

	Model	Primary Sensory		High-level Cognitive		Subcortical		-	Avg. R↑
		Cuneus	Heschl's Gyrus	Middle Frontal	Precuneus Anterior	Putamen	Thalamus	Global Signal	
Intra-scan	BIOT[59]	0.531±0.223	0.518±0.207	0.490±0.162	0.459±0.110	0.410±0.205	0.411±0.231	0.493±0.133	0.473
	LaBraM[22]	0.540±0.176	0.519±0.197	0.493±0.153	0.490±0.176	0.411±0.179	0.449±0.177	0.487±0.167	0.484
	BEIRA [25]	0.357±0.241	0.396±0.240	0.294±0.228	0.320±0.220	0.234±0.194	0.328±0.197	0.456±0.240	0.341
	Li, et al. [31]	0.460±0.228	0.515±0.207	0.376±0.169	0.457±0.204	0.324±0.183	0.398±0.194	0.583±0.170	0.445
	NeuroBOLT (ours)	**0.588±0.166**	**0.566±0.183**	**0.502±0.168**	**0.559±0.141**	**0.437±0.184**	**0.480±0.213**	**0.587±0.162**	**0.531**
Inter-subject	FFCL [29]	0.326±0.094	0.412±0.039	0.327±0.078	0.437±0.091	0.243±0.125	0.373±0.082	0.512±0.048	0.376
	CNN Transformer [44]	0.218±0.204	0.412±0.114	0.298±0.097	0.316±0.153	0.232±0.086	0.180±0.106	0.282±0.185	0.273
	STT Transformer [48]	0.269±0.197	0.188±0.056	0.226±0.130	0.280±0.143	0.074±0.126	0.142±0.101	0.347±0.124	0.218
	BIOT [59]	0.457±0.123	0.512±0.039	0.393±0.128	0.445±0.084	0.299±0.063	0.413±0.073	0.529±0.110	0.435
	LaBraM [22]	0.177±0.116	0.211±0.105	0.153±0.132	0.170±0.152	0.047±0.111	0.147±0.122	0.150±0.152	0.151
	BEIRA [25]	0.421±0.112	0.482±0.063	0.384±0.147	0.452±0.149	0.241±0.135	0.410±0.097	0.492±0.106	0.412
	Li, et al. [31]	**0.505±0.063**	0.430±0.048	0.415±0.114	0.416±0.076	0.217±0.139	0.424±0.072	0.529±0.092	0.419
	NeuroBOLT (ours)	0.482±0.100	**0.561±0.046**	**0.423±0.115**	**0.496±0.136**	**0.335±0.144**	**0.453±0.106**	**0.564±0.115**	**0.473**

* Please refer to the paper for detailed results.

- Achieved consistent better performance compared with other EEG encoding frameworks and EEG-fMRI translation baselines.

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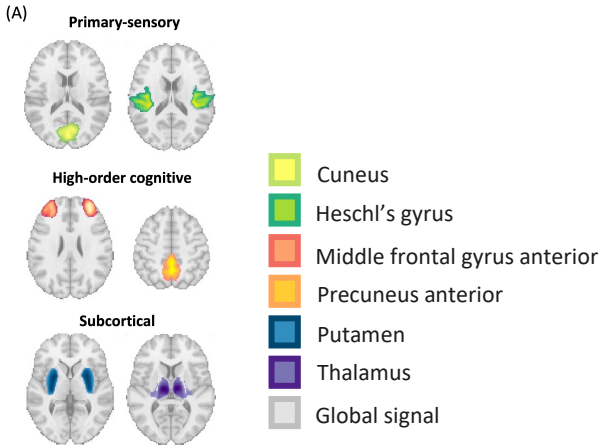

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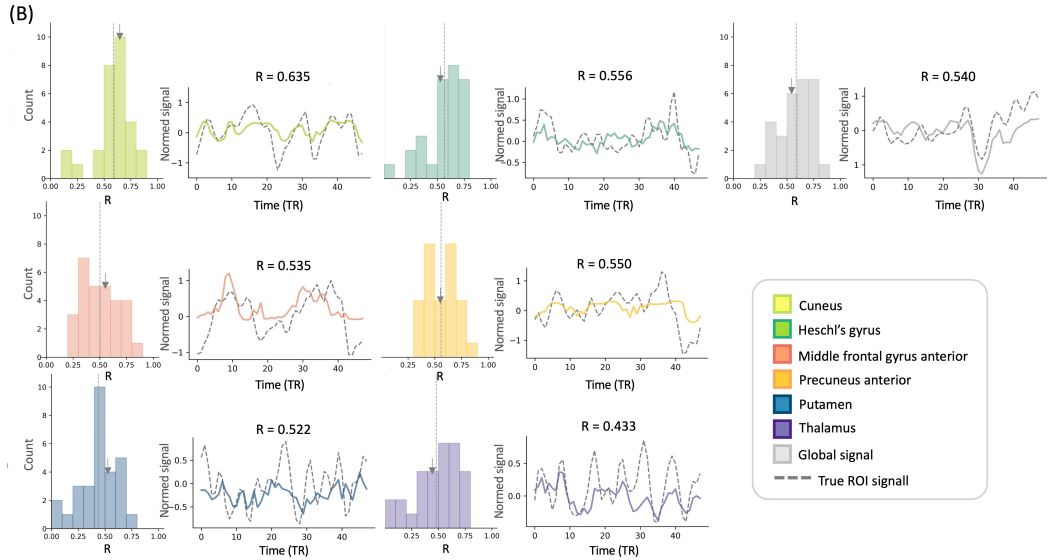
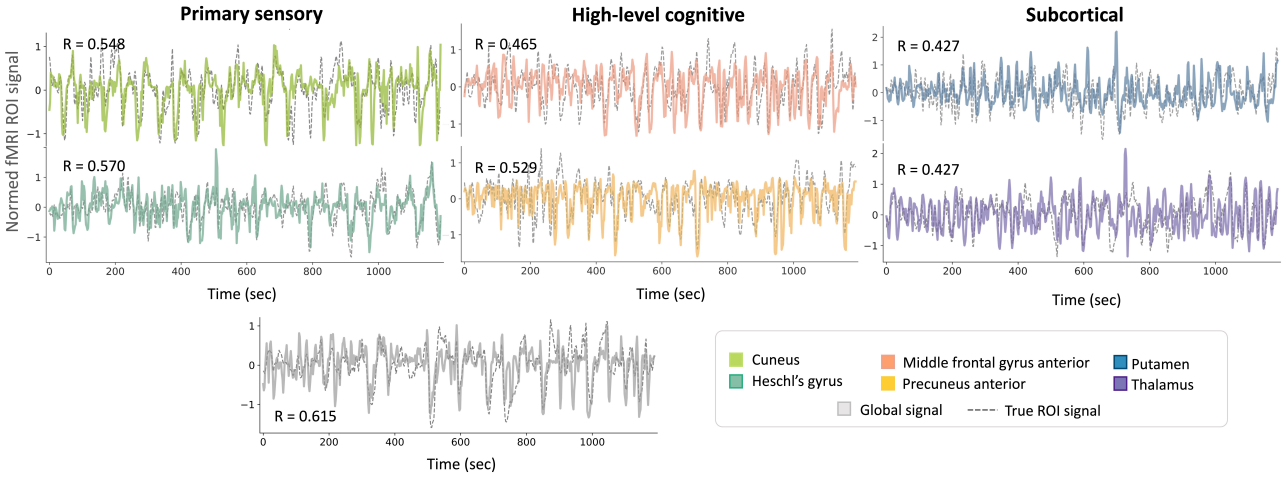
Intra-subject Prediction



Inter-subject (unseen scan) Prediction



* Only the scans with median performance are presented here. For additional prediction examples, please refer to Appendix F in our paper.

Results – Generalization performance

Auditory Task Dataset

- **Simultaneous EEG-fMRI data:** 16 scans from 10 healthy volunteers
- **Scan duration:** Each scan lasted either 17.5 or 24 minutes
- During these scans, binaural tones were delivered with randomized inter-stimulus intervals.
- **Task data are collected at a different site.**

Experiments (unseen task-scan prediction):

- **Zero-shot prediction**: Evaluate the model's performance on task-based data using a model pretrained solely on resting-state data, without any task-specific training.

Table 3: Performance of NeuroBOLT in inter-subject prediction in resting-state and auditory task fMRI. Mean R values between prediction and g.t. are shown. RS: Resting-State, AT: Auditory Task, RS-p+AT-f: Pretraining on RS and finetuning on AT, RS+AT: joint training of RS and AT.

Training	Testing	Primary Sensory		High-level Cognitive		Subcortical		-	Avg. R↑
		Cuneus	Heschl's Gyrus	Middle Frontal	Precuneus Anterior	Putamen	Thalamus	Global Signal	
RS	AT	0.387±0.087	0.431±0.026	0.419±0.099	0.451±0.050	0.240±0.202	0.361±0.164	0.372±0.087	0.380
AT	AT	0.428±0.141	0.479±0.084	0.407±0.058	0.460±0.071	0.187±0.253	0.362±0.166	0.287±0.120	0.373
RS-p+AT-f	AT	0.446±0.033	**0.547±0.060**	**0.437±0.089**	0.471±0.065	0.241±0.188	**0.401±0.177**	0.385±0.098	0.418
RS+AT	AT	**0.461±0.101**	0.516±0.044	0.434±0.106	**0.476±0.041**	**0.248±0.194**	0.401±0.220	**0.404±0.070**	**0.420**
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RS+AT	RS	0.478±0.110	0.560±0.049	**0.437±0.086**	0.494±0.107	0.330±0.140	0.443±0.074	0.540±0.119	0.469

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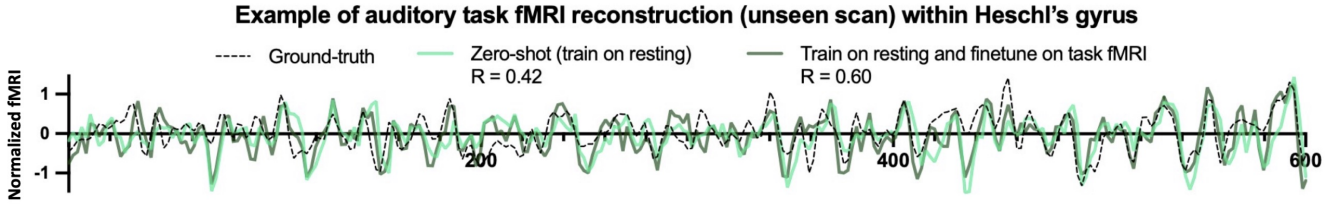

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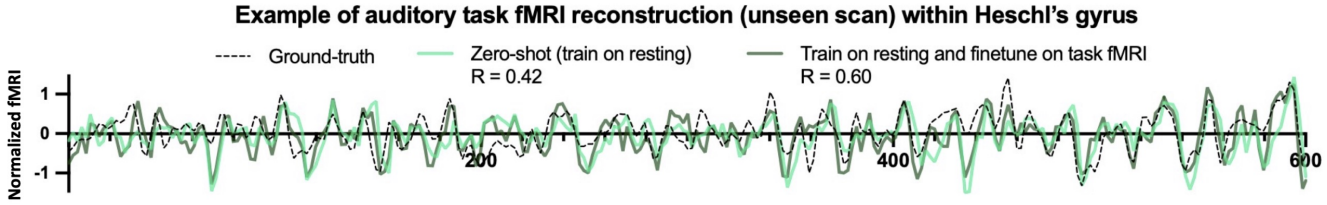


* Please refer to the paper for more results for task-condition data.

- Zero-shot prediction using model trained on resting-state data achieved even better average performance compared with the model that was trained on only on task fMRI.

Conclusions and takeaways

- We propose **NeuroBOLT**, a generalizable framework for translating raw EEG time series to the corresponding fMRI activities.
- Experimentally, **NeuroBOLT** ahieves consistent SOTA performance on subject-dependent and unseen-scan prediction for both resting-state and task condition data.

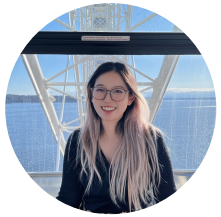
NeuroBOLT supports:

- Any configuration of EEG electrodes as input when training from scratch.
- Any subset of the existing EEG electrode configuration if using pretrained version of the model.

Acknowledgements

NEURDY LAB

Our team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Thank you!

NEURAL INFORMATION PROCESSING SYSTEMS

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