Detecting Syntactic Violations from Single-trial EEG using Recurrent Neural Networks

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Introduction

- Research goal
  - Automatic evaluations of sentences for machine translation / dialog system
  Subjective evaluations are biased & ambiguous by human evaluators
- Research purpose
  - Detecting syntactic violations in spoken sentences with single-trial EEG
  Language-related EEG is usually studied by averaging multiple-trials due to its low signal-to-noise ratio
- Overview
  - Single-trial EEG classification
    - We have to evaluate each sentence -> single-trial classification
    - [Tanaka H, et al., 2019] achieved 57.7% acc. for detecting syntactic violations
    - More accurate methods are necessary
    - Some Neural network (NN) models well performed
      - Stacked autoencoders (SAE) [Vareka L, et al., 2017]
      - Long short-term memory (LSTM) [Alhagry S, et al., 2017]
    - In this work, neural network models (SAE and LSTM) were applied to classify single-trial EEG signals for syntactic violations

Materials

- Syntactic violations
  - Japanese sentences manually crafted referring to [Takazawa S, et al., 2002]
  - Repetition of nominative case violates Japanese grammar
    a. tori-ga sora-o ton-da
       bird-NOM sky-ACC fly-PAST
       (The bird flew in the sky.)
    b. *tori-ga sora-ga ton-da (* means syntactic incorrectness)
       bird-NOM sky-NOM fly-PAST
    NOM : nominative case marker
    ACC : accusative case marker
    PAST : past tense morpheme
  - The nominative case of second phrase as synchronous onset (t=0ms)
  - 40 sentences for syntactic correct and incorrect condition respectively
  - Speech by a professional female narrator was used for stimulus

EEG Data Acquisition

- Experimental procedure
  - Carried out in a soundproof room

  ![normal or anomalous](image)
  
  (1) watch the "+" mark 1s  
  (2) listen to the sentence 4s  
  (3) press the button 2s

  ![normal or anomalous](image)

  Participant: 19 Japanese speakers (16 males & 3 females, mean age: 24.2)

- EEG recording and preprocessing
  - EEG cap: ActiCap by Brain Products (32 channel electrodes)
  - Preprocessing
    1. Re-referencing
    2. High-pass filtering
    3. Epoching at synchronous onsets
    4. Reject artifacted epochs and removing muscle/eye blink artifacts
    - 1 participant was rejected (more than 30% epochs were rejected)

- Feature extraction [Vareka L, et al., 2017]
  - Average amplitudes b/w 100 ms and 800 ms per each 50 ms time window

  ![Feature extractions](image)

  
  *The child throw the toy*

  Speech

  EEG

  Classification model

  Incorrect

  Single-trial EEG classification

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- Baseline model: linear-kernel support vector machine (SVM)
  - Training: 14 participants’ data (1040 sentences)
  - Test: 4 participants’ data (314 sentences)
  - Correct sentence: 50% / incorrect: 50% -> chance level: 0.5

Optimization of hyper-parameters

  - Grid-searching with 10-fold cross validation in the training data
  - SVM
    1. C = {0.001, 0.01, 0.1, 1, 10, 100}
    2. SAE
      - Number of hidden units: (10, 50, 100, 200, 300)
      - Number of hidden layers: (1, 2, 3)
      - Activation functions: (sigmoid, rectified linear unit)
    3. LSTM
      - Number of hidden units: (5, 10, 15, 20, 25, 30), others are the same as SAE

- Multiple-trials averaged analysis
  - We also investigated classification performances on averaging multiple-trials EEG signals

Results & Conclusions

- Single-trial classification results
  - Multiple-trials averaged accuracies
  - Gradually increasing while the number of averaging trials increase

  ![Single-trial classification results](image)

<table>
<thead>
<tr>
<th>Model</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVM</td>
<td>0.584</td>
</tr>
<tr>
<td>SAE</td>
<td>0.583</td>
</tr>
<tr>
<td>LSTM</td>
<td>0.613</td>
</tr>
</tbody>
</table>

- Participant number on test set

  ![Participant number on test set](image)

- Multiple-trials averaged analysis

  - LSTM could achieve over 60% accuracy higher than chance level (p<0.01)
  - Sequential models are feasible to properly classify high-dimensional sequential EEG signals

- In future
  - Raw EEG as features: NN can learn without specific feature extractions
  - Detection of semantic violations in sentences for evaluations of sentences