Subject-independent Classification of Japanese Spoken Sentences by Multiple Frequency Bands Phase Pattern of EEG Response during Speech Perception

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Research motivation

- **Developing a brain computer interface (BCI) for communication**
  - Communication prosthesis for locked-in syndrome patients
  - For real-time speech communication without body movement

BCI for online speech communication

- Electrocorticography(ECoG)-based real-time vowel synthesizer (Guenther et al., 2009)

  - based on invasive method
  - Higher accuracy

Our goal

- EEG(Electroencephalography)-based BCI to convey speech in *real time*

  - EEG-based:
    - Relatively low cost + Compact
    - Non-invasive method
  - But, difficult task

Our focus in the current study

Non-invasive neural decoding of speech (EEG/ MEG)

- Imagined speech recognition
  - 2 English words (Salama et al., 2014)
  - 2 English syllables (D'Zmura et al., 2009)
  - 2 Japanese vowels (DaSalla et al., 2009)
- Heard speech recognition
  - 3 English sentences (Luo & Poeppel, 2007, etc)
  - 5 English words (Chan et al., 2011), 2 English words (Correia et al., 2015)
  - 32 English syllables (Wang et al., 2012)
  - 8 English consonants (Wang et al., 2012)

Our current purpose

improvement of spoken sentence classification for BCI

Improvement points

Previous research (Luo & Poeppel, 2007, etc)

- *Language*
  - 3 English spoken sentences
- *Apparatus*
  - Magnetoencephalography (MEG)
    - Higher spatial resolution
    - Large + relatively high cost
- *Model training*
  - Construct models for each participant
    - New users have to collect their data
    - Time-consuming to collect a large amount of brain data from one person
- *Feature + classifier*
  - classifier: template matching
  - features: theta phase patterns

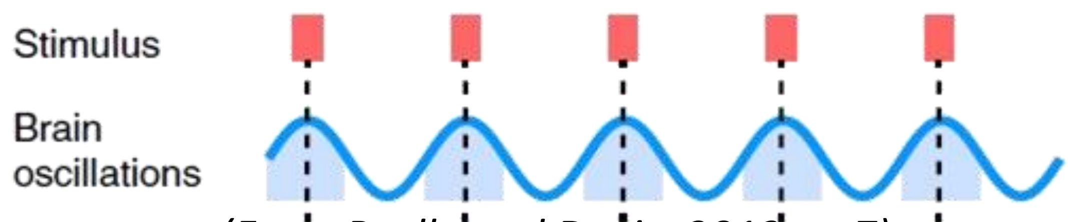
Current research

- 3 Japanese spoken sentences
- EEG
  - Poor spatial resolution
  - Compact + low cost
- Subject-independent model
  - Data collection is unnecessary before use
  - Large data set by combining all user's data
- classifier: support vector machine
  - suitable for fewer + high dim. dataset
- features: phase patterns in various frequency bands

Phase-locked responses

Neural oscillation tracks speech rhythm

- Phase-locked responses
  - Phase-matching between external rhythm & brain oscillation
  - Extract linguistic information from speech



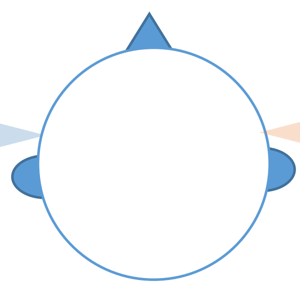
(From Peelle and Davis, 2012 , p.7)

Left hemisphere

phonetic rhythm: ~ 25ms

phase-matching

low-γ oscillation: ~40Hz
(~ 25ms)



Right hemisphere

syllabic rhythm: ~ 125-250ms

phase-matching

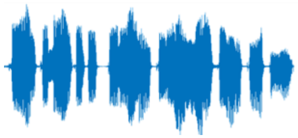
θ oscillation: ~4-8Hz
(~ 125-250ms)

(Poeppel, 2003; Luo & Poeppel, 2012)

- phase patterns inducing by phase-locked responses:
  - less individual differences (Kerlin et al., 2010)

Flowchart of classification

Speech input



Phase-locking

brain response

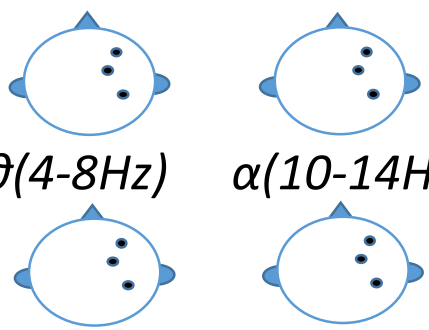
Feature extraction

crosstrial phase coherence (Luo & Poeppel, 2007)

extract phase patterns

- *short-time Fourier transformation*

Channel selection



ϑ(4-8Hz) *α(10-14Hz)*

β(16-20Hz) *low-γ(38-42Hz)*

\+ *combination of phase patterns in all freq. bands*

Model training

Template matching → Subject-independent model

SVM → Subject-dependent model

Evaluation

Leave-one-subject-out cross-validation

Leave-one-out cross-validation

EEG data collection

■ EEG data collection

- Participants
  - L1 10 Japanese speakers (age: μ=24.3; 1 participant was excluded)
- Speech stimuli
  - 3 Japanese spoken sentences
  - Average duration: 3,146 ms
- Stimuli presentation
  - 24 times/ speech = total 72 presentation
  - Total # of trials = 605 trials (after artifact rejection + preprocessing)

Results

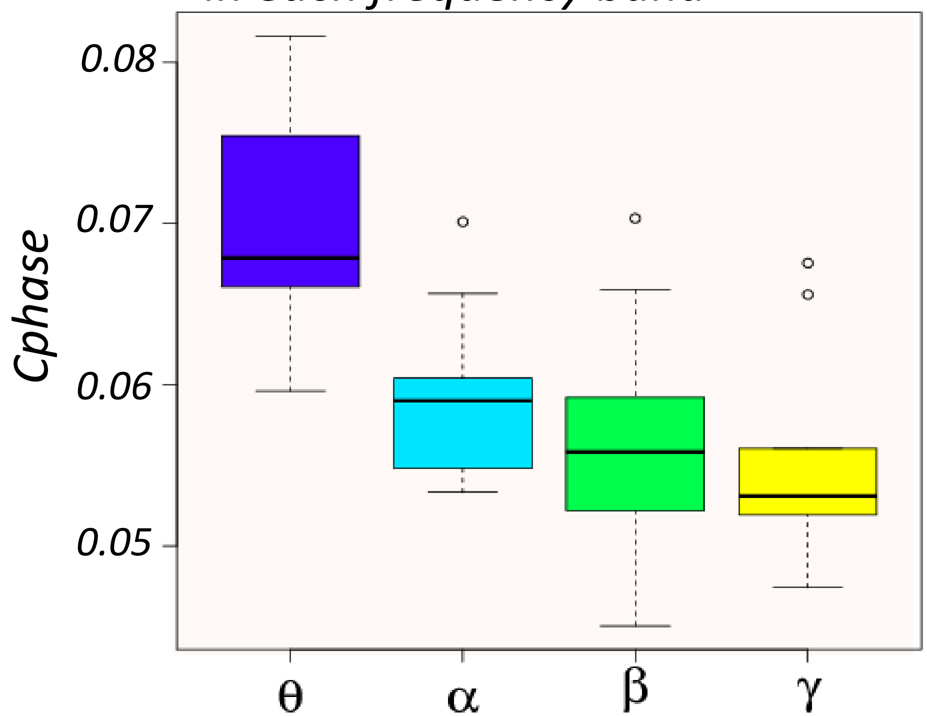
Phase-locked responses

- **Crosstrial phase coherence**
  (Cphase; Luo & Poeppel, 2007)
  - Calculated per channel
  - how consistent phase values are in each frequency band among trials

θ > α, β, low-γ

(*p*<.05, paired t-tests with Holm's p-value adjustment)

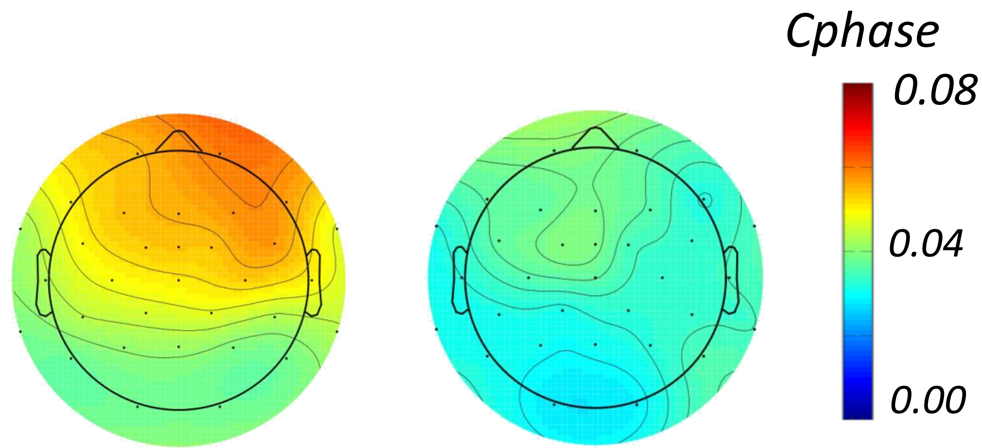
Boxplot in all subjects' Cphase in each frequency band



Cphase distribution map

Cphase distribution map

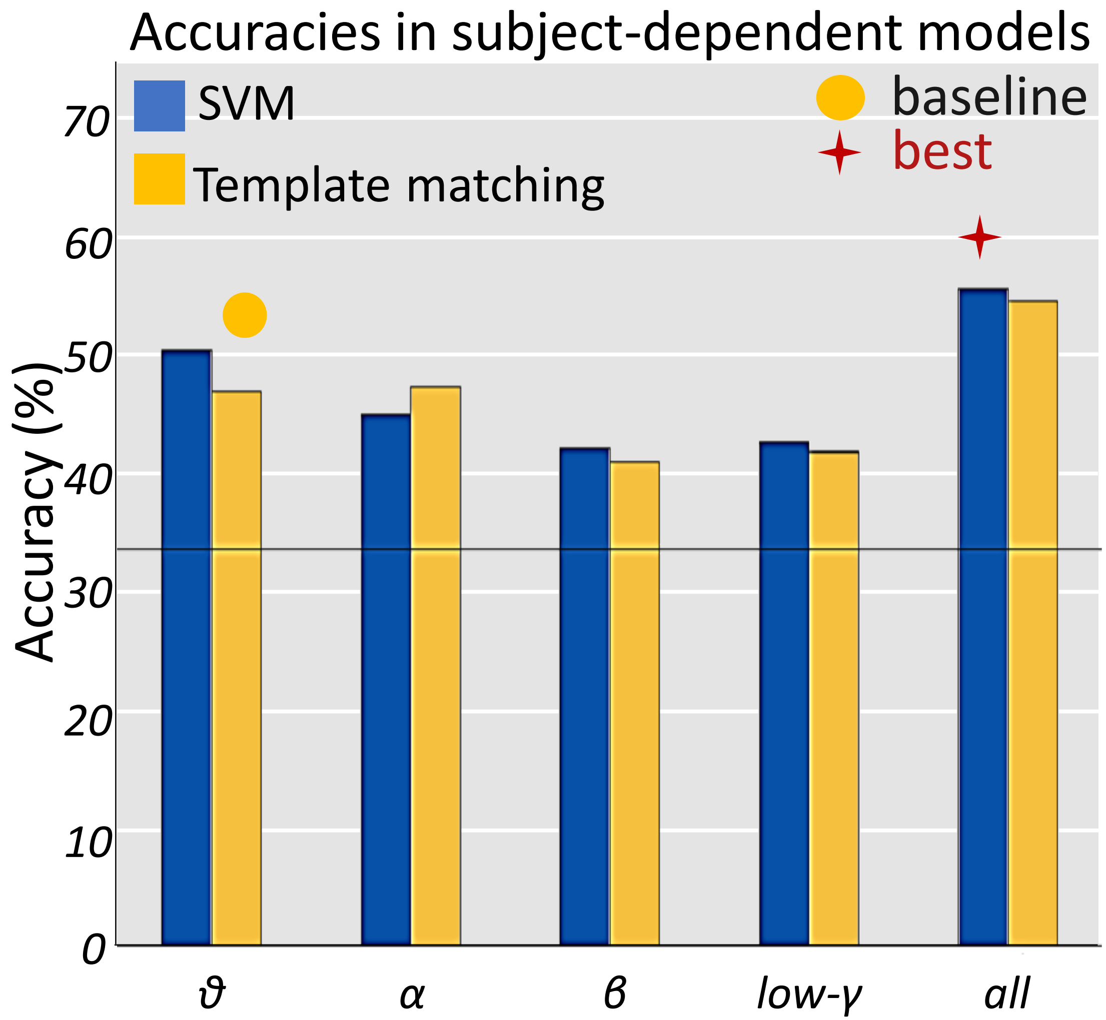
- theta
  - Right hemisphere lateralization
- low-gamma
  - Tendency of left lateralization



ϑ (4-8Hz) low-γ (38-42Hz)

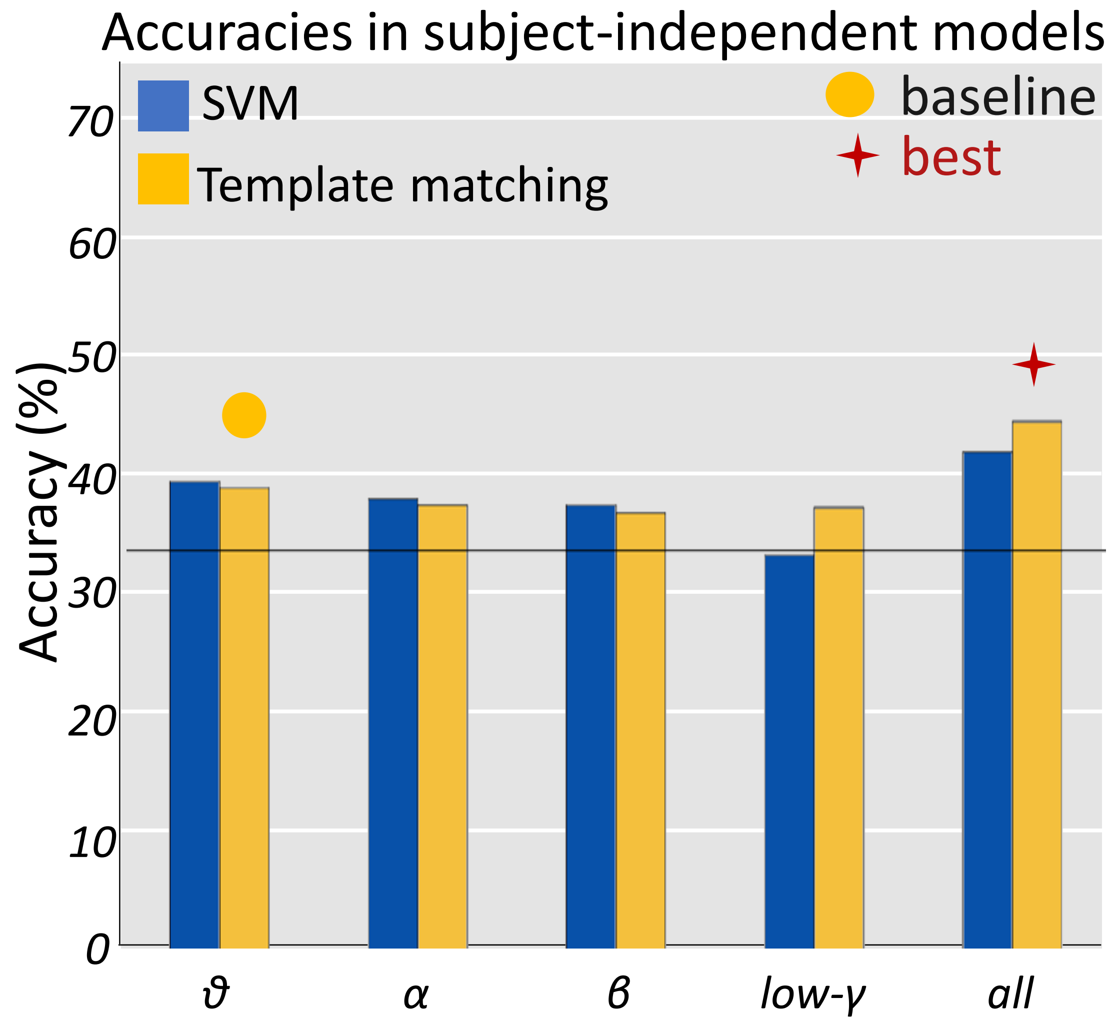
Subject-dependent models

- Accuracy improvement
  - Template matching by θ: 46.6%
  - SVM by 'all': 55.2%
  - + 8.6% (*p*<.05)
- Differences b/w classifiers
  - No differences in 'All' feature



Subject-independent models

- Accuracy improvement
  - Template by θ: 38.5% ($p<.05$)
  - Template by 'all': 44.0% ($p<.05$)
  - + 5.5% (p<.054)
- Differences b/w classifiers
  - No differences in 'All' feature



Discussion + Future plan

Phase-locked responses to Japanese spoken sentences

- syllable tracking in theta
  - tracking acoustic feature (Howard & Poeppel, 2010)
  - syllable timing: consistent across languages
- phoneme tracking in low-gamma: Not conclusive
  - might be partially due to low S/N ratio in higher frequency band

Classification performances

- Accuracy improvement in 'All' feature
  - above chance-level in subject-independent classification
  - based on neurophysiological speech perception model (Poeppel, 2003, etc)
- SVM: no better performances than template matching

Future plan

- Other classification algorithm + more amount of data
- application to imagined speech recognition

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Thank you for listening

How to calculate Cphase