Single-trial Detection of Semantic Anomalies from EEG during Listening to Spoken Sentences

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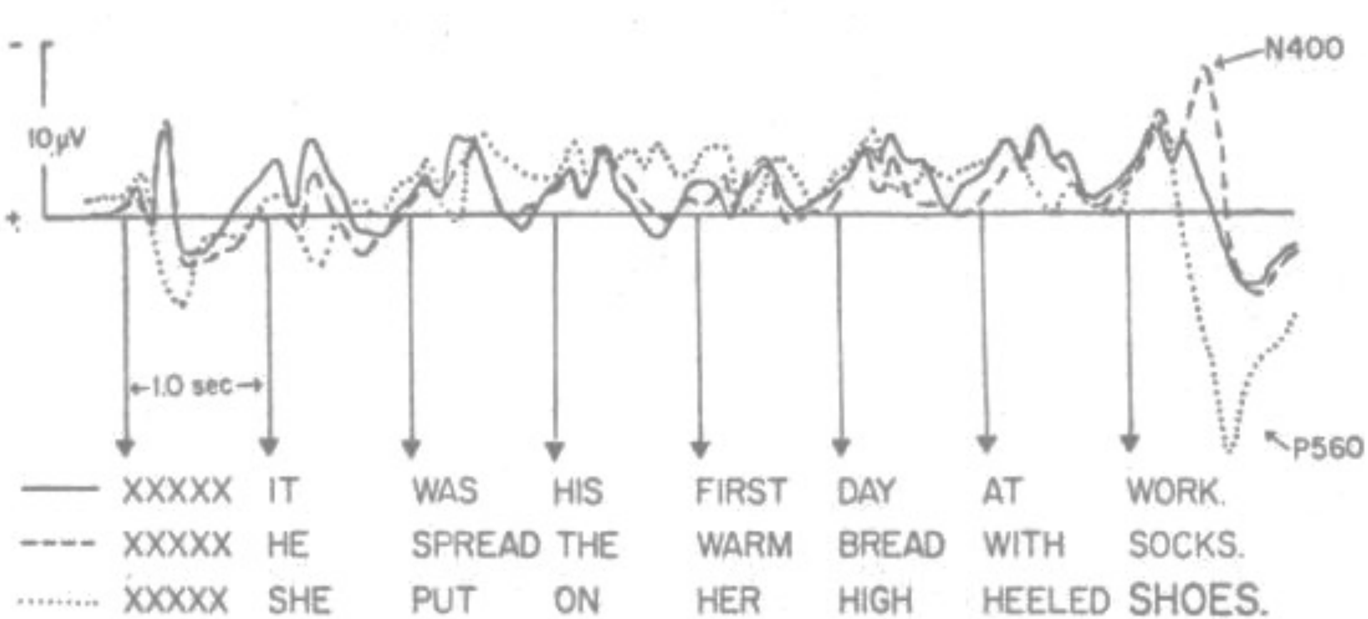
How do we detect semantic anomalies?

- Known as event-related potential (ERP) in EEG: **N400**
- Visual stimuli [Kutas M., and Hillyard S., 1980]
- N400 was observed by **signal averaging**

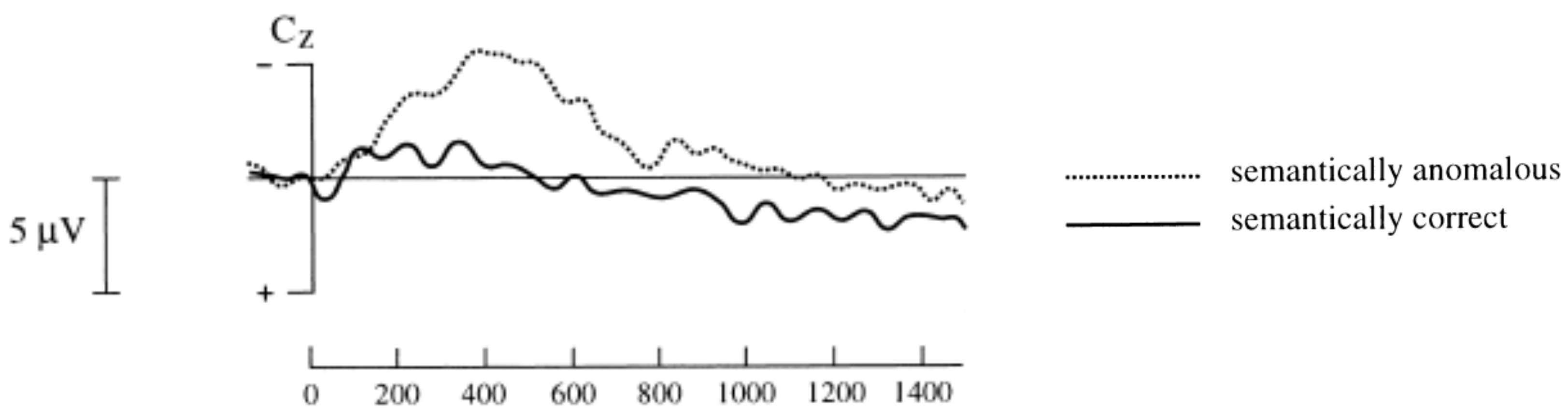


Semantic anomalies in listening to speech

- N400 of listening to speech [Hagoort et al., 2000]

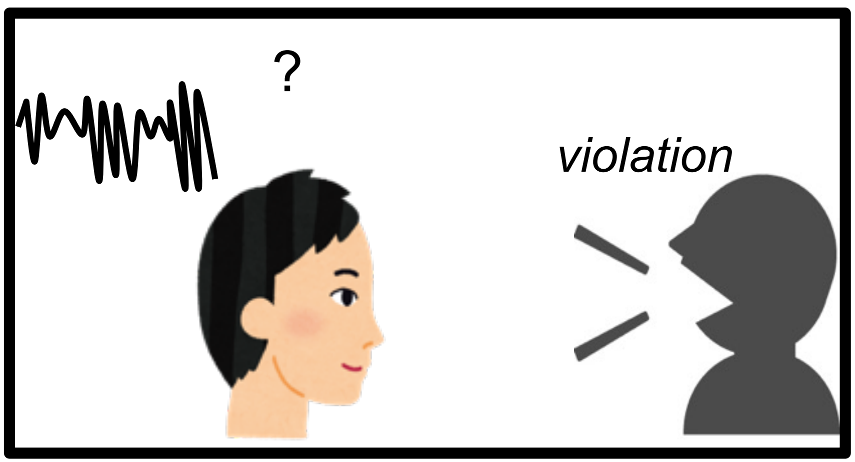
Semantically correct sentence:
The children like to play in the *garden*.

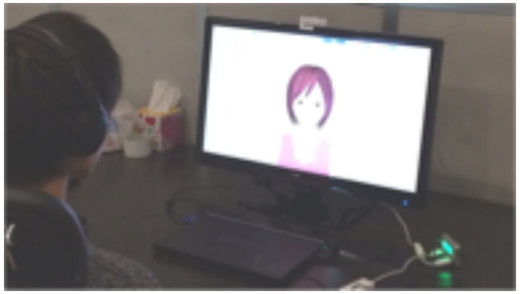
Semantically incorrect sentence:
The girl dropped the candy on the *sky*.



Detecting anomalies in communication

- Single-trial (one-shot) detection of anomalies
  - Can be applied to evaluation and feedback of spoken dialogue and speech recognition systems [Tanaka et al., 2017]
- This study focuses on detecting semantic anomalies

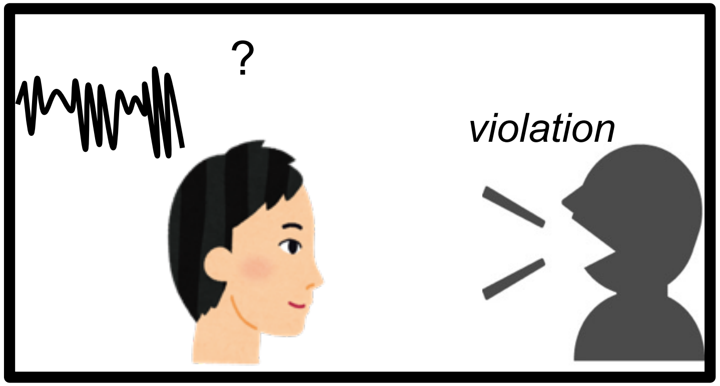




Our contribution

- Previous work need signal averaging computation to observe N400
- No study of single-trial detection [Putze F. and Stuerzlinger W., 2017] of semantic anomalies in (Japanese) spoken language

- Investigate how we can detect single-trial semantic anomalies
- Propose machine learning approaches considering all channels
  - Linear discriminant ratio, SVM, and random forest

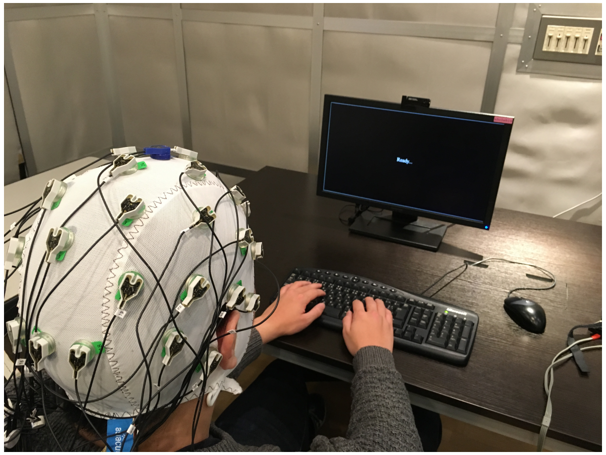


Proposed methods

EEG Recording

- 8 participants
  - Approved by ethical board of the Nara Institute of Science and Technology
  - Graduate students (nine males and one female)
  - Without any history of psychiatric problems, right-handed

- EEG: Brain Products, 32ch
- Earphones: Insert type ER1



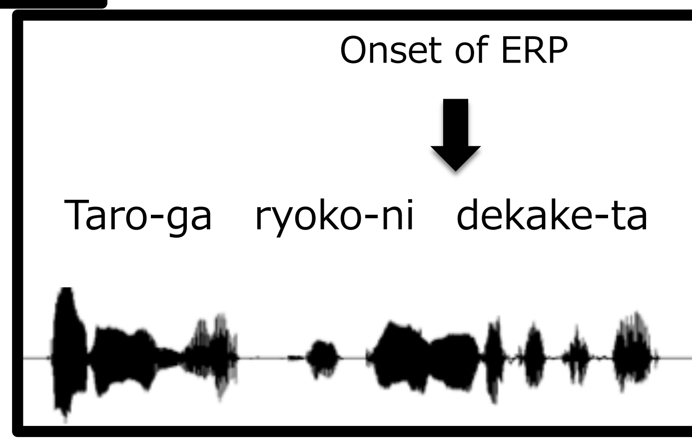
Stimuli and timing

a.	Taro-ga	ryoko-ni	dekake-ta
	Taro-NOM	a journey-DAT	set out-PAST
	Taro set out on a journey.		
b.	*Taro-ga	jisho-ni	dekake-ta
	Taro-NOM	a dictionary-DAT	set out-PAST
	Taro set out on a dictionary.		

NOM: nominative case marker;
DAT: dative case marker;
PAST: past tense morpheme.

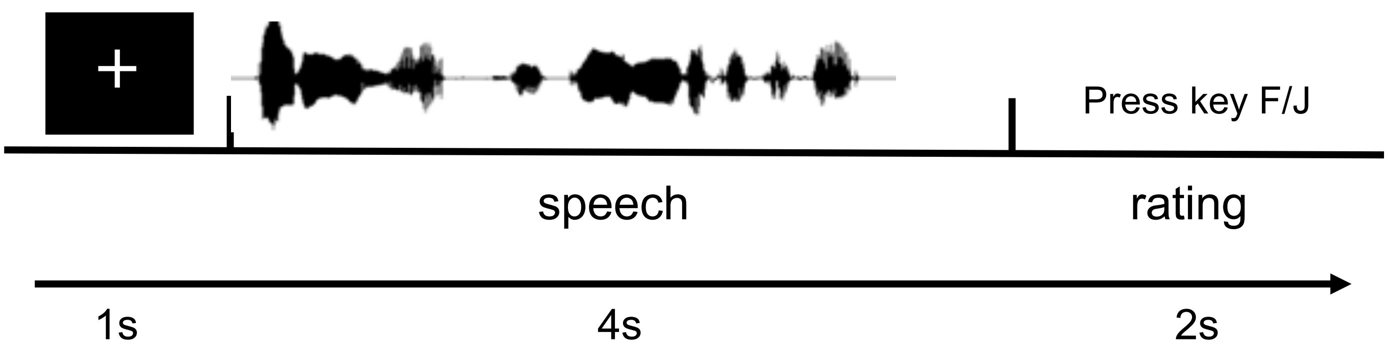
- Created by three people based on [Takezawa et al., 2002]
- All three phrases

- Record sounds naturally spoken by a female professional narrator
- Two people marked the synchronized onset



Experiment procedure

- A total of 200 sentences
  - semantic incorrect: 40, semantic correct: 40
  - syntactic incorrect: 40, syntactic correct: 40
  - fillers: 40
- Behavioral rating: press a key to determine whether each speech is correct (key F) or not (key J)



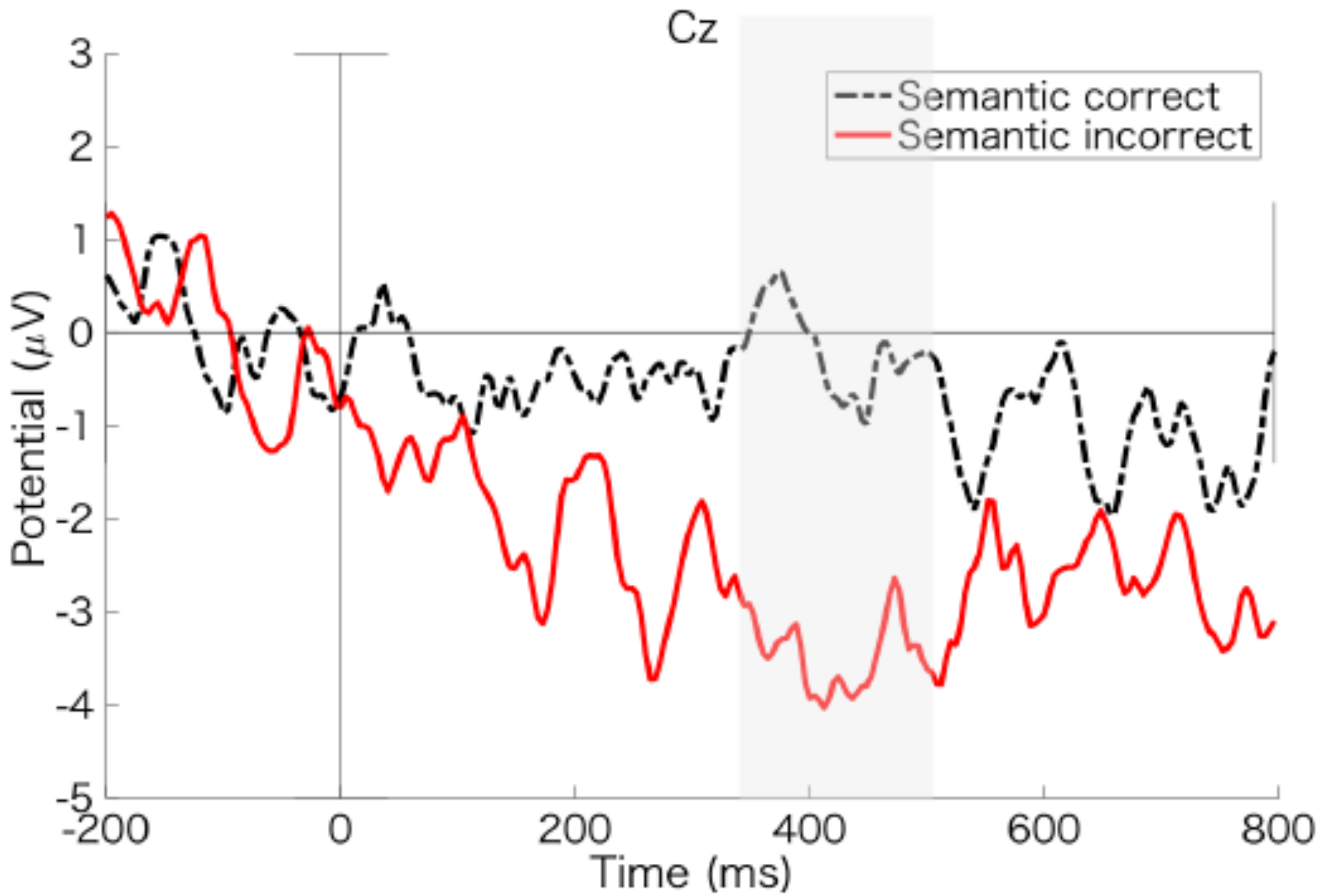
Analysis

- Pre-processing
  - Band-pass filter (0.1–30Hz)
  - Independent component analysis (ICA) to remove eye blink
- N400
  - Grand average of all participants
- Single-trial detection
  - Features: 32ch of time domain (200-300ms, 350-500ms, 500-750ms) [Hagoort et al., 2000] + spectral domain
  - Feature selection: **Linear discriminant ratio (LDR)**
  - Classifiers: **SVM and Random forest (RF)**
  - 10-fold cross validation

Results and Conclusion

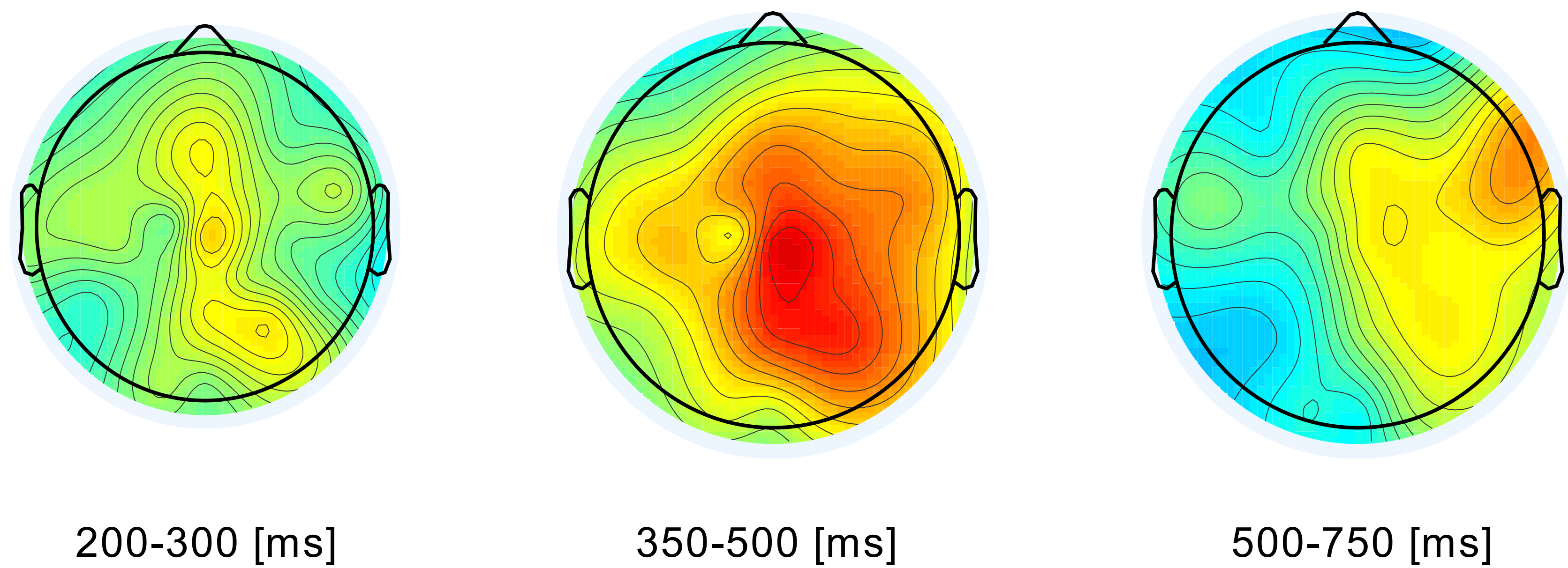
N400 at Cz channel

$p < 0.05$



Scalp mapping

- Mean amplitudes of (semantic correct – semantic incorrect)
- Large difference at latency of 350-500ms and Cz channel

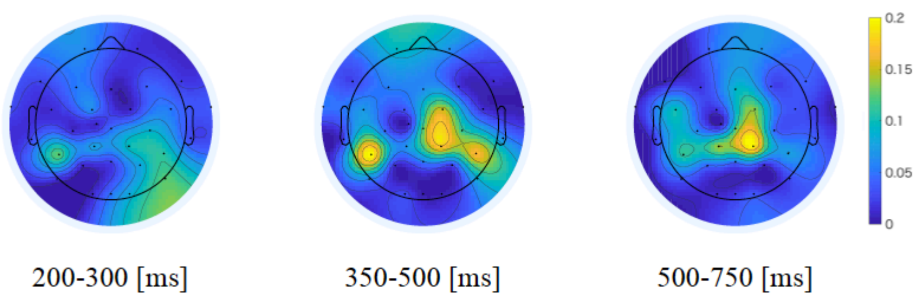


Single-trial detection performance

- Classify semantic correct or semantic incorrect
- Feature selection based on LDR was effective
- 60.67% (SVM) ($p<0.05$, comp. with chance rate)

Feature	SVM	RF
Time domain (Pz, Cz, Fz)	54.43	46.23
Time domain	56.48	54.81
Spectral domain	53.97	55.23
Time and spectral domain	56.48	57.14
Time and spectral domain (LDR: $>$ 80%)	**60.67**	59.62

Feature weights based on LDR
(time domain)



Conclusion

- We design EEG experiment that elicits semantic anomalies
- We observe N400 in auditory and Japanese
- Try single-trial detection of semantic anomalies through all channel data and machine learning
- Feature selection is important and we achieve 60% accuracies
- Future work
  - Compare our method to conventional synchronous addition
  - Apply tensor decompositions [Maki H. et al., 2018]
  - Consider other anomalies such as syntax [Tanaka et al., under review]