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Hand Joint Reconstruction from Electroencephalography Signals with Deep Learning

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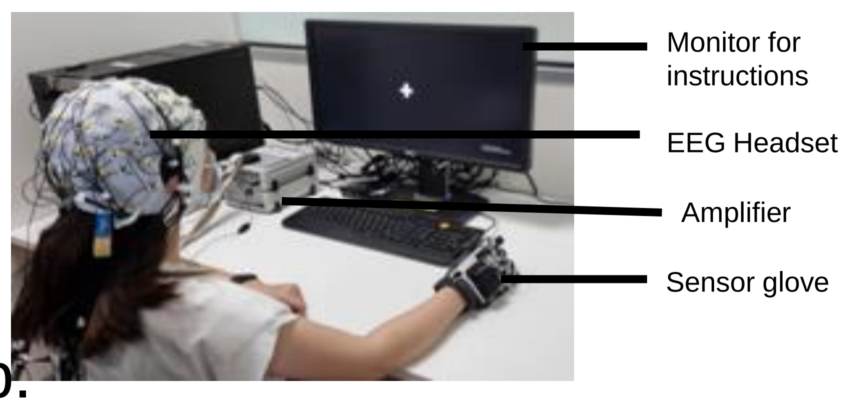
BACKGROUND

Motion Trajectory Prediction Brain-Computer Interfaces (MTP-BCIs) are systems that continuously decode motion states using concurrently recorded EEG signals. These interfaces offer a non-muscular communication pathway to external devices for robot control, neuro-prosthetics, and neural rehabilitation, etc.

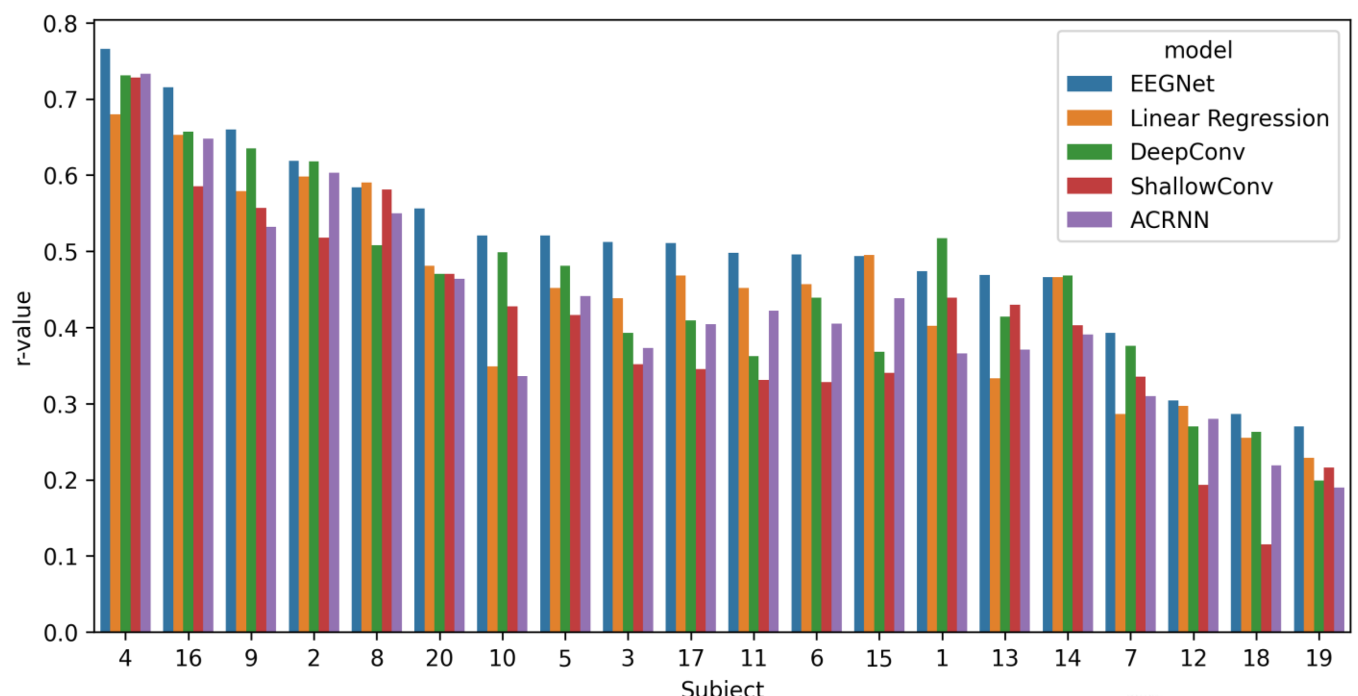
Compared to the reconstruction study on legs, hands and arms, fingers have received significantly less attention despite their critical role in many daily tasks. Furthermore, the potential of deep learning models in hand joint decoding performance is under explored.

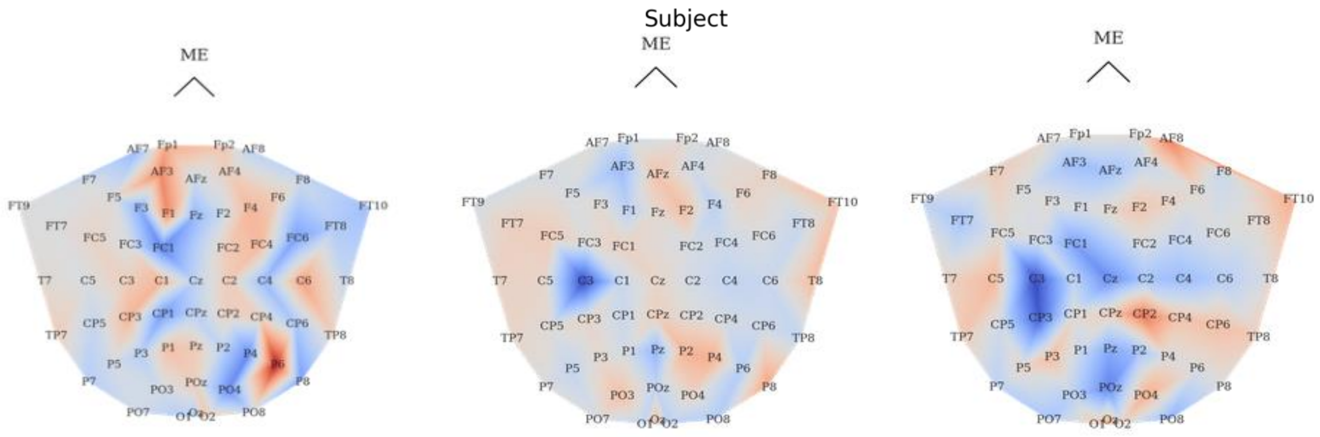
METHODS

The study engaged 20 healthy subjects in performing and imagining open-and-close hand actions, with 64-channel EEG recorded. After signal pre-processing, deep learning models and linear regression are trained with motor execution data. They are evaluated with a subject-specific 10-fold cross-validation approach. The model decodes the PIP and DIP joint angles of fingers, excluding the thumb.



RESULTS



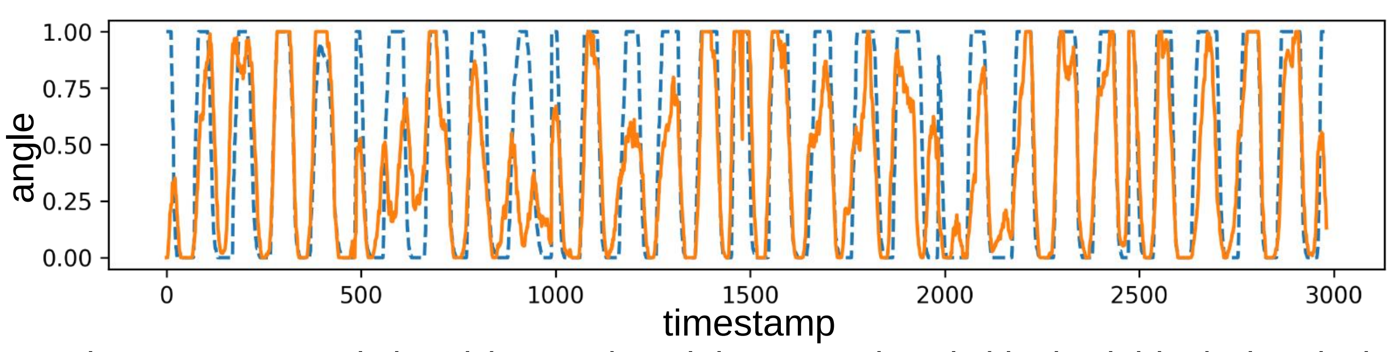


Group analysis of channel importance, from high r-value(left), average r-value(middle), and low r-value(right)

The result reveals a notable variance in decoding performance across subjects. EEGNet has the highest average r-value, and the average r-value of top 5 best subjects reaches 0.669. Explainable AI algorithm is applied to analyse the channel importance.

Model	Average r-value
Linear Regression	0.448 ± 0.130
EEGNet	**0.506 ± 0.130**
ACRNN	0.424 ± 0.137
DeepConv	0.454 ± 0.136
ShallowConv	0.406 ± 0.145

Model	Top 25%	Bottom 25%
Linear Regression	0.620 ± 0.044	0.280 ± 0.040
EEGNet	**0.669 ± 0.073**	**0.344 ± 0.083**
DeepConv	0.631 ± 0.077	0.292 ± 0.071
ShallowConv	0.594 ± 0.080	0.237 ± 0.093
ACRNN	0.613 ± 0.081	0.267 ± 0.061



The reconstructed signal (orange) and the ground-truth (dashed, blue) signal when r=0.79

CONCLUSION & FUTURE WORK

By experimenting various state-of-the-art deep networks on a novel dataset, this study demonstrates the feasibility of MTP-BCI based on finger movement, which can be applied for the development of new types of BCI commands.

The future work will be focused on the enhancement of decoding accuracy and prediction robustness, particularly during the imagined and no movement state. Robust predictions can benefit the development of Asynchronous BCI as well. Further exploration on the transferability of models from execution data to imagery data will be conducted.